Integrating NAMs and Field Studies for Environmental Risk Assessment

Ayesha Siddique, Matthias Liess and many others
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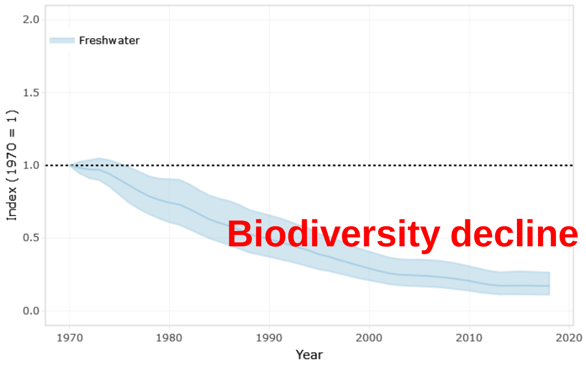
Challenge

Living Planet Index (LPI)



Living planet Report 2022

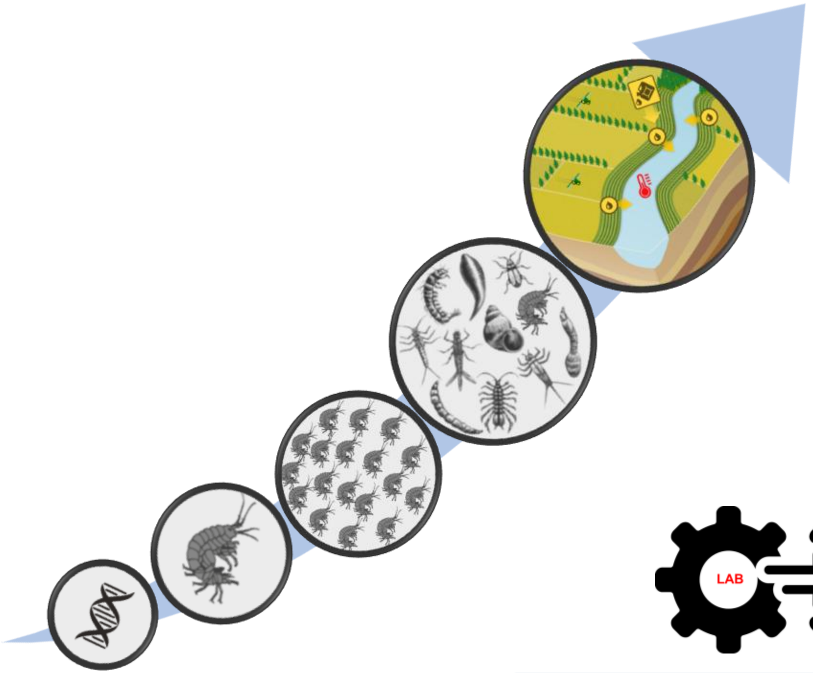
Agricultural pesticides are used within “safe” limits, yet reduction in macroinvertebrates taxa mainly due to pesticides Europe, Australia, Russia (Beketov et al., 2013; Rumschlag et al., 2023; Worischka et al., 2023)

Gap

Standard risk assessment doesn’t capture **long-term**, **low-dose**, and **cascading effects**.

Relevance

Our group specializes in linking **mechanistic processes** to **real-world ecological risk**.



Regulatory needs for Risk assessment

Partnership FOR THE Assessment OF Risks FROM Chemicals

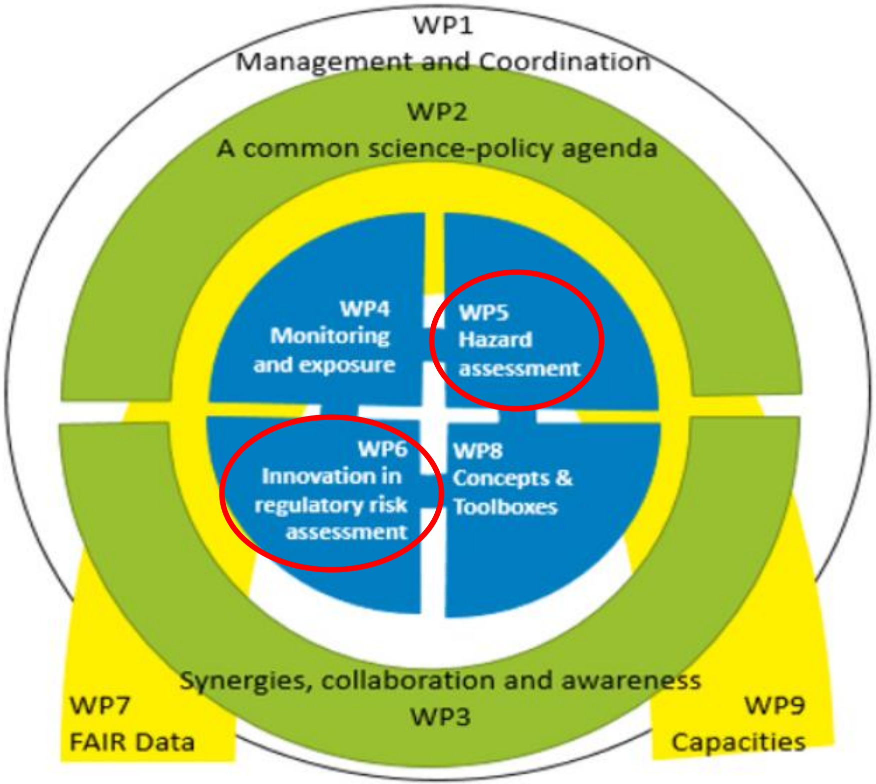
WP5

BPA alternatives in the environment and NAMs development

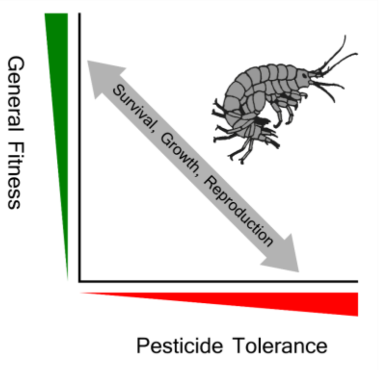
1. Multistress stress effects of Bisphenol S and Esfenvalerate under food limitation
2. Effect prediction using Stress Addition Model SAM (Liess et al., 2016)

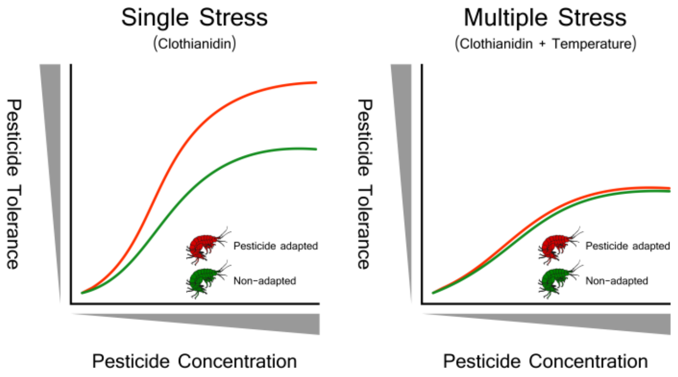
WP6

1. Mechanistic understanding of effects of chemicals
2. Field monitoring for current situation on sensitive species



Mechanistic understanding of effects of chemicals, some examples





Siddique et al., 2020:
Even at concentrations deemed "safe," Gammarus populations adapt, but this adaptation comes with fitness costs (lower survival, growth, reproduction).

Indicates hidden, long-term risks not considered in regulation.

Siddique et al., 2021:
Adaptation helps under pesticides alone, but under multiple stressors (warming + pesticides), the advantage is lost.

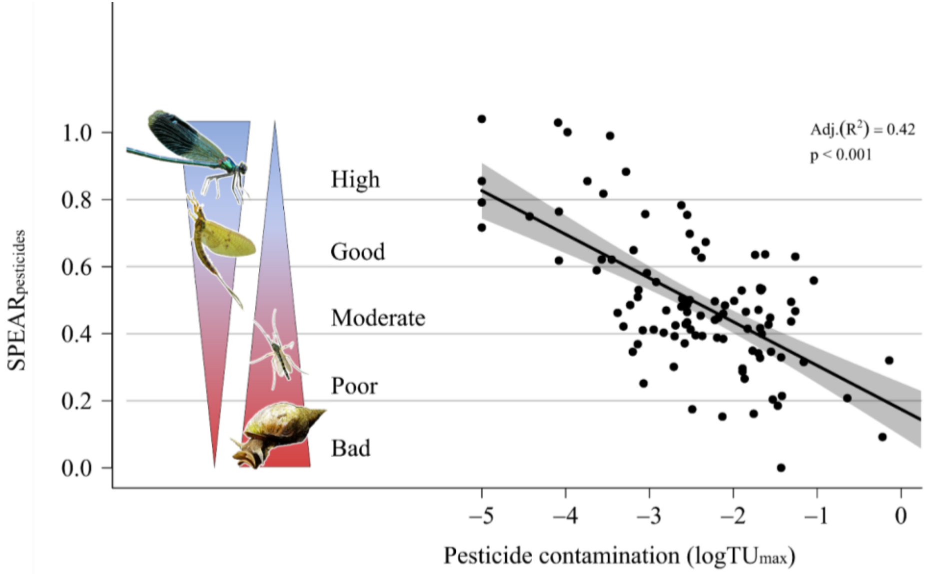
Demonstrates trade-offs and vulnerability under global change.

Siddique et al., 2024:
First evidence of a **cascade from genes → individuals → communities**: pesticide-adapted Gammarus show reduced genetic diversity and fecundity, yet dominate communities because competitors disappear.

This bridges molecular, ecological, and community-level impacts.

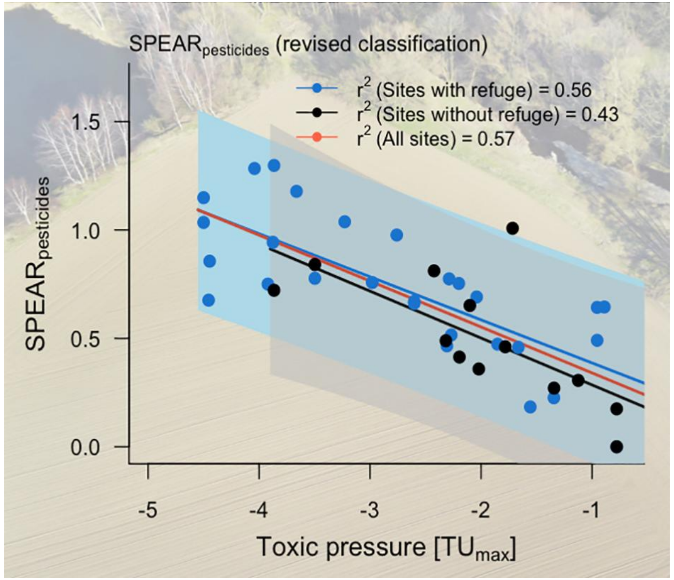
Field monitoring for current situation and tools for assessment

KgM monitoring 2018/2019



Liess et al., 2021

Species distribution



Knillmann et al., (2018)

Extending assessment tools across Europe

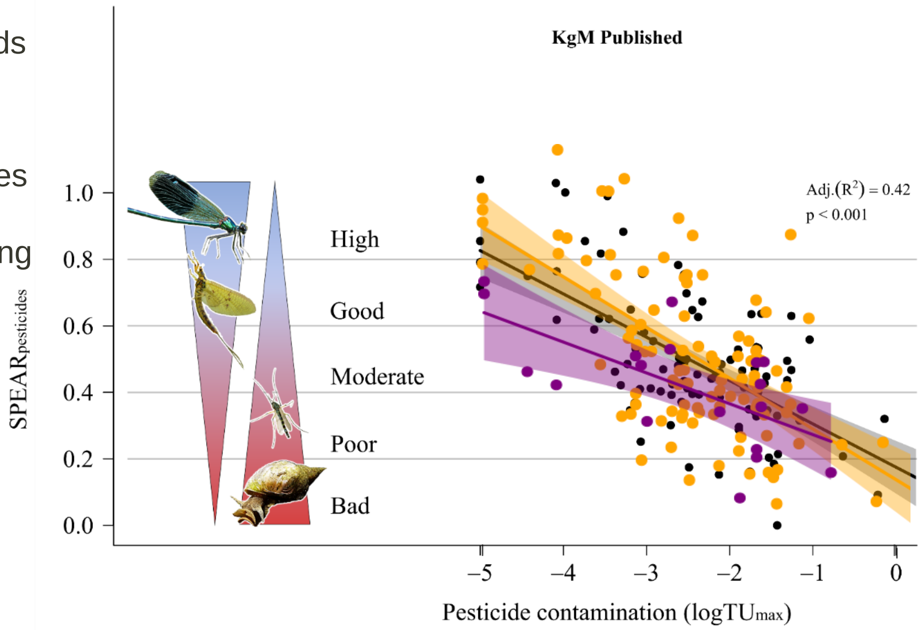
From freshwater bodies,
Exposure data, mainly pesticide monitoring
Effect data, mainly macroinvertebrates monitoring

Optimising tools:

SPEAR$_{pesticides}$ adapted to climate change and regional variation

1. Refuge species are now considered sensitive considering **climate change** and **drying** periods in summer

2. Considering distribution of species in different EU regions, **regional caliberation** of each dataset is being done



KgM 2018/19 dataset considering refuge species not as sensitive & with regional calibration

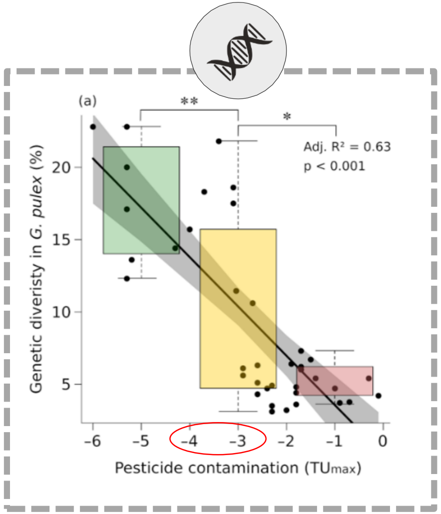
KgM 2018/19 dataset considering refuge species as sensitive & with regional calibration
Adj. R2 = 0.4, *p* < 0.001

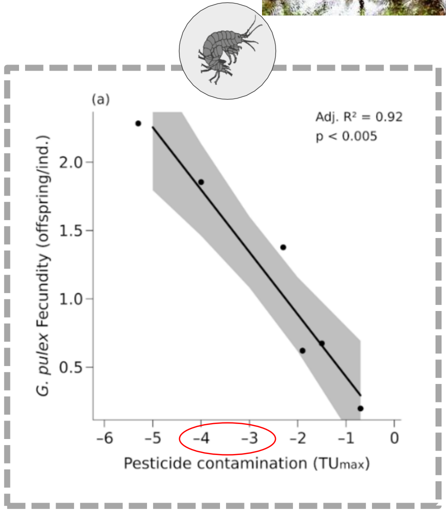
KgM 2018/19 dataset considering refuge species as sensitive & with regional calibration
Adj. R2 = 0.41, *p* = 0.005

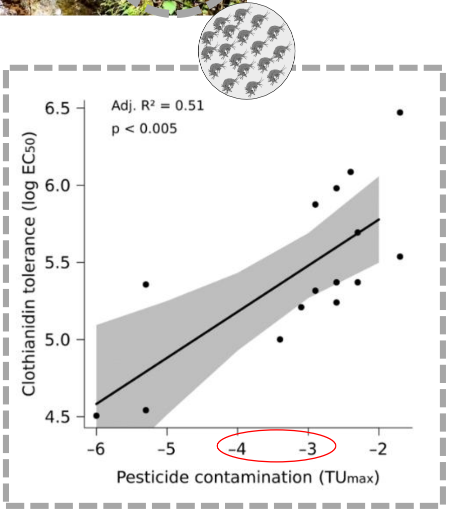
Siddique et al., in preparation

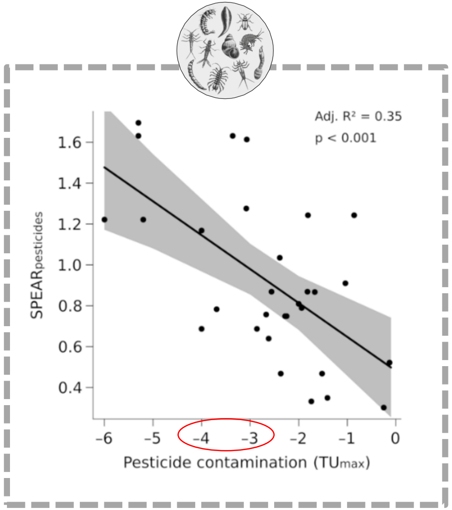
Up next - Analysis of Swedish dataset in process….

Integrating NAMs in Risk assessment







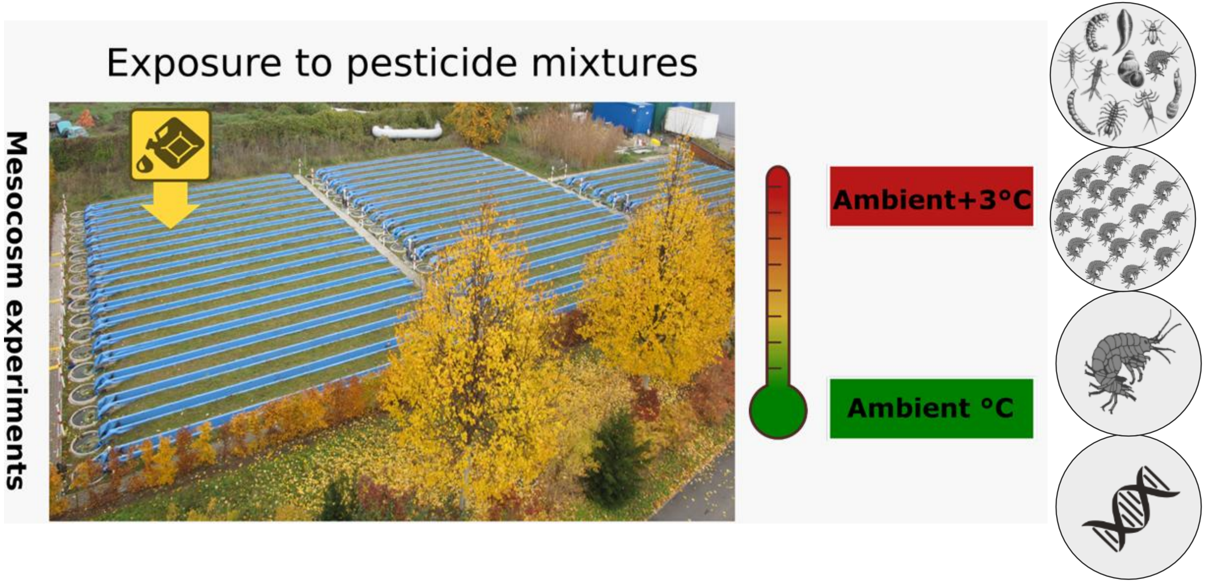


Similar effect threshold at gene, individual, population and community level

Integrating NAMs in Risk assessment

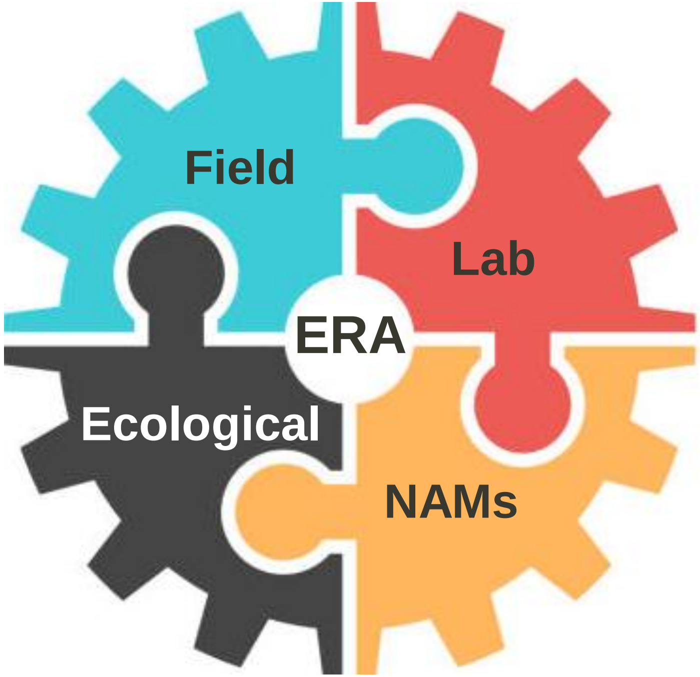
Pesticide induced transcriptomic response in soil organisms

ETOX
MOLSYB
EXPO
UMB

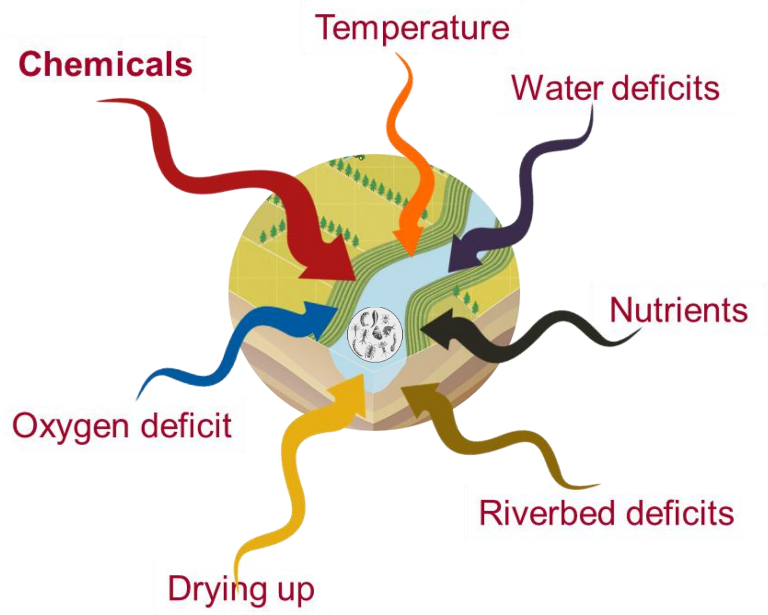


Overarching goal

A risk assessment framework that predicts not only acute toxicity but also **long-term ecosystem resilience**.

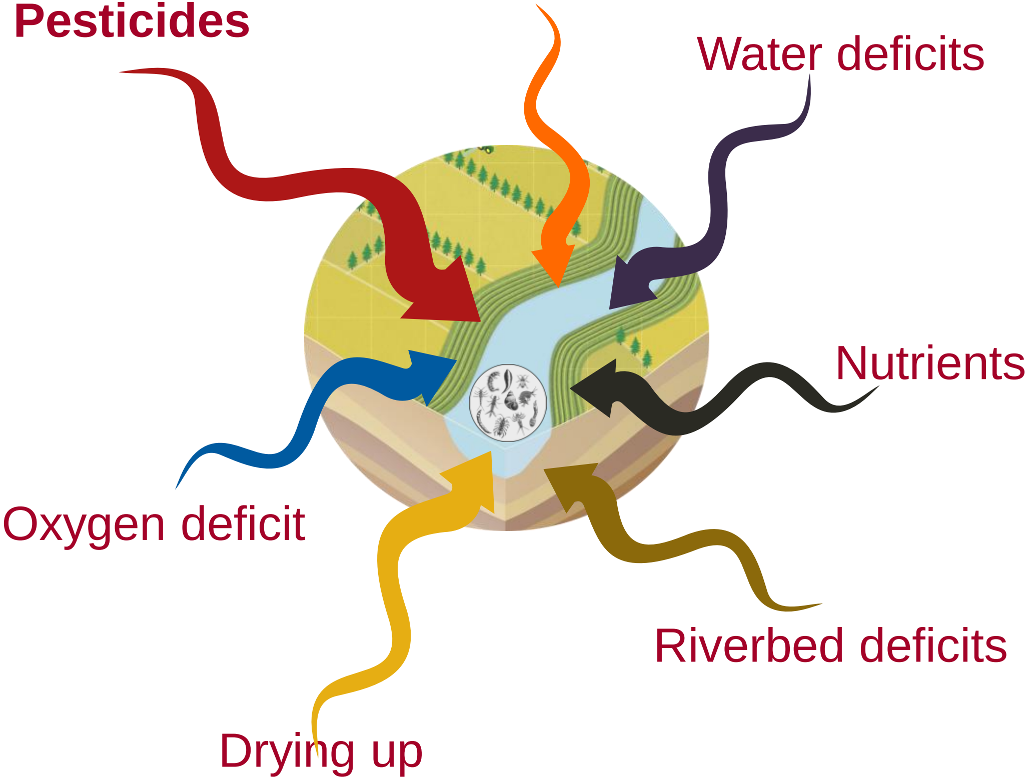


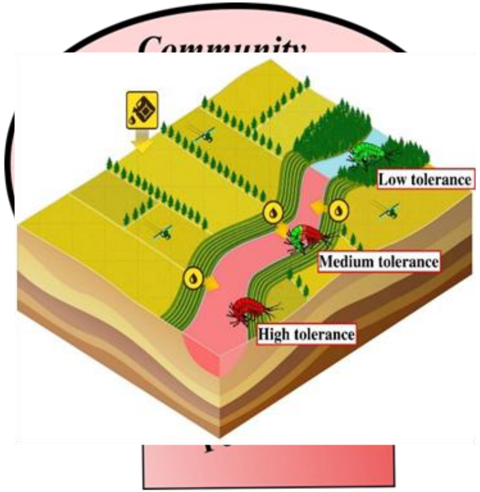
Ecological effects of pesticides under field relevant conditions



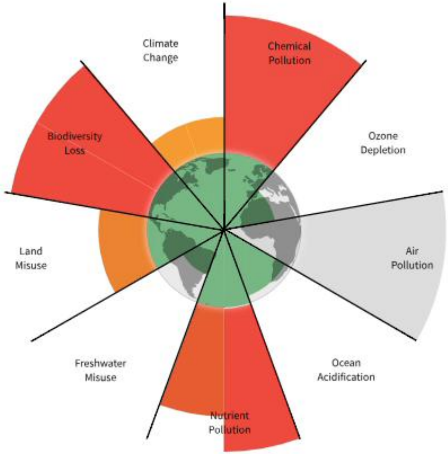
Naeem Shahid
Helmholtz Centre for Environmental Research - UFZ,
Working group System-Ecotoxicology
Contact: naeem.shahid@ufz.de

Background


Temperature
Pesticides
Water deficits
Nutrients
Oxygen deficit
Riverbed deficits
Drying up


Low tolerance
Medium tolerance
High tolerance

Background



Based on Richardson et al. 2023

Need?

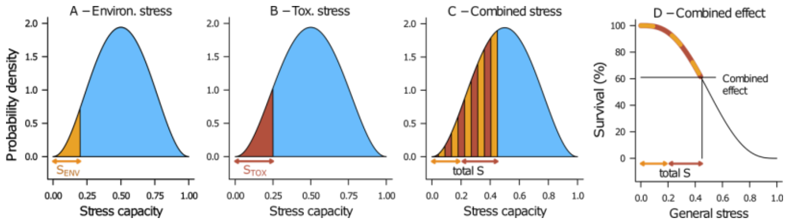
Relevant Factors

- **Pesticide Mixture**
- **Environmental Stressors**
- **Pesticide adaptation**
- **Prediction of combined effects**

SCIENTIFIC REPORTS

OPEN **Predicting the synergy of multiple stress effects**

Matthias Liess[1,2], Kaarina Foit[1], Saskia Knillmann[1], Ralf B. Schäfer[3] & Hans-Dieter Liess[4]



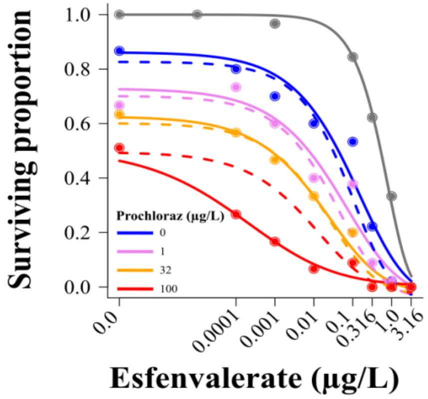
Stress Addition Model (Liess et al., 2016)

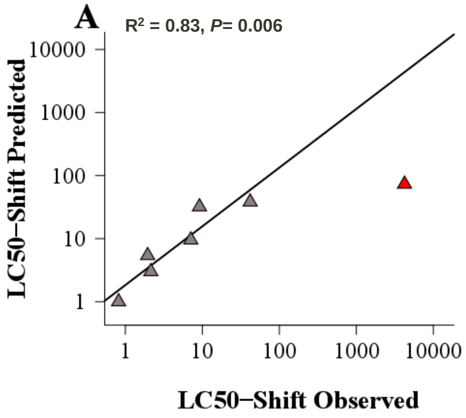
Results

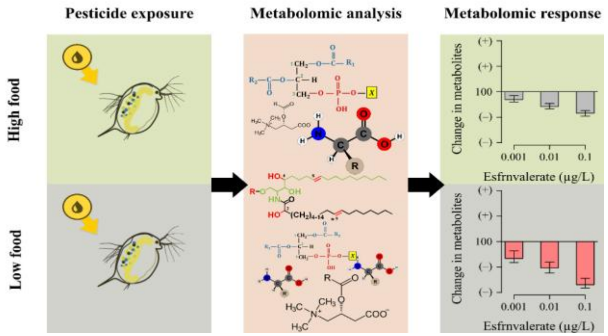
Mixture + Env. Stress

Toxicant + Env. Stress

(Shahid et al., 2021)







Environmental Science & Technology

Article

Cite This: Environ. Sci. Technol. XXXX, XXX, XXX−XXX

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Environmental Stress Increases Synergistic Effects of Pesticide Mixtures on *Daphnia magna*

Naeem Shahid,[*,†,‡,§] Matthias Liess,[†,‡] and Saskia Knillmann[†]

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Pesticide-induced metabolic changes are amplified by food stress

Naeem Shahid [a,b,c,d,*], Ulrike Rolle-Kampczyk [e], Ayesha Siddique [a,b], Martin von Bergen [e], Matthias Liess [a,b]

Results

Mixture + Env. Stress

Toxicant + Env. Stress

Mixture + Env. Stress

(Shahid et al., 2024a)

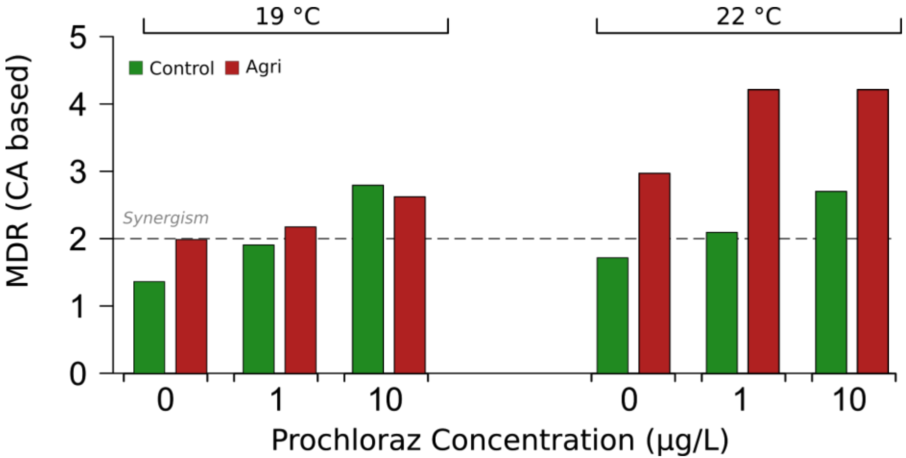

Fig. 1: Combined effects of multiple stressors including pesticide mixture and temperature.

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Predicting the Combined Effects of Multiple Stressors and Stress Adaptation in *Gammarus pulex*

Naeem Shahid,* Ayesha Siddique, and Matthias Liess

Results

- Mixture + Env. Stress
- Toxicant + Env. Stress
- Mixture + Env. Stress
- **1 Tox + 2 Env. Stress**

(Shahid et al., 2024b)

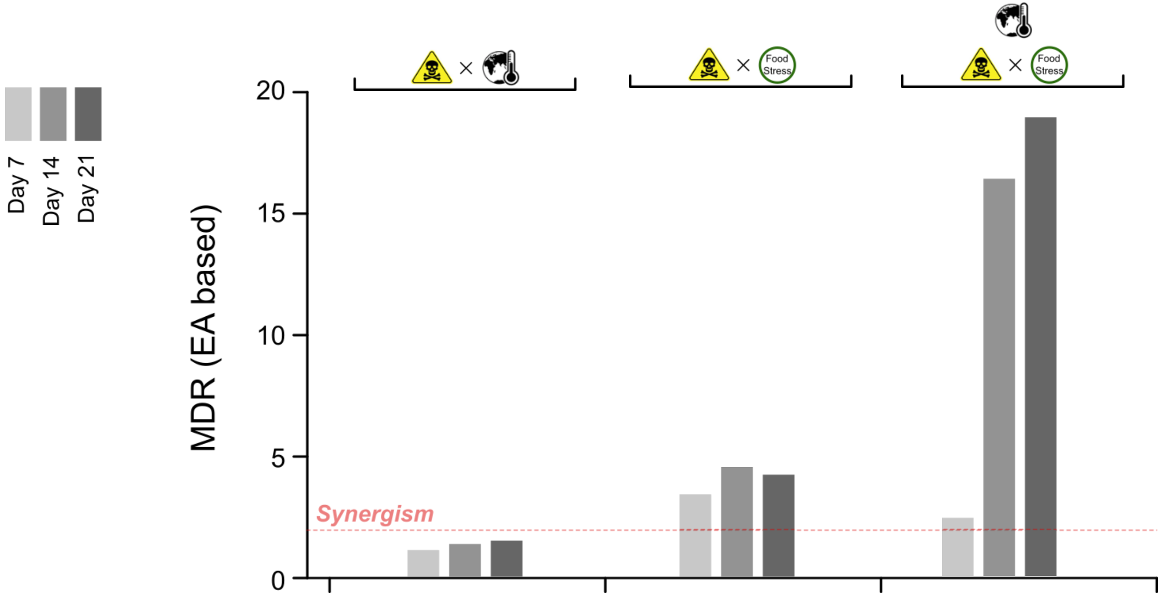


Fig 1. Synergistic interaction between esfenvalerate and environmental stressors including food limitation and temperature stress.


Environmental Pollution 363 (2024) 125109

Contents lists available at ScienceDirect

Environmental Pollution

journal homepage: www.elsevier.com/locate/envpol

ELSEVIER

Synergistic interaction between a toxicant and food stress is further exacerbated by temperature☆

Naeem Shahid [a,b,*], Ayesha Siddique [a], Matthias Liess [a,c,**]

Methods

- Mixture + Env. Stress
- Toxicant + Env. Stress
- Mixture + Env. Stress
- 1 Tox + 2 Env. Stress
- **13 Tox + 2 Env. Stress**

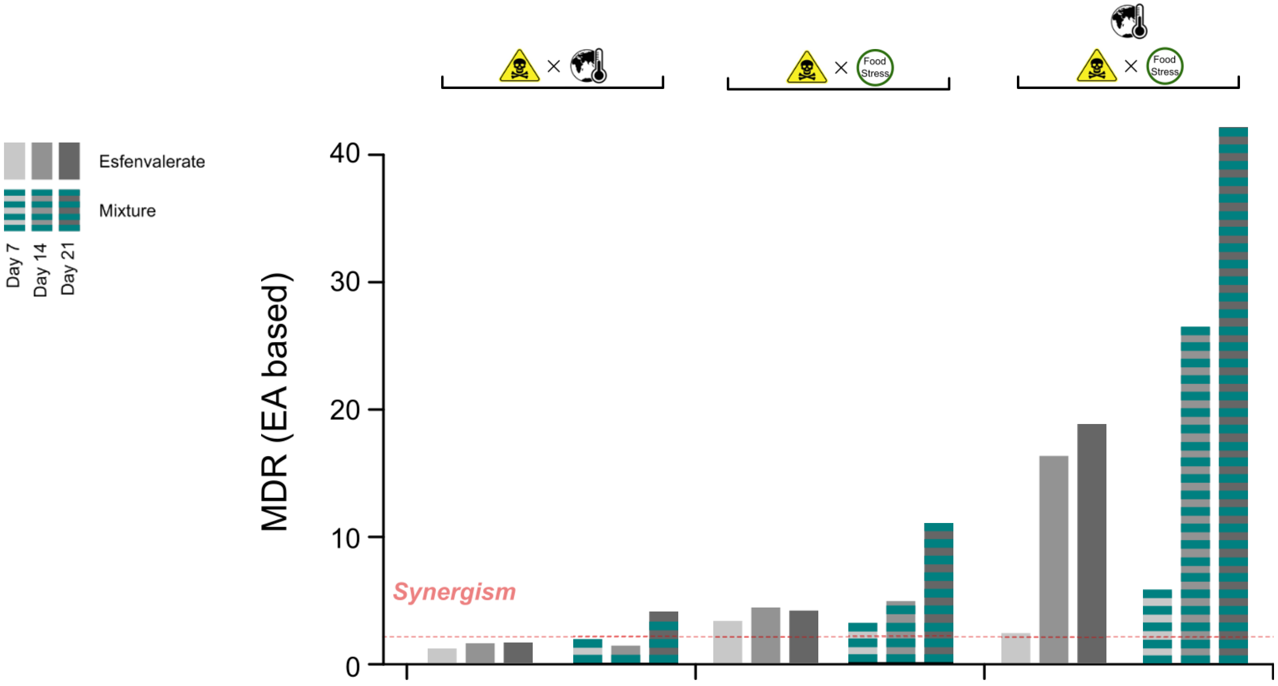


Fig 1. Synergistic interaction between toxicants and environmental stressors including food limitation and temperature stress.

Contents lists available at ScienceDirect
Journal of Hazardous Materials
journal homepage: www.elsevier.com/locate/jhazmat
ELSEVIER

Double Trouble: The Synergistic Threat of Environmental Stressors and Pesticide Mixtures

Naeem Shahid[1, 2, *, 4], Ayesha Siddique[1], Martin Krauss[3], Alexander Böhme[3], Werner Brack[2, 3], Annika Jahnke[3], Matthias Liess[1, 4]

Take-Home Message


Mixture + Env. Stress

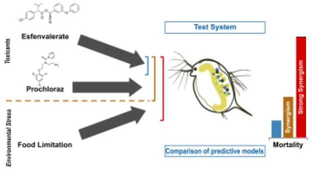

Toxicant + Env. Stress


Mixture + Env. Stress

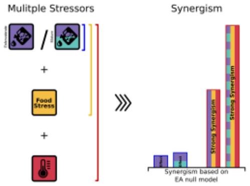

1 Tox + 2 Env. Stress


13 Tox + 2 Env. Stress

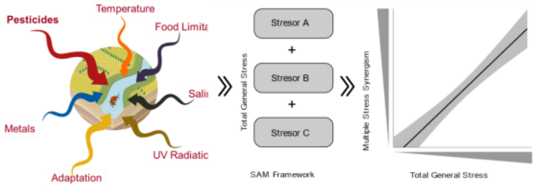
- Pesticide mixtures with different modes of action may interact synergistically



- Mixtures show stronger synergism under multiple environmental stressors (up to 15)

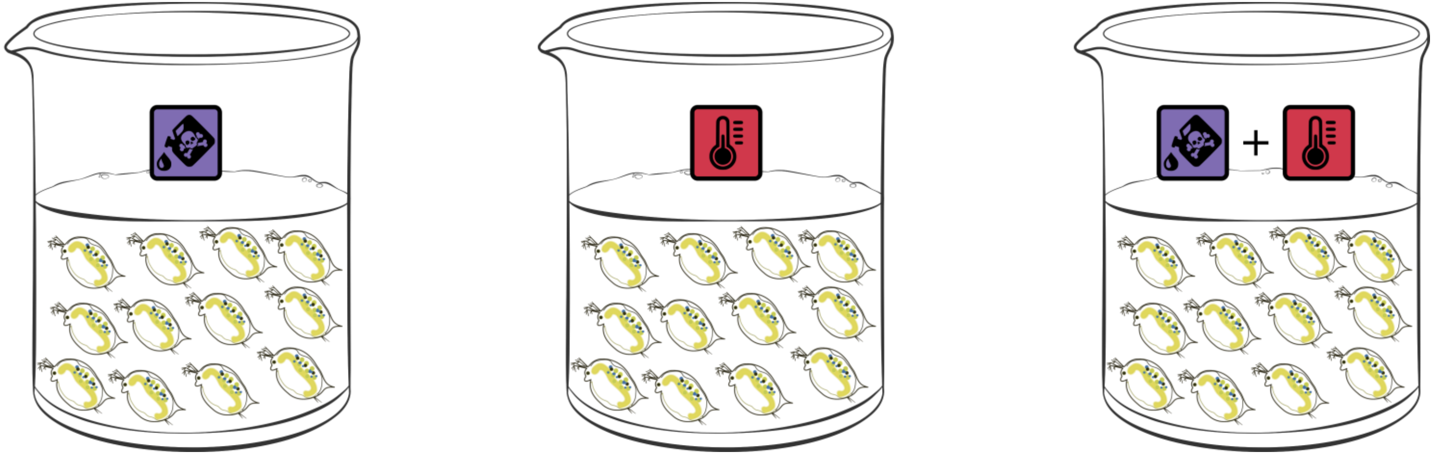


- Combined effects of multiple stressors can be predicted by SAM.



- **Adaptation to multiple stressors**
- **Effects of multiple stressors under more complex conditions**

Adaptation



Multi-generation experiment to study adaptation to multiple stressors

MuSt$_{Field}$

Exposure to pesticide mixtures

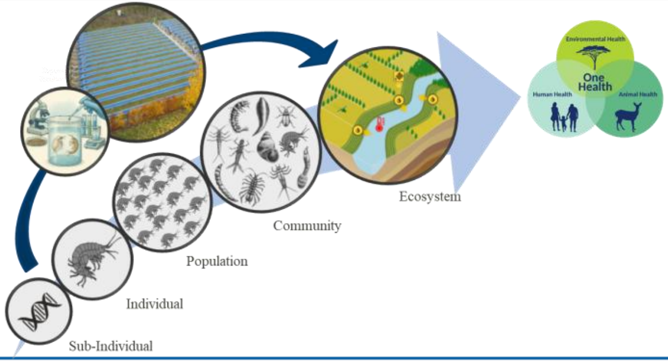
Mesocosm experiments

Ambient+3°C

Ambient °C

Endpoints

- Drift & Mortality (short-term and long-term)
- Nutrient Dynamics (temporal changes in nutrients)
- Chemical Degradation & Bioaccumulation
- Leaf Litter Decomposition
- Macroinvertebrate Community responses
- Diatom Communities (algae/biofilms structure and function)
- Adaptation & Recovery (community tolerance, resilience)
- Sub-organismic Effects (omics, eDNA, bioassays)
- Antimicrobial Resistant Genes (ARGs)



eawag aquatic research

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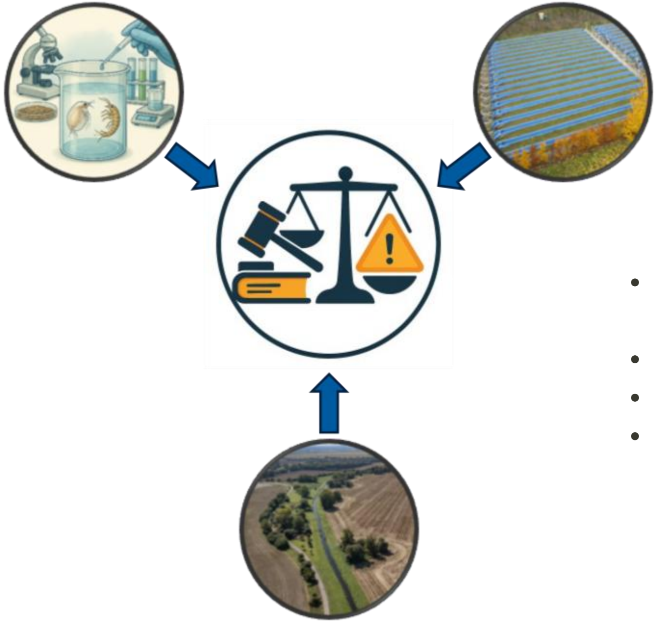
RPTU Rheinland-Pfälzische Technische Universität Kaiserslautern Landau

Regulatory Risk Assessment



- Integrates mechanistic (lab), ecological (mesocosm), and field evidence under real-world conditions
- Enhances mixture risk assessment beyond simple additive models
- Incorporates multiple environmental stressors into assessment frameworks
- Connects mechanistic and ecological endpoints to regulatory protection goals

HELMHOLTZ
Zentrum für Umweltforschung

Partitioning and ecotoxicological effects of pyrethroids in streams – Dissolved fraction mediates invertebrate toxicity

Jonas Gröning, Alexander Böhme, Mara Römerscheid, Benjamin Schwarz, Nadin Ulrich, Matthias Liess

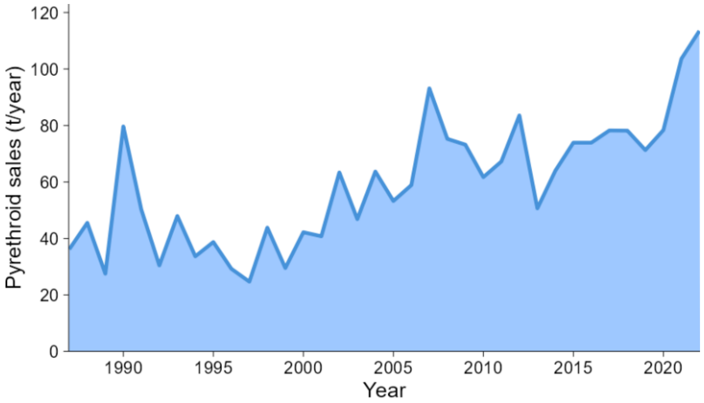
Motivation

Pyrethroids …

– are becoming more relevant due to increasing use

– have a high invertebrate toxicity

– occur in very low concentrations in the aquatic environment (especially in the water phase)



Objectives

i. Assess pyrethroid exposure in streams across phases

ii. Identify which pyrethroid fractions is ecotoxicologically effective

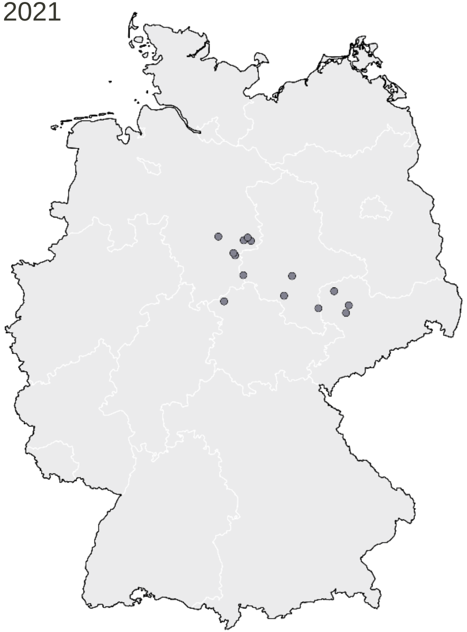
iii. Test whether suspended matter or sediment equilibrium concentrations or Sorb-Star passive sampler measurements are suitable for effect assessment

Methods

Study sites, asssessment of pyrethroid exposure, effects on invertebrate communities

KgM Kleingewässer Monitoring

2021



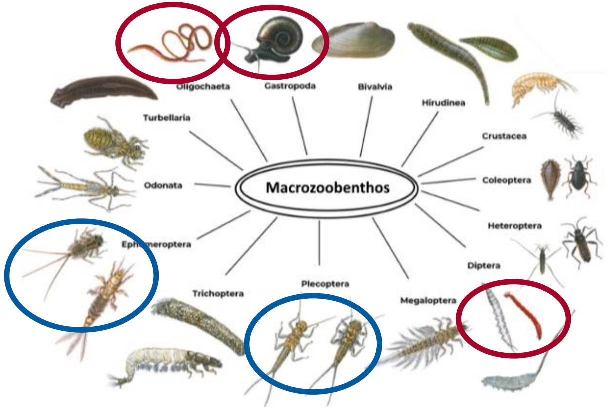
Exposure assessment – TU_{max}

- Water (dissolved)
- Water (particulate)
- Water (total)

- Suspended matter equilibrium
- Sediment equilibrium

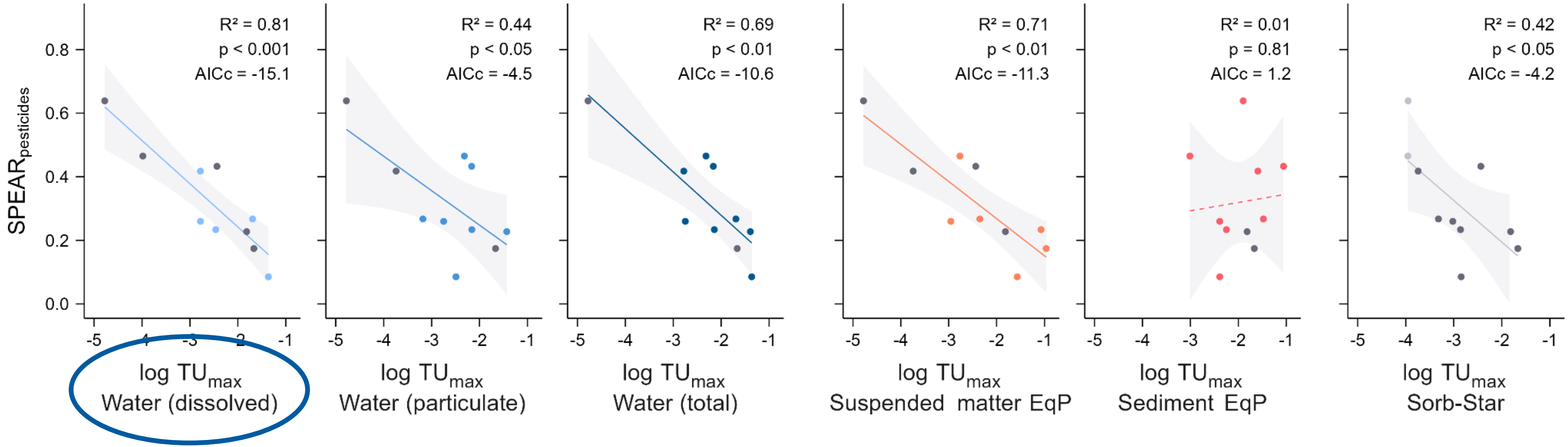
- Sorb-Star

Effect assessment – $SPEAR_{pesticides}$



$$SPEAR_{pesticides} = \frac{\sum_{i=1}^{n} \log(4x_i + 1) \times y_i}{\sum_{i=1}^{n} \log(4x_i + 1)}$$

Results

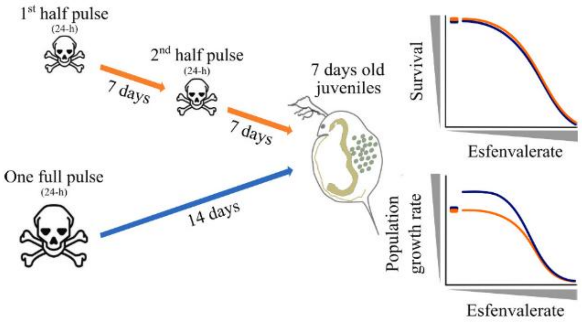


SPEAR$_{pesticides}$
0.8
0.6
0.4
0.2
0.0
R² = 0.81
p < 0.001
AICc = -15.1
R² = 0.44
p < 0.05
AICc = -4.5
R² = 0.69
p < 0.01
AICc = -10.6
R² = 0.71
p < 0.01
AICc = -11.3
R² = 0.01
p = 0.81
AICc = 1.2
R² = 0.42
p < 0.05
AICc = -4.2
-5 -4 -3 -2 -1
log TU$_{max}$
Water (dissolved)
log TU$_{max}$
Water (particulate)
log TU$_{max}$
Water (total)
log TU$_{max}$
Suspended matter EqP
log TU$_{max}$
Sediment EqP
log TU$_{max}$
Sorb-Star

Conclusion

- Dissolved pyrethroids drive ecotoxicological effects on invertebrate communities
- Particle-bound pyrethroids do not contribute to invertebrate toxicity
- Concentrations across water, suspended matter, and sediment are not in equilibrium
- Direct measurement of dissolved pyrethroids needed for risk assessment

Sequential pesticide exposure: Concentration addition at high concentrations - Inhibition of hormesis at ultra-low concentrations

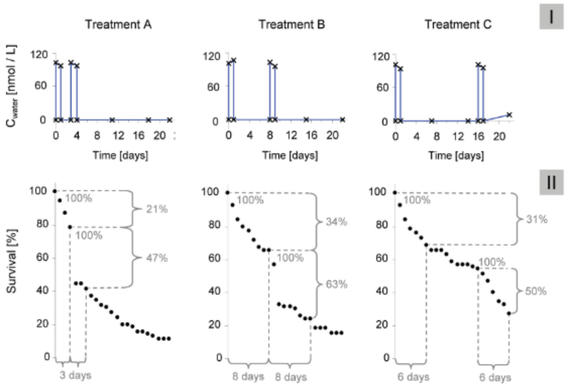


Imrana Mushtaq, Naeem Shahid, Ayesha Siddique, Matthias Liess

Presenter: Imrana Mushtaq

Contact: imrana.mushtaq@ufz.de

Background



(Ashauer et al., 2010)

Most previous studies focus on:

- High concentrations only
- Sequential exposure with time and recovery period

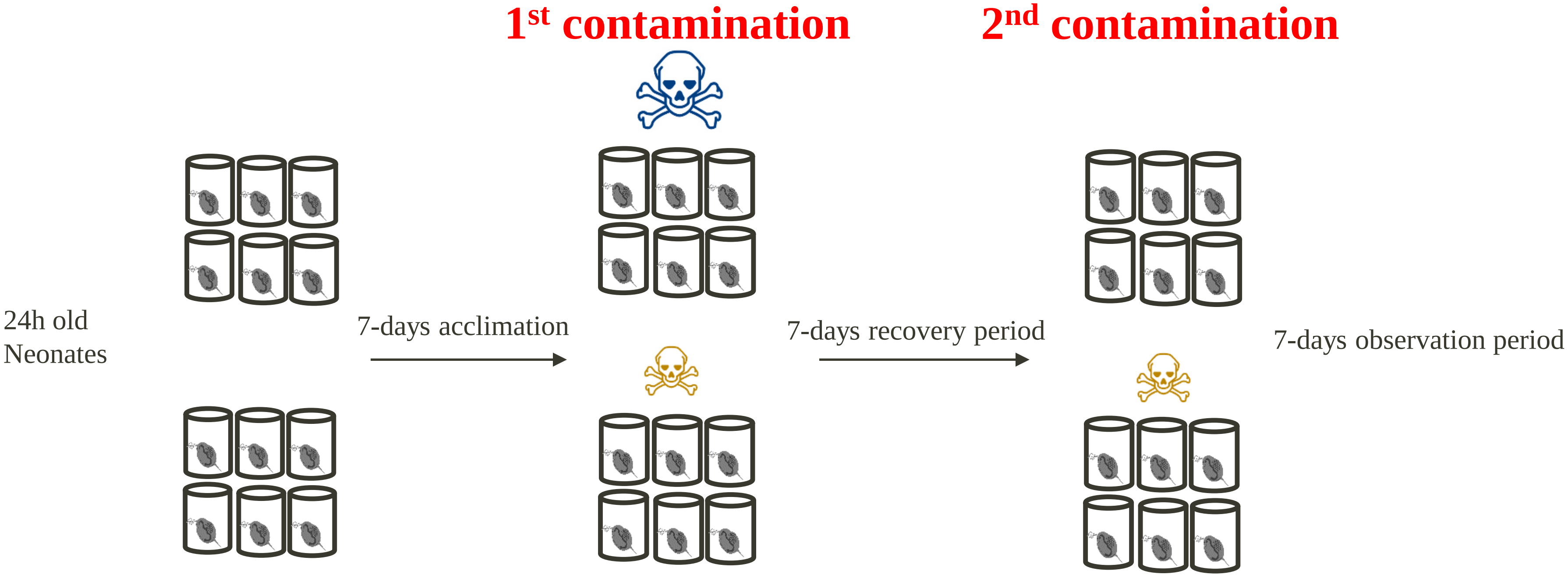
Missing ?

- No full pulse vs sequential pulse comparison
- Sublethal/ultra-low concentration effects

Knowledge Gap:
No clear understanding of lethal and sub-lethal effects in comparison to a single pulse.

Hypothesis: Introducing a 7-day recovery period between two half-pulses will reduce toxicant effects compared to one single pulse?

Study design



Conc. (µg/L)		Conc. (µg/L)		Conc. (µg/L)
0		0		0
0.001		0.0005		0.0005
0.01		0.005		0.005
0.0316	=	0.0158	+	0.0158
0.1		0.05		0.05
0.316		0.158		0.158
1		0.5		0.5
3.16		1.58		1.58

Results

Dose-response curve and survival

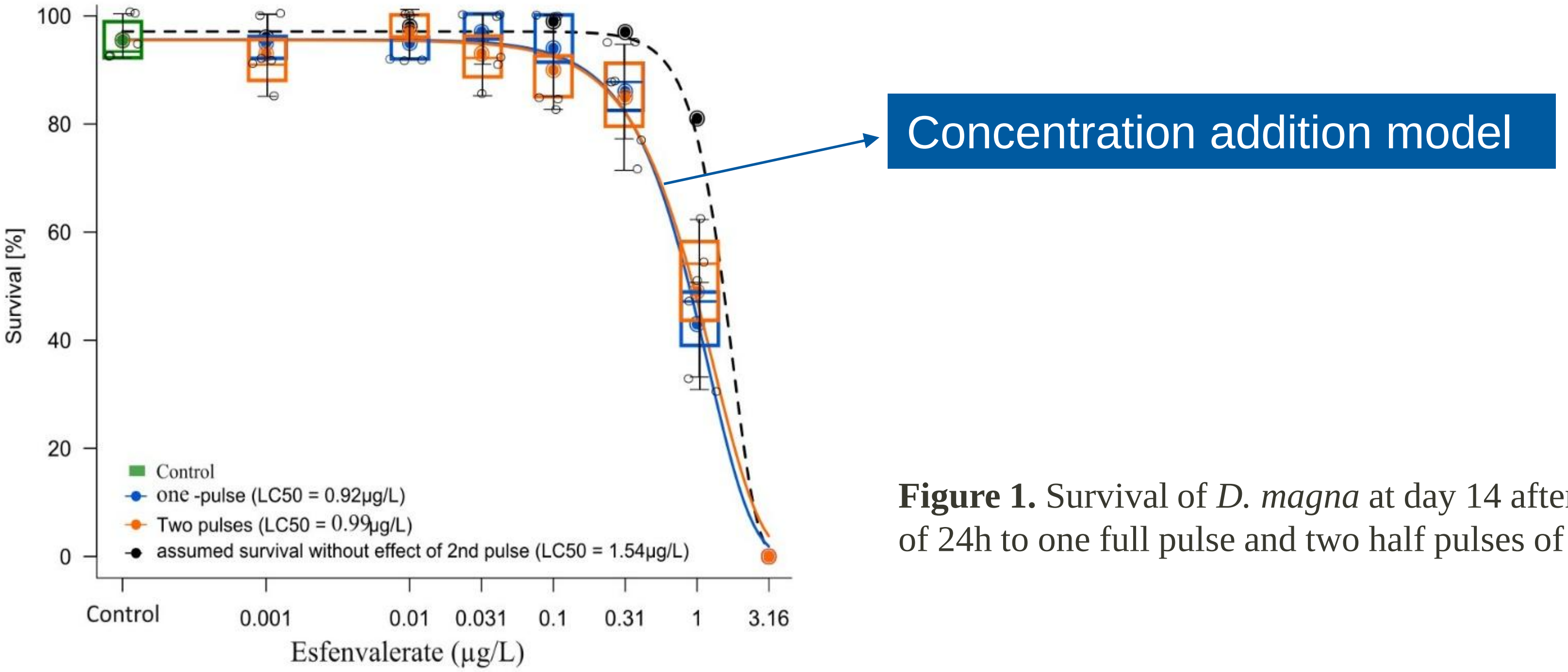


Figure 1. Survival of *D. magna* at day 14 after an exposure of 24h to one full pulse and two half pulses of esfenvalerate.

Results

Population growth rate

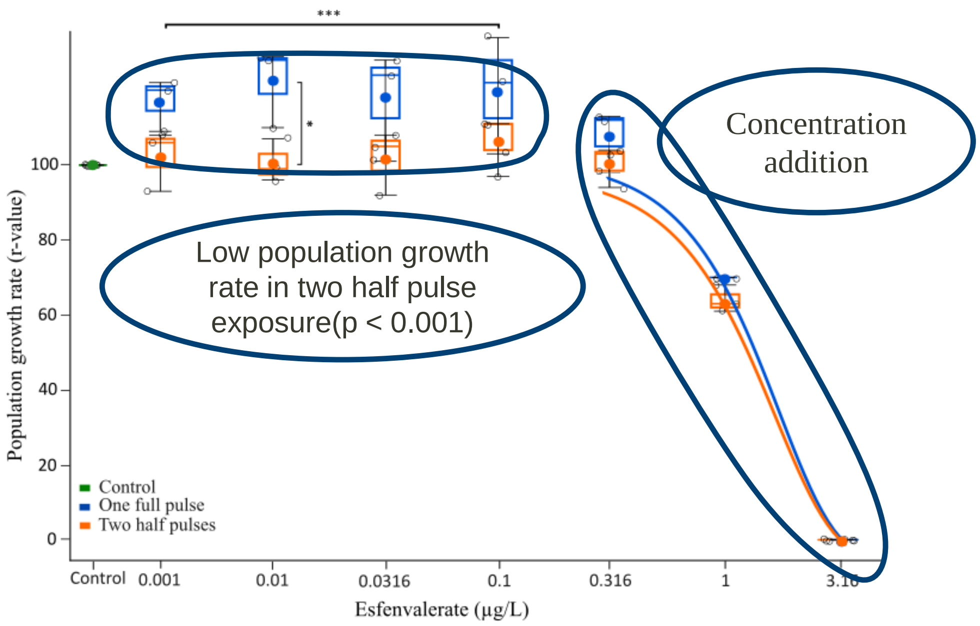


Figure 2. Population growth rate of *D. magna* under one full pulse and two half pulses of esfenvalerate after 14 days of contamination.

- Effect at high concentrations
- Effect at low concentrations
- Hormesis

Conclusion

Our Findings:

- ✓ Direct comparison of single vs sequential pulses
- ✓ Prediction of repeated sequential exposure outcomes by Concentration addition at high doses
- ✓ Relevance of sub-lethal effects at repeated sequential exposure

Future Questions:

- Role of pulse timing?
- Consistency across pesticide classes?
- Ecological implications?

→

To address this gap, the ERA should include:

- ➢ Sub-lethal and ultra-low exposure effects
- ➢ Test sequential and repeated pulse designs
- ➢ Account for non-linear dose-responses