Bioaccumulation Evaluations

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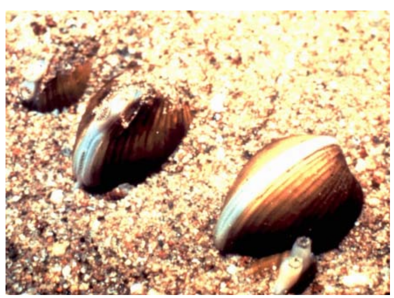
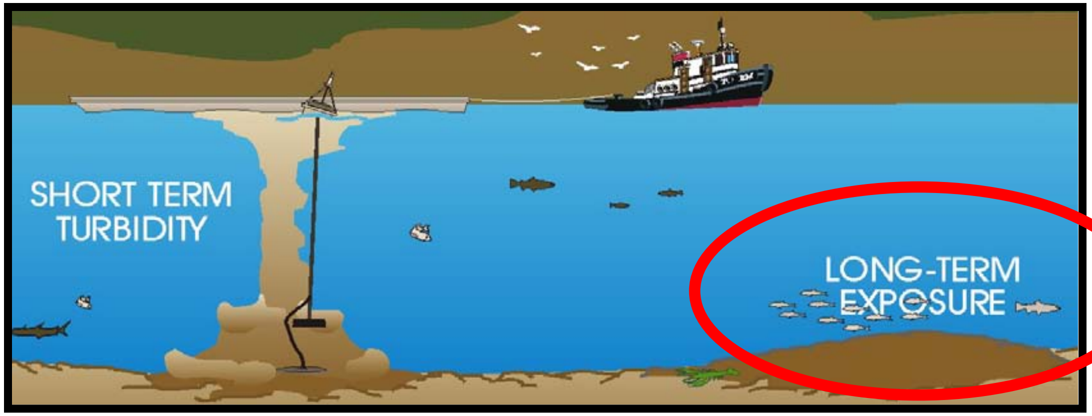
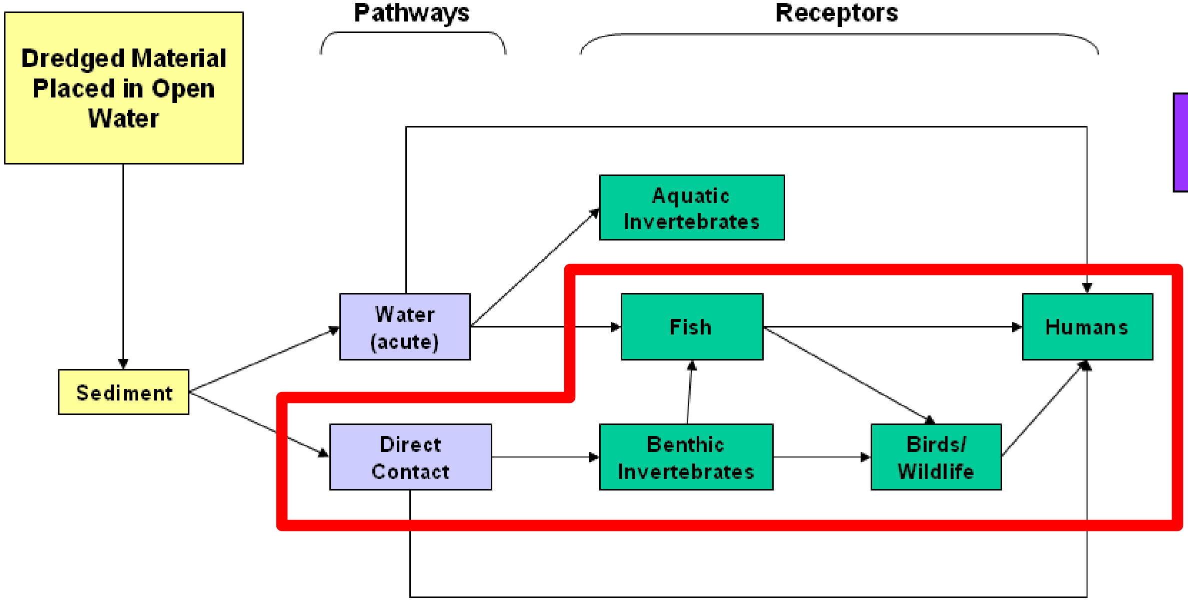
Benthic Bioaccumulation Evaluation

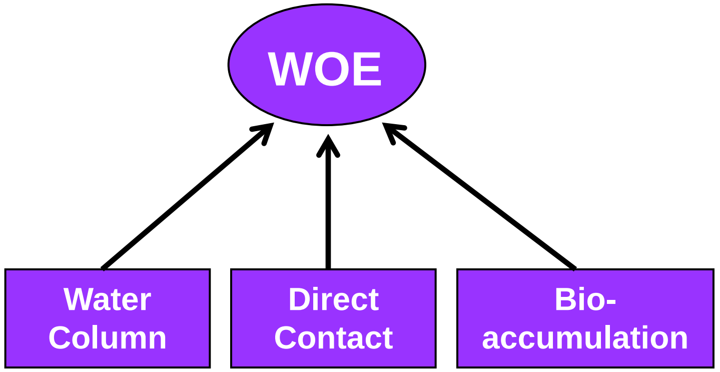
- **Used to estimate potential for adverse effects through trophic transfer of contaminants**
- **One <u>line of evidence</u> to support decision concerning suitability for open water disposal**



Conceptual Model

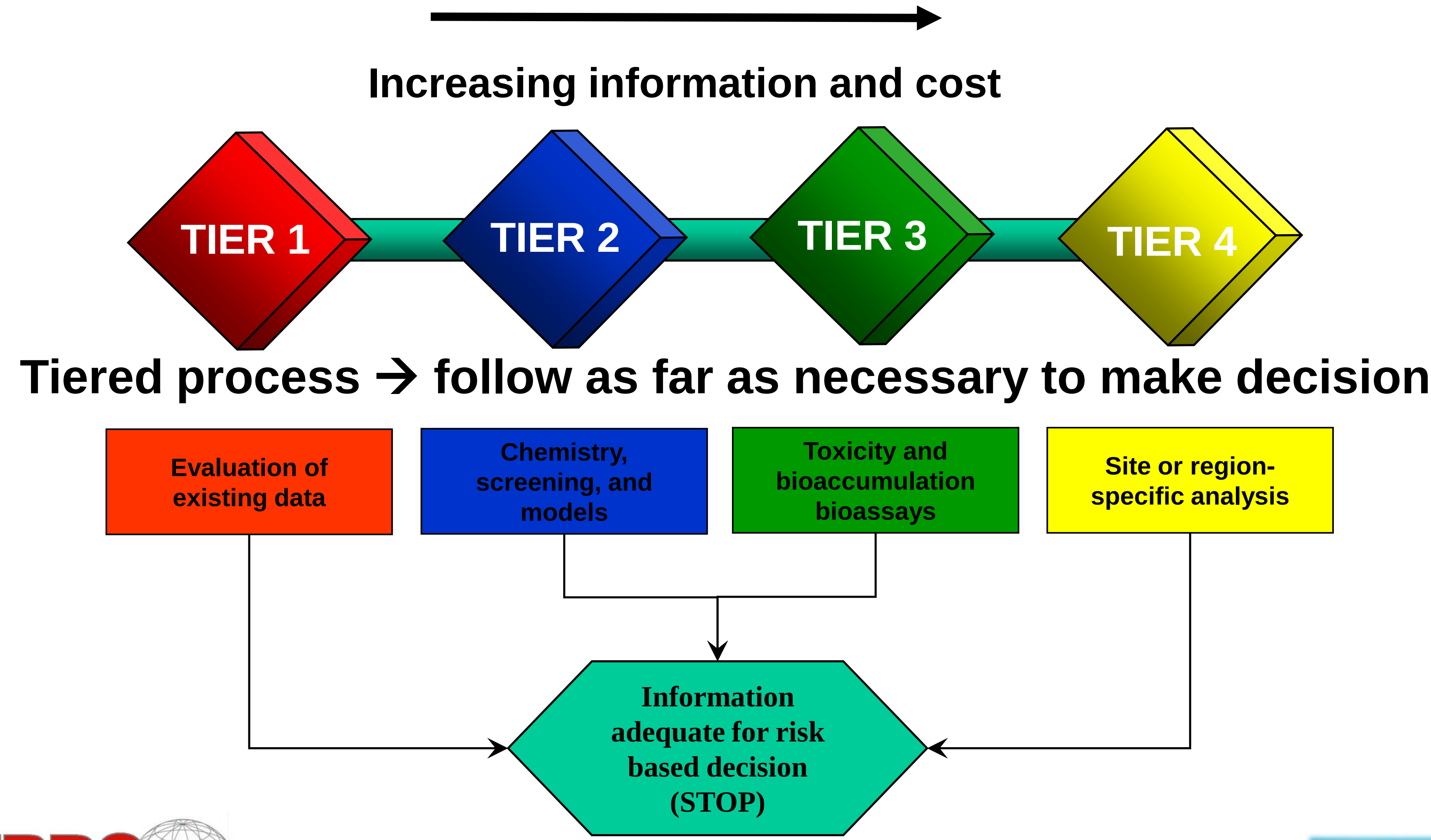




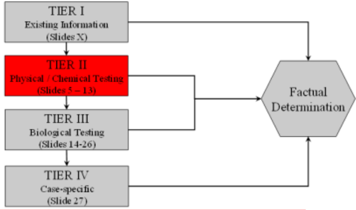


Lines of Evidence

Bioaccumulation Evaluation



Bioavailability and Bioaccumulation: Definitions

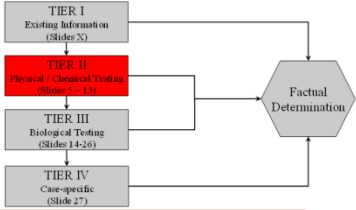


Benthic organisms are not exposed to $C_{sediment}$ or C_{total}.
Only "bioavailable" chemicals can be taken up

Bioavailability describes the phenomenon that not the *total* compartment concentration is available for uptake by organisms, but only a specific *fraction*

- Bioavailable: Portion of the total quantity or concentration of a chemical in the environment that is potentially available for uptake by organisms.
- Uptake: Movement of a contaminant into an organism.
- Biotransformation: Chemical alterations of a compound occurring within the organism.
- Elimination: Movement of a contaminant out of an organism
- Bioaccumulation: Net uptake of a chemical from all sources following exposure over a exposure period.

Tier II: Predicting Bioaccumulation



Thermodynamically-based
Theoretical Bioaccumulation Potential (TBP)

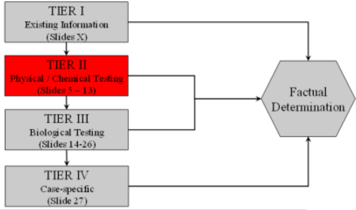
- An estimate of the steady-state concentration of non-polar organic chemicals in organisms exposed to contaminated sediment

- Used as a coarse screening tool to determine if bioaccumulation testing is warranted

- Compare TBP for Reference and DM

- Only works for non-polar (hydrophobic) organics
  - PAHs, PCBs, Chlorinated pesticides

Tier II: Predicting Bioaccumulation



$$\mathrm{TBP} = \mathrm{BSAF}\ \frac{C_s}{\%\mathrm{TOC}} \times \%L$$

BSAF = biota/sediment accumulation factor

C_s = conc. in sediment (any units)

%TOC = total organic carbon content of sediment

%L = lipid content of organism

$$\mathrm{BSAF} = \frac{C_{org}\ \textit{(lipid normalized)}}{C_s\ \textit{(organic carbon normalized)}}$$

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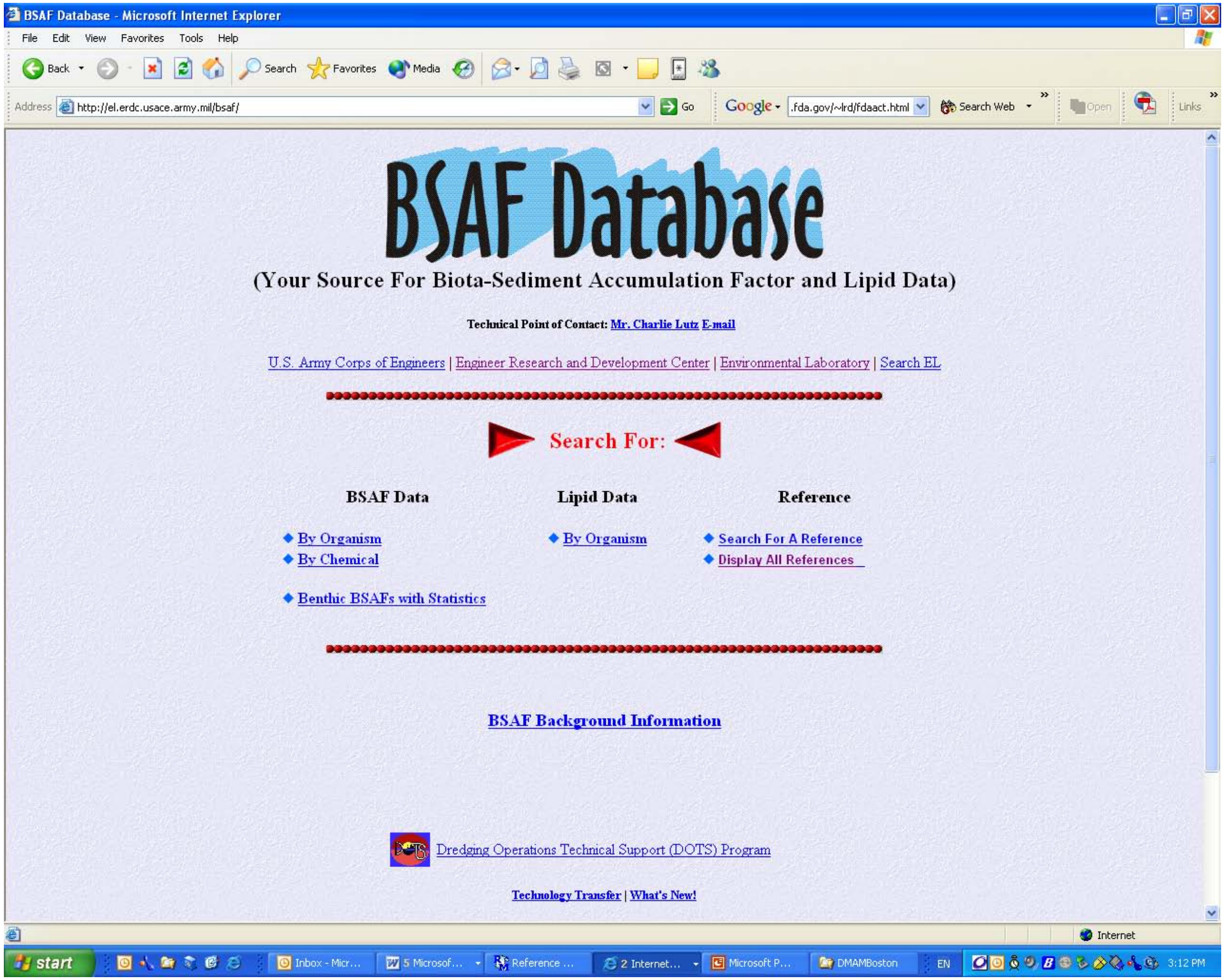
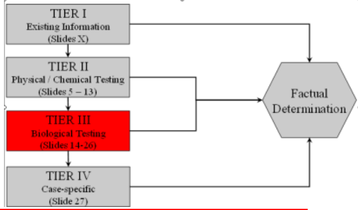
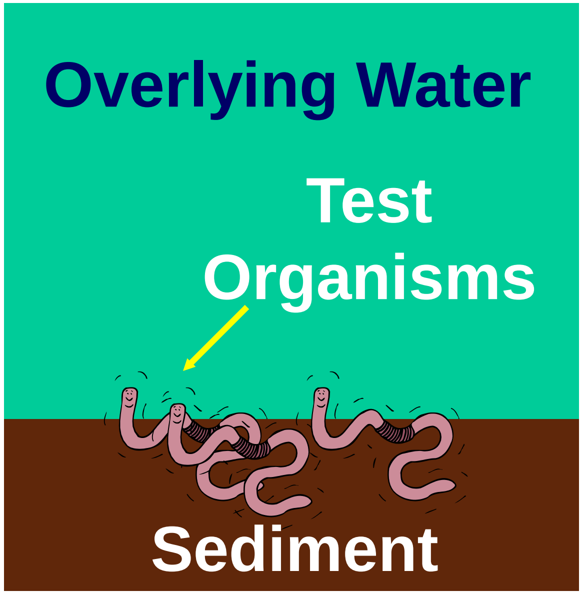
BSAF Database - http://el.erdc.usace.army.mil/bsaf



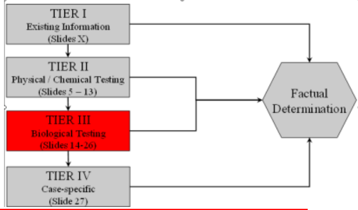
Tier III: Bioaccumulation Test



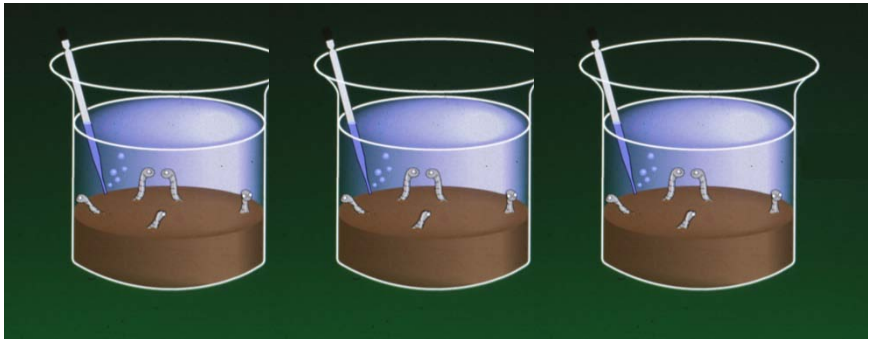


- Conduct whole-sediment bioaccumulation tests
- Compare DM to reference
- Accumulation of chemicals of interest in organisms as endpoint

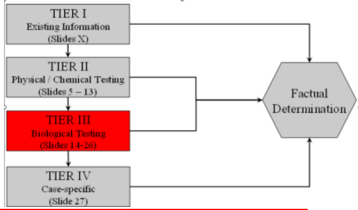
Tier III: Bioaccumulation Test



Test Design



- Time zero tissue analysis
- 28-day exposure
- No feeding
- Minimum 3 replicates/treatment
- Measure tissue concentration at conclusion of exposure



Selection of Test Species

Desirable characteristics

- Sediment ingester
- Infaunal
- Tolerant of contamination
- Easily collected or cultured
- Inefficient metabolizer (PAHs)
- Adequate biomass

- **2 species should / must be used**

(CWA / MPRSA)

Bioaccumulation Test Species
Freshwater

Oligochaete

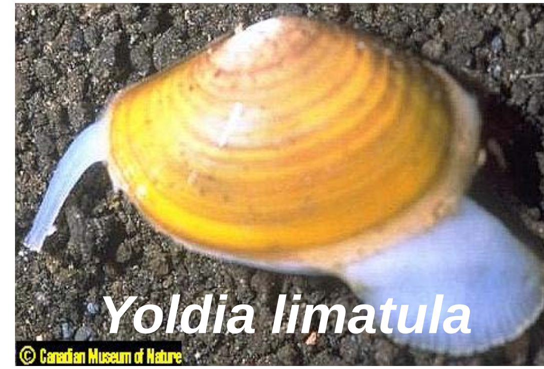
Lumbriculus variegatus

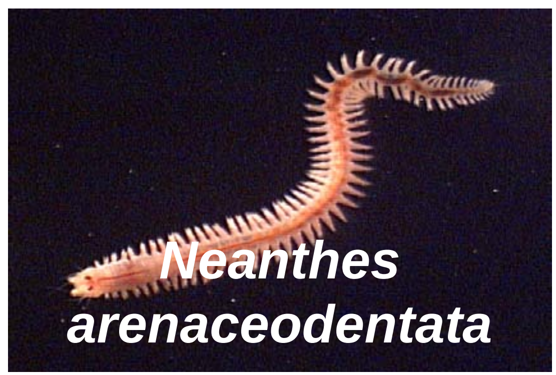
Asian Clam

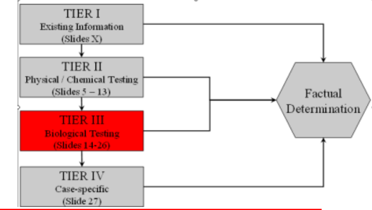
Corbicula fluminea

Bioaccumulation Test Species

Marine / Estuarine





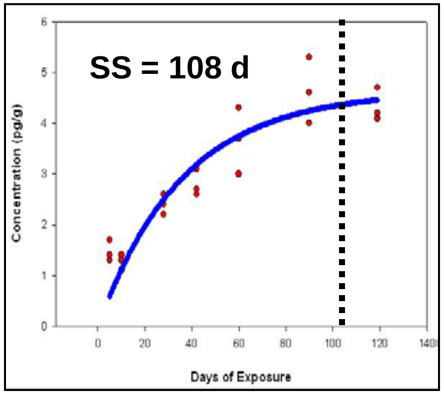


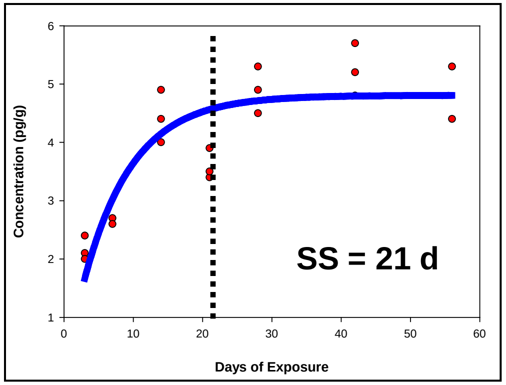
Exposure duration

- **Steady State –** final stable concentration of a contaminant in tissue under constant exposure conditions
- **SS will not always be reached in 28-d depending on:**
  - ➢ contaminant hydrophobicity
  - ➢ species ability to biotransform and eliminate contaminants

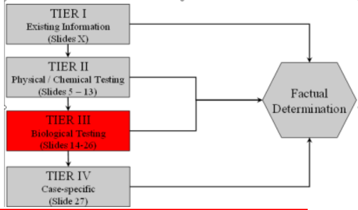
Macoma nasuta ***Nereis virens***

Example: 2,3,7,8 TCDF





Engineer Research and Development Center



Exposure duration

Exposures up to 56 d to New York harbor sediments and kinetic method to determine fraction of SS at 28-d

- 28-d exposure adequate for *Nereis virens* but longer exposure required for *Macoma nasuta*
- Site-specific determinations of SS can be made in Tier IV or correction factors may be applied
- Correction factor of 2 or less appears appropriate for most compounds and species

ERDC/EL TR-10-2

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Dredging Operations and Environmental Research Program

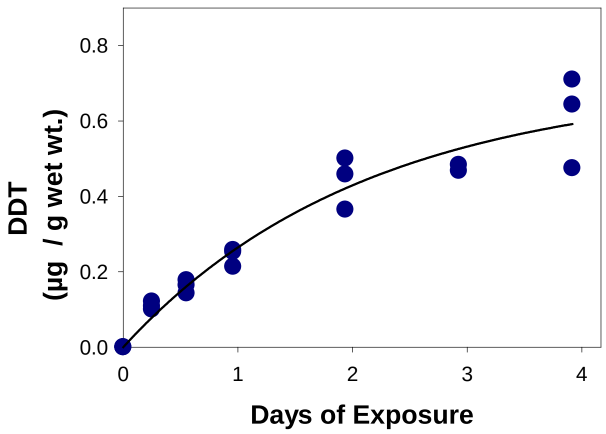
Determining Steady-state Tissue Residues for Invertebrates in Contaminated Sediment

Alan J. Kennedy, Guilherme R. Lotufo, Jeffery A. Steevens, and Todd S. Bridges

May 2010

Time to Steady-state Bioaccumulation

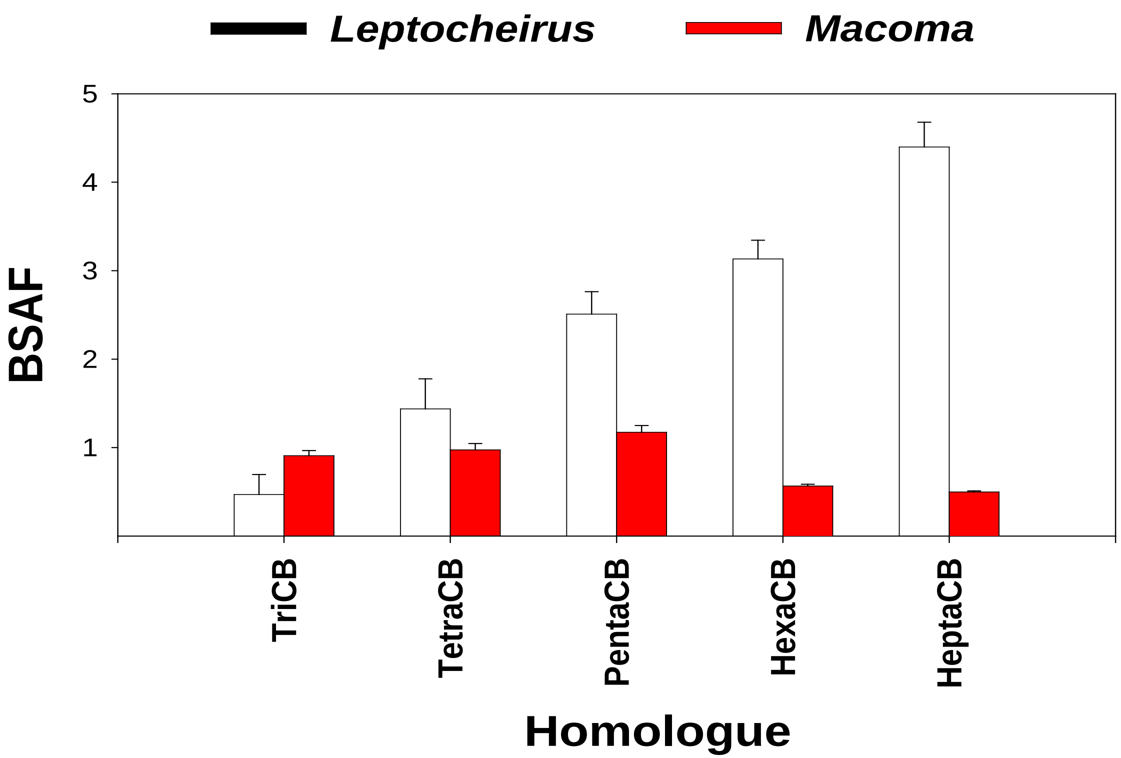
While over 90 days are necessary for DDT to approach steady-state in *Macoma nasuta*,



toxicokinetics modeling predicts steady-state body residues of DDT in 6 days in *Leptocheirus plumulosus*

- Microscale analytical methods were developed and are routinely used at ERDC
- Small mass requirement (e.g., 100 mg) while maintaining adequate method sensitivity
- 25-30 amphipods exposed in 200 g of sediment generate enough tissue for PCB congeners analysis

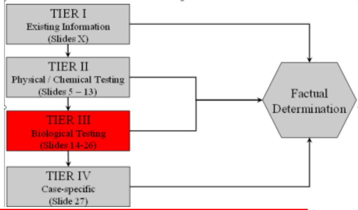
Comparative Bioaccumulation



Exposure to New Bedford Harbor sediment

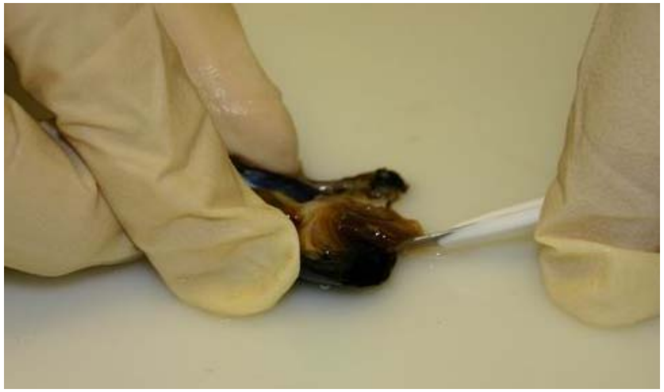
- *Leptocheirus* BSAF values for PCBs were higher than those for *Macoma*, substantially so for high congeners.
- More conservative surrogate for benthic bioaccumulation.
- Uptake from ingestion of fine sediment likely more relevant pathway for *Leptocheirus*, contributes to higher BSAFs.
- *Leptocheirus* under evaluation for routine use in bioaccumulation evaluation

Tier III: Bioaccumulation Test



Conclusion of Exposure

- Collect all remaining/surviving organisms from exposure chambers
- Allow organisms to purge gut content or excise gut
- Conduct chemical analysis of tissues

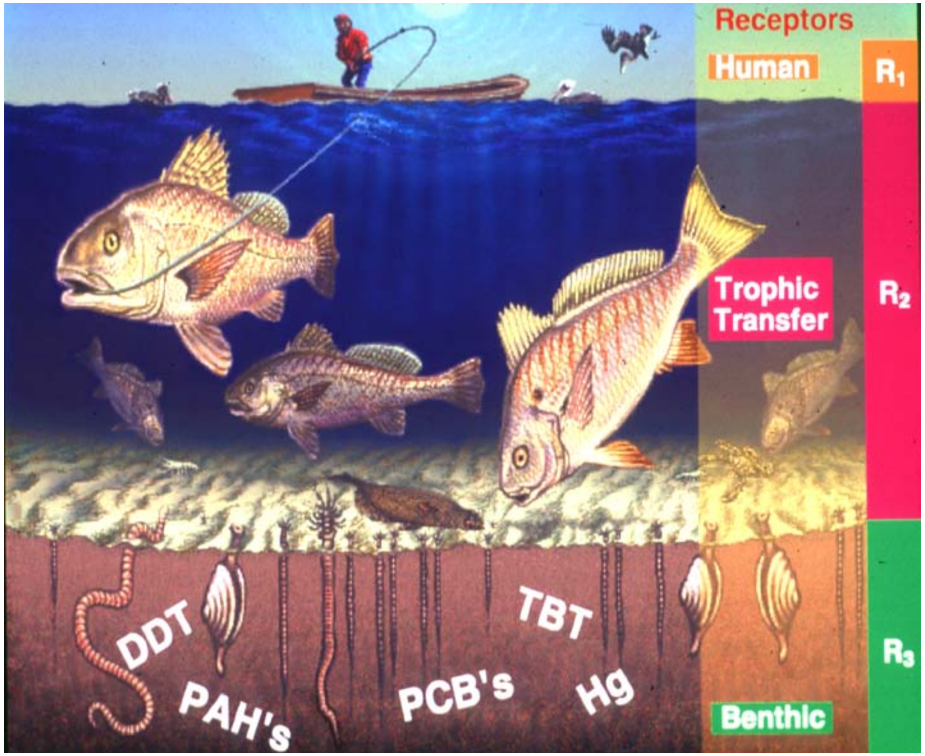


Interpreting Bioaccumulation Data

- Statistical comparison to FDA action levels or state fish advisories
- Statistical comparison of bioaccumulation in DM vs. Reference Material
- Assess toxicological relevance and magnitude
- Compare to background
- Compare residue to effect values
- Evaluate propensity to biomagnify
- Evaluate potential to impact higher trophic levels

Food Web / Trophic Transfer

- **When biomagnification suspected, higher-trophic level receptors include d in the evaluation**
- **Trophic Transfer Models**
  - Use bioaccumulation test data to estimate residue in higher trophic levels
- **Use site-specific information**

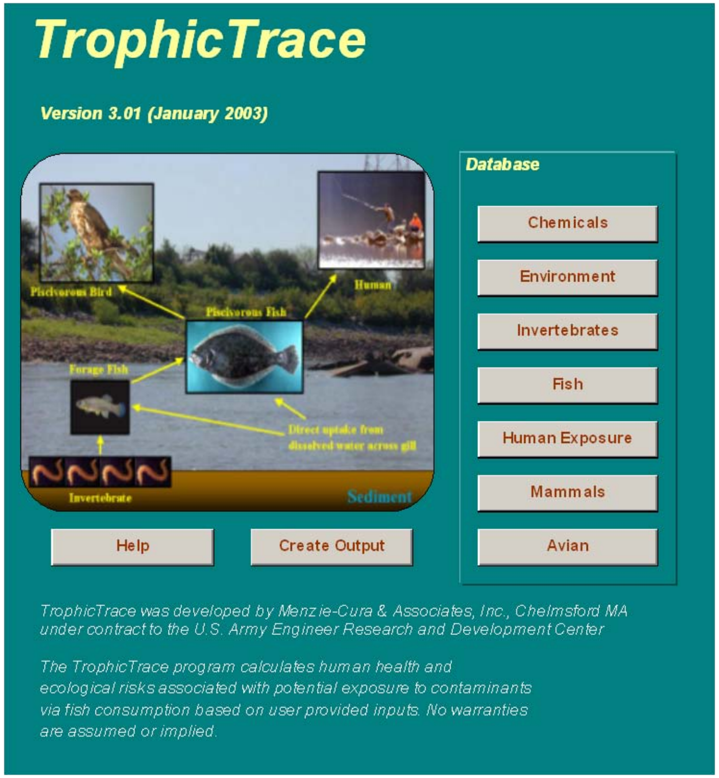


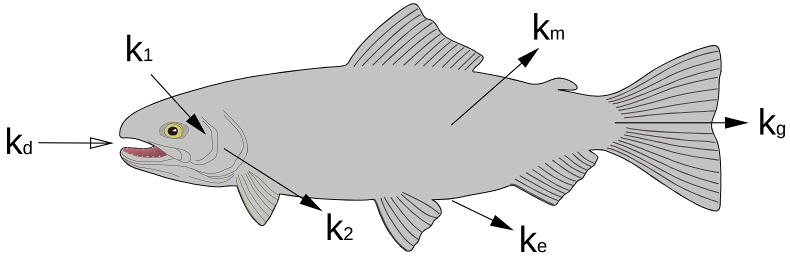
"all models are wrong and some are useful"

Food Web Model: TrophicTrace

http://el.erdc.usace.army.mil/trophictrace/index.html

- Executable program to calculate, with inputs provided by users, potential human health and ecological risks due to bioaccumulation
- Fish concentrations estimated via a food web model (hydrophobic compounds) or trophic transfer factors (metals)





$$C_f = \frac{k_1 * C_{wd} + k_d * C_{diet}}{k_2 + k_e + k_m + k_g}$$

Food Web Model: TrophicTrace

- Calculate risks to ecological receptors (e.g., fish, osprey, bald eagle, mink, and otter) evaluated by comparing to toxicity reference values (TRVs)

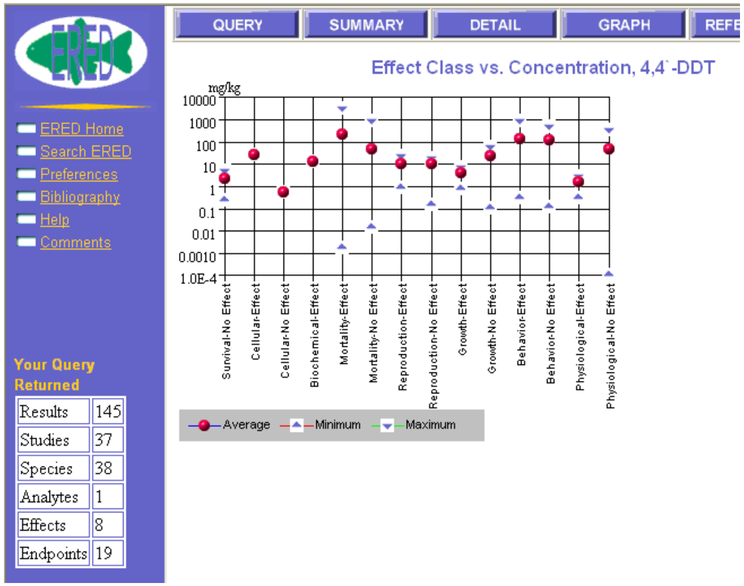
- Potential human health effects are evaluated through Reference Doses for noncarcinogenic outcomes and Cancer Slope Factors for carcinogenic outcomes

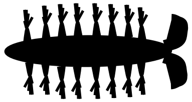
von Stackelberg, K., Burmistrov, D., Linkov, I., Cura, J., and Bridges, T. S. 2002. The use of spatial modeling in an aquatic food web to estimate exposure and risk. *Science of the Total Environment* 288: 97-110.

Linkov, I., von Stackelberg, K. E., Burmistrov, D., and Bridges, T. S. 2001. Uncertainty and variability in risk from trophic transfer of contaminants in dredged sediments. *Science of the Total Environment* 274: 255-269.

Interpretation of Tissue Residue

- **Environmental Residue Effects Database**
- Web-based resource
- > 15,000 records for >400 chemicals
- Lethal and sublethal endpoinds
- Includes data from 2,400 studies
- Updated regularly





500 µg/kg PCB

→

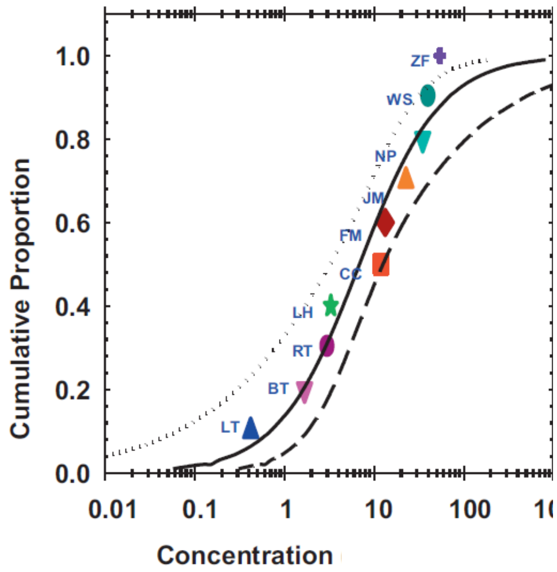
Literature: (lowest effect value)
No-effect: 300 µg/kg clam
Lowest-effect: 1,530 µg/kg worm

ERED found at: http://el.erdc.usace.army.mil/ered/

Interpretation of Tissue Residue

Species Sensitivity Distribution (SSD)

- Distribution of literature data reporting effect associated with tissue concentration
- Use the SSD to select the level of species protection and degree of conservatism



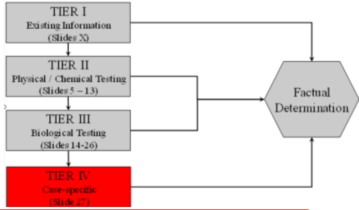
Sappington, K. G., Bridges, T. S., Bradbury, S. P., Erickson, R. J., Hendriks, A. J., Lanno, R. P., Meador, J. P., Mount, D. R., Salazar, M. H., and Spry, D. J. 2011. Application of the tissue residue approach in ecological risk assessment. *Integrated Environmental Assessment and Management* 7: 116-140.

Steevens, J. A., Reiss, M. R., and Pawlisz, A. V. 2005. A Methodology for deriving tissue residue benchmarks for aquatic biota: A case study for fish eposed to 2,3,7,8-tetrachlorodibenzo- p-dioxin and equivalents. *Integrated Environmental Assessment and Management* 1: 142-151.

Interpretation of Metals

- **Potential for trophic transfer**
  - Only metal in certain compartments is biologically available
  - High metal distribution in the prey and potential for detoxification (metallothioneins, granules)
- **Critical body residues**
  - Essential (Fe, Cu, Zn) vs. non-essential metals (Hg, Pb, Cd, U)
  - Concentration at site of toxic action not necessarily related to whole-body accumulation due to sequestration mechanism
  - Therefore, difficult to predict effects from whole-body concentration

Tier IV Evaluation



Steady State Bioaccumulation

- e.g., extended sediment exposure; derivation of site specific kinetics

Detailed Evaluation of Impact to Higher Trophic Levels

- e.g., ecological and human health risk assessment

Conclusions

- Evaluation of bioaccumulation, typically using laboratory sediment exposure, provides information for assessing long-term effects to higher trophic-level receptors

- As a line of evidence, bioaccumulations should be used along with other ones (e.g., direct toxicity) in a weight of evidence approach to determine risk

- Evaluation complexity ranges widely from simple modeling to full risk assessment. Increase complexity as necessary to reach a conclusion

Direct Measurement of Bioaccumulation

- **Allows for site-specific determinations**
- **Site species may be used**
- **Standardized and validated approach**

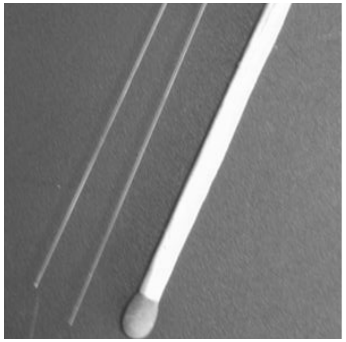
Problems

- Traditional approaches use lengthy and costly bioaccumulation laboratory exposures.
- Variability across species(e.g., time to steady-state, routes of uptake, metabolism) hampers extrapolation
- Health of test organisms
- Organism availability and challenging biomass requirement for chemistry

Passive Samplers for Use in Sediment

Passive sampler accumulates freely-dissolved organic contaminants from surrounding water into a solid phase (e.g., polymer). Technique based on simple equilibration between porewater and sorbent phase

Use cost-effective approaches for estimating porewater concentration and predicting bioaccumulation



PDMS (or SPME)
Polydimethylsiloxane fiber

PED
polyethylene

POM
Polyoxymethylene

Passive Sampler Assessment of Bioaccumulation

Sediment

Slow + very slow desorbing fraction

Fast desorbing fraction

Non-depletive extractions (partition based / biomimetic) that measure freely dissolved concentrations with passive samplers: Measuring what is “actually available”

1. ‘Calculation’ approach (indirect; $K_{sampler}$, BCF needed)
2. ‘Comparison’ approach (direct)

Freely dissolved concentration in pore water

BCF

1

$K_{sampler}$

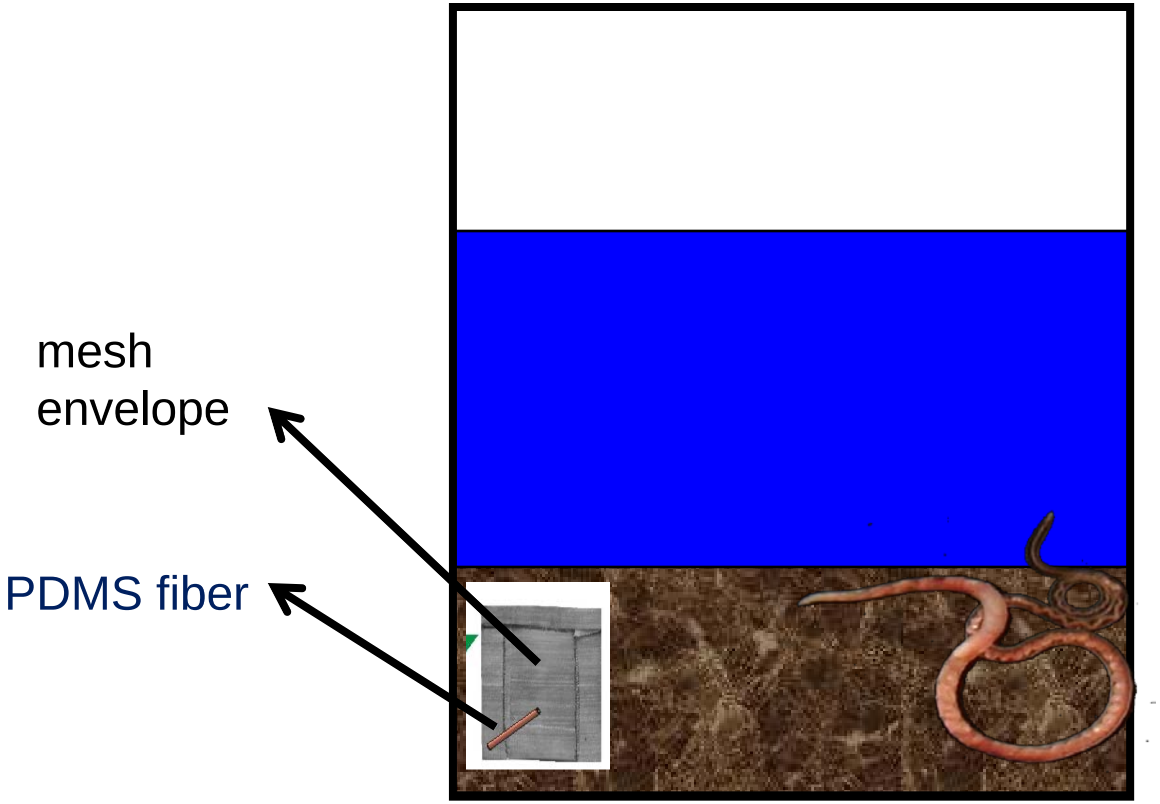
Concentration in passive sampler

Organism

2

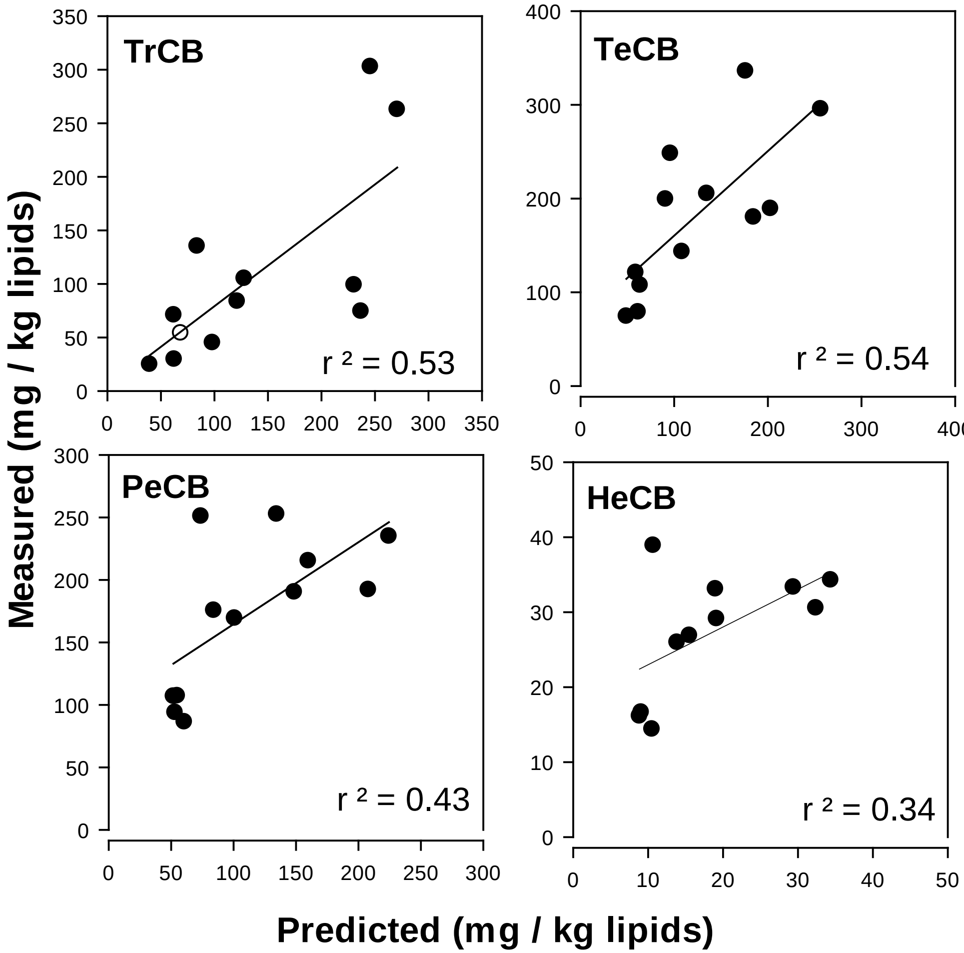
PW-estimated and Directly-measured Bioaccumulation

Passive sampler and benthic invertebrate co-exposed to sediment



PW-estimated and Directly-measured Bioaccumulation

Leptocheirus plumulosus



Bioavailability Assessment: Comparison of Approaches

	Advantages	Disadvantages
Theoretical Modeling (e.g., BSAF)	Cheap and fast – uses sediment chemistry only	Highest uncertainty Least site specificity. Commonly over predicts.
Direct Measurement (e.g., laboratory bioaccumulation test)	Allows for site-specific determinations Site species may be used Standardized and validated approach	Costly, complex and lengthy. Complicating factors: variability across species, sediment avoidance, metabolism, health of organisms, tissue mass requirements.
Passive Sampler (e.g., SPME)	Cheaper than direct measurement. Can provide a common unbiased analysis approach across sites. In situ deployment far simpler and cheaper than caged organisms. Can be modeled or calibrated to predict bioaccumulation. Ideal for intense spatial and temporal site characterization.	Lack of standard methods. Uncertainty in establishing when equilibrium occurs. Uncertainly in predicting bioaccumulation in species of concern.

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