Sediment Bioassays as a Tool to Inform Injury and Restoration

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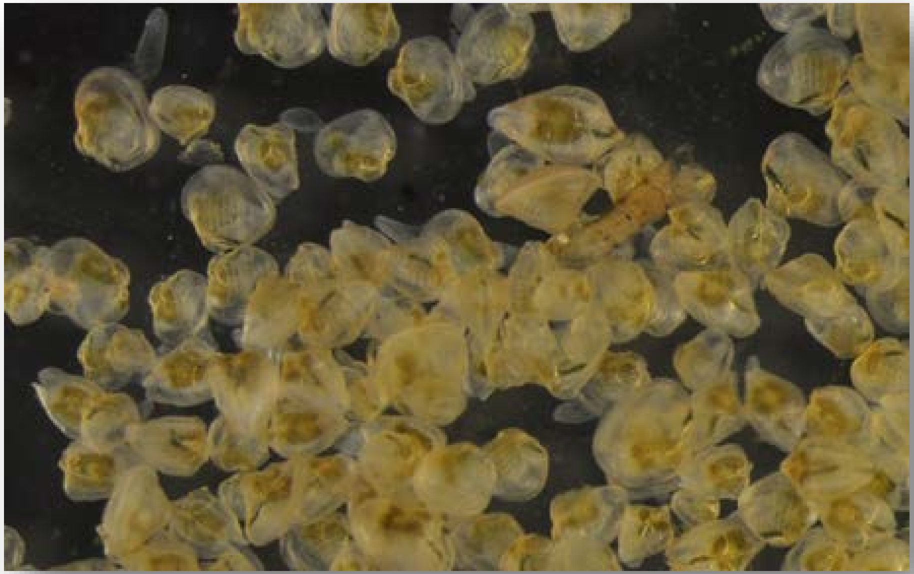
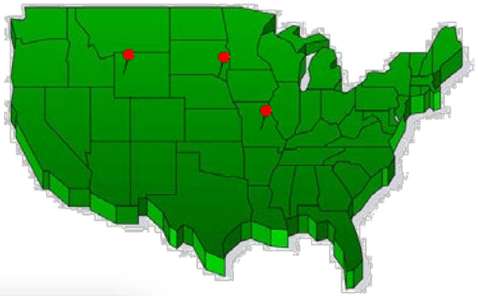


Juvenile *Lampsilis siliquoidea* (fatmucket) mussel used for sediment toxicity bioassays. Photo by Douglas Hardesty, USGS-CERC

U.S. Department of the Interior
U.S. Geological Survey

Columbia Environmental Research Center

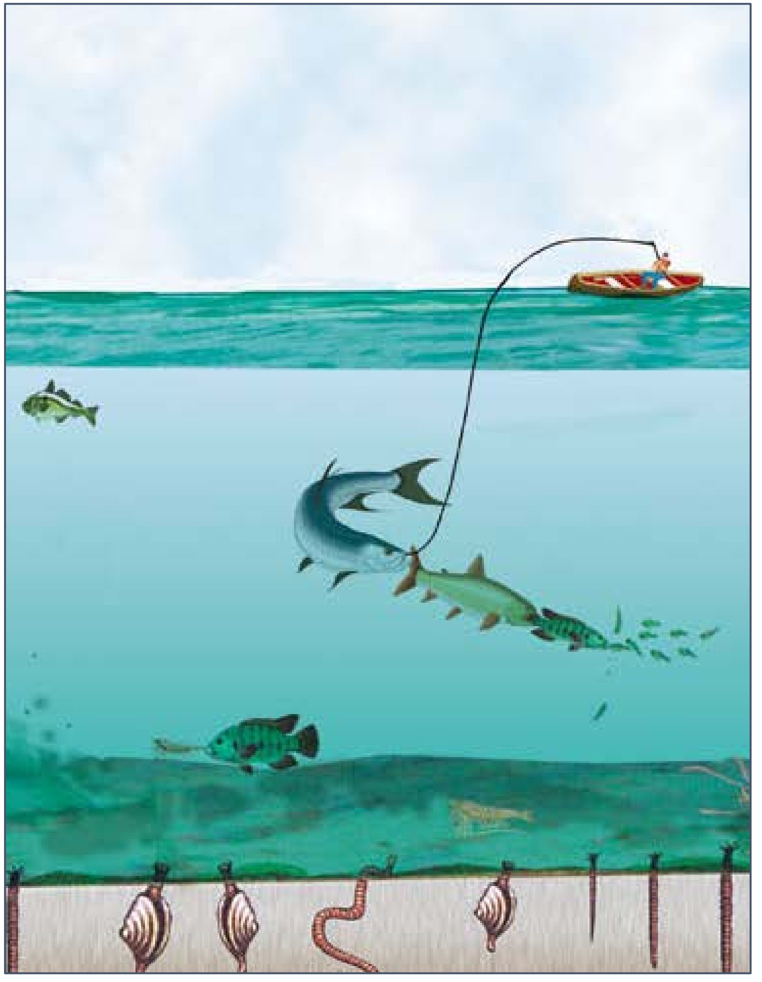


- USGS research center supporting Department of Interior mission
- Located in Columbia, MO with field stations in Jackson, WY and Yankton, SD
- 150 Scientists, Staff, Students, Volunteers
- Partner with national, state and local agencies, non-governmental organizations and universities

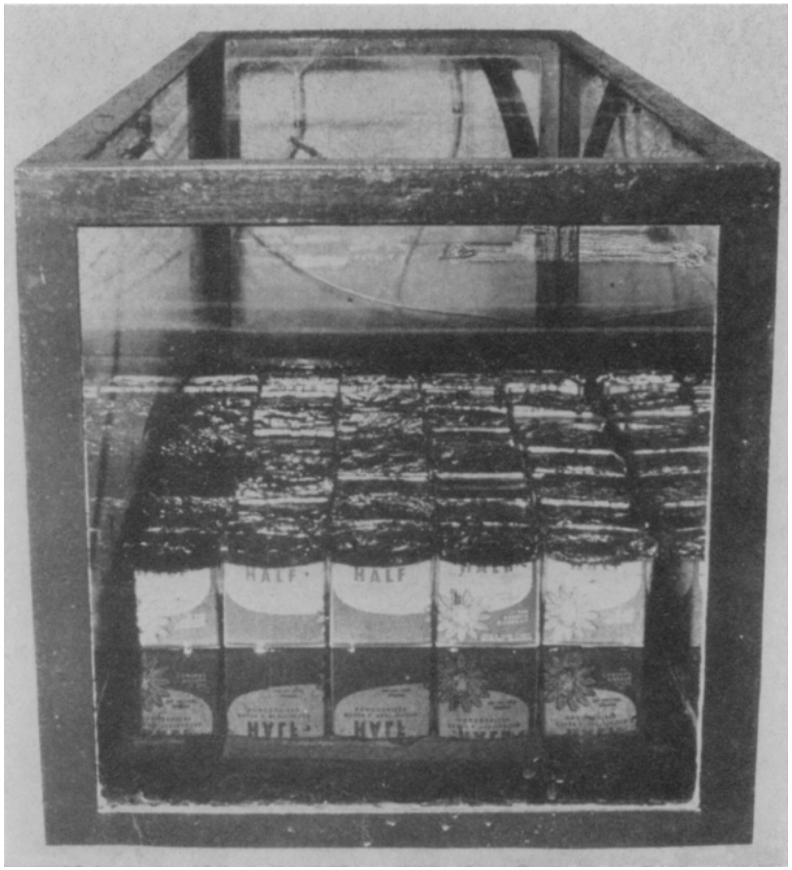
CERC conducts research needed to address national and international environmental contaminant issues and effects of habitat alterations on aquatic and terrestrial ecosystems

Why Focus on Sediment?

- Sediment is a contaminant “sink”
- Contaminants are bound to sediment particles
- Benthic organisms interact with sediment resulting in toxicity or uptake



Sediment Toxicity Bioassays



Gannon JE, Beeton AM. Procedures for determining the effects of dredged sediments on biota-benthos viability and sediment selection tests. *J. Water Pollut Control Fed* 43: 392-398; Funded by the US Army Corps of Engineers

- First sediment toxicity test was by Gannon and Beeton, 1971 at the University of Wisconsin

  "The tests provided data that could not be obtained by routine environmental surveys. The methods used are simple, require minimal expenditures of materials and labor, and can easily be modified to answer other questions of concern in water pollution biology using different organisms in other water bodies."

Context of Sediment Bioassays

Toxicity →

- Measurable direct effect
- Develop concentration response models – to quantify injury
- Restoration/monitoring endpoint

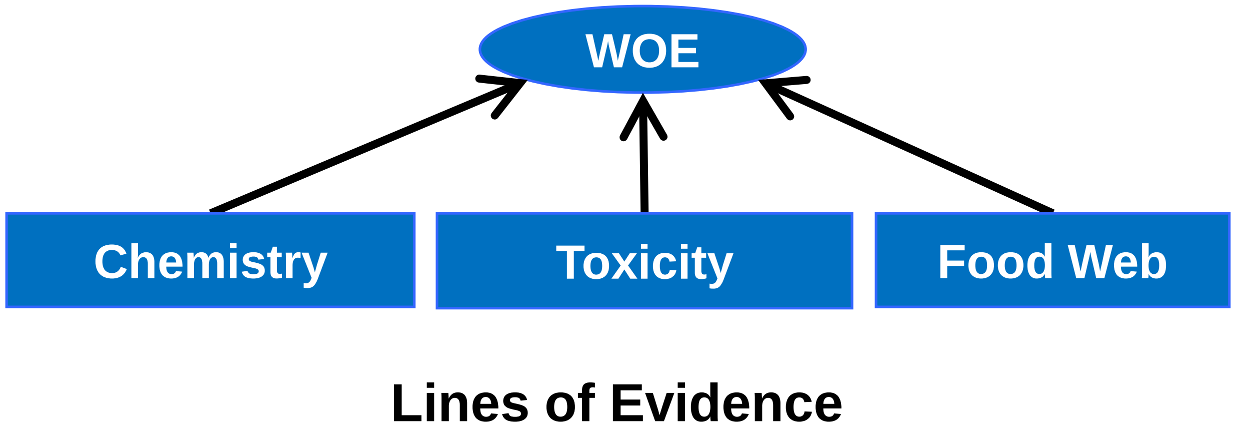
Bioaccumulation →

- Directly measure chemical available in sediment
- Uptake into foodweb – effects on benthic community, fish/wildlife, humans
- Restoration/monitoring endpoint

- Advantages: measures bioavailable fraction, direct measure of toxicity, assess mixtures, rapid/inexpensive, legal precedent and standard methods, linkage of chemistry to natural benthic community
- Disadvantages: sediment handling, factors controlling bioavailability unknown, limitations in linking lab to field, do not assess effects on humans

Weight of Evidence Approach

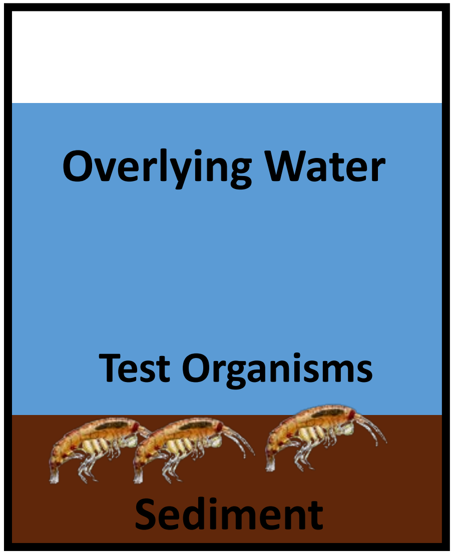
WOE - Framework for synthesizing individual lines of evidence, using qualitative or quantitative approaches to develop conclusions regarding questions related to contaminant exposure and injury.



Integrate multiple lines of evidence qualitatively or quantitatively using weighting, ranking, or indexing as well as structured decision or statistical models.

Linkov et al., 2009

Sediment Toxicity Bioassay



- **Method for assessing toxicity of contaminants in sediment directly using field collected sediments**
- Standardized EPA/ASTM protocols used with precedence in regulatory programs
- Acute exposures (10-day) and chronic exposures (28+ days)
- Compare responses from site(s) to a reference site(s)
- Endpoints survival, growth and reproduction

Chironomus dilutus

Lampsilis siliquoidea

Hyalella azteca

Common Toxicity Test Species

Freshwater

Hyalella azteca

Chironomus dilutus

Lampsilis siliquoidea

Hexagenia limbata

Tubifex tubifex

Marine

Leptocheirus plumulosus

Ampelisca abdita

Neanthes arenaceodentata

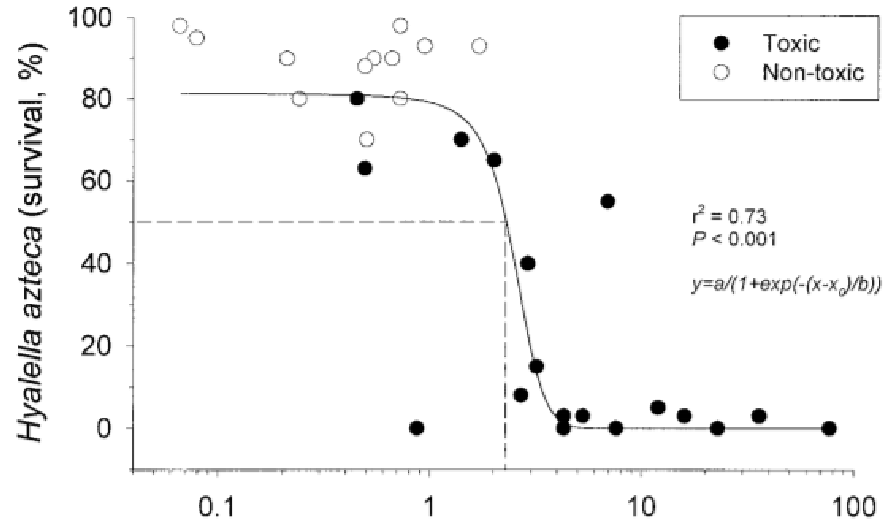
Eohaustorius estuarius

Americamysis sp.

Hyalella azteca, a freshwater amphipod

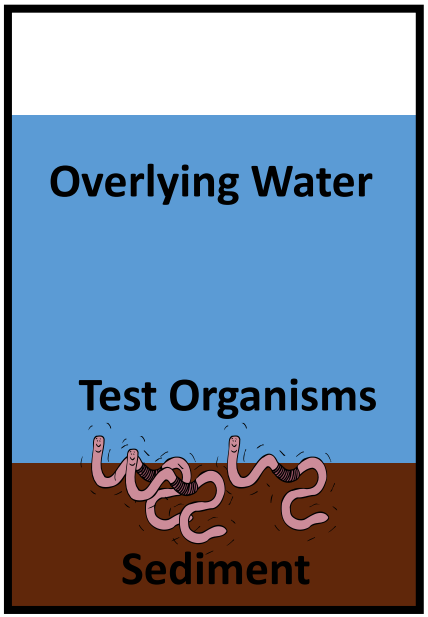
Background: An Example of a Successful NRDAR Assessment Grand Calumet River

- Sediment toxicity using *H. azteca* and *L. variegatus* bioassays
- Combined with other lines of evidence: Sediment chemistry, porewater chemistry, benthic community to support the conclusion that sediment injury has occurred in the assessment area.



"Whole sediments, pore water, or elutriates from the assessment area were frequently toxic to aquatic organisms, including sediment-dwelling species" Ingersoll et al. 2002. *Arch Environ Cont Tox*

Sediment Bioaccumulation Tests



- Use bioaccumulation test to indicate/determine the uptake of chemical in organism exposed to sediment
- Standard methods (ASTM and EPA)
- Typically a 28 day duration with steady state correction
- Data is used to estimate potential for contaminants to move into food web and cause adverse effects to fish, birds, wildlife, and people
- Select a relatively insensitive organism that is unlikely to metabolize the contaminant

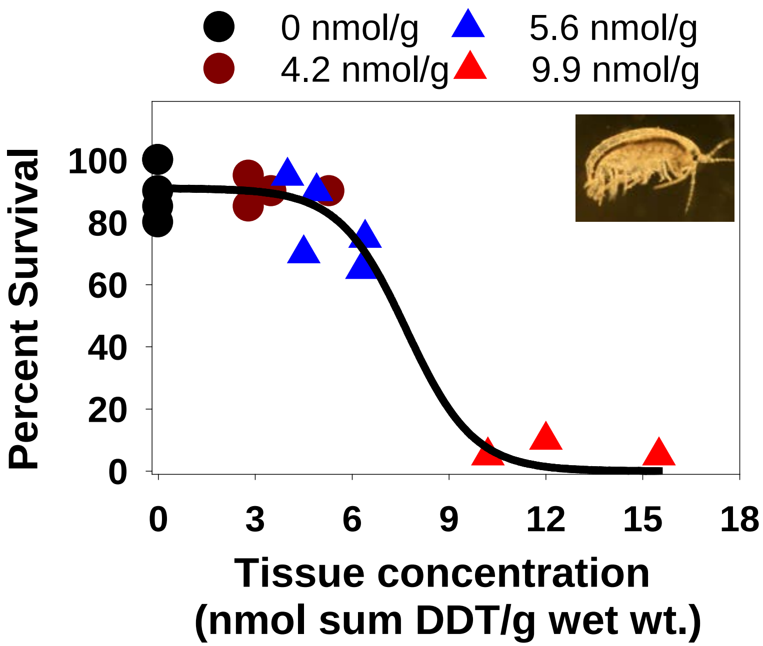
Lumbriculus variegatus

Macoma nasuta

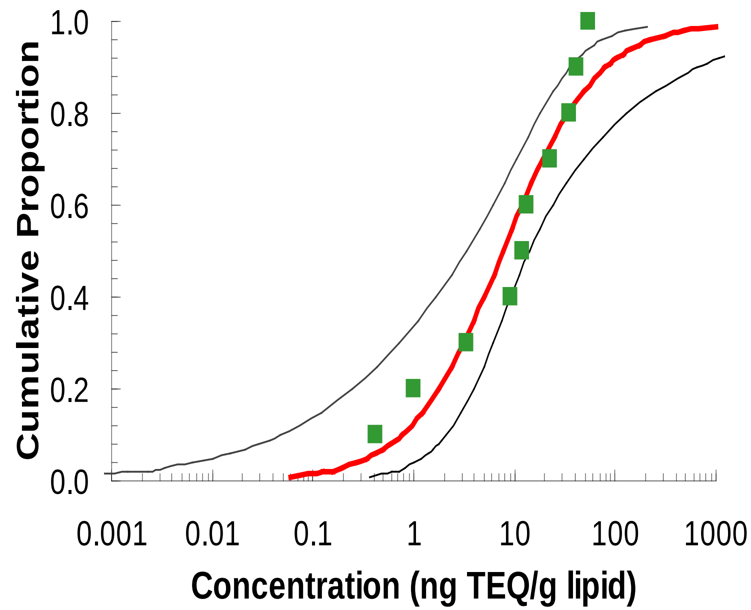
Nereis Virens

Linking Bioaccumulation to Toxic Effects

Use concentration in tissue of test organism to (left) relate directly to effects on benthic invertebrates or (right) relate to fish that consume invertebrates



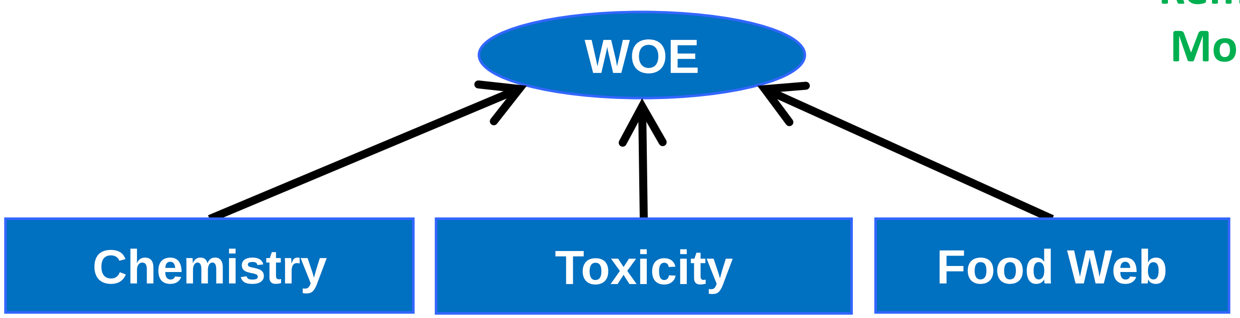
Critical body residue for ∑ DDT in tissues of *H. azteca*. From *Lotufo et al. 2001. Arch. Environ. Toxicol.*



Species sensitivity distribution for dioxin compounds in invertebrates associated with effects on early life stage fish. *From Steevens et al. 2005. Int. Environ. Assess. Manage.*

Approaches Beyond Standard Methods

4. Evaluate Remedy and Monitoring



Lines of Evidence

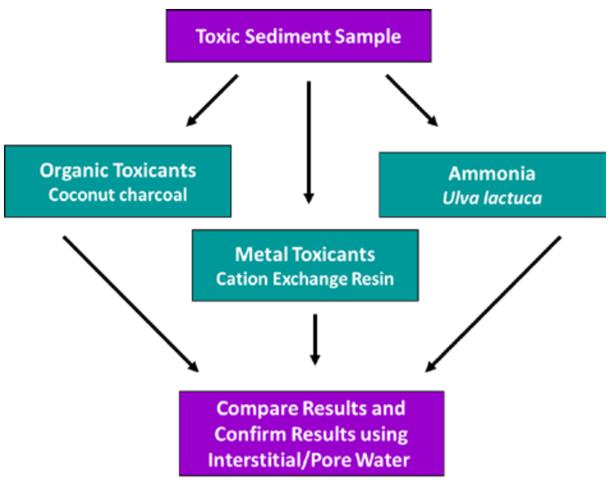
1. Toxicity Identification

2. Couple Passive Samplers

3. Linking Geochemistry and Biology

Sediment Toxicity Identification Evaluation

- Goal is to evaluate toxicity, identify the toxicant class, and confirm the suspected toxicant is causing the effect
- Typically employ a resin/substrate amended to sediment to affect the availability and subsequent toxicity of contaminants
- Alternatively an indirect treatment such as ultraviolet light or different temperature can be used to affect metabolism/reactivity of chemicals and subsequent toxicity
- Can also be used to inform remediation and restoration strategies



Zeolite

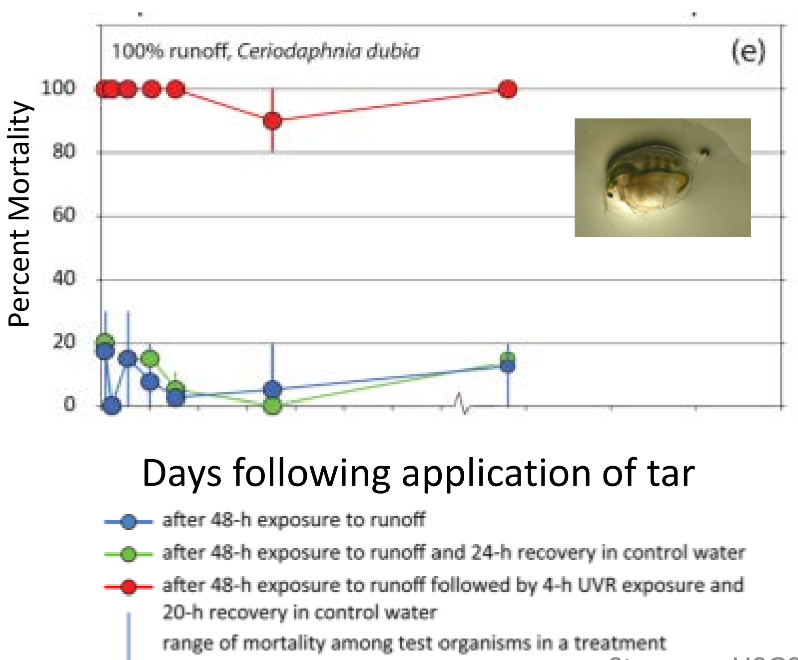
SIR-300

Coconut Charcoal

UV Light to Confirm Toxicity of Polycyclic Aromatic Hydrocarbons (PAH)

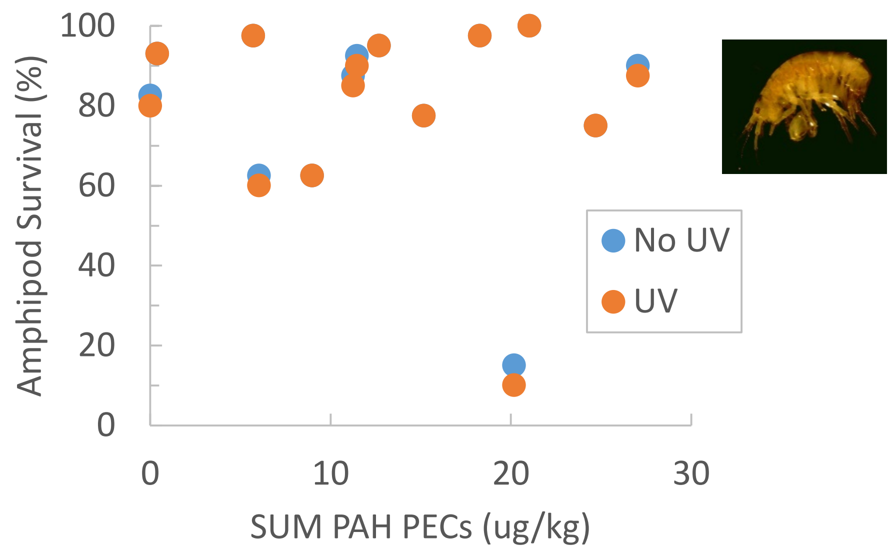
1. Organisms from toxicity study are exposed to sample.
2. Surviving organisms are placed in clean water and exposed to UV light – assesses toxicity of bioaccumulated compounds

Toxicity of Tar Coated Pavement



Toxicity of Sediments (NAWQA)

(indicates toxicity not from PAH)

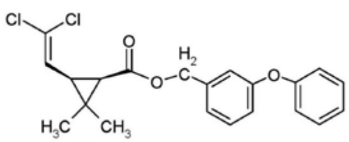


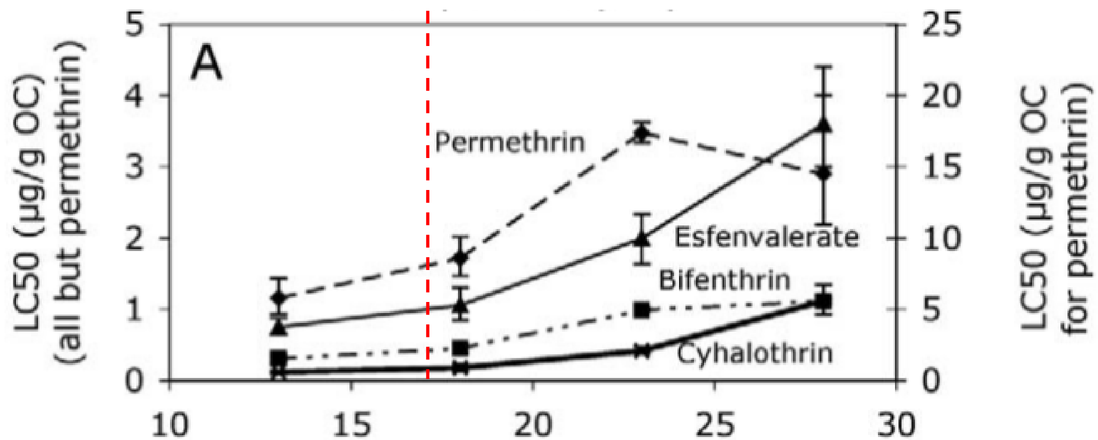
(left) Mahler et al. 2015. *Env Sci Tech.*

(right) Kemble et al. 2017. Preliminary Data

Temperature to Confirm Toxicity of Pyrethroid Pesticides

Pyrethroid toxicity increases at lower temperatures due to decreased biotransformation and increased accumulation of parent compounds





Weston et al. 2009. *Environ. Tox. Chem.*

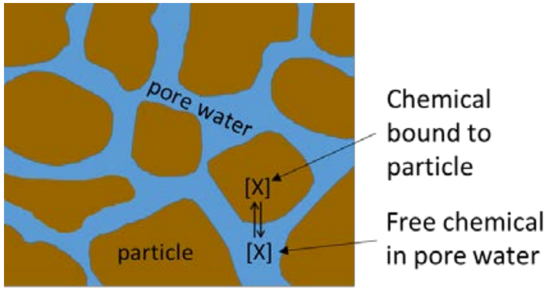
It offers a low cost method to rule “in” or “out” toxicity for specific compounds of interest

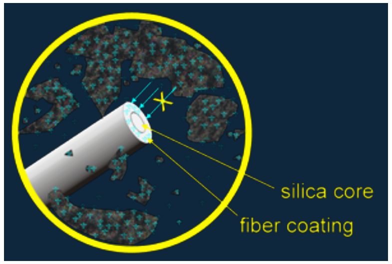
We plan to use this in the NAWQA California 2017

Passive Samplers

- Passive samplers used to assess bioavailable fraction of contaminants through absorption or dialysis
- Provide information about equilibrium concentrations in pore water
- Samplers are equilibrated in sediment, removed, extracted for contaminant of concern and analyzed
  - For organics: solid phase micro extraction (SPME) fibers, semi-permeable membrane devices (SPMD), polyoxymethylene (POM)
  - For metals: diffuse gradients in thin films (DGT), dialysis sampler (peepers)

Use as part of a bioassay to assess bioavailability and bioaccumulation



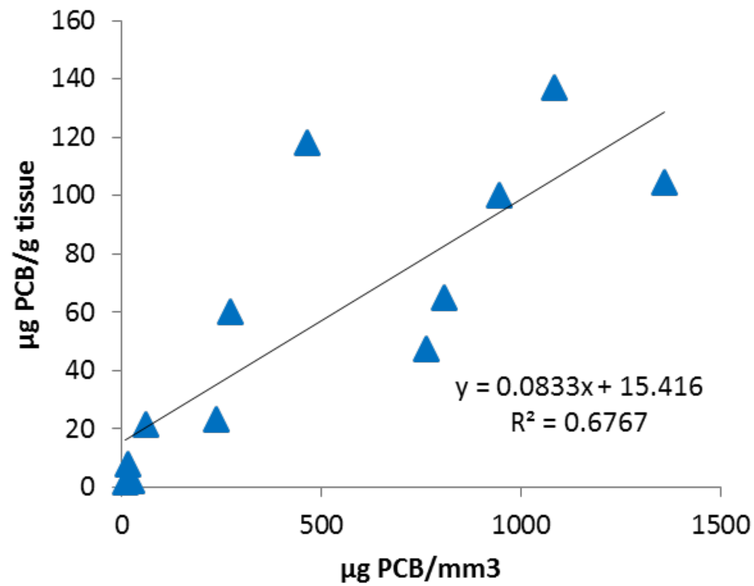


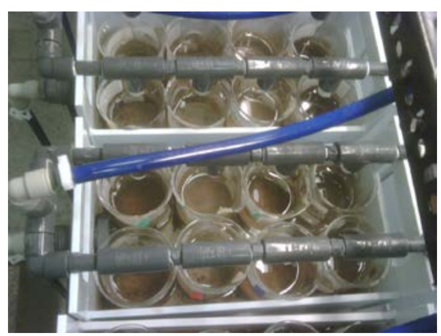
Solid phase micro extraction (SPME) fibers

Equilibrium Samplers (‘peepers’)

Use of passive samplers to assess bioavailability

- Application:
  1. Measure bioavailability of PCB; direct measure of bioavailable fraction
  2. Use as a line-of-evidence (LOE) within a weight-of-evidence approach
- Benefits: relatively easy and inexpensive; majority of cost is from chemical analysis





Anniston, AL assessment, Steevens et al., 2013

Linking Geochemistry with Biology:
TVA Kingston Fossil Plant Ash Spill

- Fly ash collected from 60 years of coal energy production
- Spill December 22, 2008
- 5 million yd^3 in Emory River



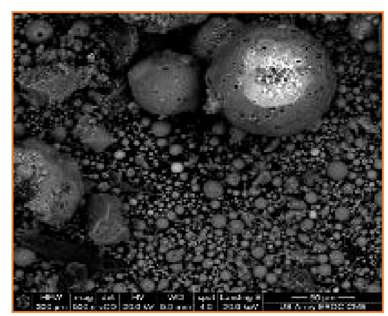

Bioavailability of Metals in Fly Ash

Toxicity

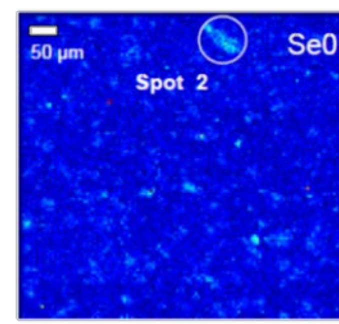
- High concentrations of metals detected in bulk material
- Low partitioning to water
- Low toxicity (bulk sediment, elutriates)
  - Amphipods, mussels, fish
- High uptake
  - Associated with ash in gut
  - Low bioaccumulation

Geochemistry

- Traditional methods do not address flux and dynamic nature of ash
- Evaluate biphasic system
  - Speciation of metals determined using synchrotron based techniques (XANES, XRF mapping) and microscopy
  - Geochemical modeling

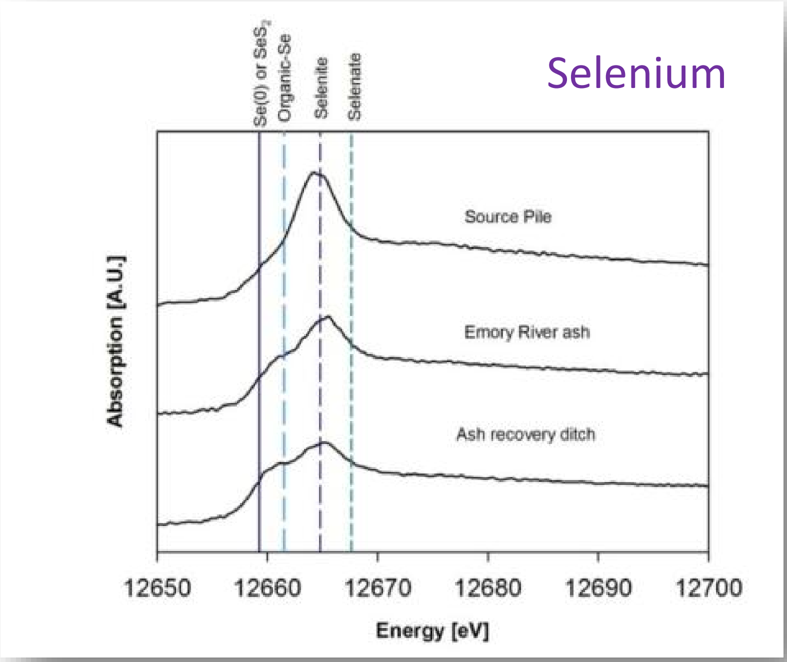


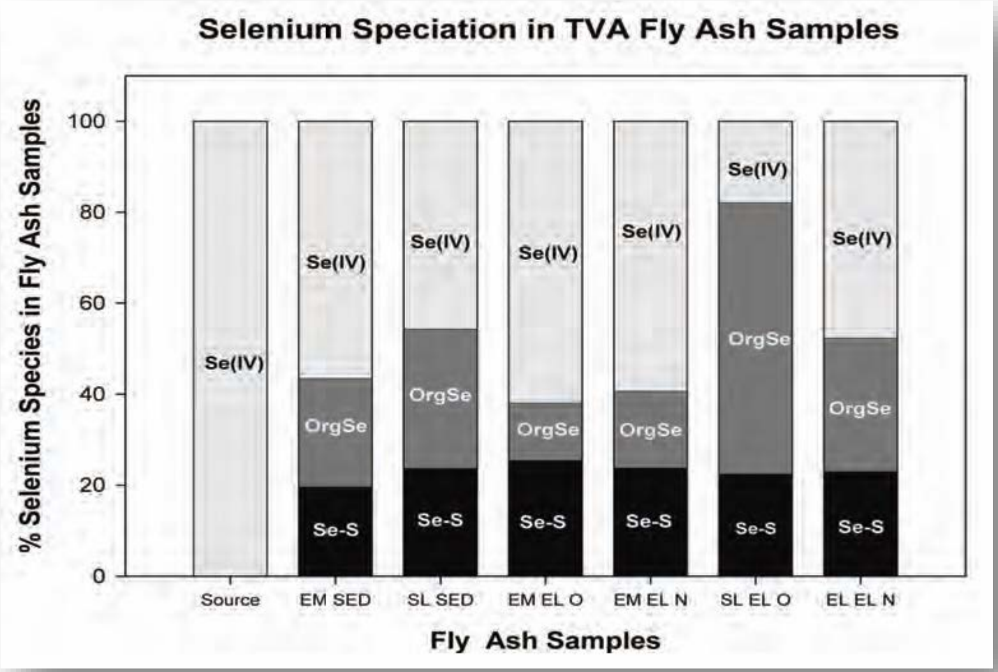
SEM-EDX Analysis



XRF Mapping

X-ray Near Edge Spectroscopy (μ-XANES)





Source Pile: mainly Selenite - Se (IV)
Emory River & ARD: Mixture of Se(IV), organoselenium (-II), Se(IV)-sulfides

Chappell et al.(2014) Chemosphere; Bednar et al. (2013) Chemosphere; Stanley et al. (2013) Environ Tox Chem

Take Home Message: Biphasic chemical speciation linked with biological information improved our understanding of processes in this system – guide remediation decisions

Use Bioassays to Guide Remediation/Restoration?

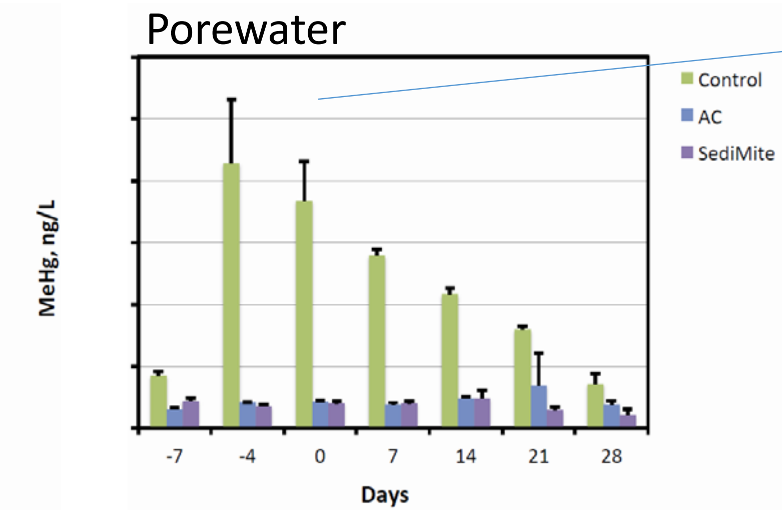
- Remediation techniques (e.g., In situ amendments) rely on reducing bioavailable fraction of chemical
- Case: Historical estuarine site with PCB and Hg
- Measure bioavailable fraction
  - directly (pore water chemistry)
  - indirectly using toxicity bioassay or bioaccumulation in tissues of organism
- Goal is to assess the efficacy of activated carbon amendments (GAC)

Field collected sediment

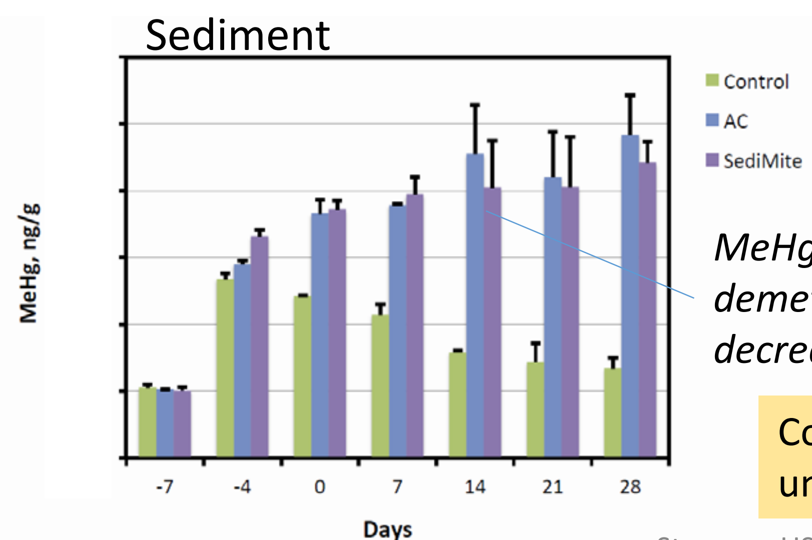
Amend sediment with GAC (top) or sedimite™ (bottom)

Does amendment decrease
- MeHg in porewater?
- MeHg in sediment?
- bioaccumulation of MeHg?

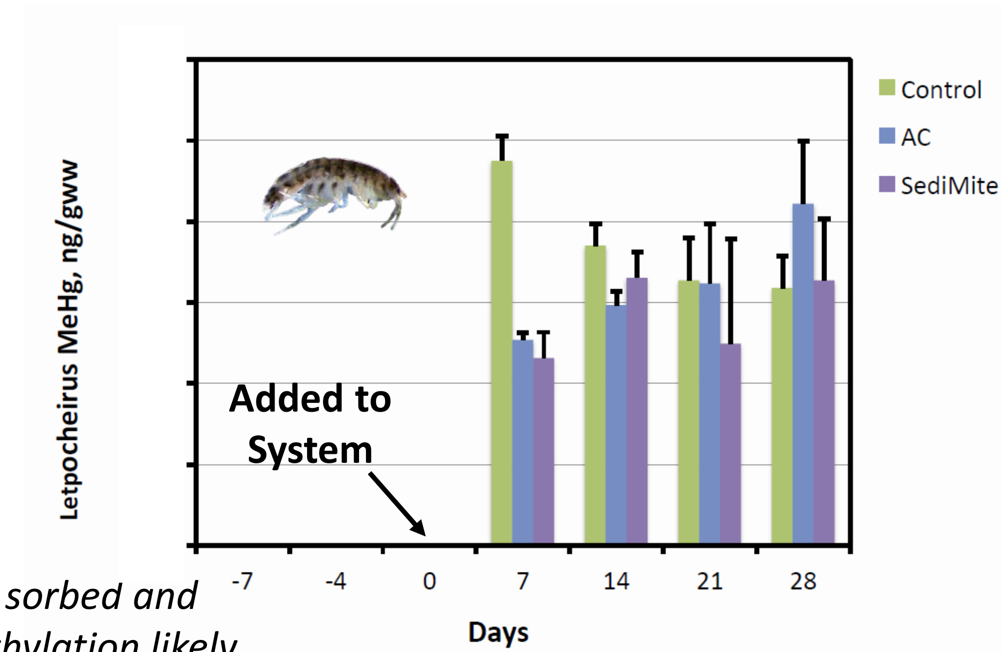
Methyl Mercury Concentrations in Sediment/Porewater/Tissue of Organisms



Significant amount of MeHg produced after homogenization



MeHg sorbed and demethylation likely decreased by AC

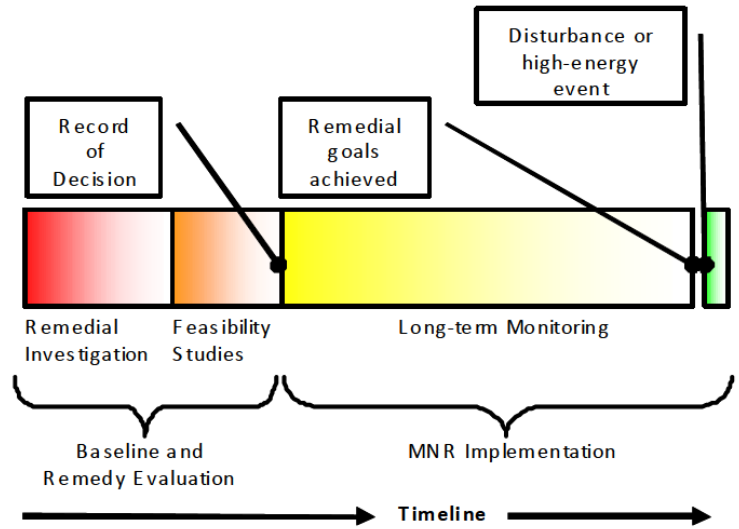


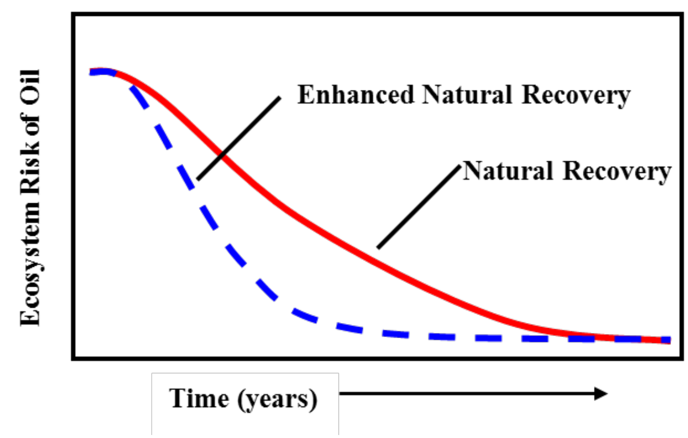
Coupling bioassay and geochemical measures improves our understanding of this dynamic system

Steevens et al., 2015

Using Bioassays As a Tool in Monitored Natural Recovery

- Monitored natural recovery (MNR) requires lines of evidence on which to base remediation/ restoration predictions
- Bioassays can be used as baseline data and for long-term monitoring





Magar and Steevens. 2009. ESTCP

Summary

- Sediment bioassays can be a cost effective tool for assessing toxicity in NRDAR
- Used as part of weight of evidence with chemistry and other biological data
- New techniques can be used to inform bioavailability, remediation, management, restoration and support long-term monitoring

Call me at 573-876-1819 or email at jsteevens@usgs.gov
if you have any questions or ideas!