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Aquatic Toxicity of Metals

Submitted by: Rio Tinto

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Aquatic Toxicity of Metals

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Presentation Outline

- **Bioavailability and toxicity**
- **Bioconcentration and bioaccumulation**
- **Biomagnification**
- **Trophic transfer**

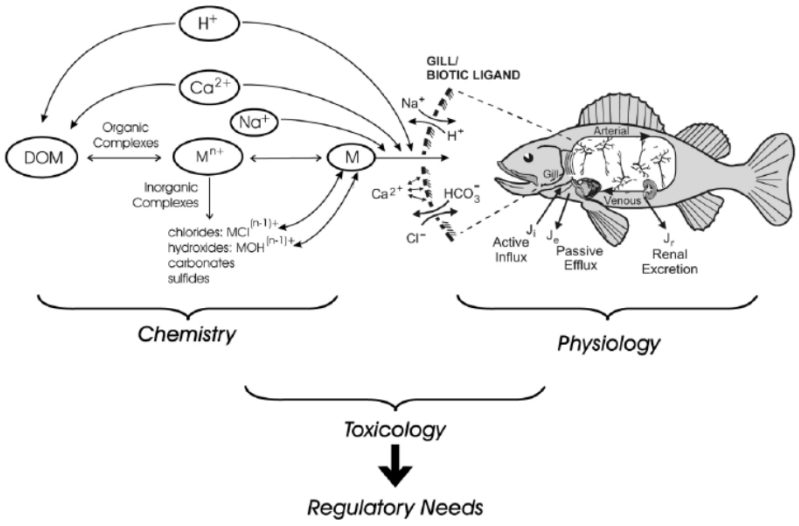
2

Bioavailability

- **Metal bioavailability is a function of water chemistry!**
- **Ca, Na, Mg, DOC and pH are the key drivers for cationic metals (Ag, Al, Cd, Cu, Fe, Ni, Pb, Zn)**
- **Total metal is not a good indicator of toxicity**
  - Exceptions are Al and Fe
- **Dissolved metal (<0.45 mu) is most often used**
- **Free metal ion is the best descriptor of toxicity**
- **Biotic ligand model (BLM) widely used to assess bioavailabity for cationic metals**

3

Biotic Ligand Model



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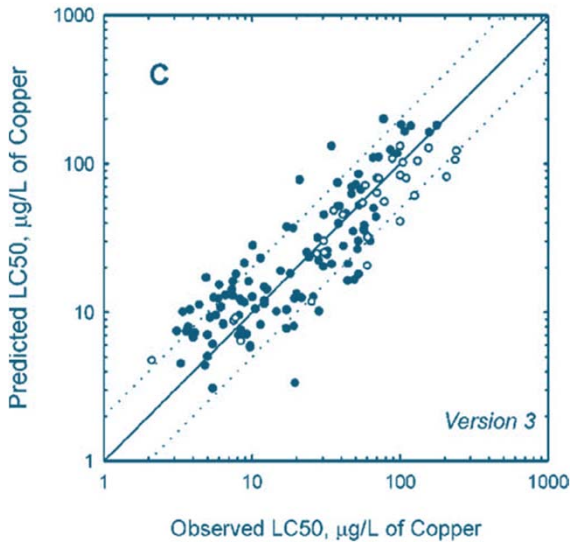
Biotic Ligand Model Verification



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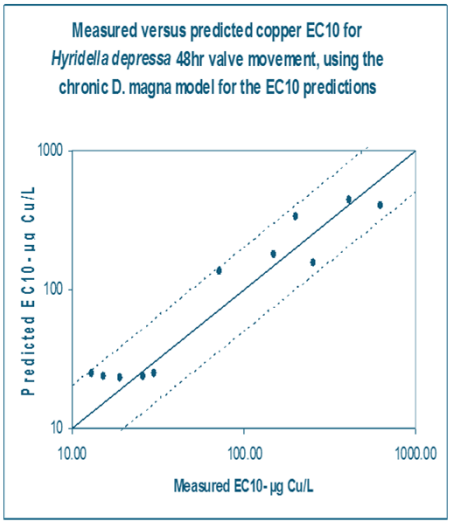
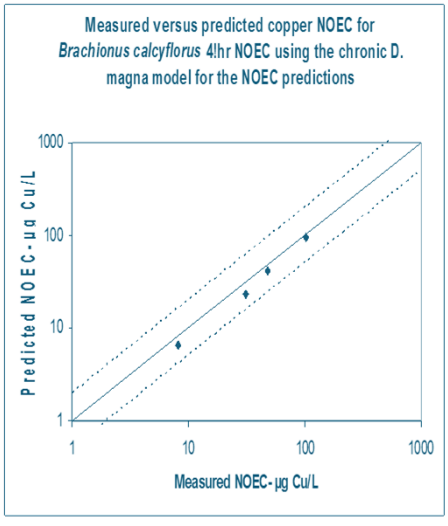
BLM Verification





6

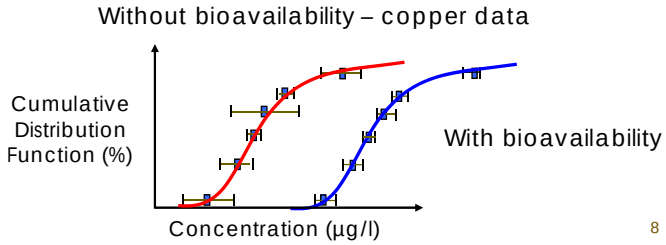
Bioavailability Correction

- Fish, Daphnia and Algal models have been used to reduce the variability in large ecotox data sets by normalizing all toxicity values to a given set of water chemistry
- The current U.S. EPA water quality criterion is derived using a similar BLM approach

7

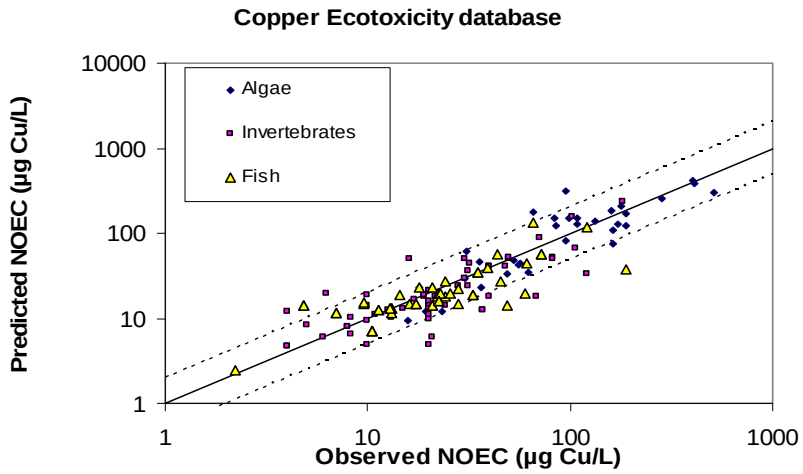
Importance of Bioavailability

- There is a need to correct studies for water chemistry
  - pH, hardness and organic carbon
- Significant reduction in data spread
- Typical water value increases from 8 to 30 µg/L
- Fathead minnow variability decreased from a factor of 74 to 8



8

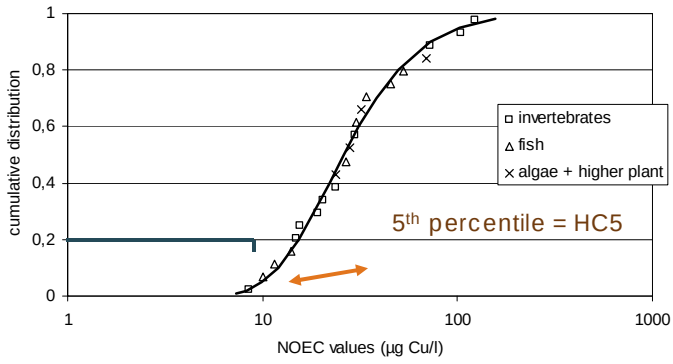
Bioavailability Correction



9

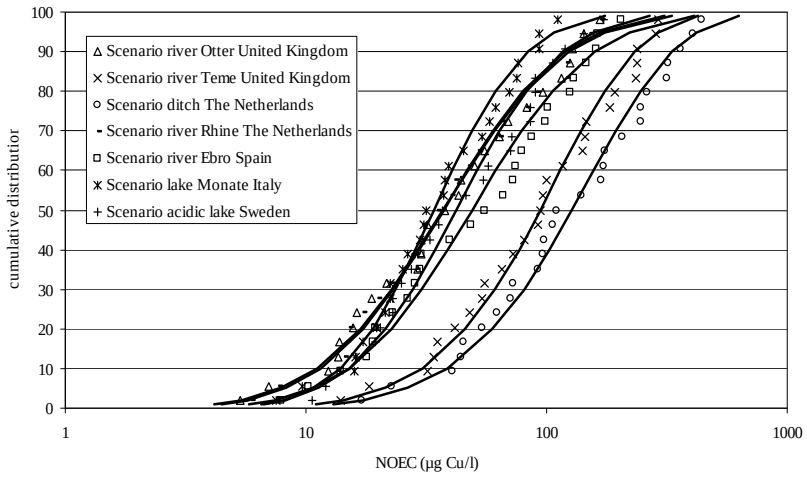
Importance of Bioavailability

- **Cumulative frequency distribution for normalized species mean NOECs for copper and freshwater organisms**



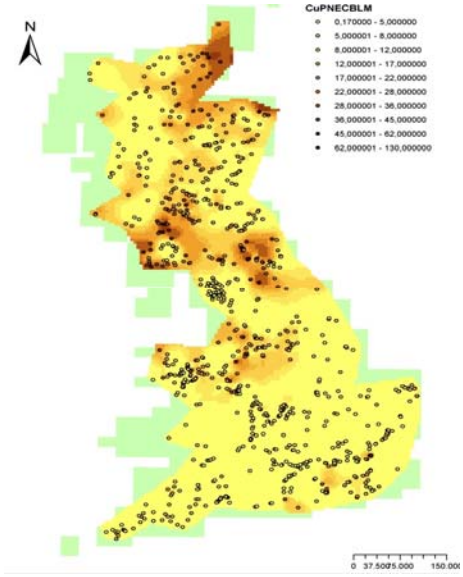
10

Bioavailability Correction



11

Bioavailability Correction



Copper HC5
-50 values for the
United Kingdom
17–130 µg/L

12

Predicting Copper Toxicity in China's 5 Main Rivers by Using Biotic Ligand Model (BLM) (Li Guogang)

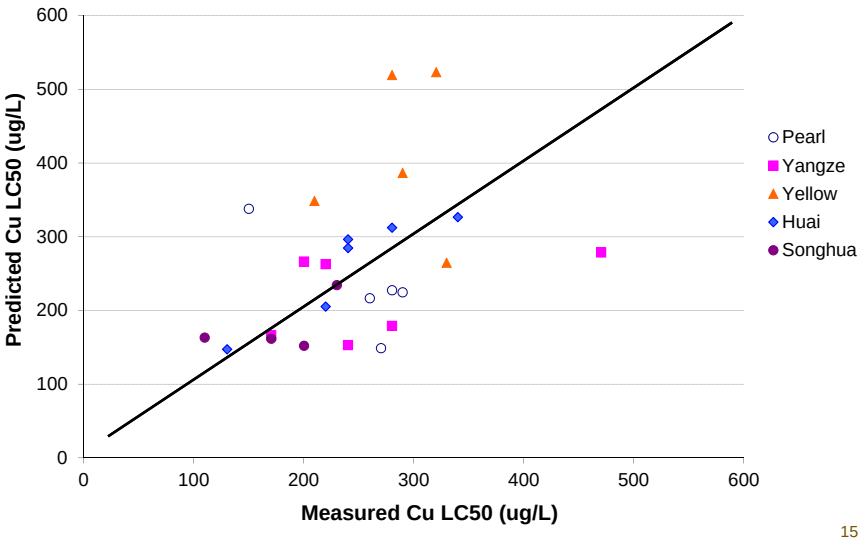
13

Predicting Copper Toxicity in China's 5 Main Rivers by Using BLM

- Water samples were collected Pearl River, Yangze River, Yellow River, Huai River and the Songhua River
- Toxicity test were performed with Rainbow trout and laboratory water
- Water effects ratios (WER) were calculated (lab result/river water result)
- Water effect ratios were measured and predicted by the BLM

14

Predicted Versus Measured Toxicity for 5 Chinese Rivers



15

Predicting Copper Toxicity in China's 5 Main Rivers By Using BLM

- **Results**
  - Water effect ratios (WERs) were measured and then separately predicted by the BLM
  - All of the measured WERs are larger than 1 (normal for copper); Average WERs are ~ 3 — that is river water is protective against toxicity
  - Results showed that the WERs and BLM predicted WERS are in good accordance
  - BLM predictions are a viable alternative to conducting rainbow trout toxicity tests

16

Biotic Ligand Model (BLM)

BLM: A Historical Review

Paul Paquin, Joe Gorsuch, Simon Apte, Graeme Batley, Karl Knowles, Peter Campbell, Charles Delos, Dominic DiToro, Robert Dwyer, Fernando Galvez, Robert Gensemer, Gregory Goss, Christer Hogstrand, Colin Janssen, James McGeer, Rami Naddy, Richard Playle, Robert Santore, Uwe Schneider, William Stubblefield, Chris Wood, Kuen Wu.

Comparative Biochemistry and Physiology Part C, 133 (2002) 3-35

17

Bioaccumulation Factors

$$BCF/BAF = \frac{\text{Tissue Concentration}}{\text{Water Concentration}}$$

BCFs are based on water only exposures (lab data)

BAFs are derived from water and dietary exposure (field data)

18

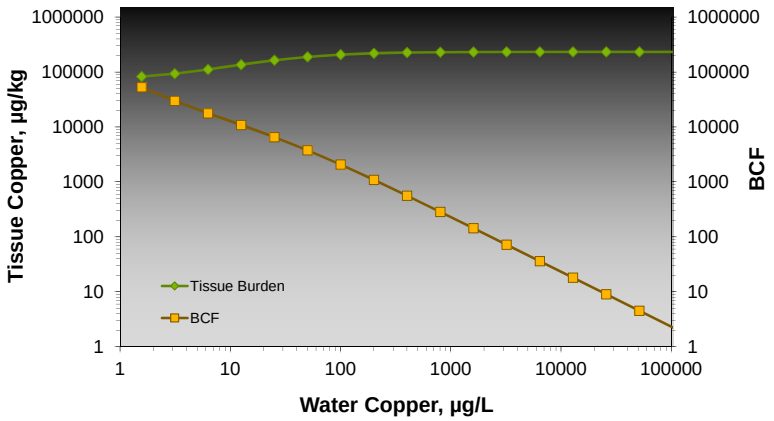
Bioaccumulation Factors

- **BCFs, BAFs, TTFs are inversely related to exposure concentrations – they are not an intrinsic property for metals**
- **This identifies a problem for metal hazard assessment**
  - Big BCF/BAFs do not indicate hazard !!
  - Larger values indicate low exposure and low potential for chronic effects or secondary poisoning
  - Trophic transfer factors (TTFs) are inversely related to exposure concentration

19

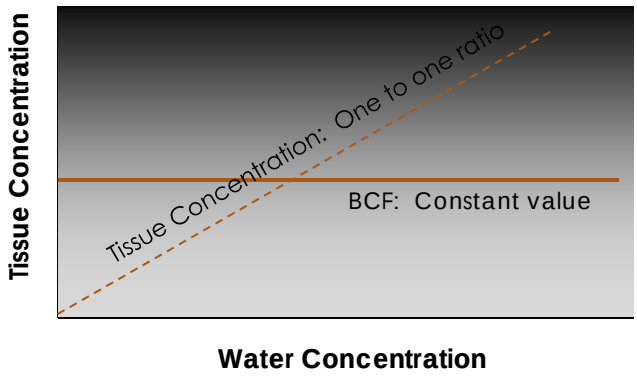
Pharmaco-Kinetic Model of Cu Bioconcentration in *Hyalella azteca*

Adapted from Borgmann et al. (1995)



20

Bioconcentration Factor Concept: Non Polar Organic Substances



21

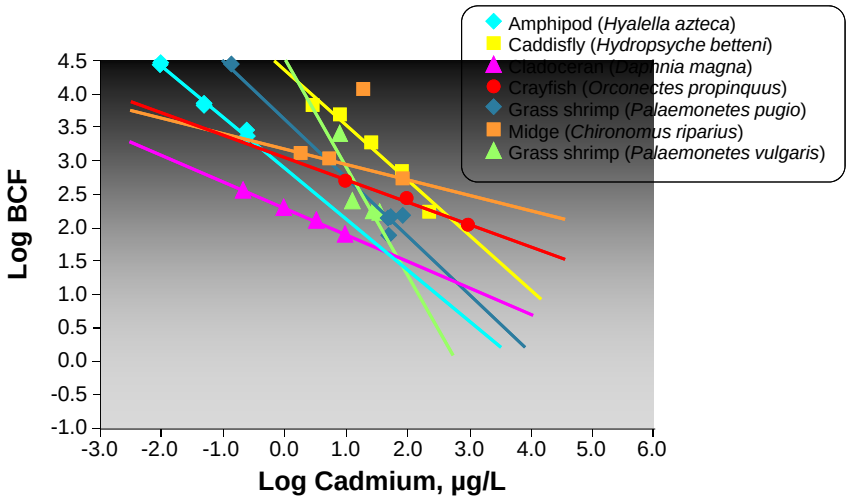
Bioconcentration Factors (BCFs)

Supporting Data

Inverse relationship between tissue concentration and exposure level for several metals

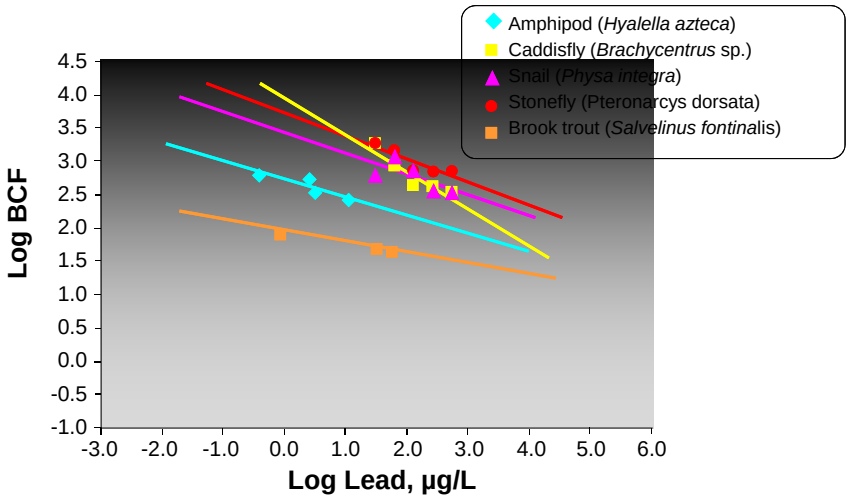
22

Cadmium BCFs: Invertebrates



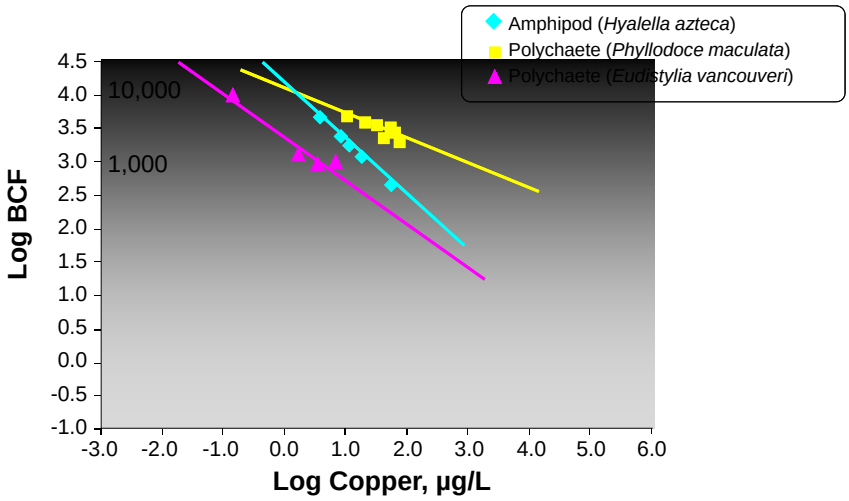
23

Lead BCFs for Fish and Invertebrates



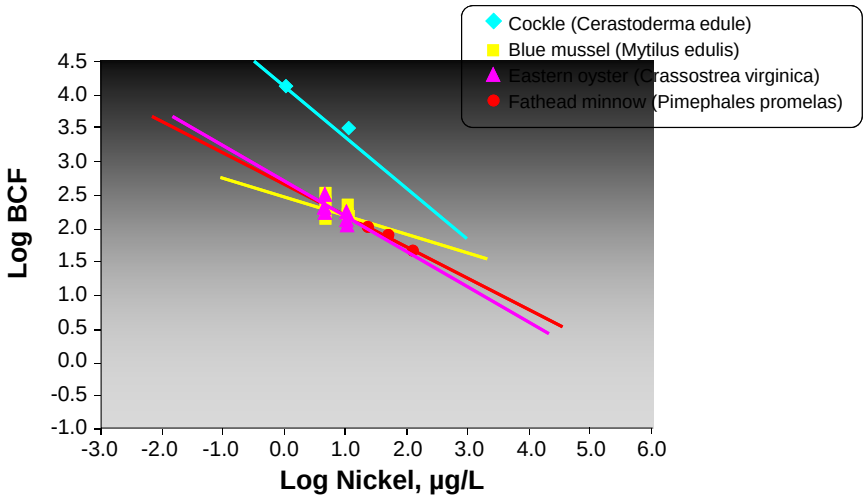
24

Copper BCFs: Invertebrates



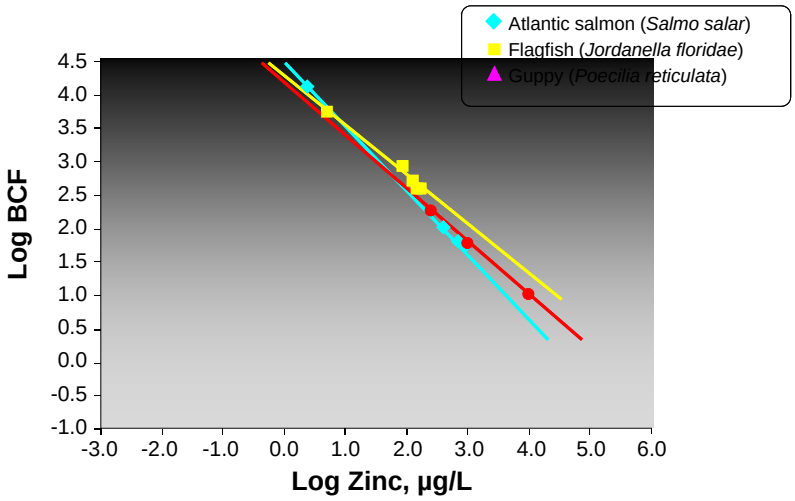
25

Nickel BCFs for Fish and Invertebrates



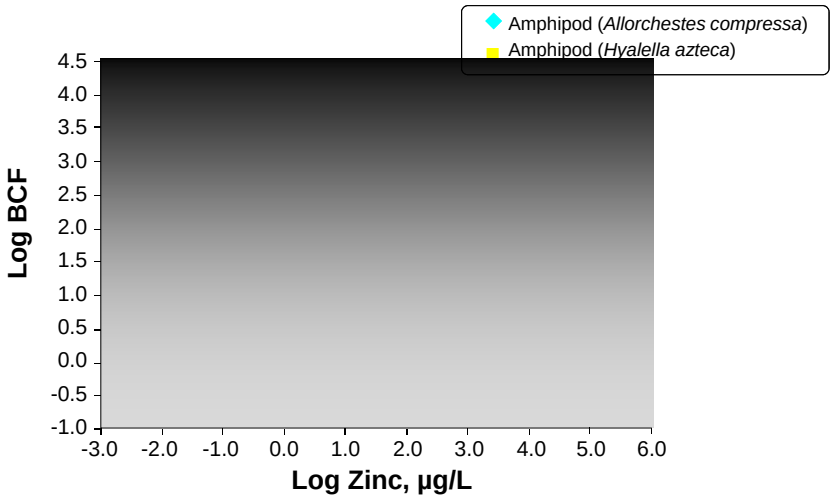
26

Zinc BCFs for Fish



27

Zinc BCFs: Invertebrates



28

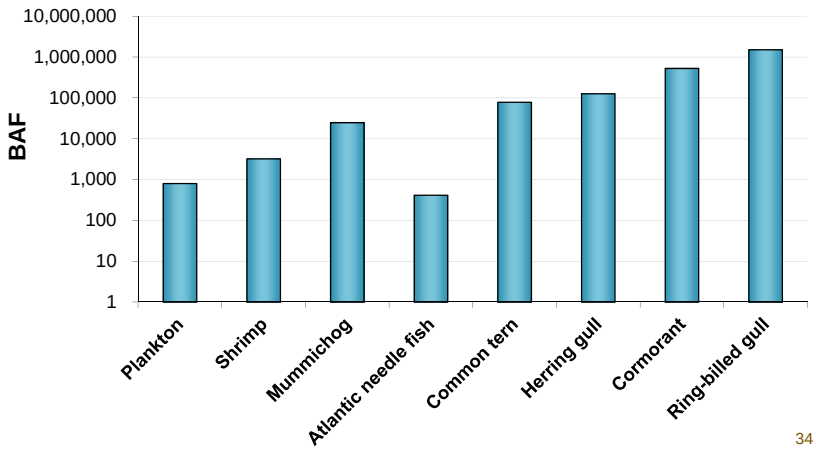
BAFs versus BCFs

Field collected organisms = (dietary and water exposure)

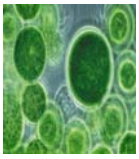
29

Biomagnification: Clear Example

DDT residue BAFs for various trophic levels in the Carmans River Estuary, Long Island, (data from Woodwell et al. 1967)



34

Algae  Daphnia

Trophic Transfer Factors (TTF)

$$TTF = \frac{\text{Tissue Concentration in Predator}}{\text{Tissue Concentration in Prey}}$$

TTF are used to assess food chain accumulation, i.e., secondary poisoning

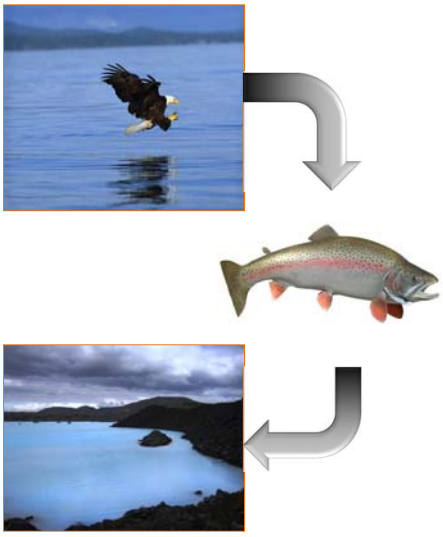
36

Approach for Assessing Bioaccumulation

- **Regression approach**
  - Back-calculation from toxicity threshold to waterborne metal concentration

38

Regression Approach



Given a wildlife dietary toxicity threshold

↓

Tissue concentration in prey

↓

What concentration in water will lead to accumulation that equals the tissue concentration in prey that causes toxicity?

39

Bioaccumulation Conclusions

- **Bioaccumulation factors (BCFs, BAFs, TTFs) are not an intrinsic property for metals**
- **BCFs and other Accumulation Factors for metals are clearly inversely related to water (and sediment concentrations)**
- **Hazard and potential for chronic effects cannot be evaluated by magnitude of BCFs or BAFS**
- **Bioaccumulation can be assessed by use of regression models**

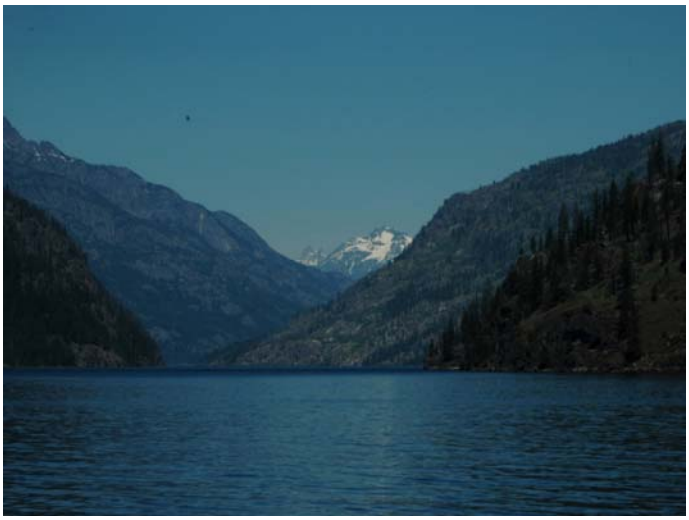
41

Biomagnification of Metals

- **Conclusions**
  - Biomagnification of Cu, Cd, Ni, Zn is uncommon
  - TTFs are commonly inversely related to dietary conc.
  - Dietary effects are not observed with larger TTFs or BMFs, but the opposite
  - BMFs >1, when observed, are usually in found in low exposure environments
  - Biomagnification can occur when the food chain includes predatory gastropods
  - There are no studies showing effects on gastropods or fish that feed on gastropods – a research need

42

Lake Chelan/Holden Mine State of Washington

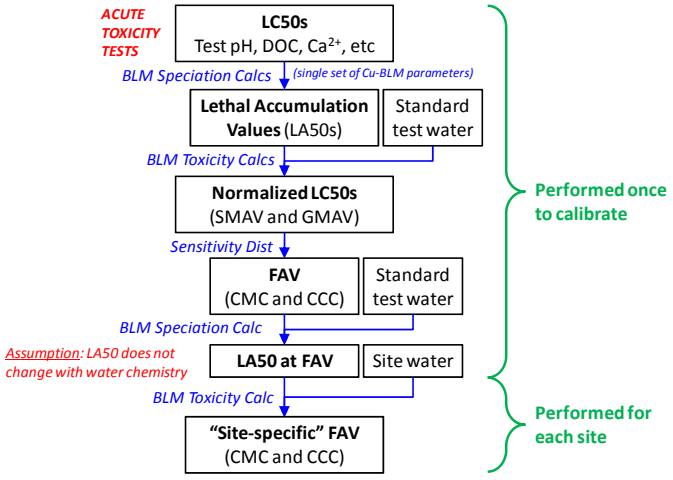


43

Backup Slides

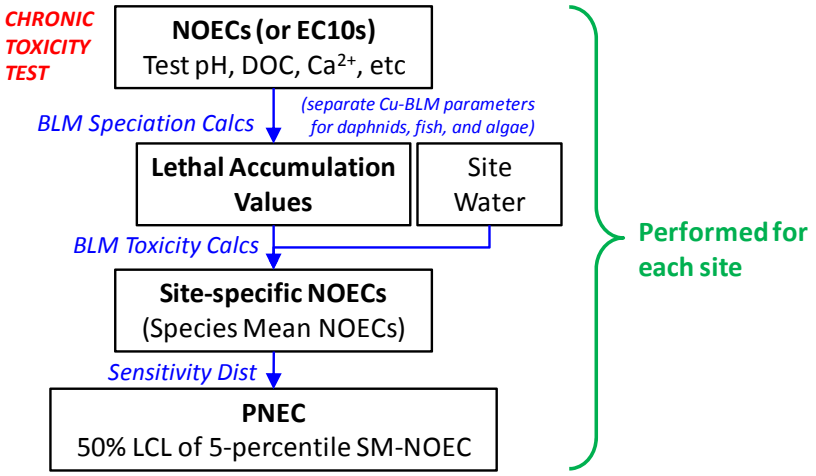
44

BLM Application in the USA



45

BLM Application in Europe



46