A field-based approach to linking biological responses of freshwater organisms to sediment contamination by metals

Iwan Jones

John Murphy, Adrian Collins, Kate Spencer, Philip Rainbow, Abby Moorhouse, Victor Aguillera, Paul Edwards, Fred Parsonage, Hugh Potter, Paul Whitehouse

The Coal Authority

Department for Environment Food & Rural Affairs

Environment Agency

Cyfoeth Naturiol Cymru Natural Resources Wales

Queen Mary University of London

NATURAL HISTORY MUSEUM

ADAS

NORTH WYKE ROTHAMSTED RESEARCH

Metals enter the environment in both dissolved and particulate forms

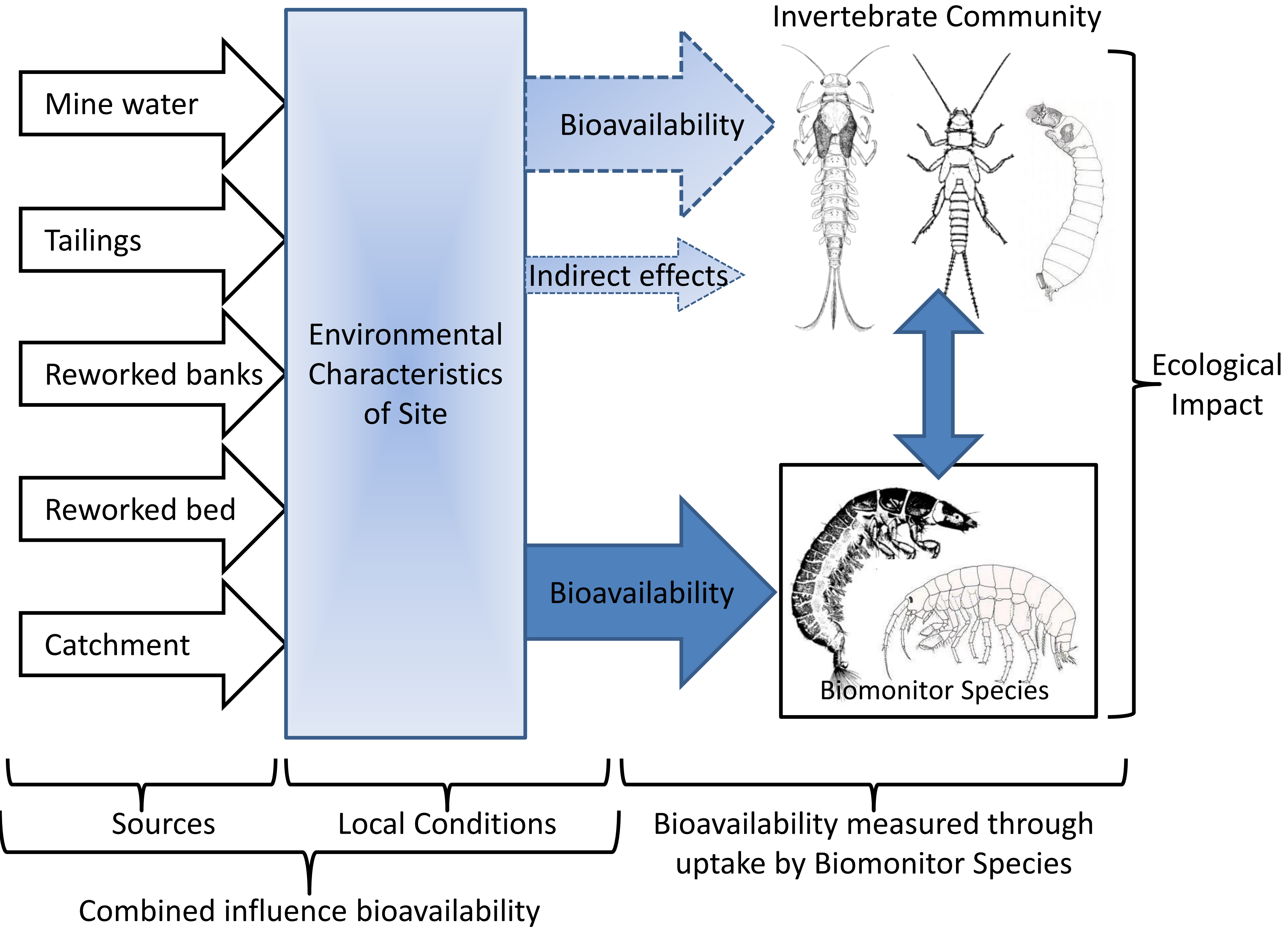
Sources of particulates?

Sources of particulates?

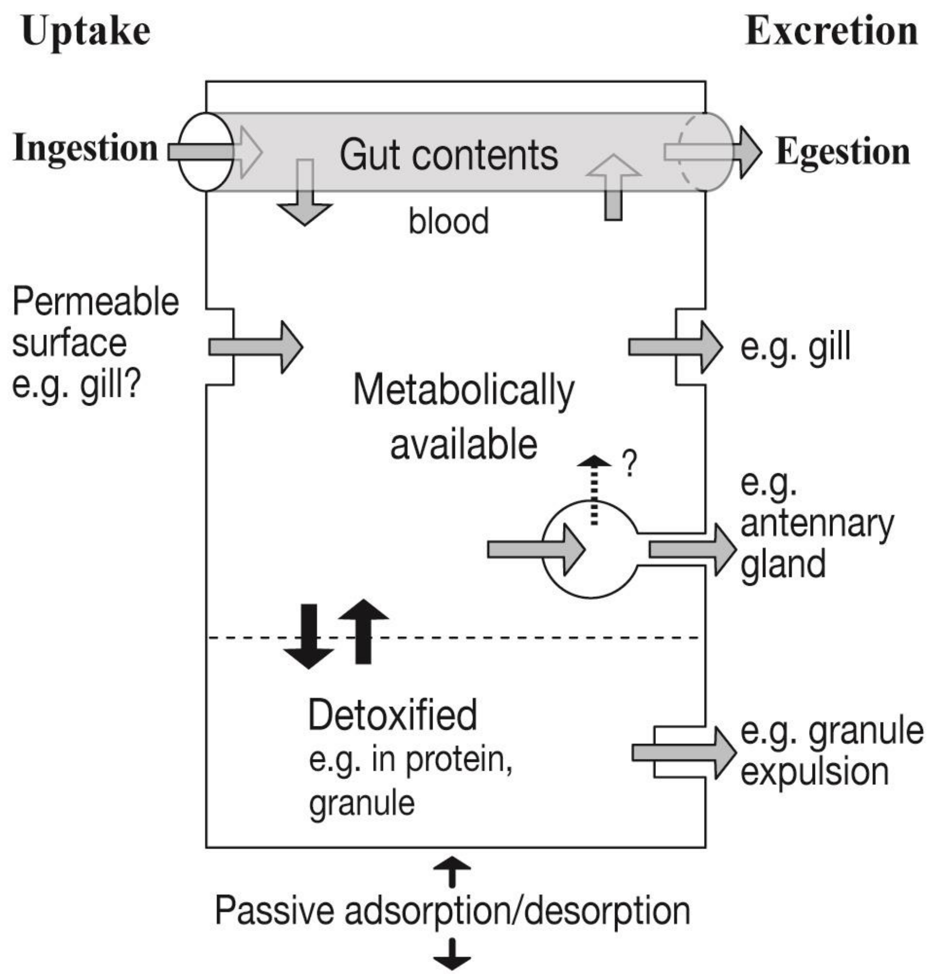
Reworked Riverbanks and Bed

Local conditions affect adsorption, precipitation and dissolution of metals

(e.g. Oxygen, pH, Organic Matter)

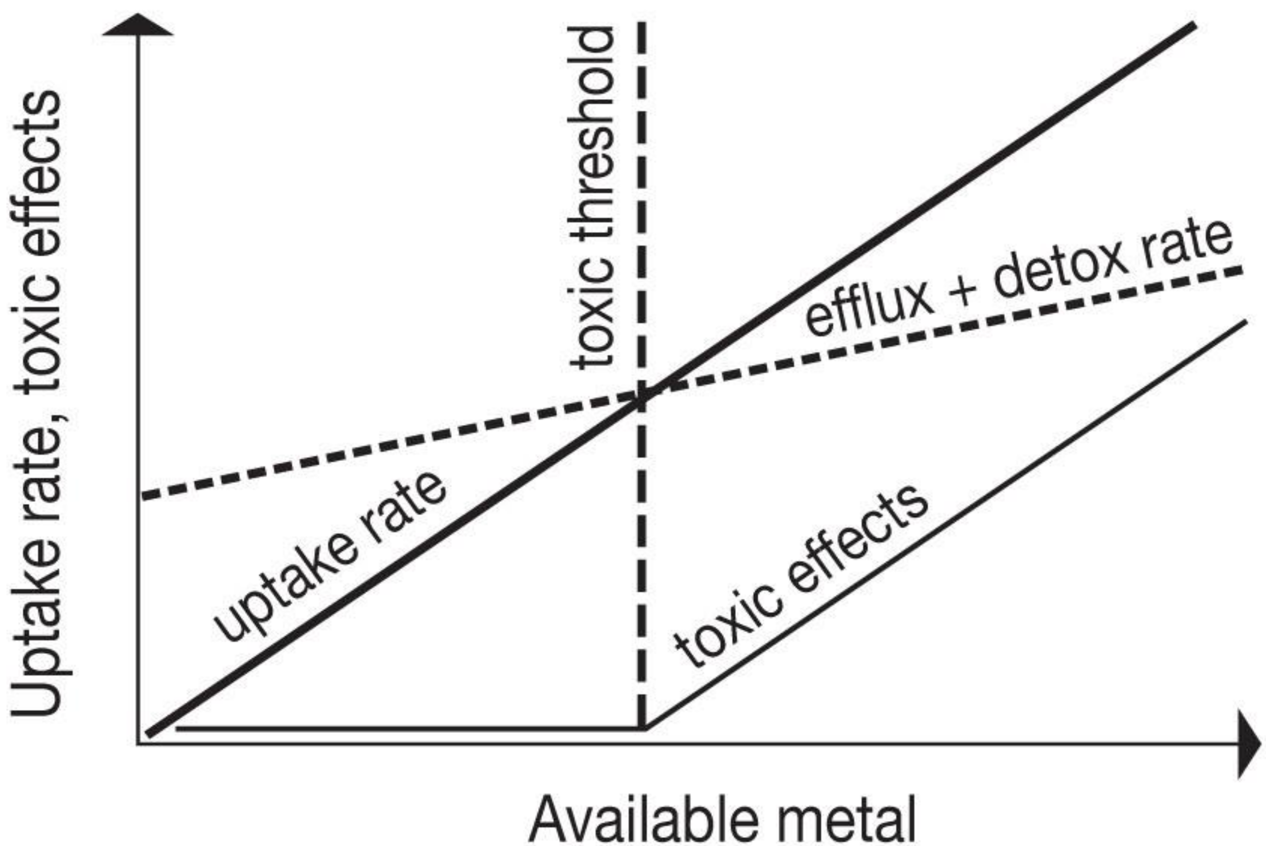

Invertebrate Community
Mine water
Tailings
Reworked banks
Reworked bed
Catchment
Environmental Characteristics of Site
Bioavailability
Indirect effects
Bioavailability
Biomonitor Species
Ecological Impact
Sources
Local Conditions
Bioavailability measured through uptake by Biomonitor Species
Combined influence bioavailability

Routes of uptake and loss of metals



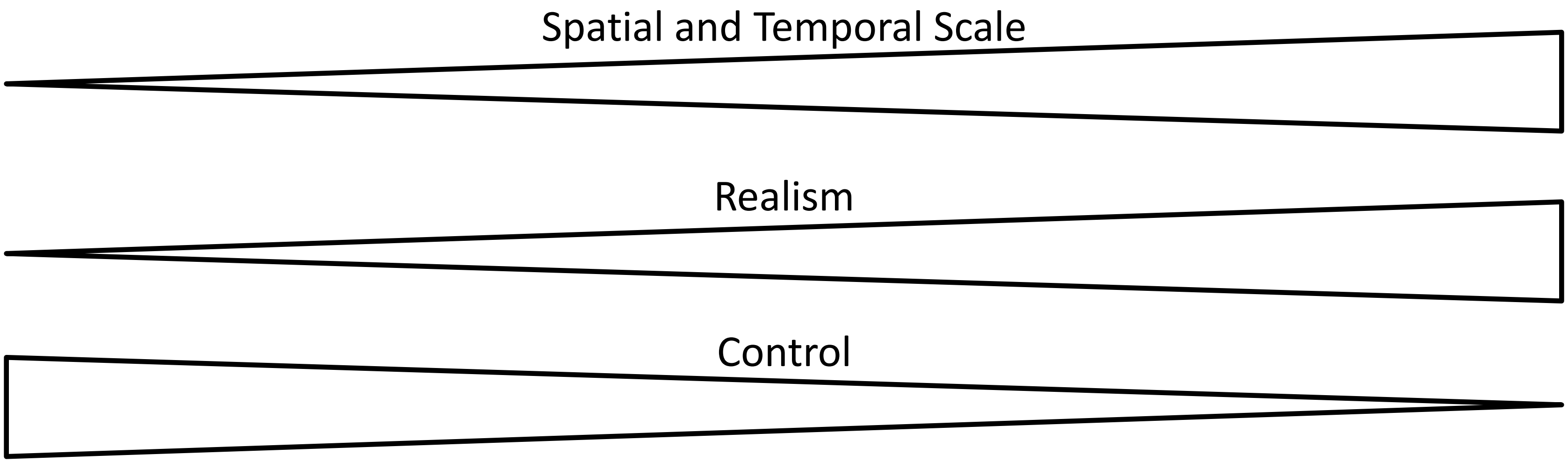
Schematic representation of uptake rate and toxicity

Toxic effects increase with the availability of the trace metal (above a threshold)
Toxic effects occur when the uptake rate exceeds the combined rates of efflux and detoxification



Need Environmentally Safe Limits for both Water and Sediment

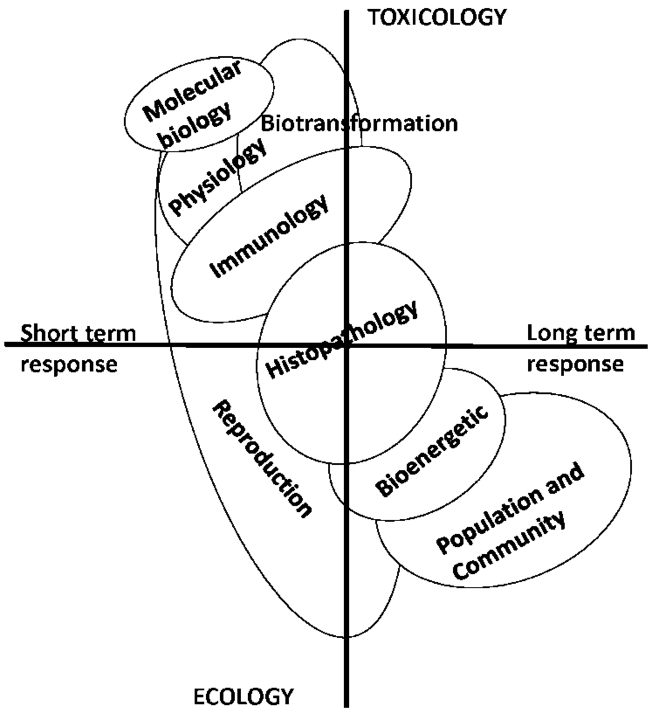
Scale of investigation influences results

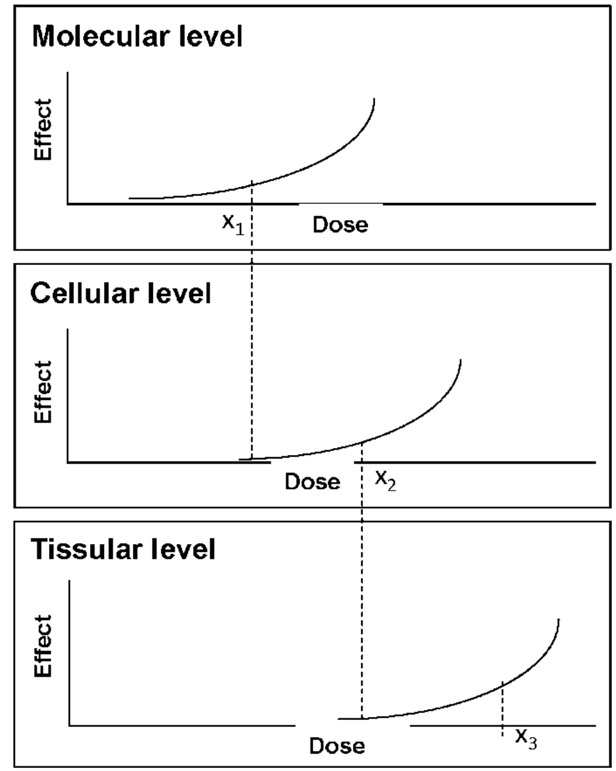


Laboratory

Field Survey

Scales of impact





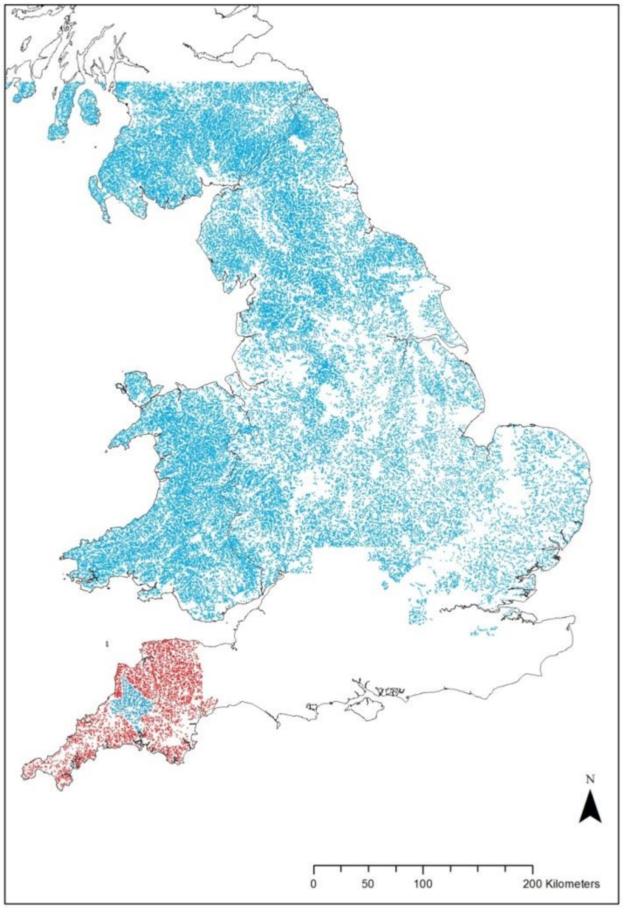
Need to develop relationships at a scale appropriate for management – Water Framework Directive

Three pronged approach:

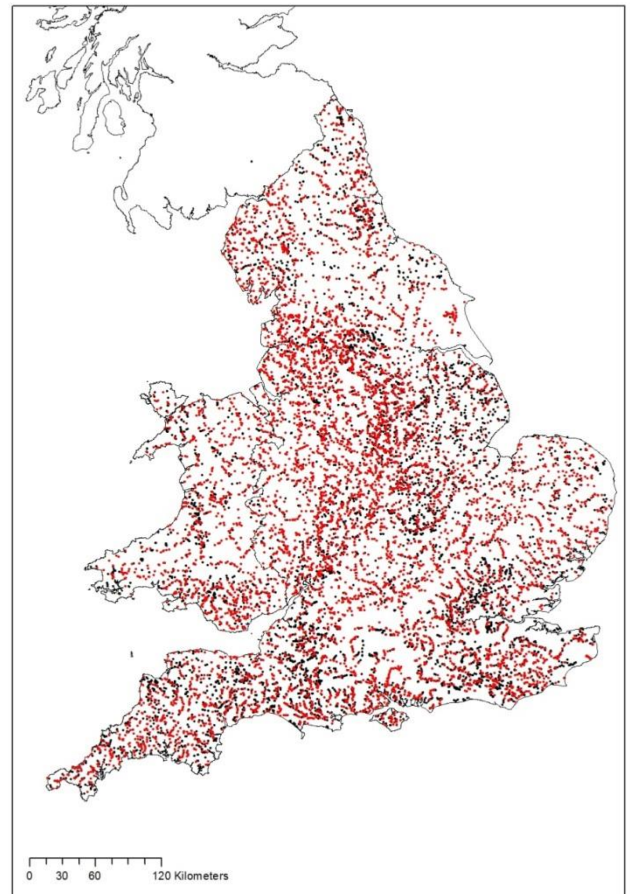
- analysis of existing field data
- new field data collection
- experiments

Compilation and analysis of existing data

G-BASE
(river sediment chemistry)

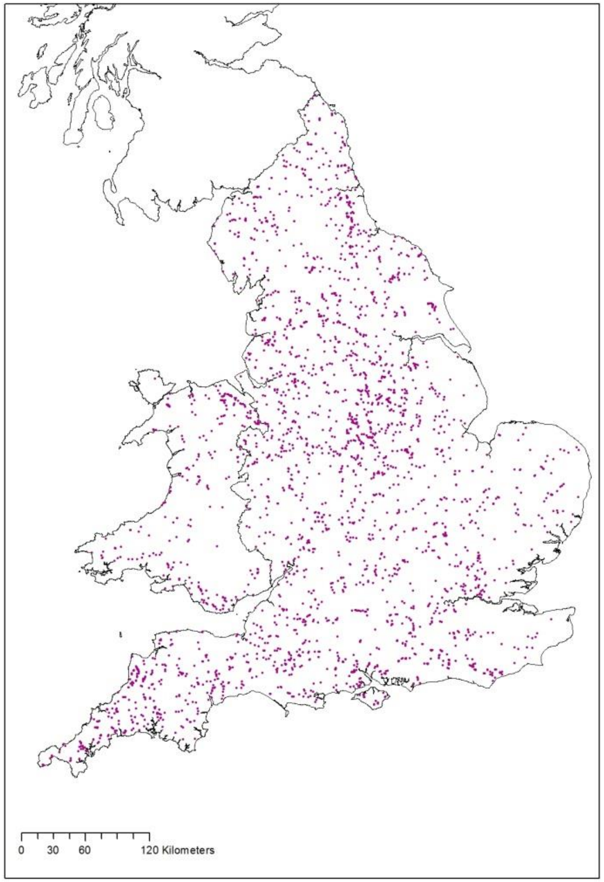


EA & NRW
Invertebrates

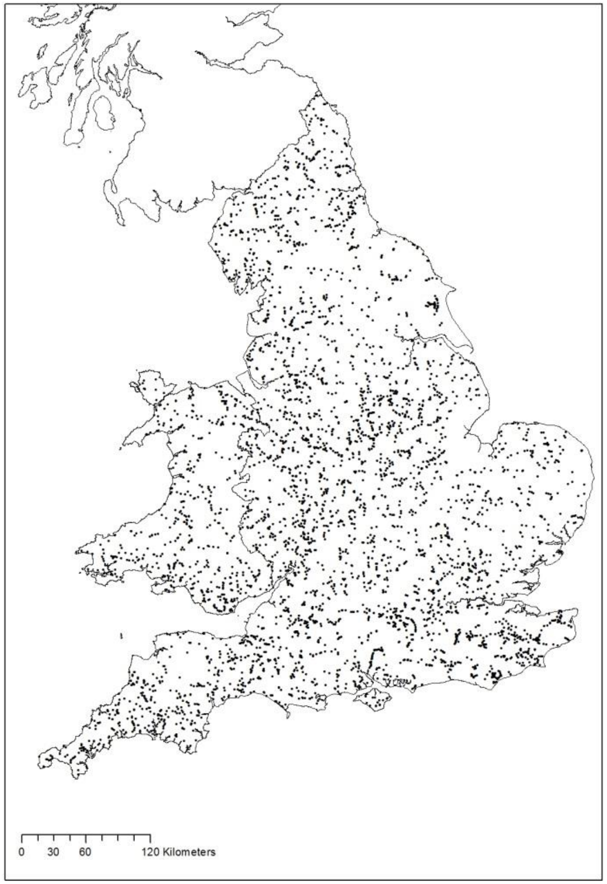


EA & NRW

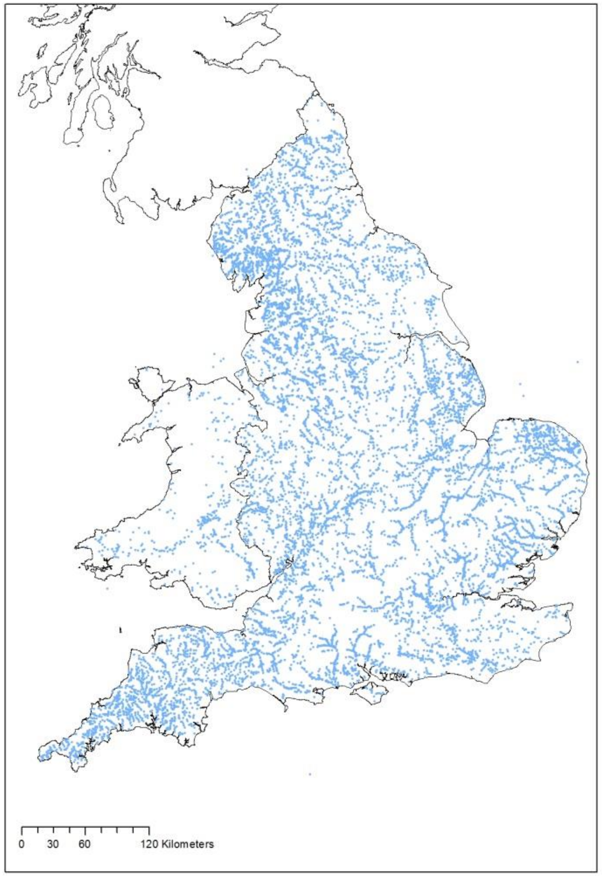
Diatoms



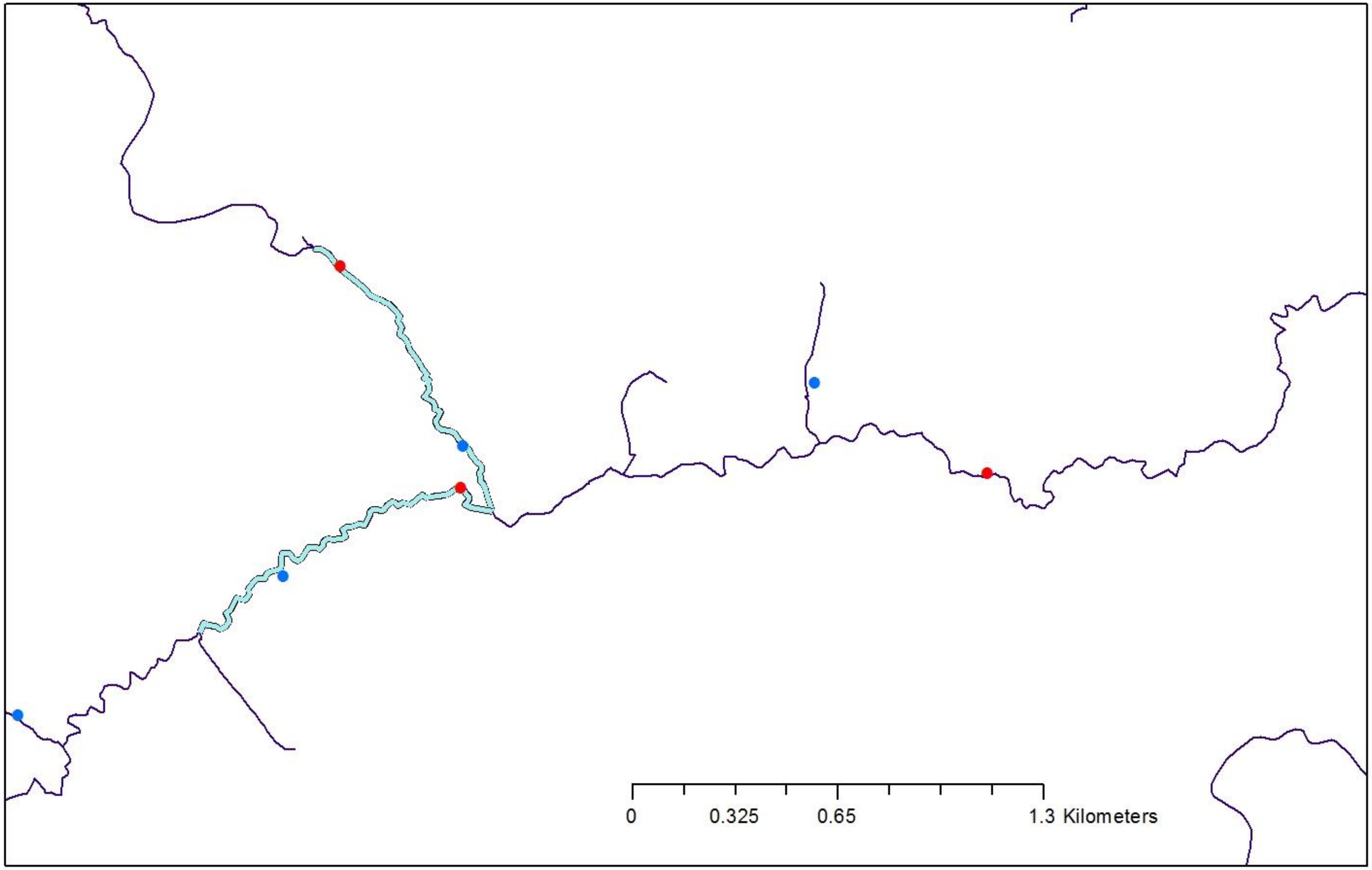
Macrophytes



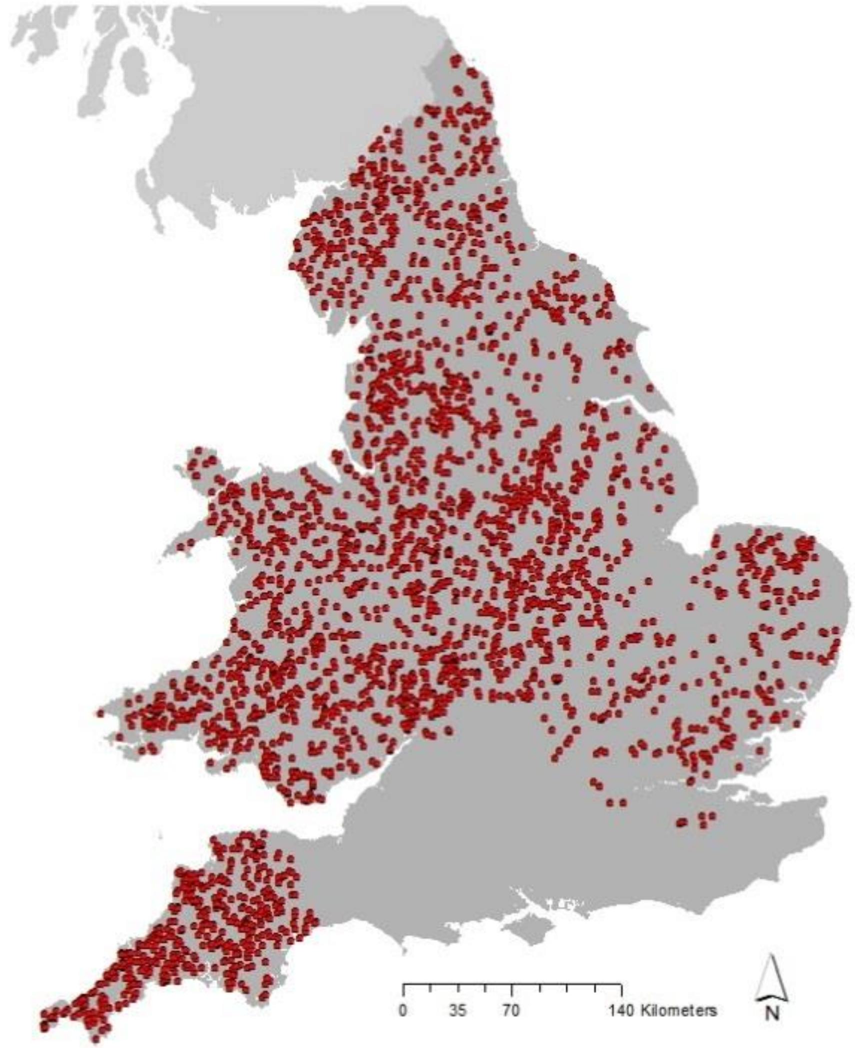
Fish



Spatial and Temporal Matching

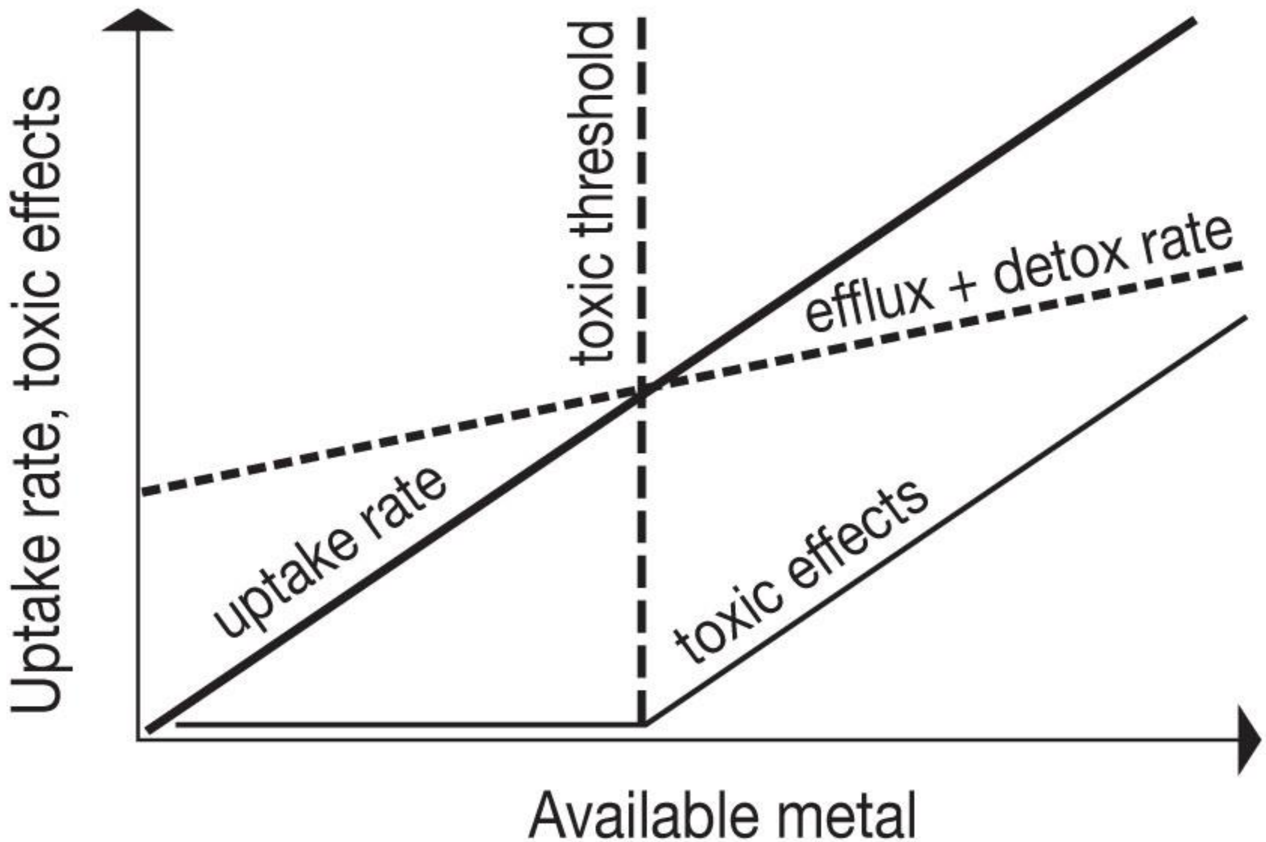


Sites with matched biology and sediment chemistry

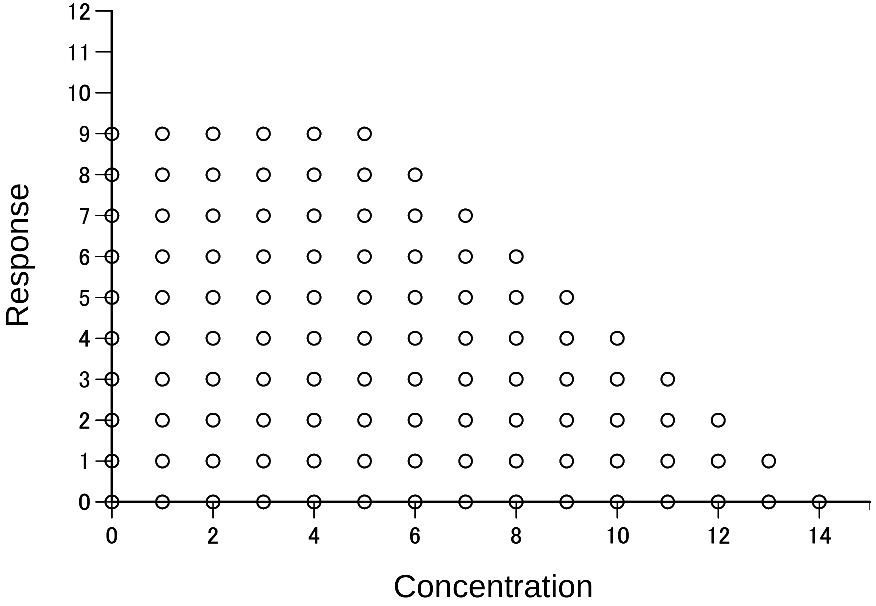


Schematic representation of uptake rate and toxicity

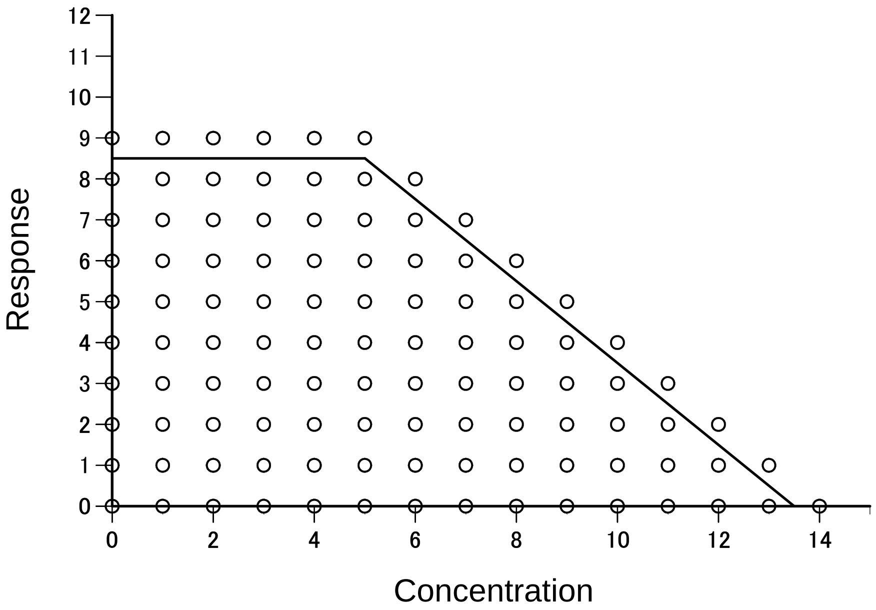
Toxic effects increase with the availability of the trace metal (above a threshold)
Toxic effects occur when the uptake rate exceeds the combined rates of efflux and detoxification



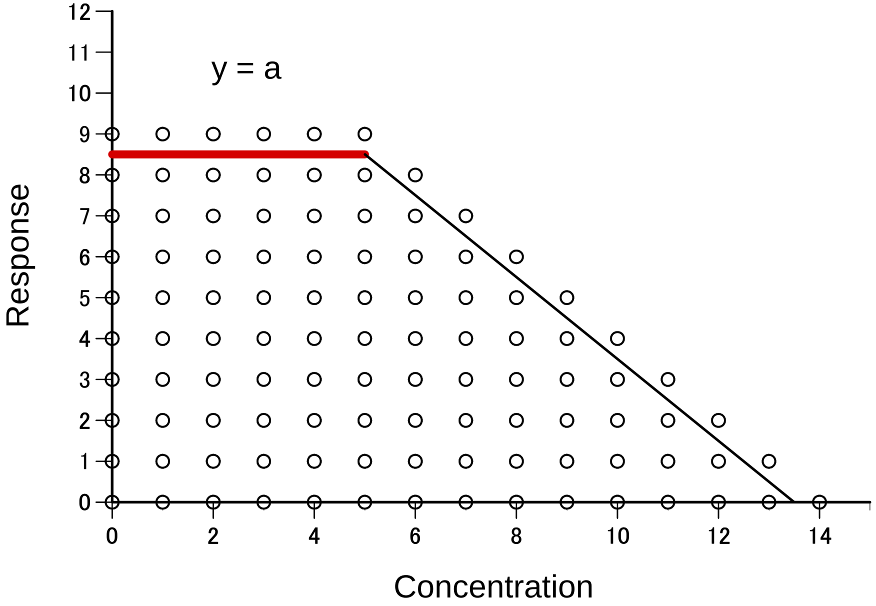
Threshold model



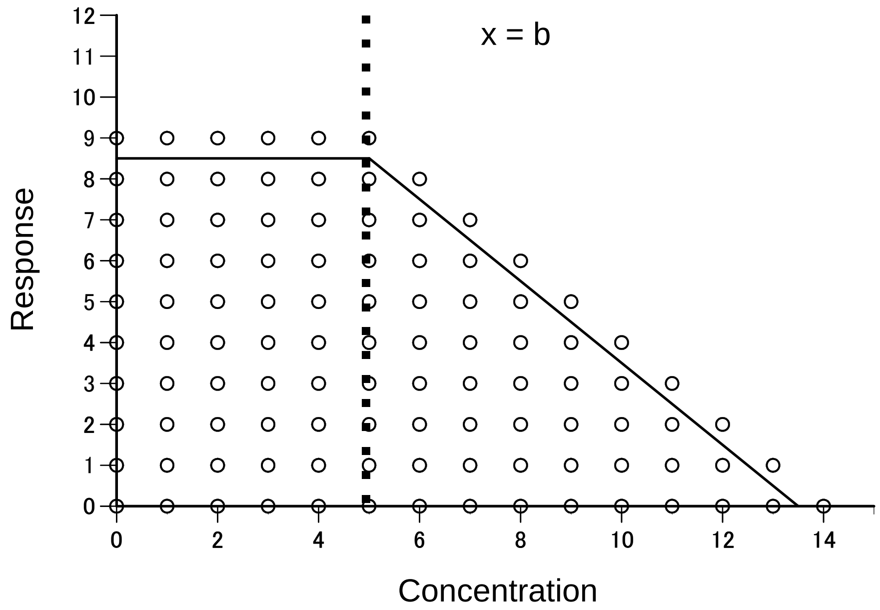
Threshold model



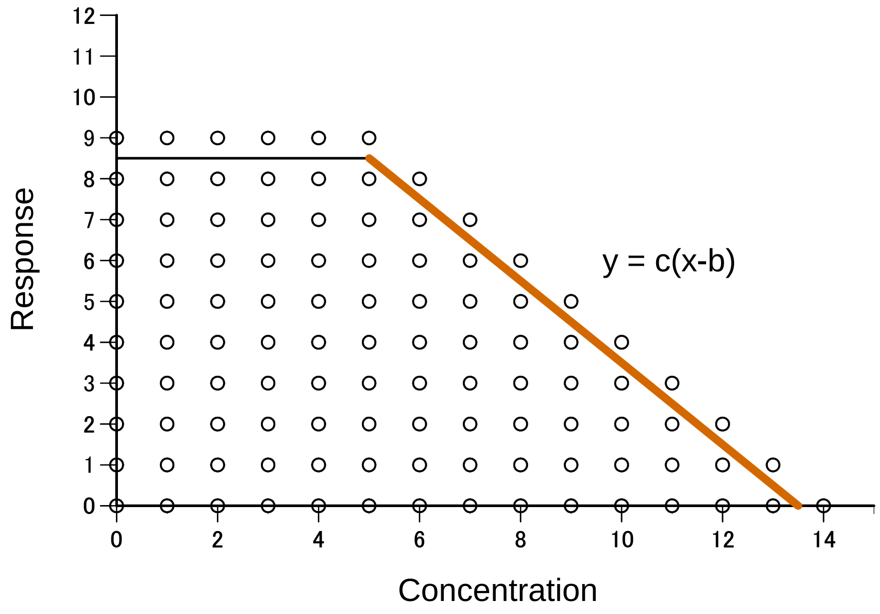
Threshold model



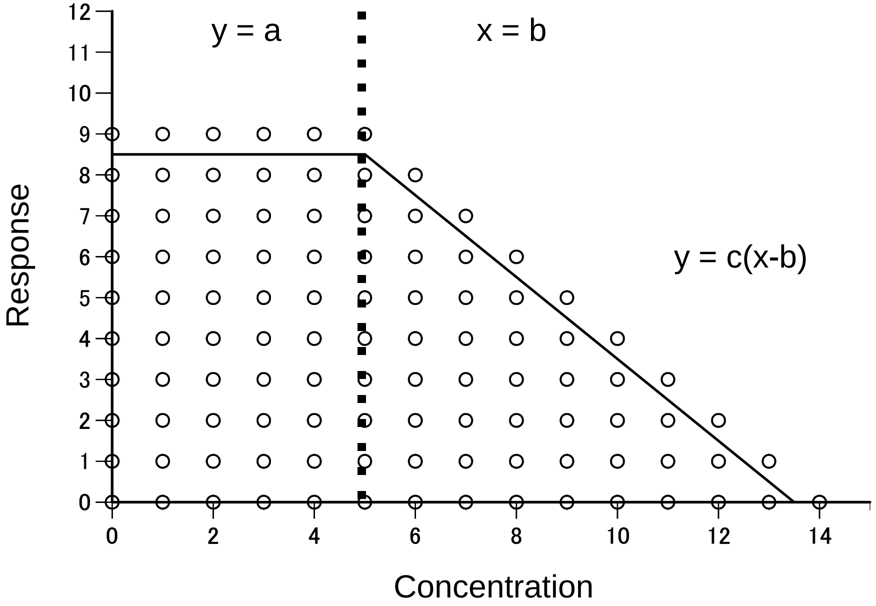
Threshold model



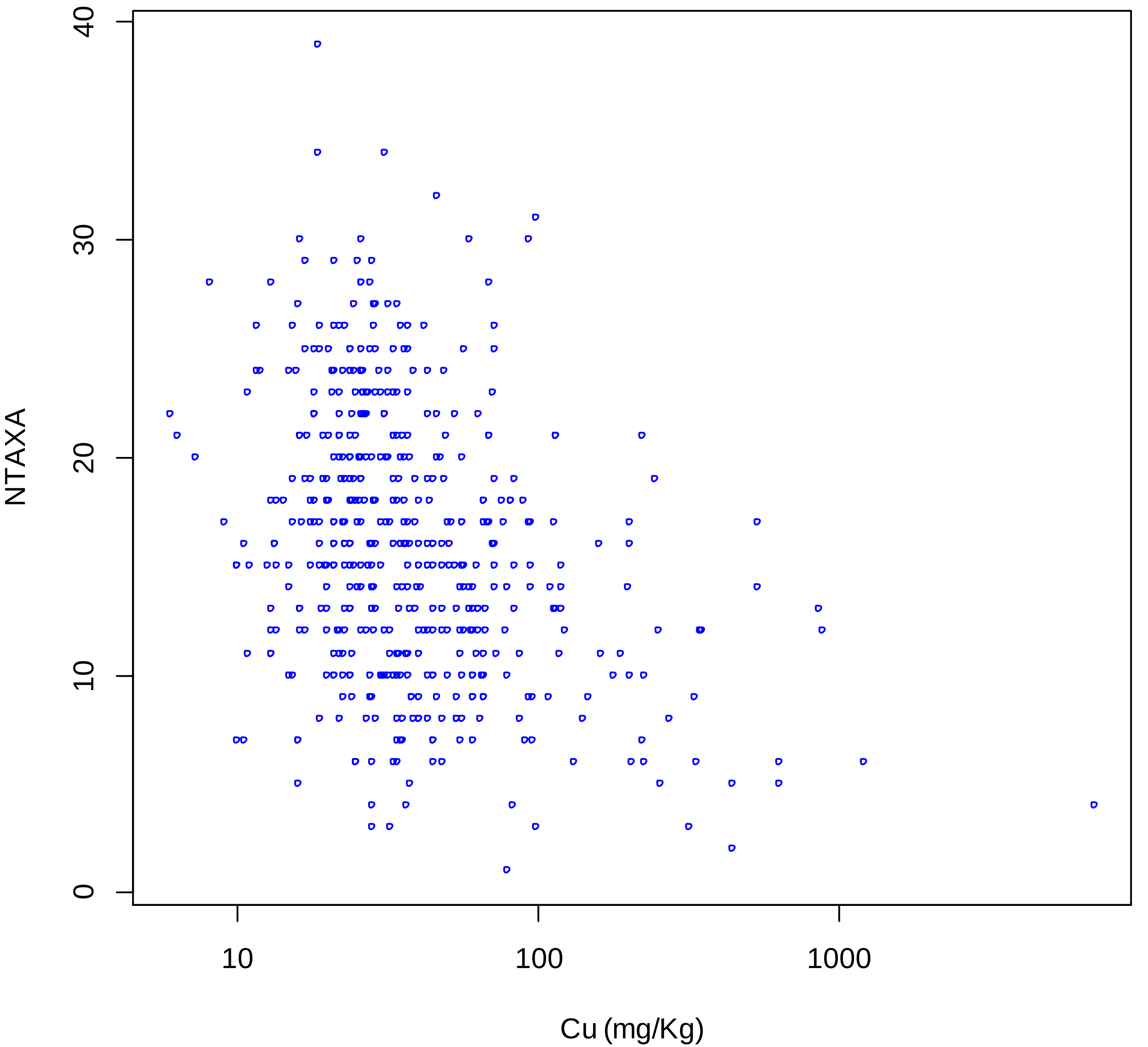
Threshold model



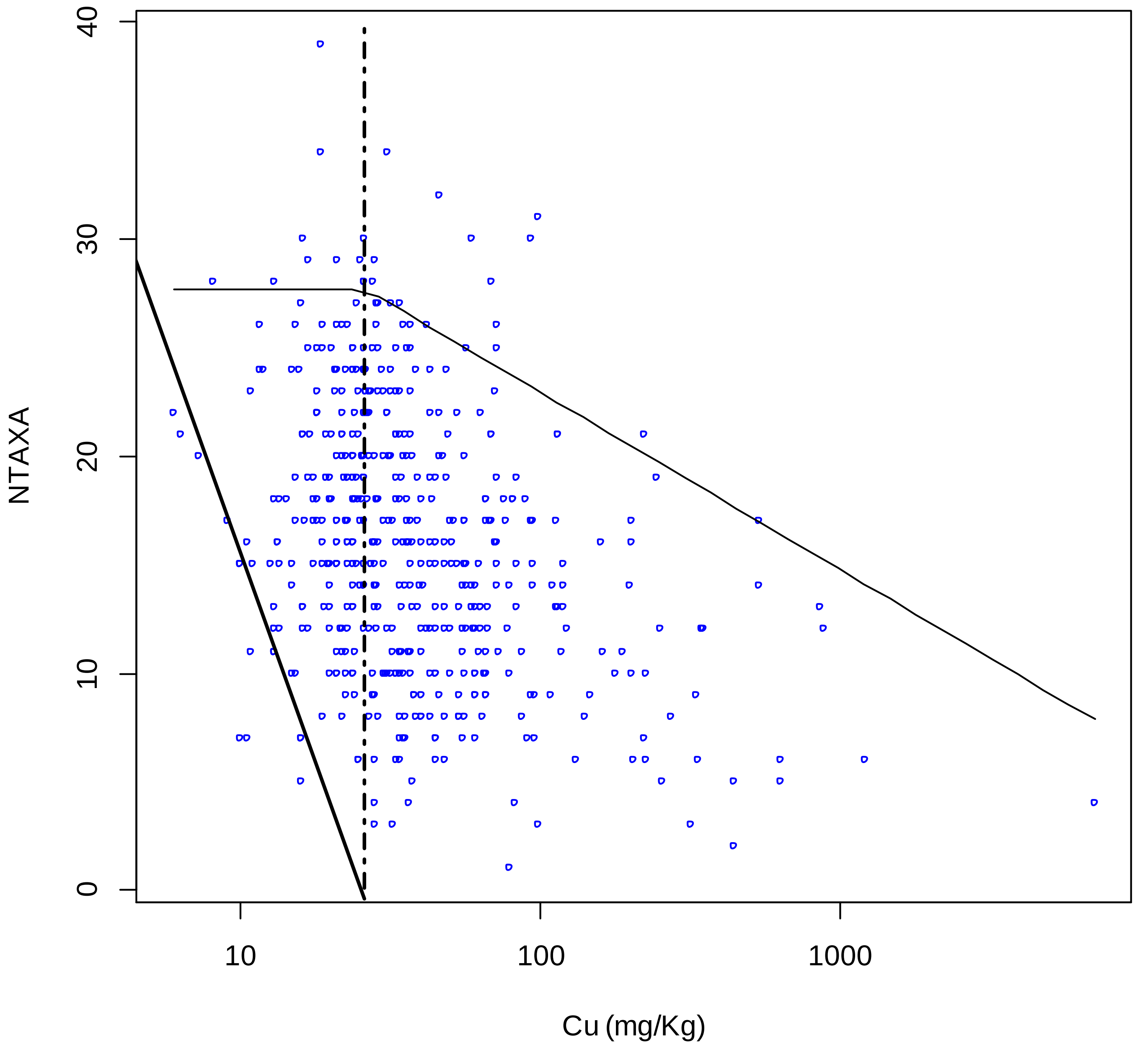
Threshold model



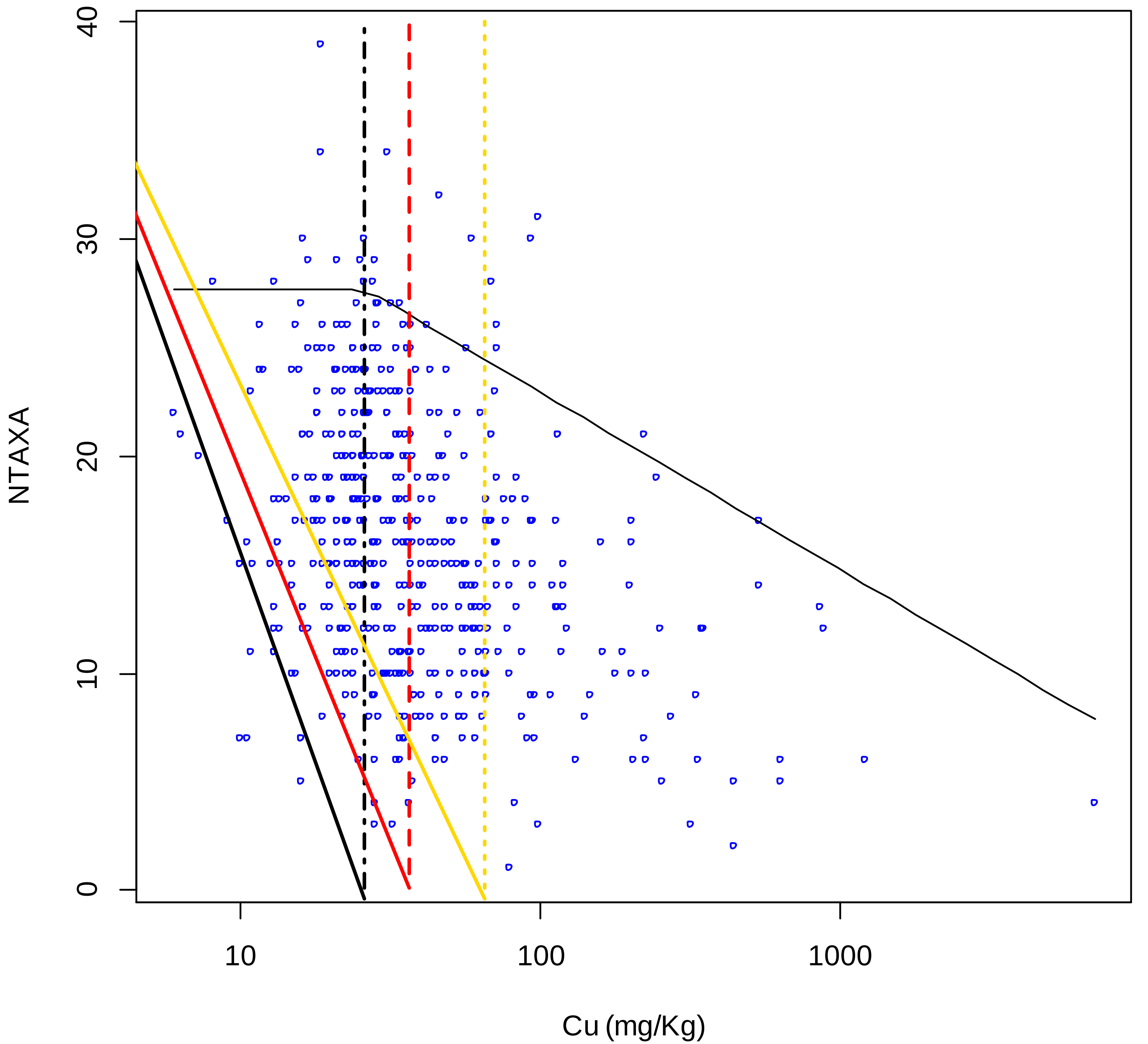
Threshold model: NTAXA - Cu



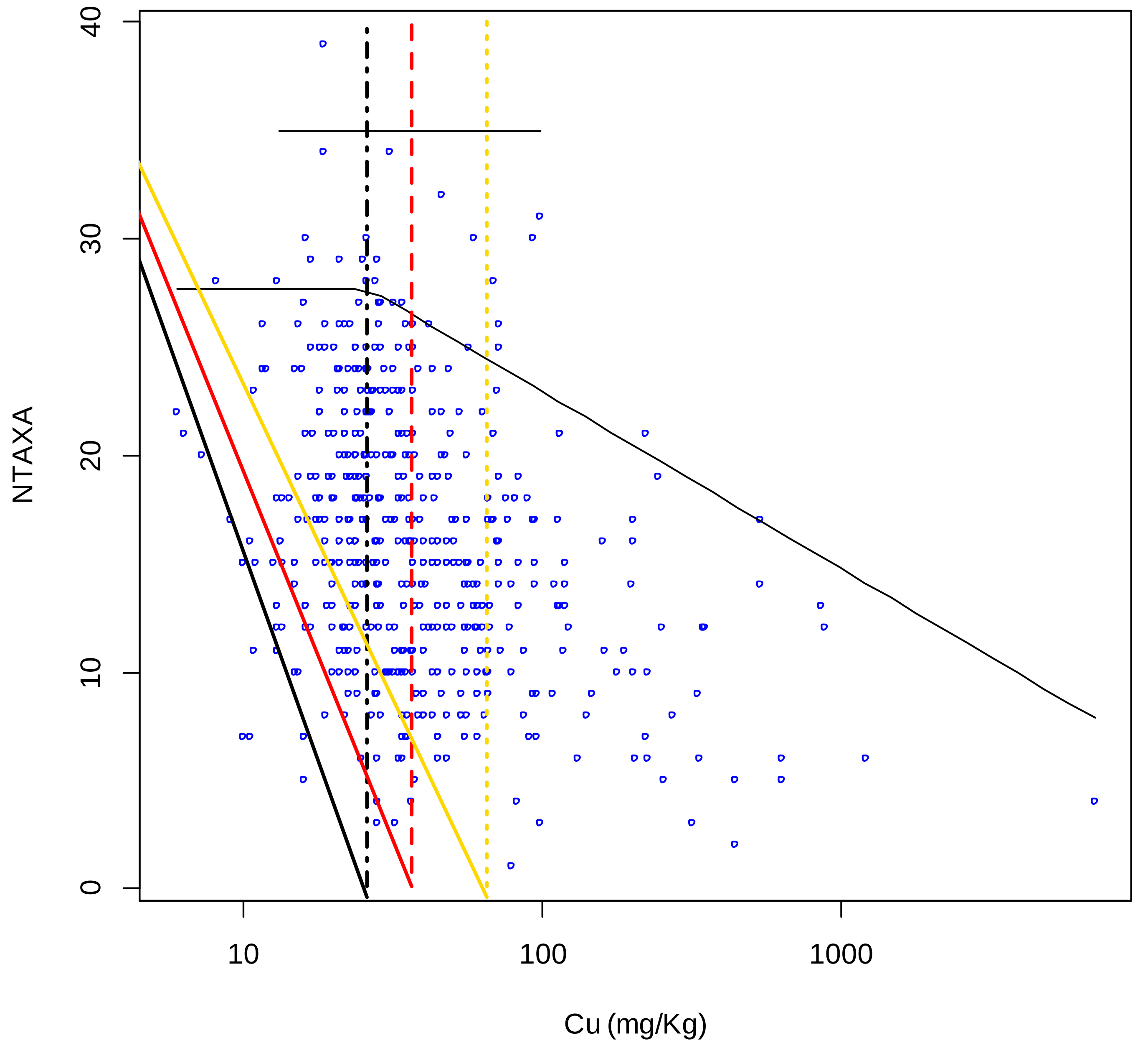
Threshold model: NTAXA - Cu



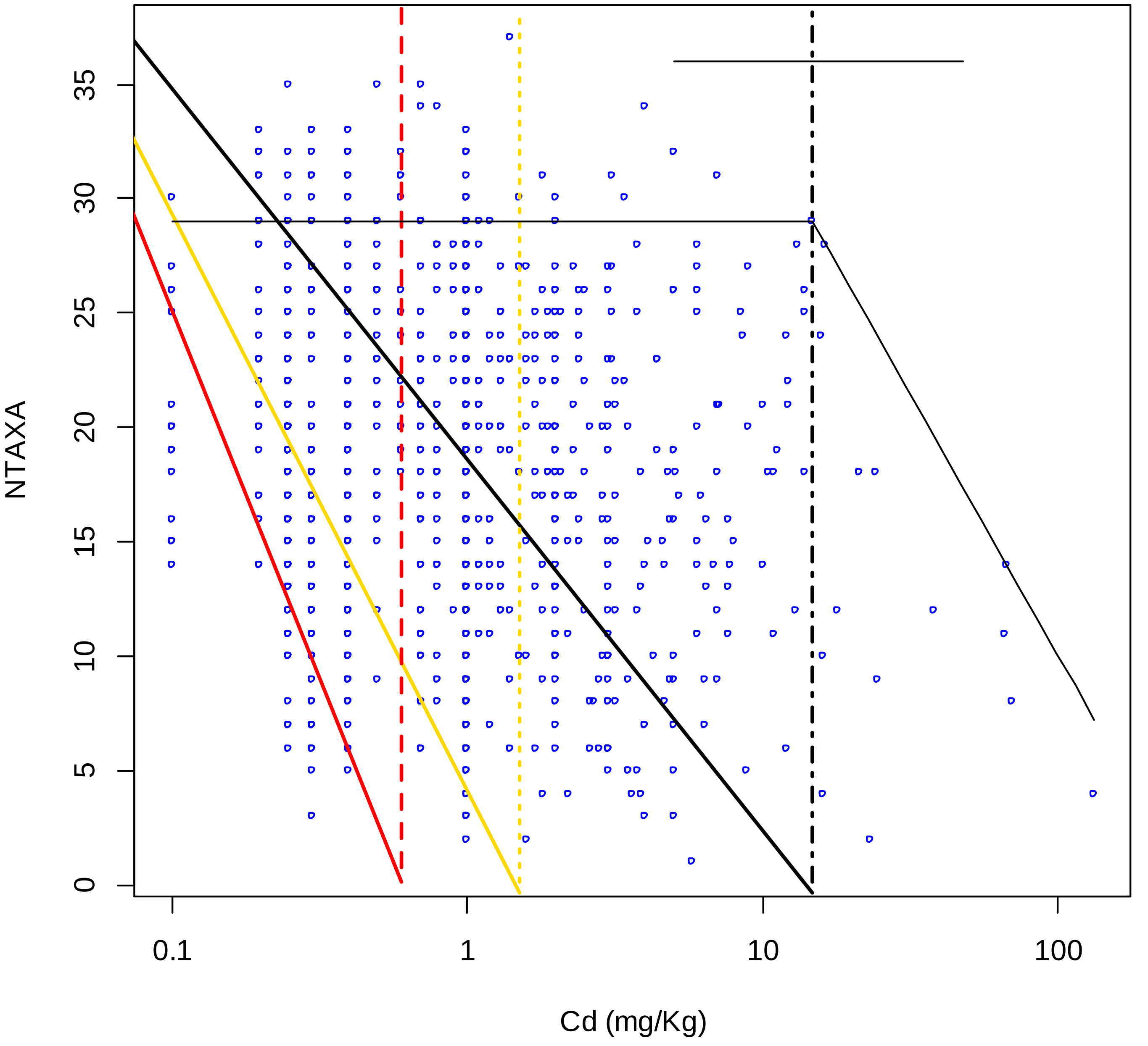
Threshold model: NTAXA - Cu



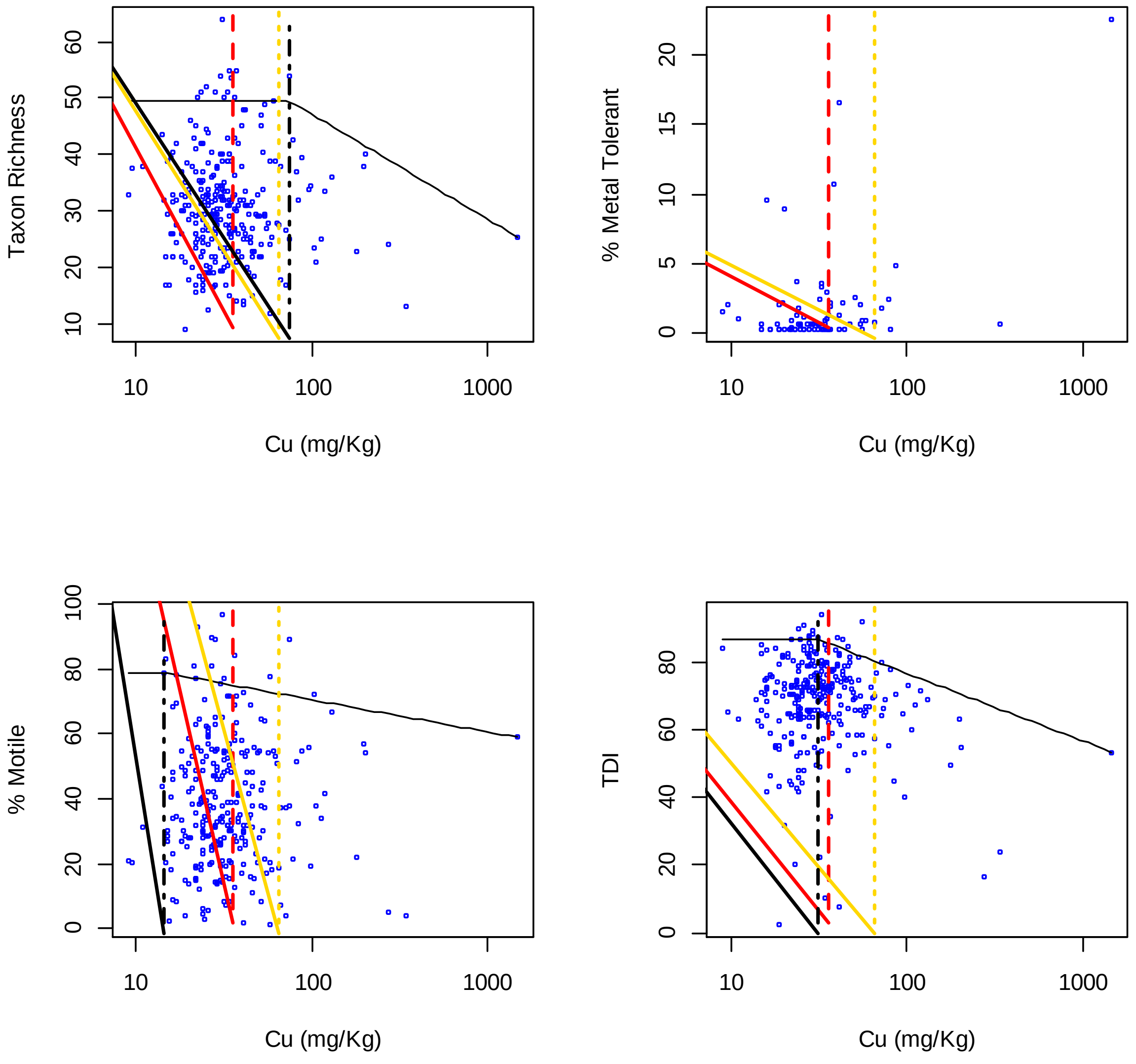
Threshold model: NTAXA - Cu



Threshold model: NTAXA - Cd



Threshold model: Diatoms - Cu



Summary of Preliminary Results of Quantile Regression Analysis

	Canada ISQG	Australia and New Zealand PEL	Invertebrates				Diatoms				Macrophytes				Fish			
			NTAXA	ASPT	EQR NTAXA	EQR ASPT	No.Taxa	% Motile	TDI	EQR	Plant Richness	No. Aquatic Taxa	RMNI	EQR	Site EQR	Salmon EQR	Trount EQR	No. Species
Cadmium	**0.6**	**1.5**	7.2	125			4	3.1							12		9.6	5.4
Chromium	**37.3**	**80**	511				182	82	51					108	128		261	
Copper	**35.7**	**65**	26		98		75		31.2			39.8						
Iron			82,590				54,134											
Lead	**35**	**50**	310												2,354			200
Nickel		**21**	215	155			41.4								169	170	197	156
Silver		**1**	8				1.3		20.2							49.6	50.6	
Tin			18.8				20		17		31				62.7	338		
Zinc	**123**	**200**	444				953	382										2053
Antimony		**2**	2.6				1.6								55.5	64.7	84.5	
Arsenic	**5.9**	**20**	83.8				46.6								104		46	168

Data in black threshold models were optimal, data in red close to optimal

All data in mg Kg^{-1}

Summary of Preliminary Results of Quantile Regression Analysis

Thresholds vary

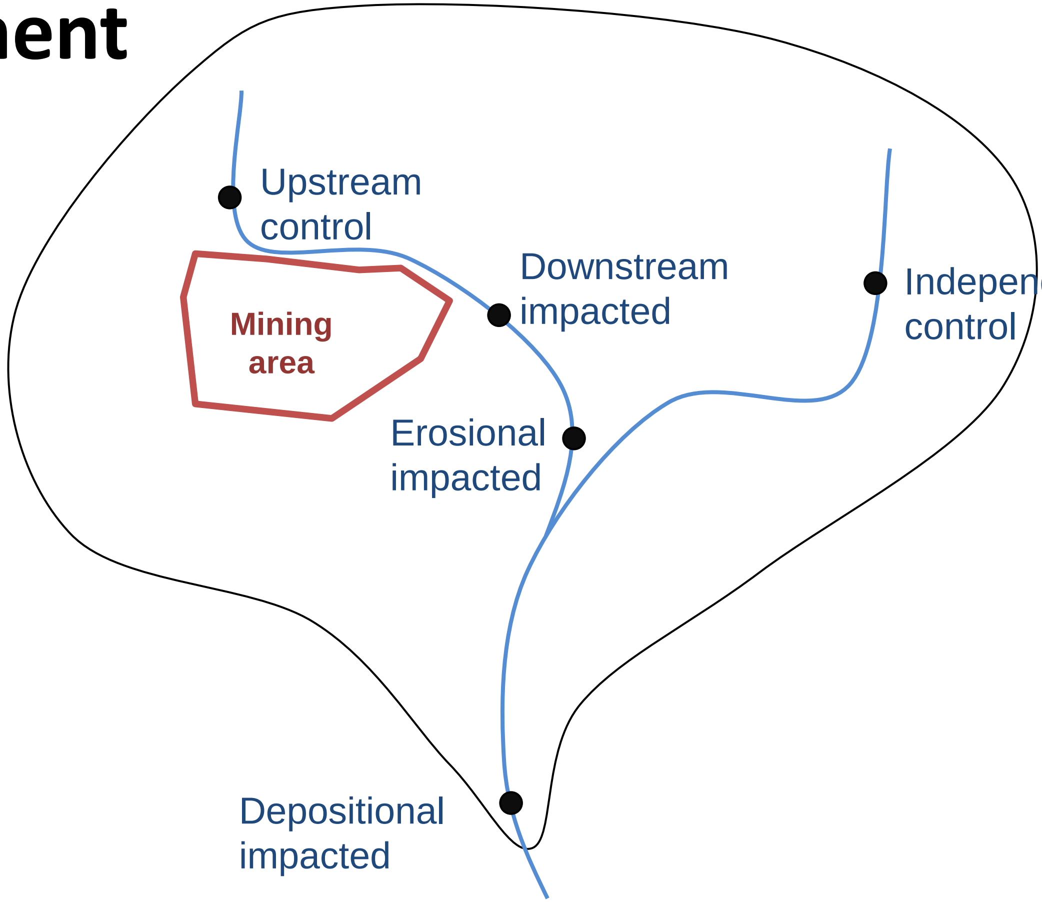
diatoms < invertebrates < fish < macrophytes

Summary of Preliminary Results of Quantile Regression Analysis

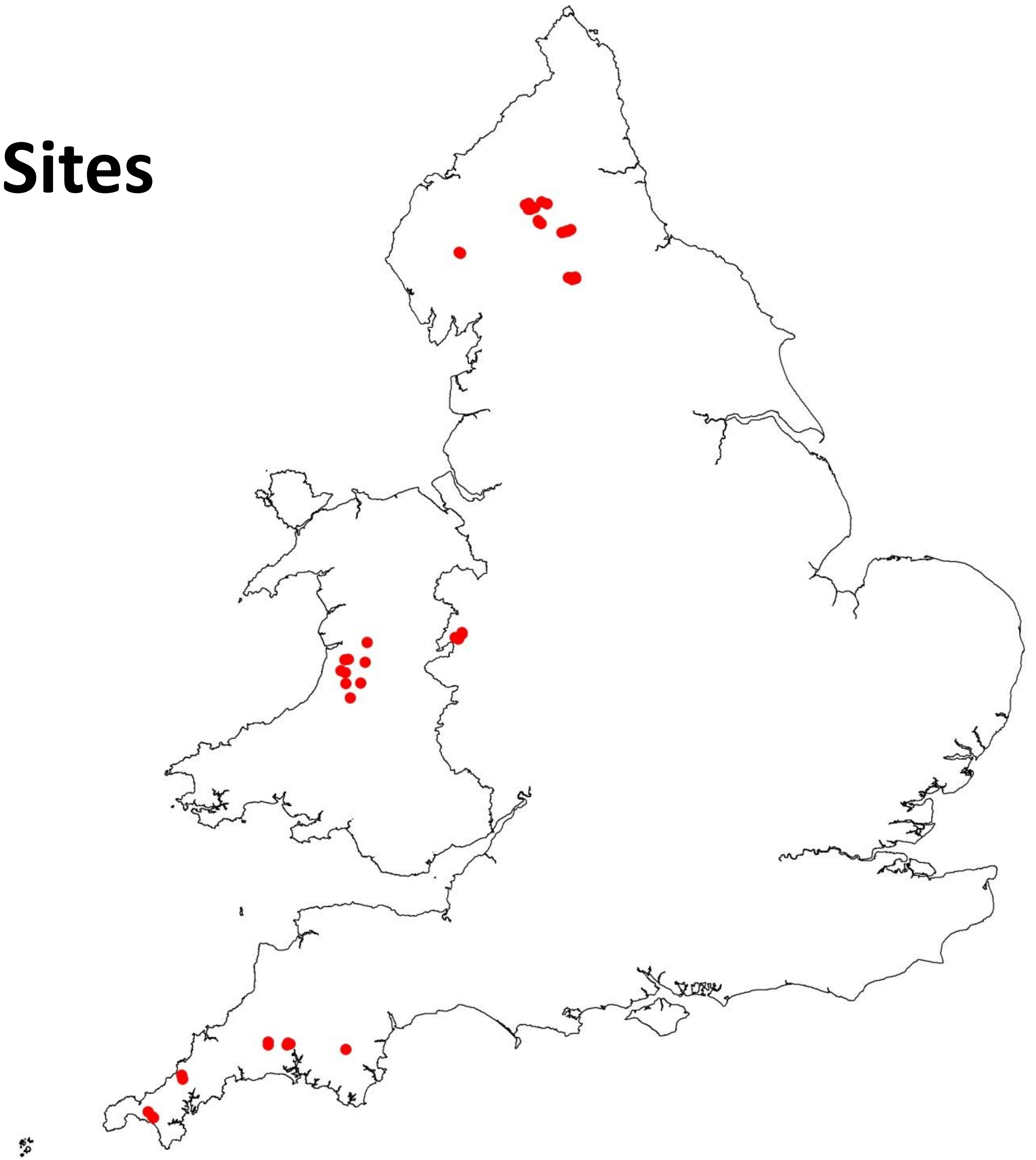
	Canada ISQG	Australia and New Zealand PEL	Geometric mean of threshold based on number of taxa	Lowest of all metrics	
Cadmium	**0.6**	**1.5**	**9.5**	**3.1**	Diatom % motile
Chromium	**37.3**	**80**	**146**	**51**	Diatom TDI
Copper	**35.7**	**65**	**47.3**	**26**	Invertebrate NTAXA
Iron			**66,865**	**54,134**	Diatom No. Taxa
Lead	**35**	**50**	**527**	**198**	Fish No. Species
Nickel		**21**	**143**	**41.4**	Diatom No. Taxa
Silver		**1**	**13.9**	**1.3**	Diatom No. Taxa
Tin			**40.2**	**18.8**	Invertebrate NTAXA
Zinc	**123**	**200**	**759**	**382**	Diatom % motile
Antimony		**2**	**16.6**	**1.6**	Diatom No. Taxa
Arsenic	**5.9**	**20**	**79.3**	**46**	Fish Trout EQR

Field based approach: linking bioavailability to community response

Schematic diagram of the arrangement of monitoring sites within each replicate catchment



Field Sites



Fine sediment geochemistry samples
Collected in N_2 filled cores

pH
Particle size distribution
Metal concentrations
Organic content

Reach scale estimates of fine sediment

[Duerdoth *et al*. (2015) *Geomorphology* 230: 37–50]

Local environmental conditions

Invertebrate community – standard kick sample

Biomonitor taxa picked in the field
Frozen for lab processing (ICPOES)

Source Apportionment - Identifying sources

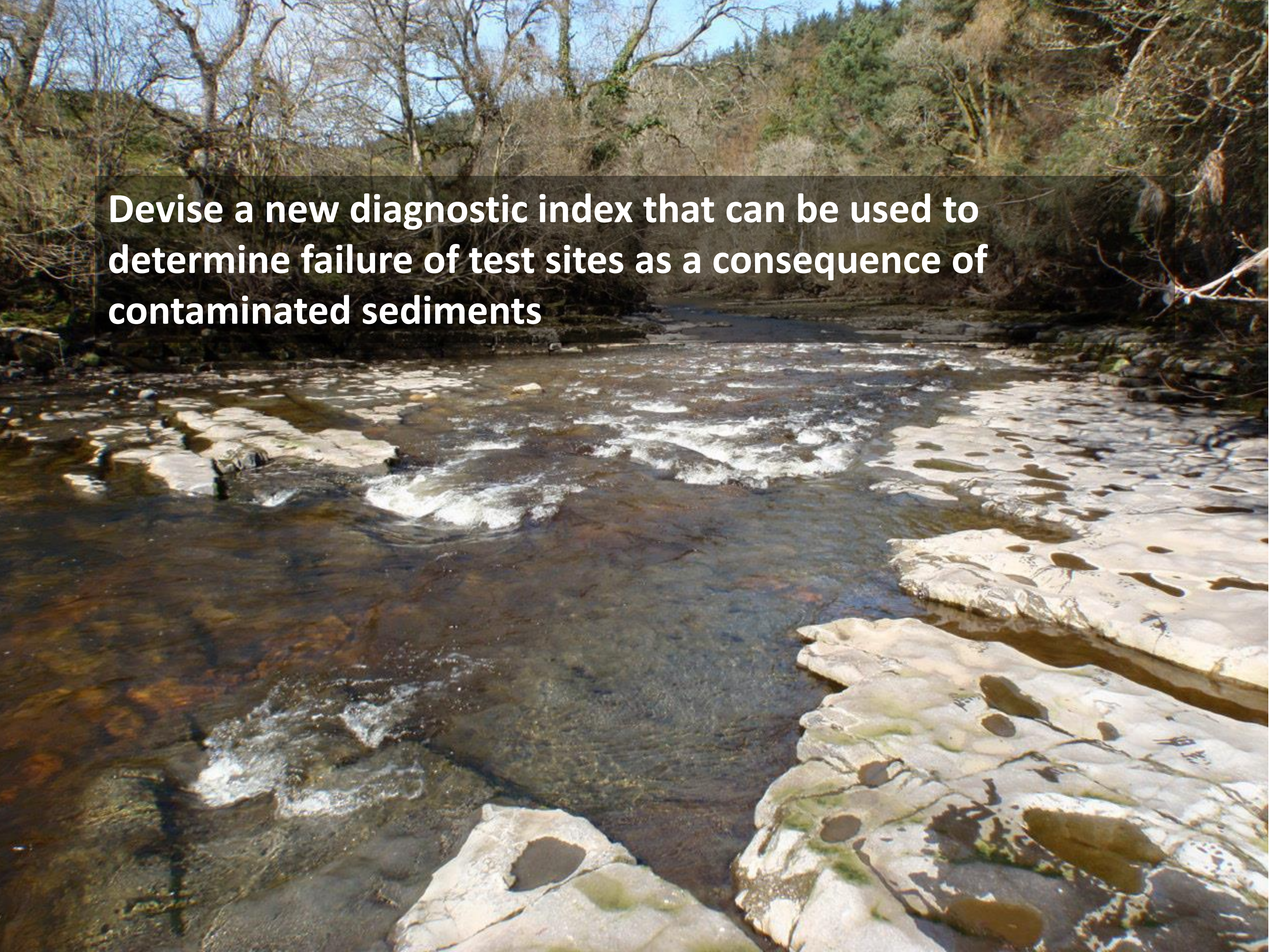
SOURCES

- agricultural topsoils
- channel banks
- damaged road verges
- urban street dust
- mine sources



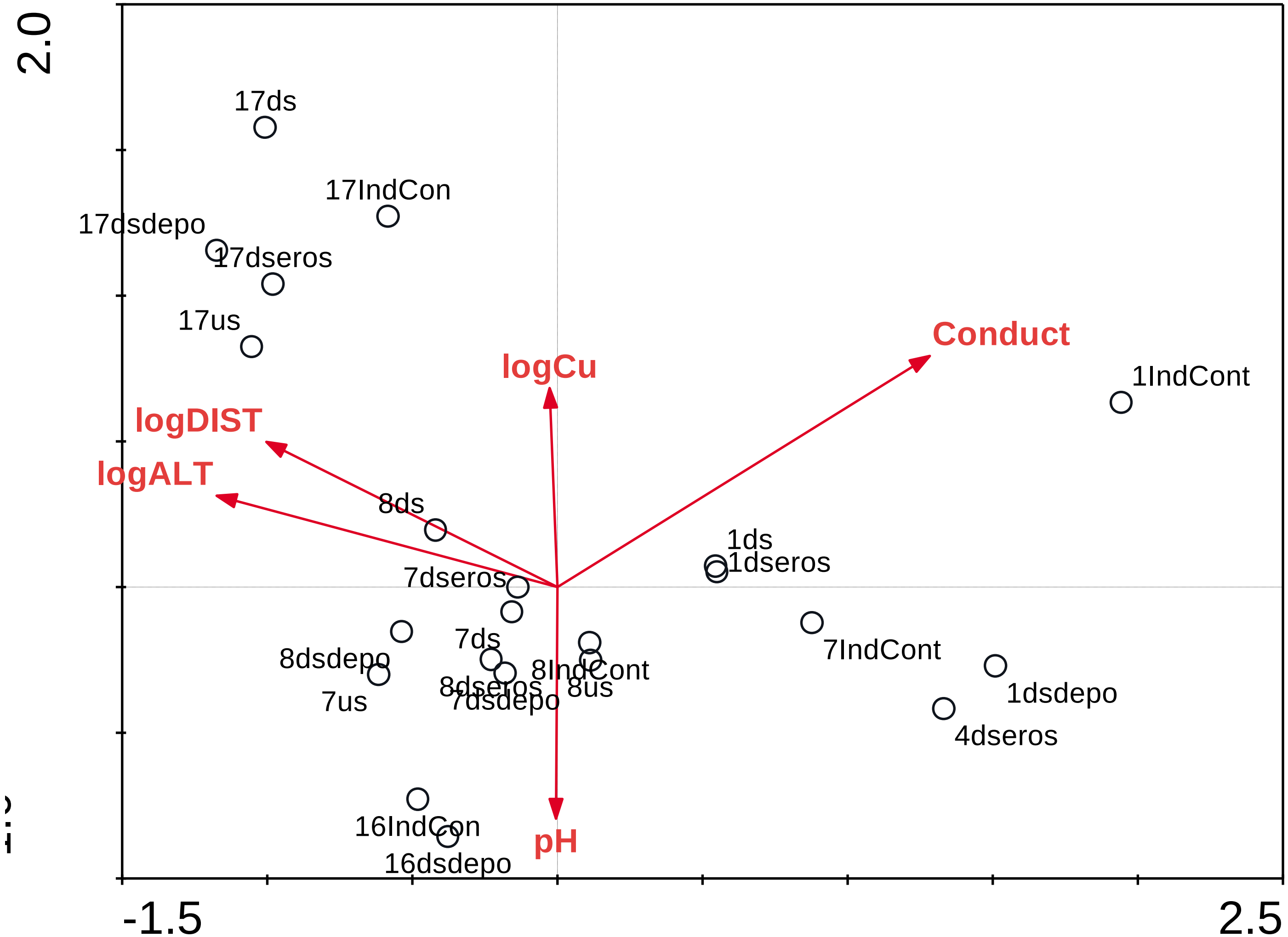

CHANNEL BED SEDIMENT

- fine-grained sediment at the sub-catchment outlet depositional sites



Devise a new diagnostic index that can be used to determine failure of test sites as a consequence of contaminated sediments

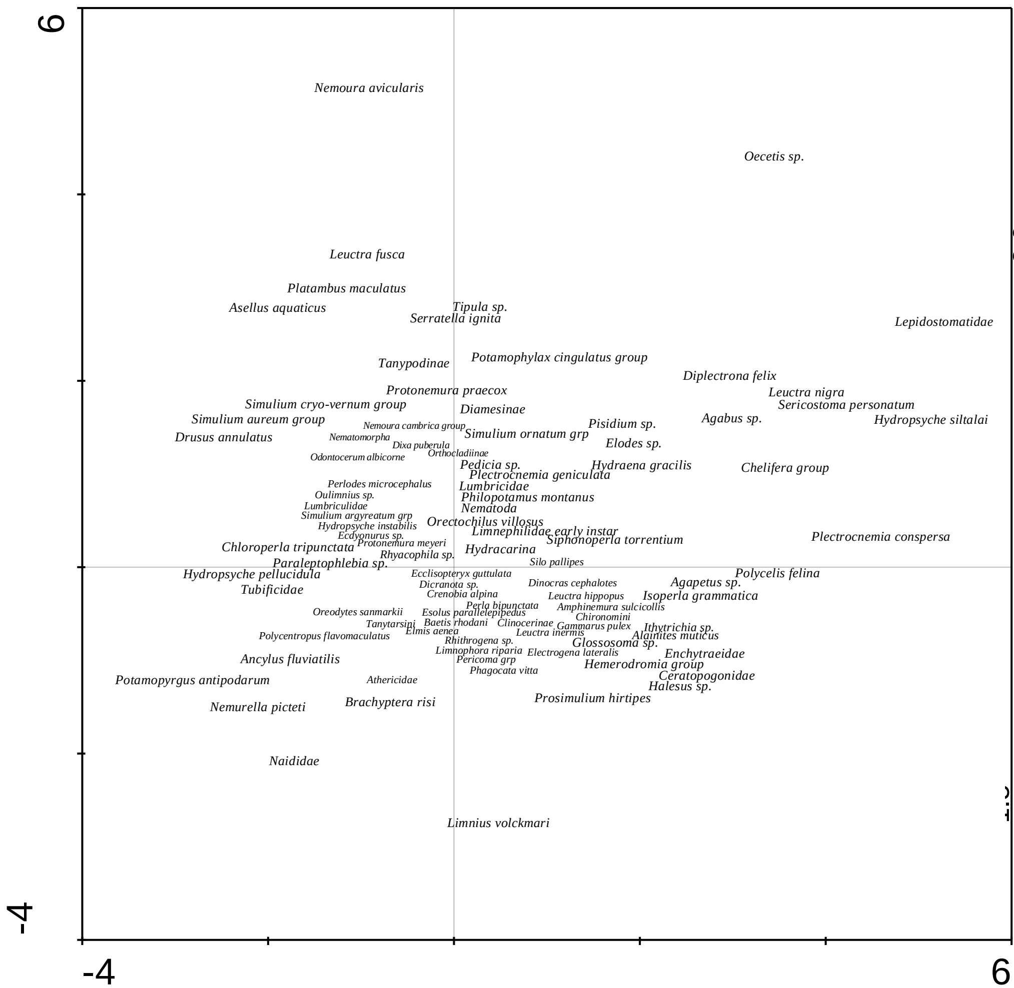
Canonical Correspondence Analysis

Site average *Hydropsyche* metal body burden and environmental variables significantly good at explaining variation in the invertebrate community

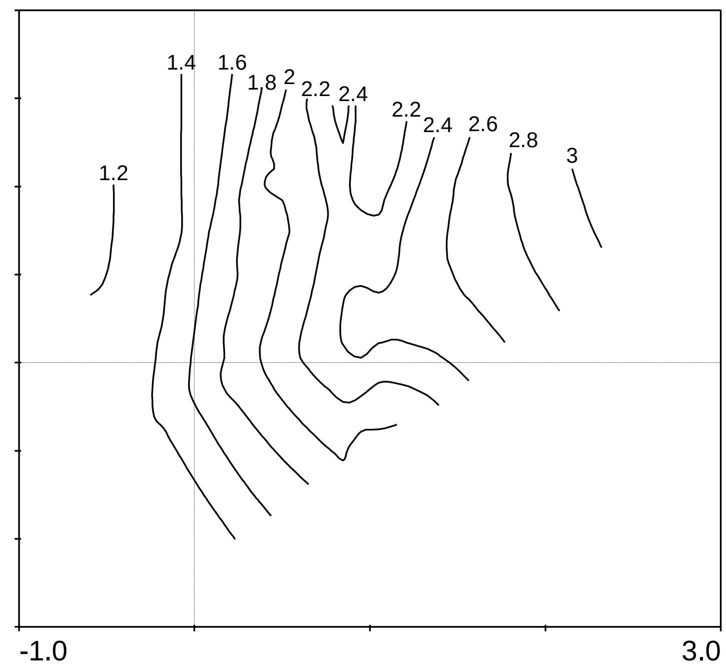


Partial Canonical Correspondence Analysis

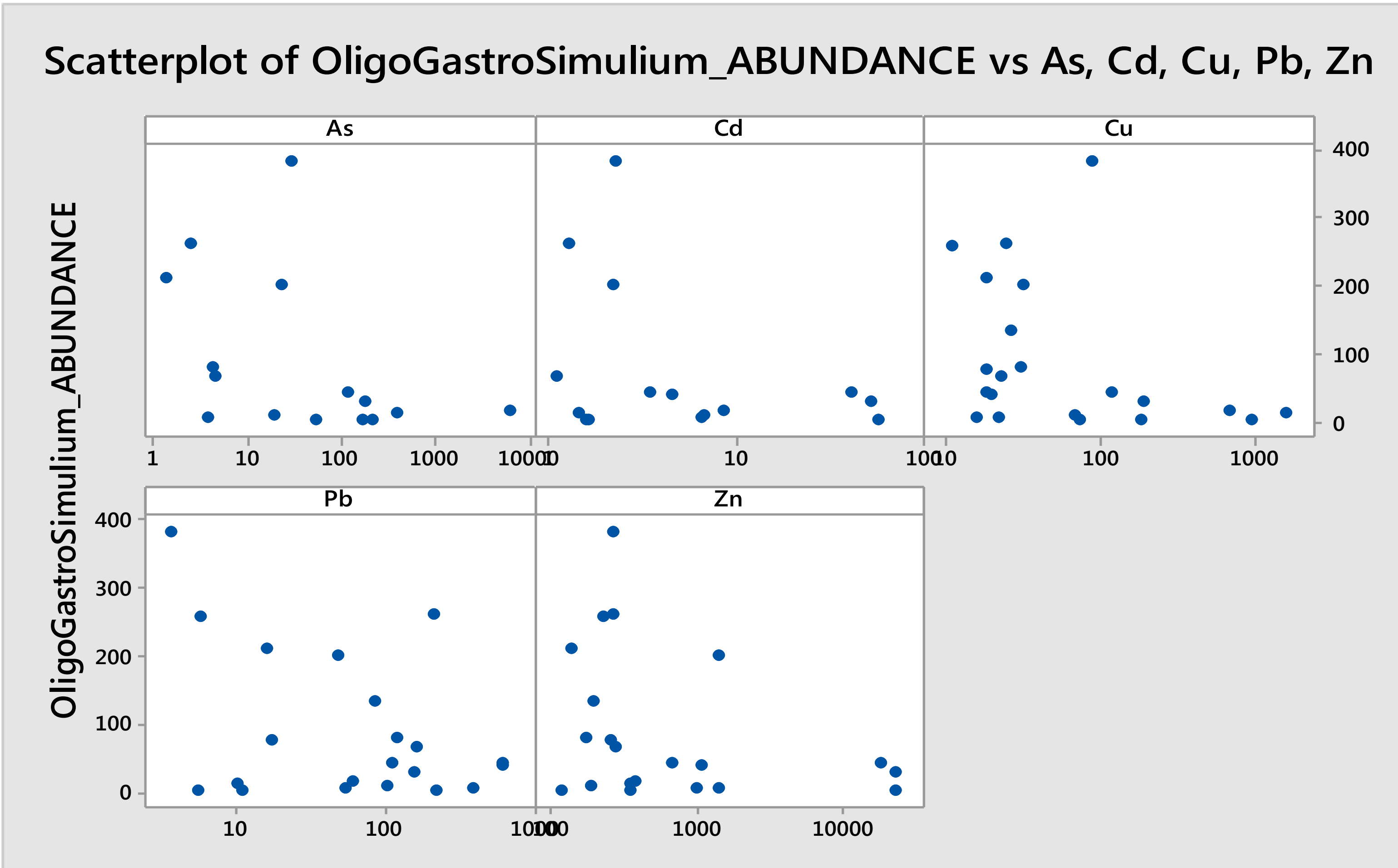
Distribution of taxa relative to site average *Hydropsyche* Cu body burden (x-axis) after variation due to environmental variables is removed (conductivity, altitude, distance from source and pH)



Contour plot showing gradient of *Hydropsyche* Cu body burden



Variation in the total abundance of Oligochaeta, Gastropoda and Simulidae with increasing bioavailability (measured as the body burden in Hydropsyche) of arsenic, cadmium, copper, lead and zinc



NEXT STEPS

NEXT STEPS

Include metal tolerance index in methods used by Environment Agency/Natural Resources Wales to detect where sediment metals are a problem

NEXT STEPS

Include metal tolerance index in methods used by Environment Agency/Natural Resources Wales to detect where sediment metals are a problem

Establish conditions that influence metal availability

NEXT STEPS

Include metal tolerance index in methods used by Environment Agency/Natural Resources Wales to detect where sediment metals are a problem

Establish conditions that influence metal availability

Conduct experiments to verify findings

NEXT STEPS

Include metal tolerance index in methods used by Environment Agency/Natural Resources Wales to detect where sediment metals are a problem

Establish conditions that influence metal availability

Conduct experiments to verify findings

Set environmental quality standards for metals

Acknowledgements

The Coal Authority

Department for Environment Food & Rural Affairs

Environment Agency

Cyfoeth Naturiol Cymru
Natural Resources Wales

Natural History Museum

Queen Mary University of London

North Wyke Rothamsted Research

ADAS