Probabilistic assessment of MP exposure, effect and risk for the environment and human health

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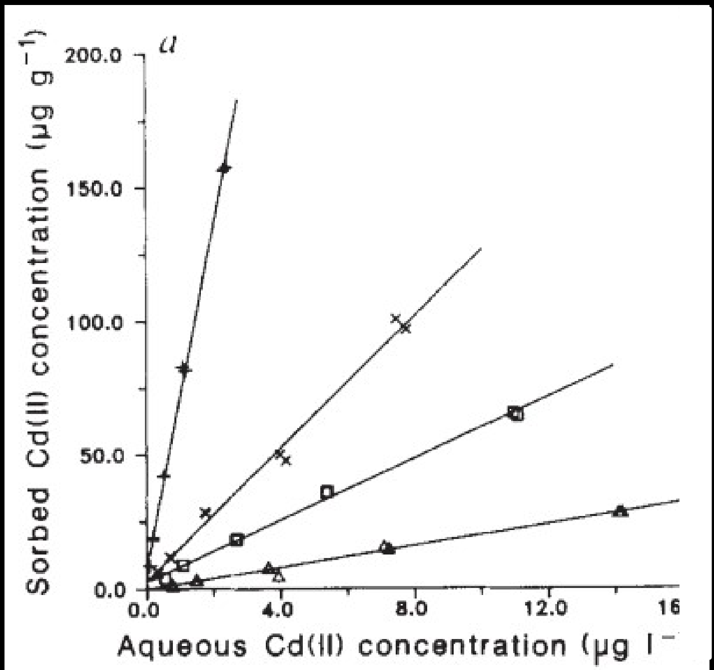
A brief history of 'X-axis questions'

Comans et al, *Nature,* 1988:

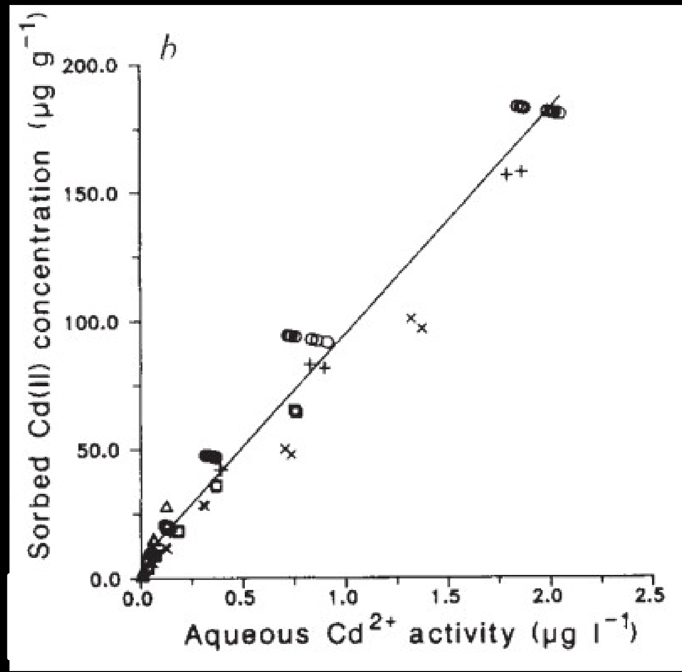


Studying uptake of cadmium …

Reaction	
Cd^{2+}	$= Cd^{2+}$
$Cd^{2+} + OH^-$	$= Cd(OH)^+$
$Cd^{2+} + 2OH^-$	$= Cd(OH)_2$
$Cd^{2+} + 3OH^-$	$= Cd(OH)_3^-$
$Cd^{2+} + 4OH^-$	$= Cd(OH)_4^{2-}$
$Cd^{2+} + F^-$	$= CdF^+$
$Cd^{2+} + 2F^-$	$= CdF_2$
$Cd^{2+} + Cl^-$	$= CdCl^+$
$Cd^{2+} + 2Cl^-$	$= CdCl_2$
$Cd^{2+} + 3Cl^-$	$= CdCl_3^-$
$Cd^{2+} + 4Cl^-$	$= CdCl_4^{2-}$
$Cd^{2+} + SO_4^{2-}$	$= CdSO_4$
$Cd^{2+} + 2SO_4^{2-}$	$= Cd(SO_4)_2^{2-}$
$Cd^{2+} + 3SO_4^{2-}$	$= Cd(SO_4)_3^{4-}$
$Cd^{2+} + 4SO_4^{2-}$	$= Cd(SO_4)_4^{6-}$
$Cd^{2+} + CO_3^{2-}$	$= CdCO_3$
$Cd^{2+} + CO_3^{2-}$	$= CdCO_3(s)$
$Cd^{2+} + 2OH^-$	$= Cd(OH)_2(s)$

New X-axis

X-axis
= f(pH
Ionic strength
Ligands
Competing cations..)



Can we do such things for (microplastic) particles ?

Comans *et al. Nature,* 1988

Two 'MP examples'

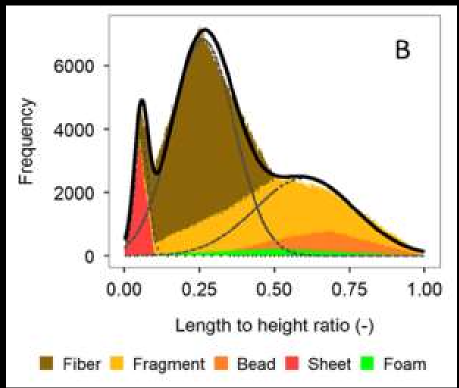
Ecological risk assessment for freshwaters

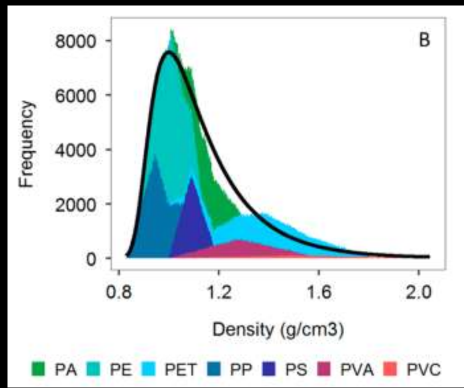
Koelmans, A.A., Redondo-Hasselerharm, P.E., Mohamed Nur, N.H., Kooi, M. 2020. Solving the non-alignment of methods and approaches used in microplastic research in order to consistently characterize risk. *Environ. Sci. Technol.* https://pubs.acs.org/doi/10.1021/acs.est.0c02982

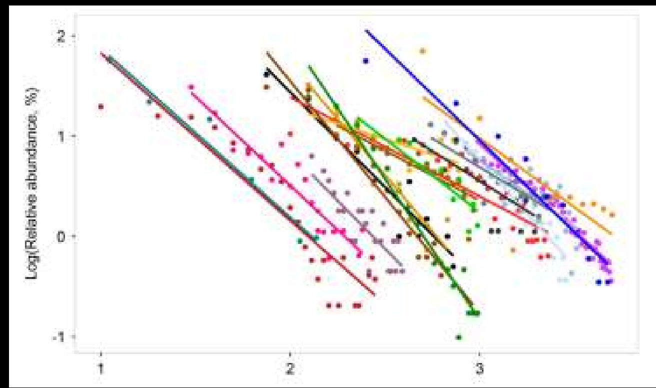
Exposure assessment for humans

Mohamed Nor, N.H.; Kooi, M.; Diepens, N.J.; Koelmans, A.A. 2020. Lifetime accumulation of microplastic in children and adults, *Submitted.*

Tackle the issue of uncertainty and diversity via probability distributions that capture the '*habits of microplastic in nature*':







Kooi & Koelmans, ES&T Letters, 2019

Ecological risk assessment for freshwaters

Steps taken to get a ‘clean’ assessment:

1. Define problem & effect mechanism
   Weight of evidence approach – only use high QA/QC data
2. Select and align exposure data
   Based on probability density function for size
3. Select and align effect data – build SSD
   Based on probability density functions for size, shape and density
4. Align and compare exposure & effect data to characterise risk

1. Define effect mechanisms

Environmental Science & Technology pubs.acs.org/est Critical Review

Table 2. Tiered Weight of Evidence (WOE) Approach for Effect Mechanisms Reported in 105 Studies, By Number of Studies That (a) Frame a Mechanism as "Suggested", (b) Frame a Mechanism as "Demonstrated", (c) Fulfil the Three Quality Assurance Criteria (Score >0) Considered Most Relevant to Identify Effect Mechanisms (Nos. 6, 11, 14), and (d) Average Score According to QA/QC of Studies That Fulfilled Those Three Quality Assurance Criteria

no.	description of mechanism explaining adverse effect	suggested[a]	demonstrated[b]	number of studies that fulfill criteria nos 6, 11, and 14[c]	average score of studies that fulfill criteria nos. 6, 11, and 14 QA/QC[d]
1	inhibited food assimilation and/or decreased nutritional value	32	9	5	21.4
2	internal physical damage	20	7	3	21.0
3	external physical damage	8	4	2	24.0
4	oxidative stress	6	8	1	16.0
5	disturbance of essential processes that affect physiology	8	3	0	
6	adjustment of energy metabolism to cope with mp	1	2	0	
7	microbial imbalance	2	1	0	
8	leaching additives or chemicals	14	0		
9	(cellular) stress	8	0		
10	effects of surface properties	2	0		
	total	100	34	11	

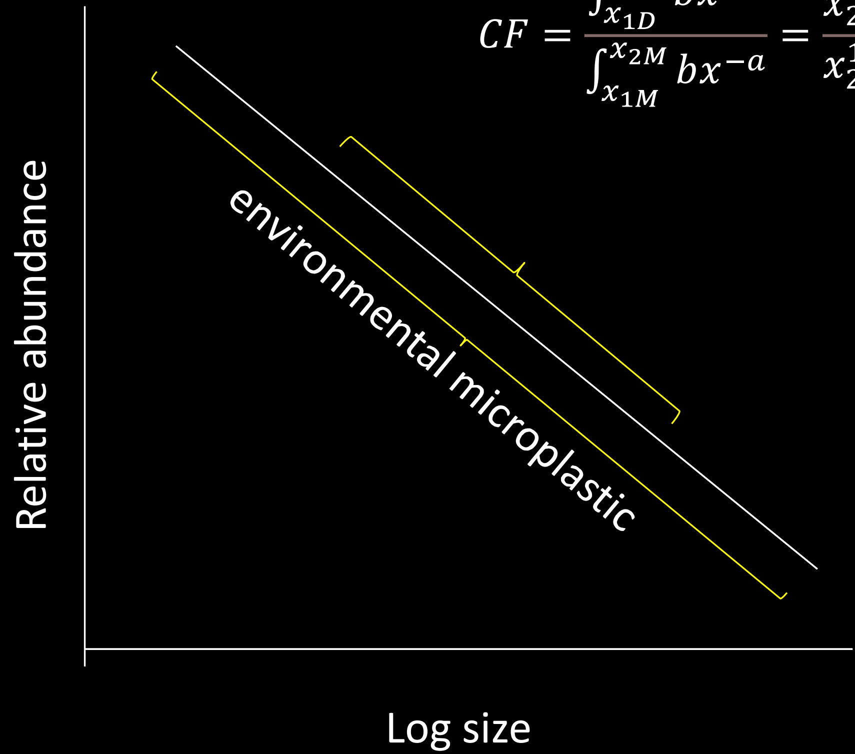
→ Risk assessment tuned to the MP 'food dilution' effect

De Ruijter *et al.* ES&T, 2020

2. Align exposure data

'default' microplastic 1 to 5000 μm

$$CF = \frac{\int_{x_{1D}}^{x_{2D}} bx^{-a}}{\int_{x_{1M}}^{x_{2M}} bx^{-a}} = \frac{x_{2D}^{1-a} - x_{1D}^{1-a}}{x_{2M}^{1-a} - x_{1M}^{1-a}}$$



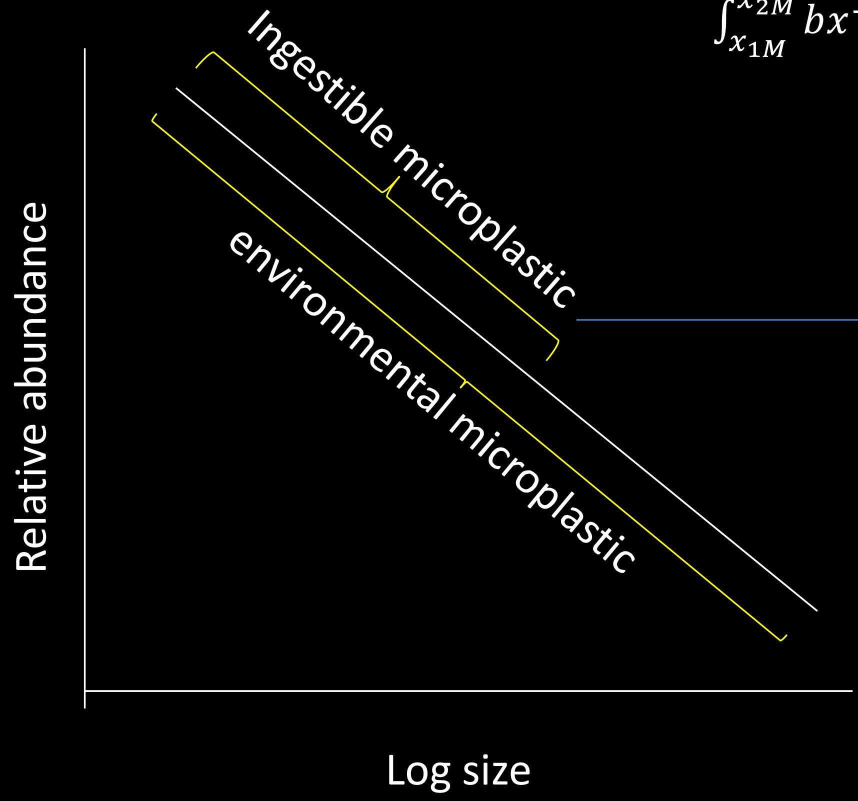
Koelmans *et al*, ES&T, 2020

2. Align effect data - I

'default, all' microplastic 1 to 5000 μm

bioavailable microplastic

$$CF = \frac{\int_{x_{1D}}^{x_{2D}} bx^{-a}}{\int_{x_{1M}}^{x_{2M}} bx^{-a}} = \frac{x_{2D}^{1-a} - x_{1D}^{1-a}}{x_{2M}^{1-a} - x_{1M}^{1-a}}$$

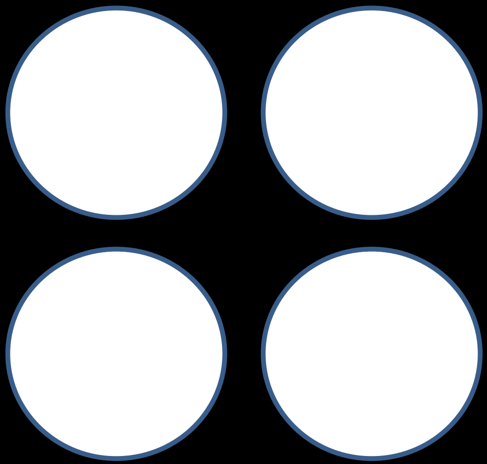


But that's still <u>highly *diverse*</u>
≠
The monodisperse MP used in lab tests

Koelmans *et al*, ES&T, 2020

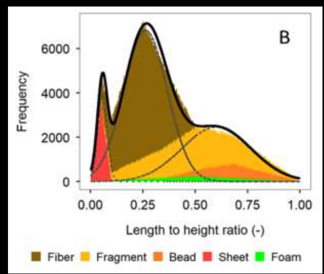
2. Alignment of effect data - II

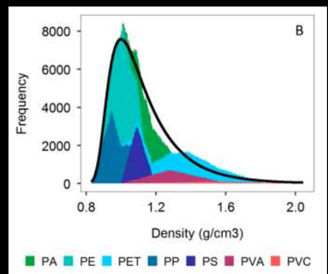
For this particular effect mechanism of food dilution, the metric relevant for effect is not number, not mass, but **ingested volume** (within the bioavailable size range)

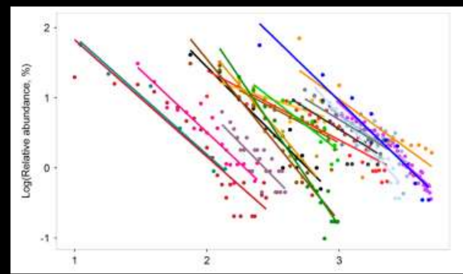


Imagine an effect threshold in the lab of 4 #/L,
Then calculate the ingested volume of the 4 particles → Volume (µm^3)

Calculate how many *ingestible* environmental (diverse) particles (here: 6) fit in that same Volume,
while that diversity is defined via realistic *distributions*

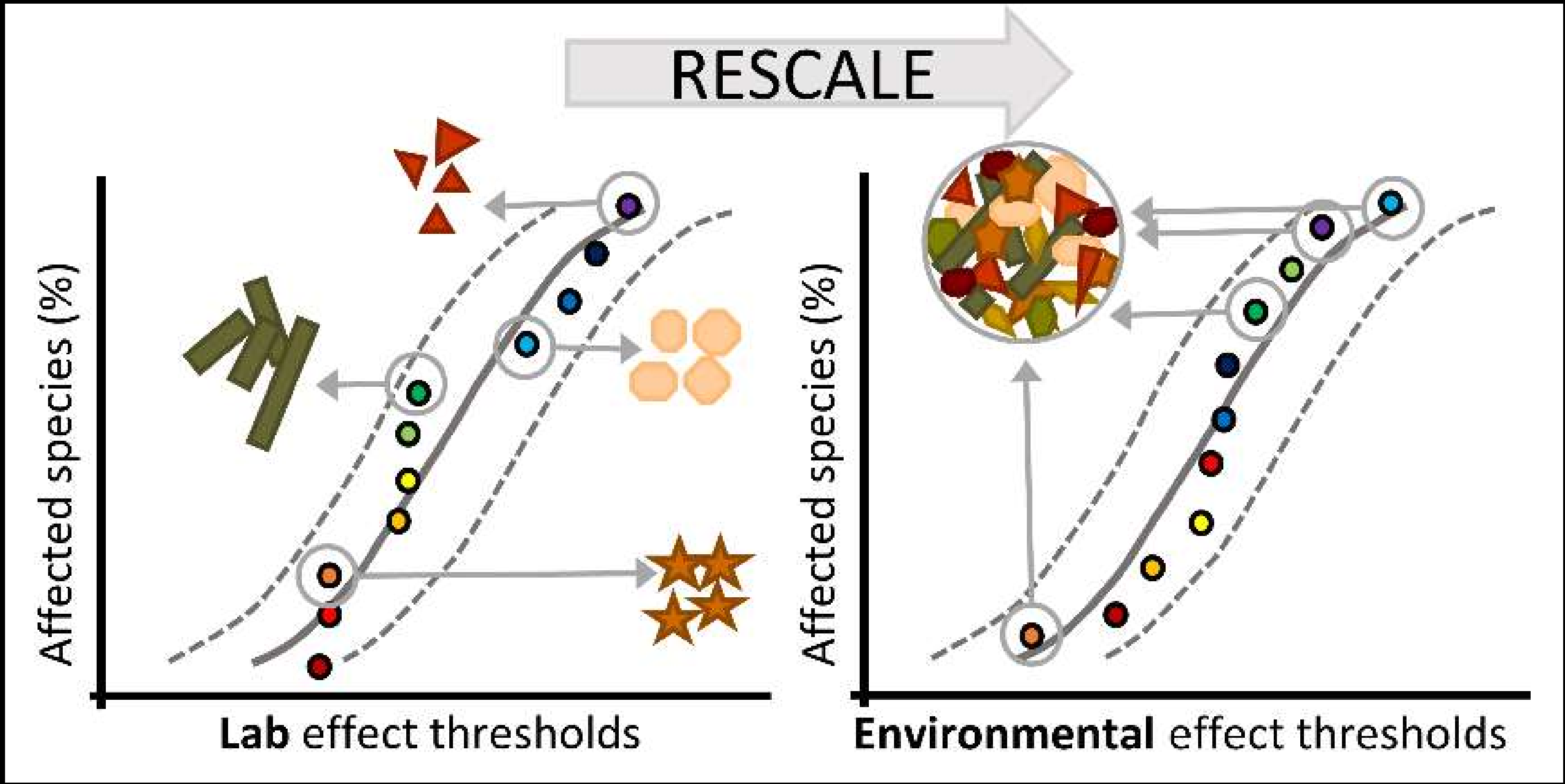


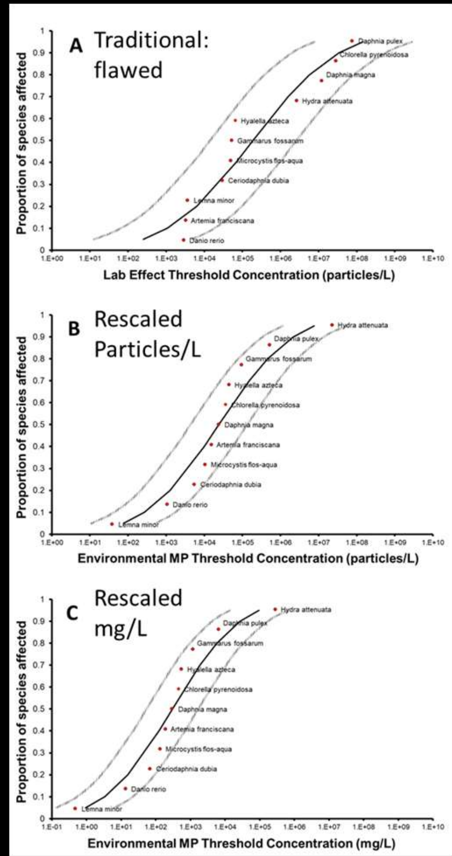




Koelmans *et al*, ES&T, 2020

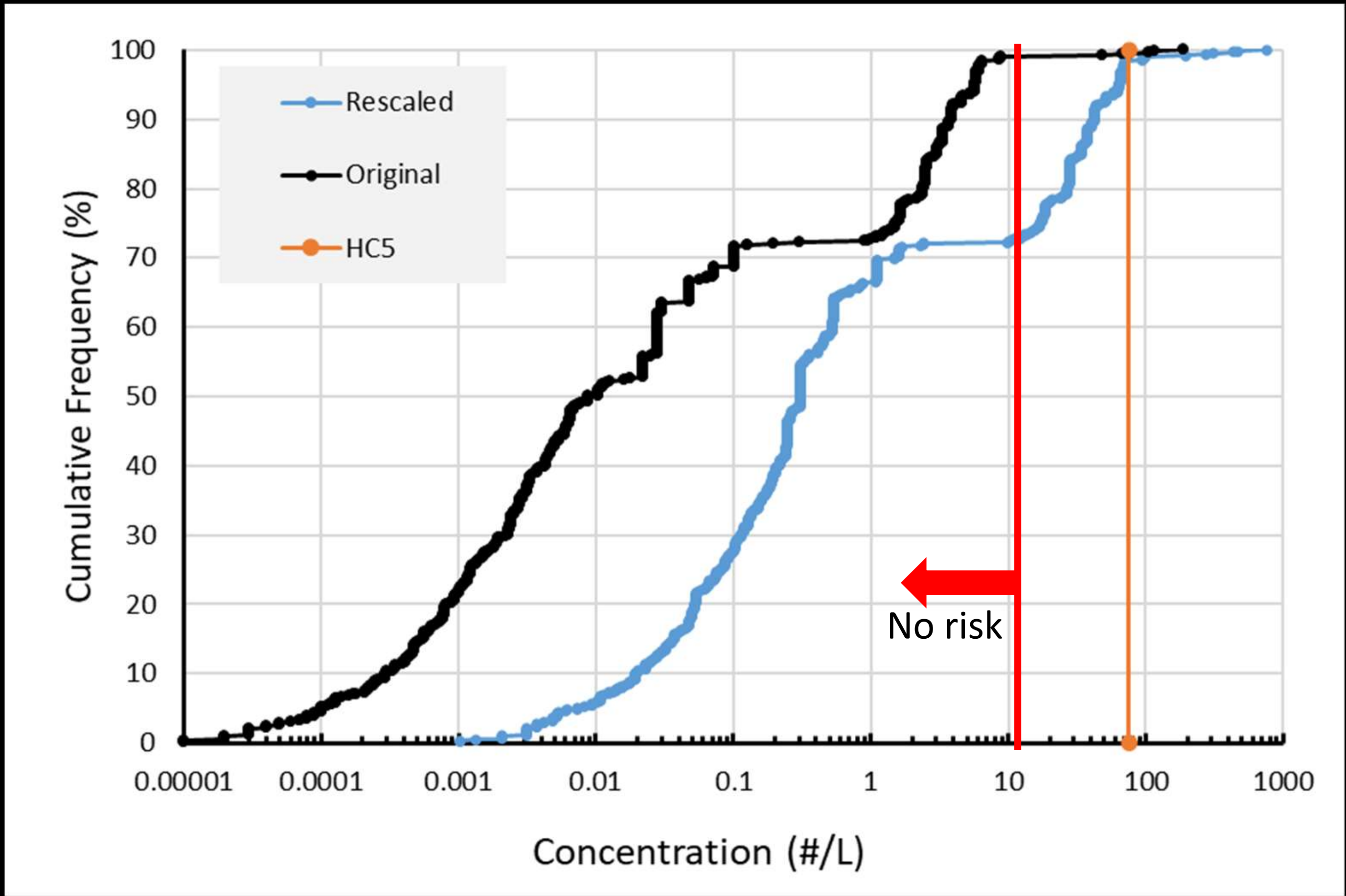
2. Alignment of effect data - III





Koelmans *et al*, ES&T, 2020

3. Risk characterisation



Koelmans *et al*, ES&T, 2020

Exposure: Global surface water data from Koelmans *et al. Water Research*, 2019.

Risk characterisation

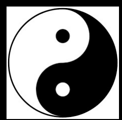
1.5% of these reported concentrations would be at risk

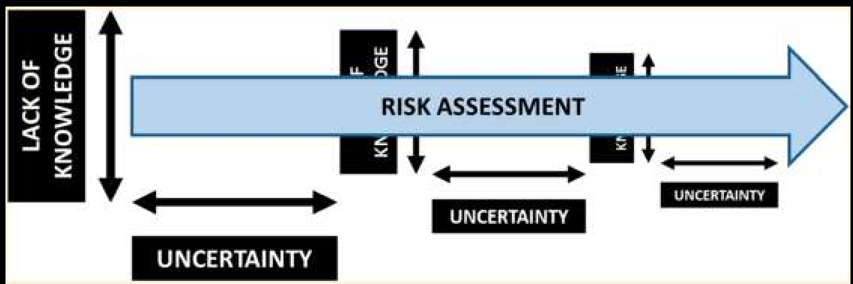
If we take the lower bound of the 95% CI (11 #/L), risk would be indicated for **28%** of the locations

Key features:

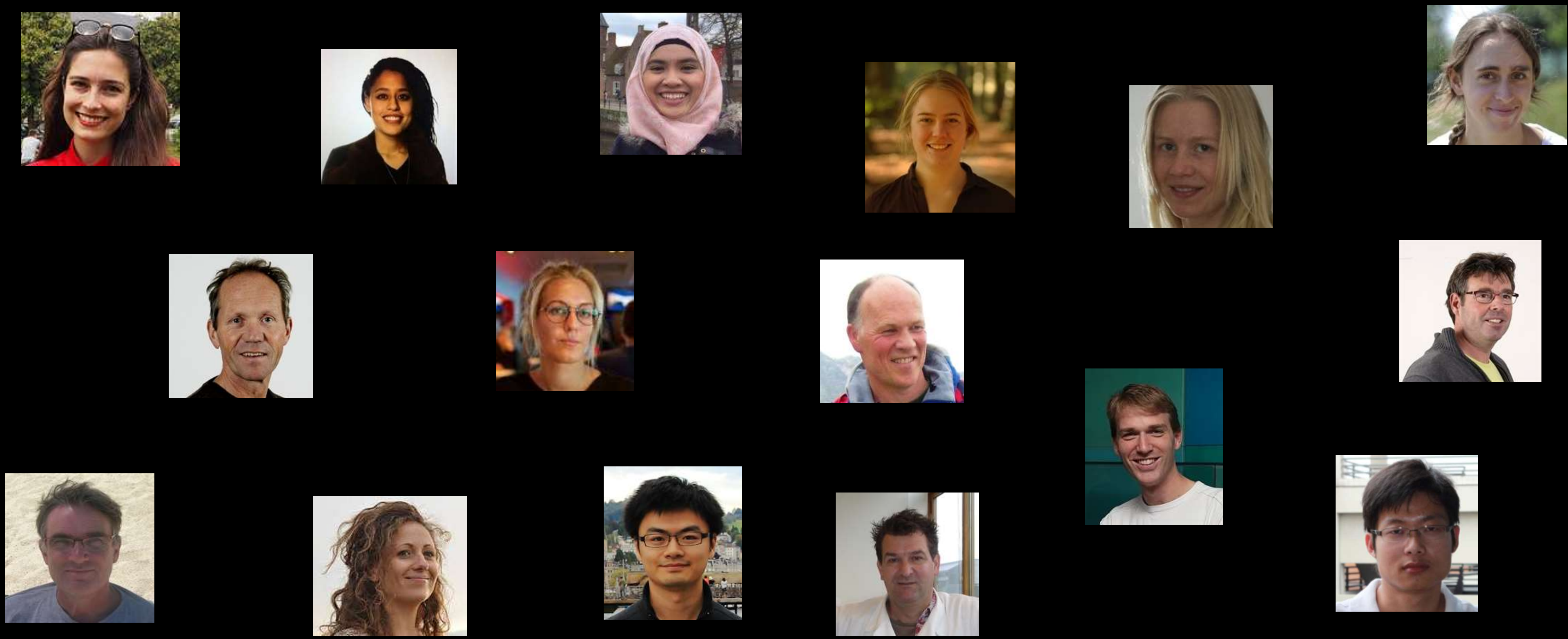
- All data for 'environmental MP'
- All data aligned w.r.t. sizes, types, effect mechanism
- Only high QA/QC

Prospect

- Workflow 1: Method harmonisation & technical innovations & data collection are likely to give best accuracy w.r.t. exposure, hazard and risk data - demands patience
- Workflow 2: pragmatic workarounds for alignment of data and probabilistic assessments - considerable uncertainties
- Hybrid approach:  (rather than parallel) best of both worlds



Thank You !



Paula Redondo, Merel Kooi, Frits Gillissen, Hazimah Mohamed Nor, Christiaan Kwadijk, Miquel Lurling, Noël Diepens, John Beijer, Edwin Peeters, Ellen Besseling, Enya Hermsen, Jeroen de Klein, Vera de Ruijter, Svenja Mintenig, Xiangzhen Kong, Changgui Pan