Aquatic Placement of Dredged Sediments: Interpreting Bioaccumulation

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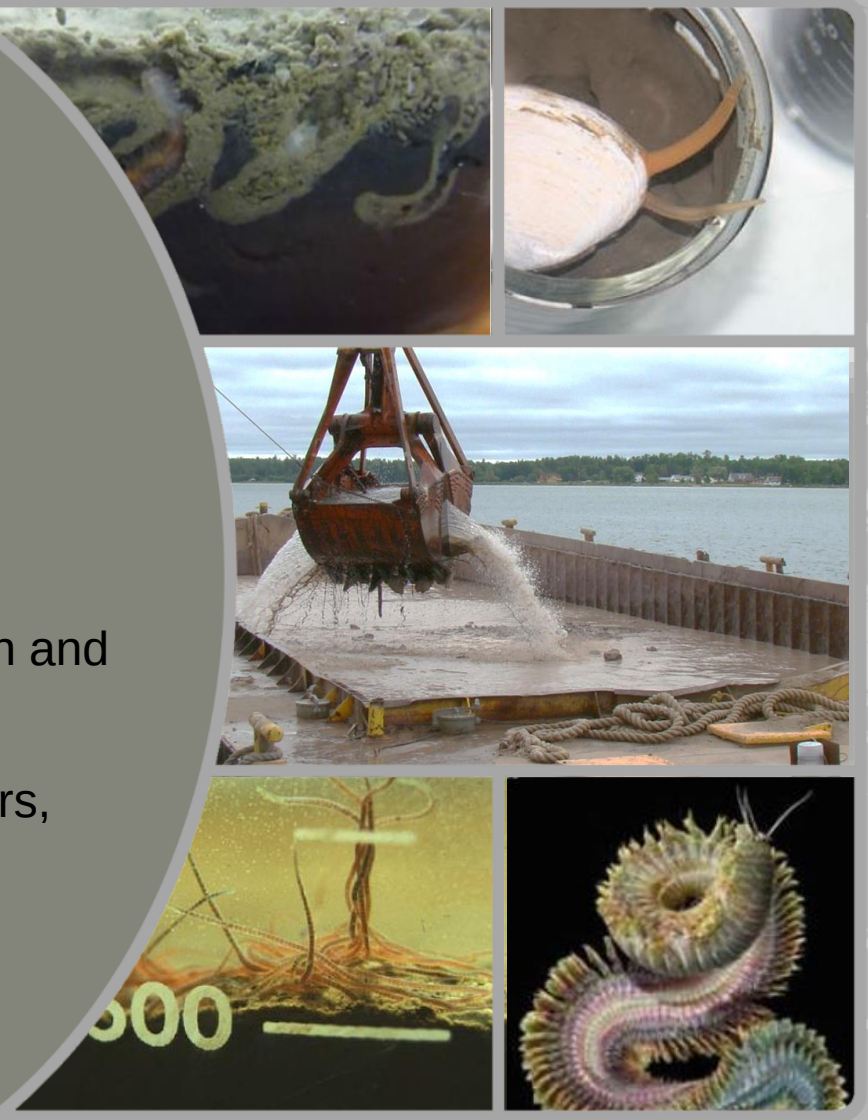

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Outline

1. Overview of bioaccumulation in context of dredged material placement

2. Evaluation of bioaccumulation assessment factors

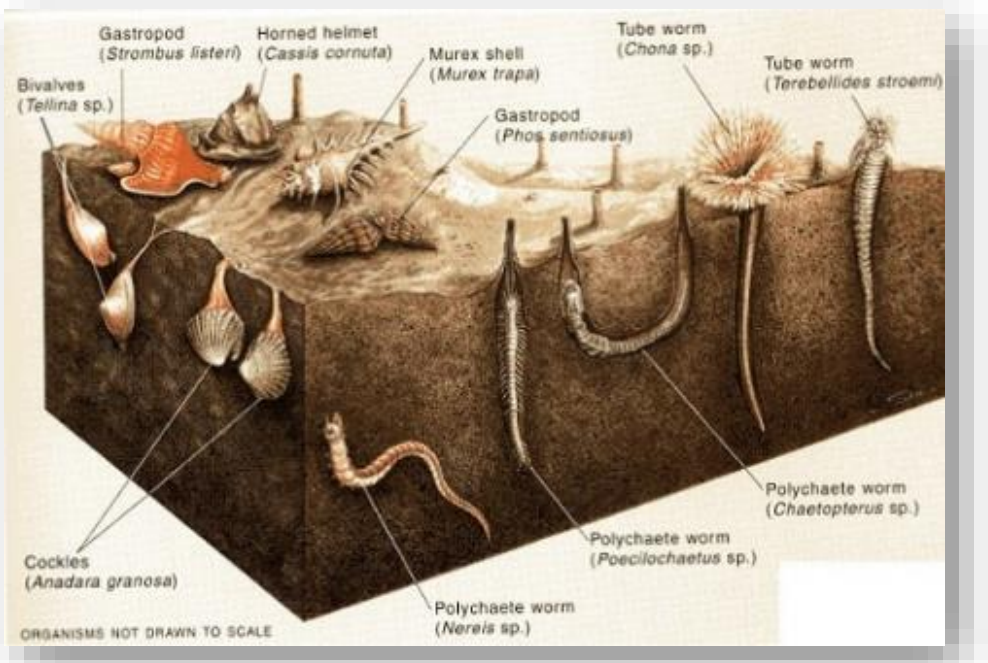
Introduction: Dredging and Bioaccumulation

- Mission requires compliance with applicable laws and regulations:
  - Address chemical, physical, and biological risks
- Consideration of **bioaccumulation** is required by:
  - Marine Protection Research and Sanctuaries Act (MPRSA)
  - Clean Water Act (CWA)
  - National Environmental Policy Act (NEPA)
- Dredge material bioaccumulation evaluations are a tiered process:
  - Ocean Testing Manual (**OTM**); Inland Testing Manual (**ITM**)

Benthic bioaccumulation

Bioaccumulation: Net uptake of a chemical from all sources following exposure over a set exposure period.

Bioavailable: Portion of the total quantity or concentration of a chemical in the environment that is potentially available for uptake by organisms



Sources of contamination:

Sediment

- Sediment particles (ingestion)
- Detritus
- Benthic prey
- Sediment porewater

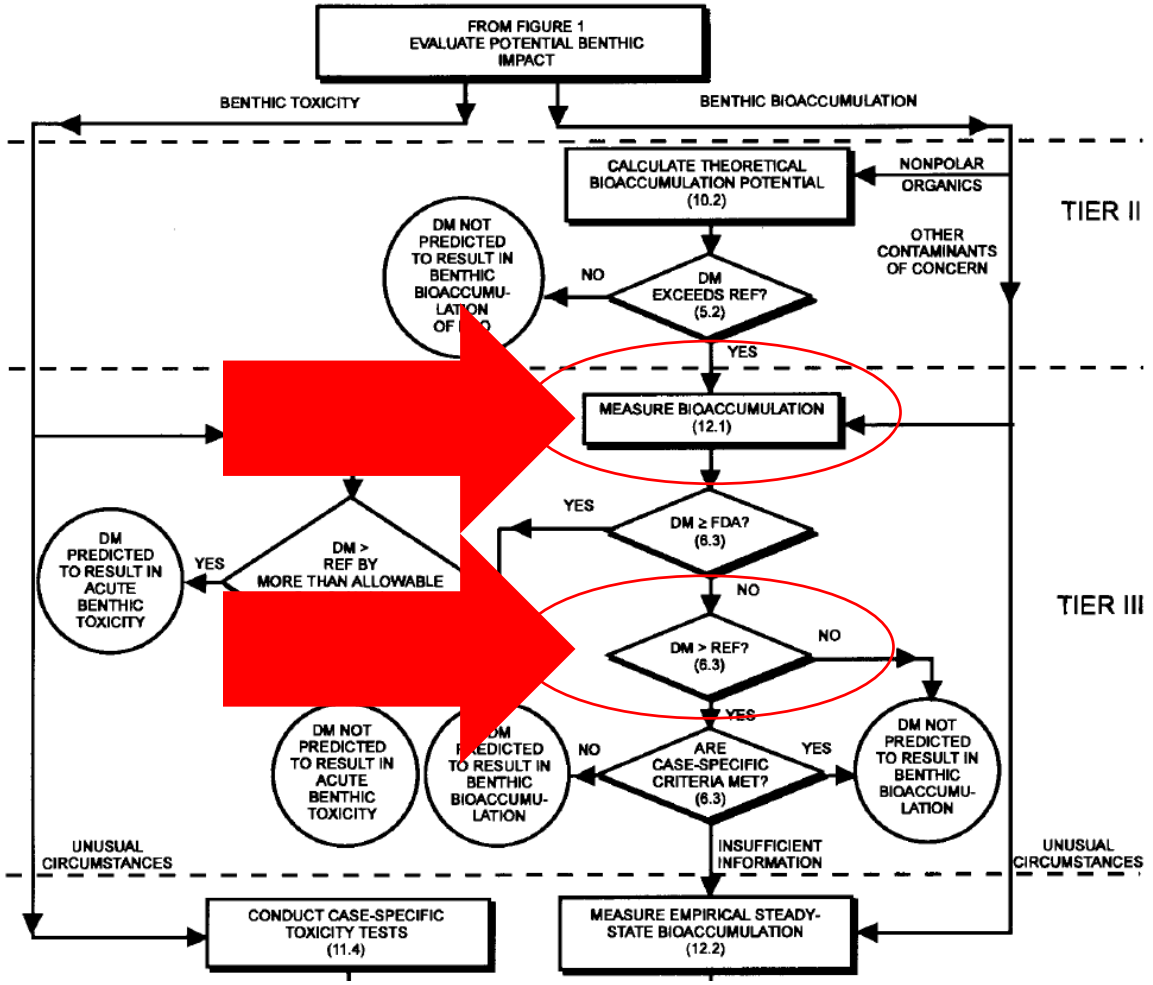
Water column

- Overlying water
- Plankton

Introduction: Bioaccumulation Tiers

Evaluations are Tiered:

- Tier I: Using readily available information
- Tier II: Theoretical modeling (e.g. BSAF, theoretical bioaccumulation potential)
- Tier III: Well-defined, nationally accepted bioaccumulation testing procedures
- Tier IV: Case-specific field testing and risk assessment



Tier III: Bioaccumulation test

Under ITM and OTM, if DM not exempted from testing, sediment bioaccumulation testing is required for decision making (regional guidance may include a screening step)

Approach

- Conduct whole-sediment bioaccumulation tests
- Compare DM to reference/placement site
- Whole-body burden chemicals of interest in benthic organisms as endpoint

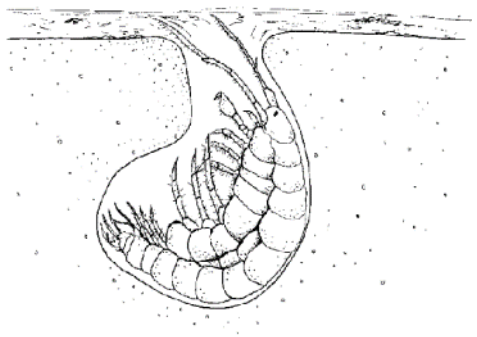
Test Design

- Time zero tissue analysis
- 28-day exposure
- No feeding
- Typically 5 replicates/treatment
- Measure tissue concentration at conclusion of exposure

Benthos diversity

Predator polychaetes

Filter-feeding clams



Burrowing amphipods

Freshwater oligochaetes

Test species

Desirable characteristics

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

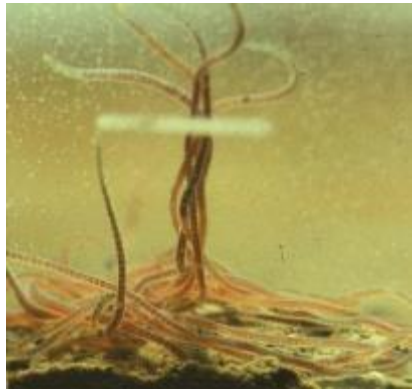
OTM: Use burrowing polychaete and a deposit-feeding bivalve mollusk

ITM: Use a single burrowing species (use of others is desirable)

Macoma nasuta

Alitta virens (formerly *Nereis*)

Neanthes arenoceodentata



Lumbriculus variegatus

Nephtys caecoides

Tier III: Bioaccumulation test termination and initial analysis

- Collect all remaining/surviving organisms from exposure chambers
- Allow organisms to purge gut content or excise gut
- Obtain whole-organism chemistry data
- Statistically compare DM and reference site body residues

Bioaccumulative Contaminants of Concern for Routine Tissue Evaluation	
Total lipids	
Cadmium	PAHs
Copper	Pesticides
Selenium	PCBs
Mercury	Butyltins

Conceptual Site Model

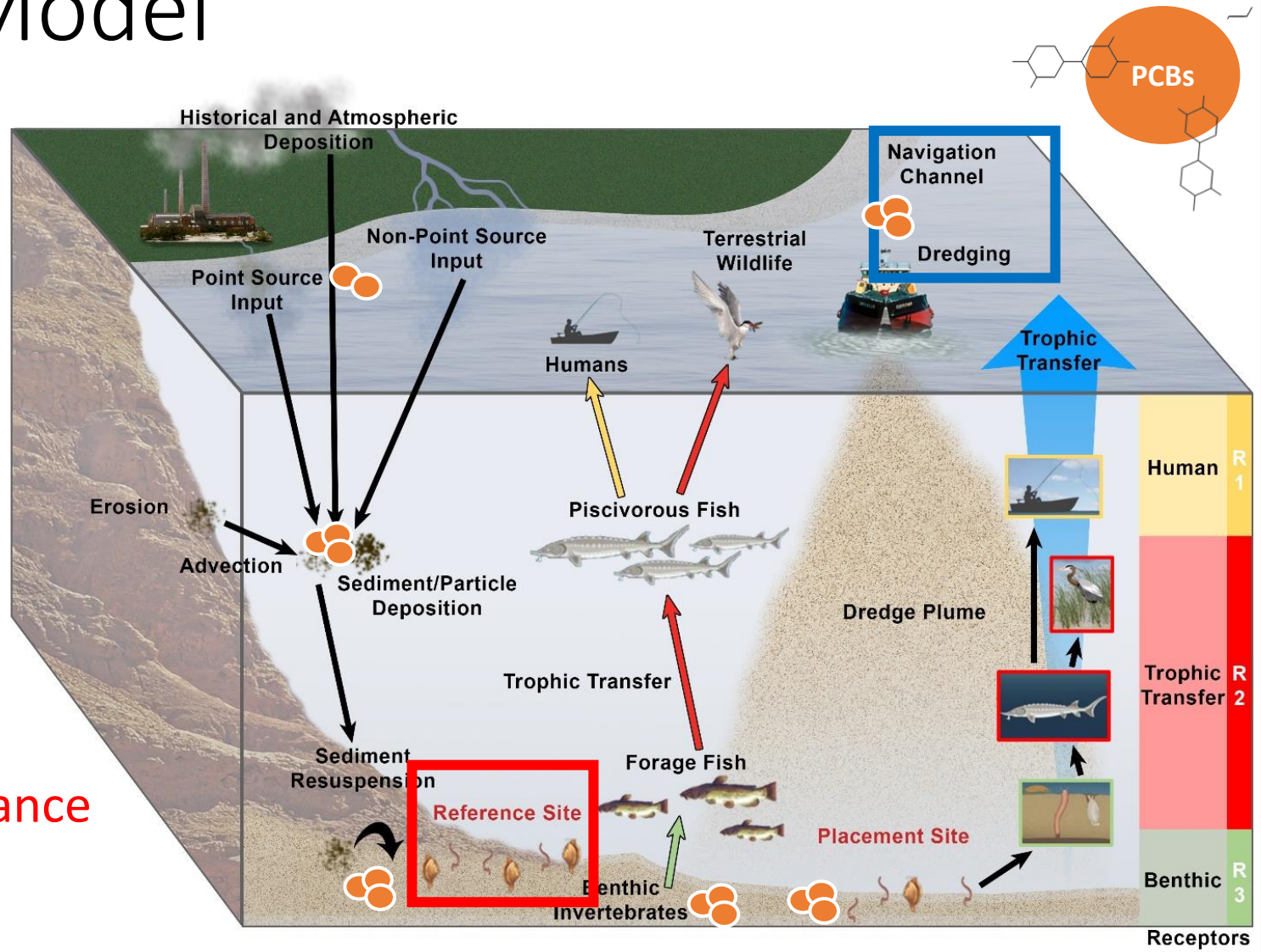
- Statistical comparison of tissue concentrations:

Ho: Dredge material = Reference

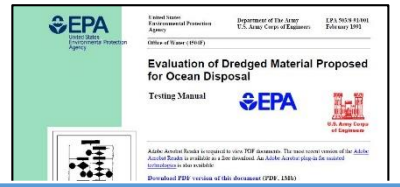
Ha: Dredge material > Reference

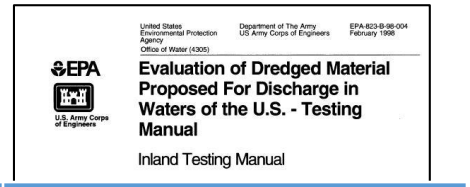
Assessment Factors

Statistical versus Ecological Significance



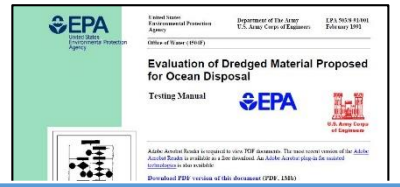
If statistically significant then…

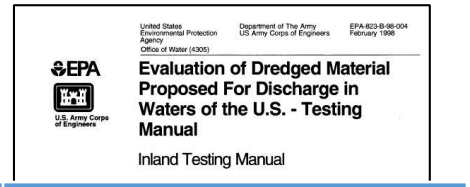




Decision Criteria	Ocean Disposal Testing Manual (OTM)	Inland Testing Manual (ITM)
1) Magnitude by which bioaccumulation exceeded reference	✓	✓
2) Magnitude by which bioaccumulation exceeded reference and comparable species in the vicinity of disposal site	✓	✓
3) Toxicological Importance	✓	✓
4) Propensity to bioaccumulate or biomagnify	✓	✓
5) Number of contaminants	✓	✓
6) Number of species	✓	
7) Phylogenetic diversity	✓	

If statistically significant then…





Decision Criteria	Ocean Disposal Testing Manual (OTM)	Inland Testing Manual (ITM)
1) Magnitude by which bioaccumulation exceeded reference	✓	✓
2) Magnitude by which bioaccumulation exceeded reference and comparable species in the vicinity of disposal site	✓	✓
What magnitude of difference (MOD) is considered biological/ ecologically relevant?	✓	✓
	✓	✓
	✓	✓
	✓	
	✓	

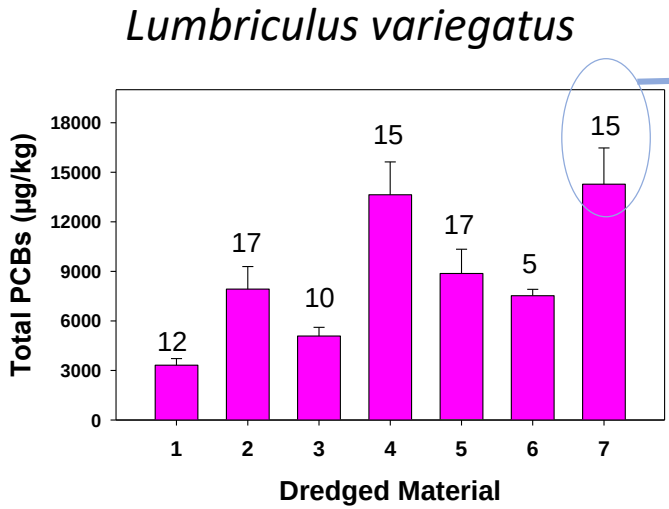
Interpreting Bioaccumulation Data Magnitude of Difference

Sources of variability

- Bioassay variability within lab (replicates): typically low
- Interlab bioassay variability
- Interlab analytical variability

Does statistical difference equate to biological/ecological significance?

ASTM (2016): "*Although there is no consensus concerning what constitutes an acceptable minimum difference, it is suggested that the bioaccumulation experiment be designed to detect a two-fold difference between tissue residues in the test and control sediments or the test and reference sediments. A two-fold difference should provide a sufficient signal for ecological and human health concerns in most cases.*"



Mean, 1 SD and coefficient of variation for 5 replicates

Objectives

Evaluate the practical and theoretical functions of magnitude of differences (MODs) as decision criteria.

Informed by (2) objectives:

1. Identify the variance (as coefficient of variance [CV]) associated with bioaccumulation measures for common testing organisms (*M. nasuta*, *A. virens*; and *L. variegatus*) and bioaccumulative constituents

2. Evaluate bioaccumulation MODs in three case studies from different geographic regions: Great Lakes, New York Harbor, Gulf of Mexico

Methods: Data Sources and Analysis

- Data Sources:
  - Peer-reviewed literature (reported variance)
  - Case Studies:
    - New York Harbor; *A. virens*
    - Gulf of Mexico; *M. nasuta*
    - Great Lakes; *L. variegatus*

- Data Analysis:
  - Descriptive statistics; coefficient of variance (CV)
  - Magnitude of difference (MOD)
  - Statistical analysis:
    - One-way analysis of variance (ANOVA); α = 0.05
    - Follow-up pairwise comparisons (GraphPad Software V. 7.0).

Coefficient of Variance (CV)

$$CV = \frac{\sigma}{\mu} * 100\%$$

Magnitude of Difference (MOD)

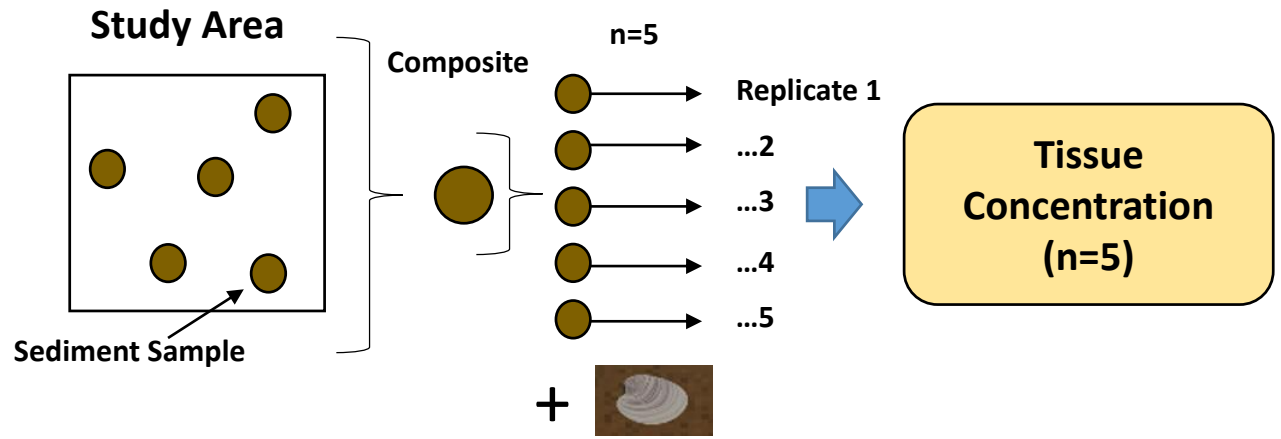
$$MOD = \frac{tissue\ [C]_{DM}}{tissue\ [C]_{ref}}$$

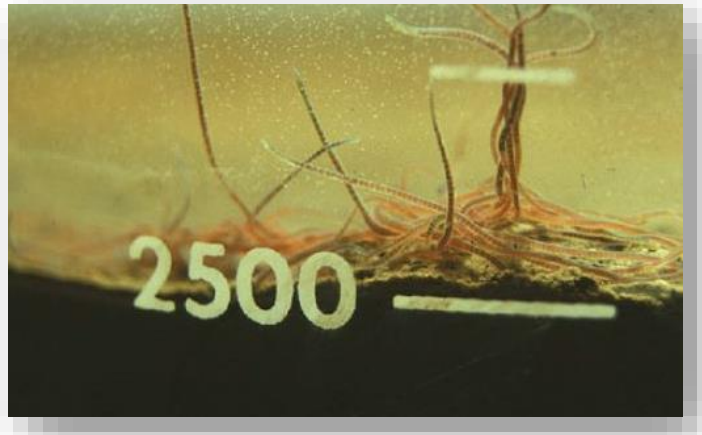
Methods

- Bioaccumulation testing:
  - USEPA/USACE 1991; 1998
  - ASTM International (2016)
  - 28-d duration; n=5 chambers
  - Marine/ estuarine; *Alitta virens* and *Macoma nasuta*
  - Freshwater; *Lumbriculus variegatus*

Marine bivalve
Macoma nasuta

Marine polychaete
Alitta virens





Freshwater oligochaete
Lumbriculus variegatus

Coefficient of Variance (CVs) example

Example of CVs:

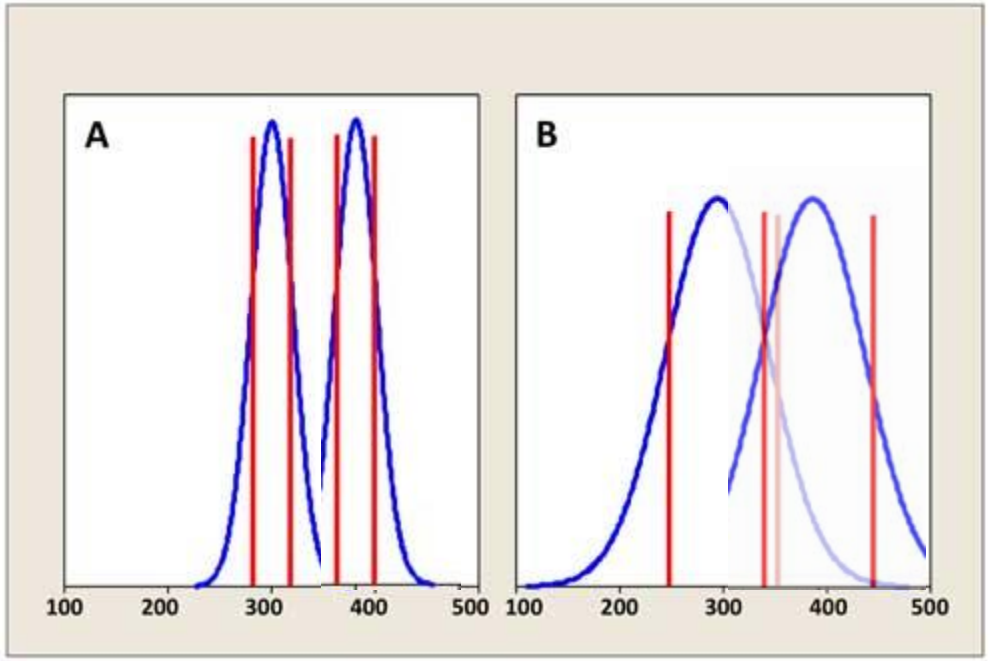
A:

- Mean (μ): 300
- Std Dev (σ) = 20
- CV = 7%

B:

Mean (μ): 300

- Std Dev (σ): 50
- CV = 17%



CV = 7%

CV = 17%

$$CV = \frac{\sigma}{\mu} * 100\%$$

Distribution image source:
http://www.wormbook.org/chapters/www_statisticalanalysis/statisticalanalysis.html

Magnitude of Difference (MOD) example

Example of CVs:

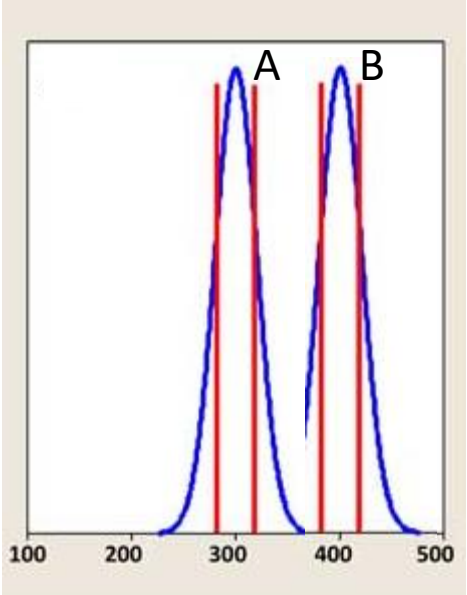
A: Reference Sediment

- Mean (μ): 300
- Std Dev (σ) = 20
- CV = 7%

B: Dredged Sediment

Mean (μ): 400

- Std Dev (σ): 20
- CV = 7%



MOD = 1.33

$$MOD = \frac{tissue\ [C]_{DM}}{tissue\ [C]_{ref}}$$

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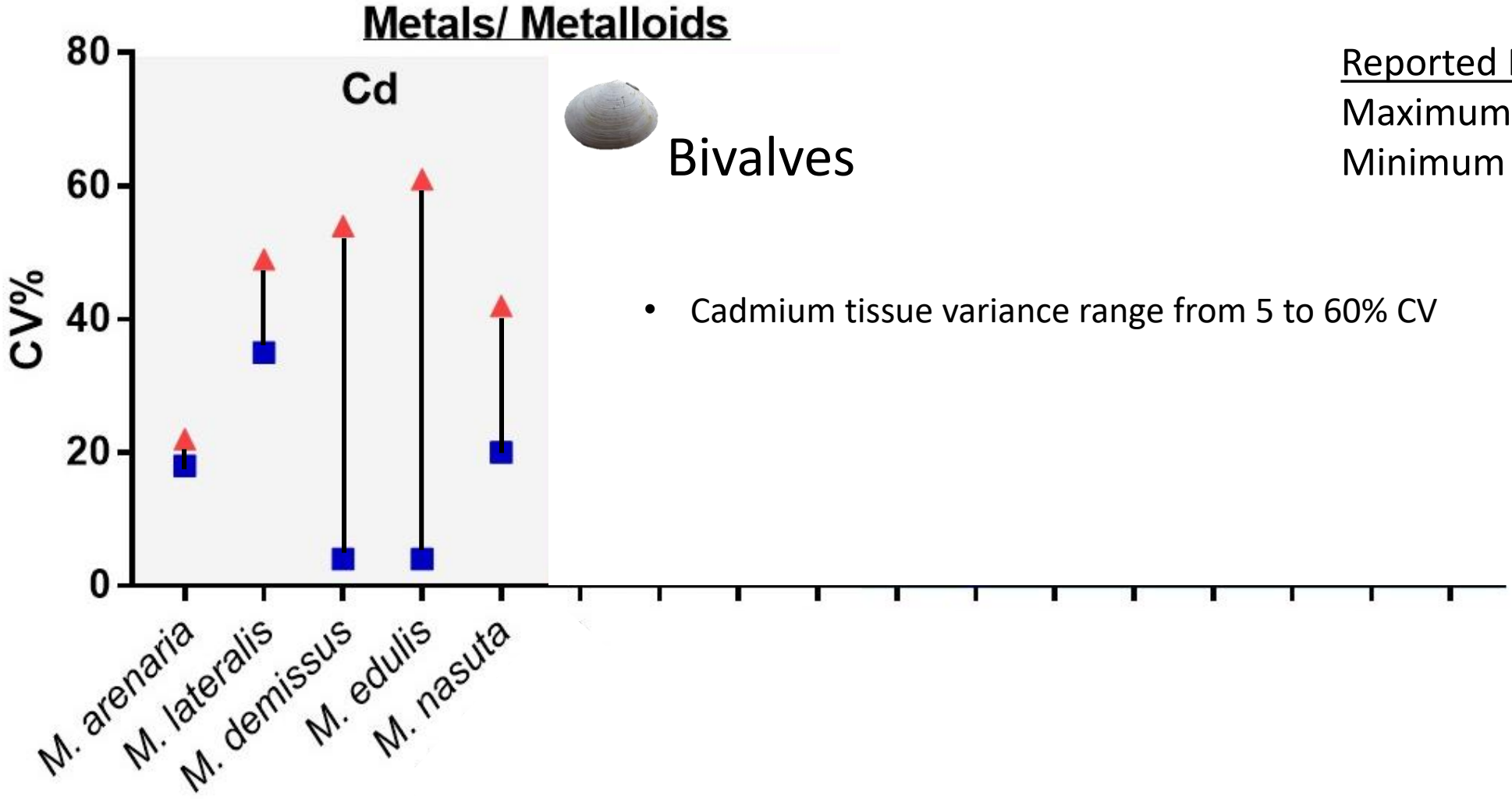
Results: Reported Coefficient of Variations (CVs)



Bivalves

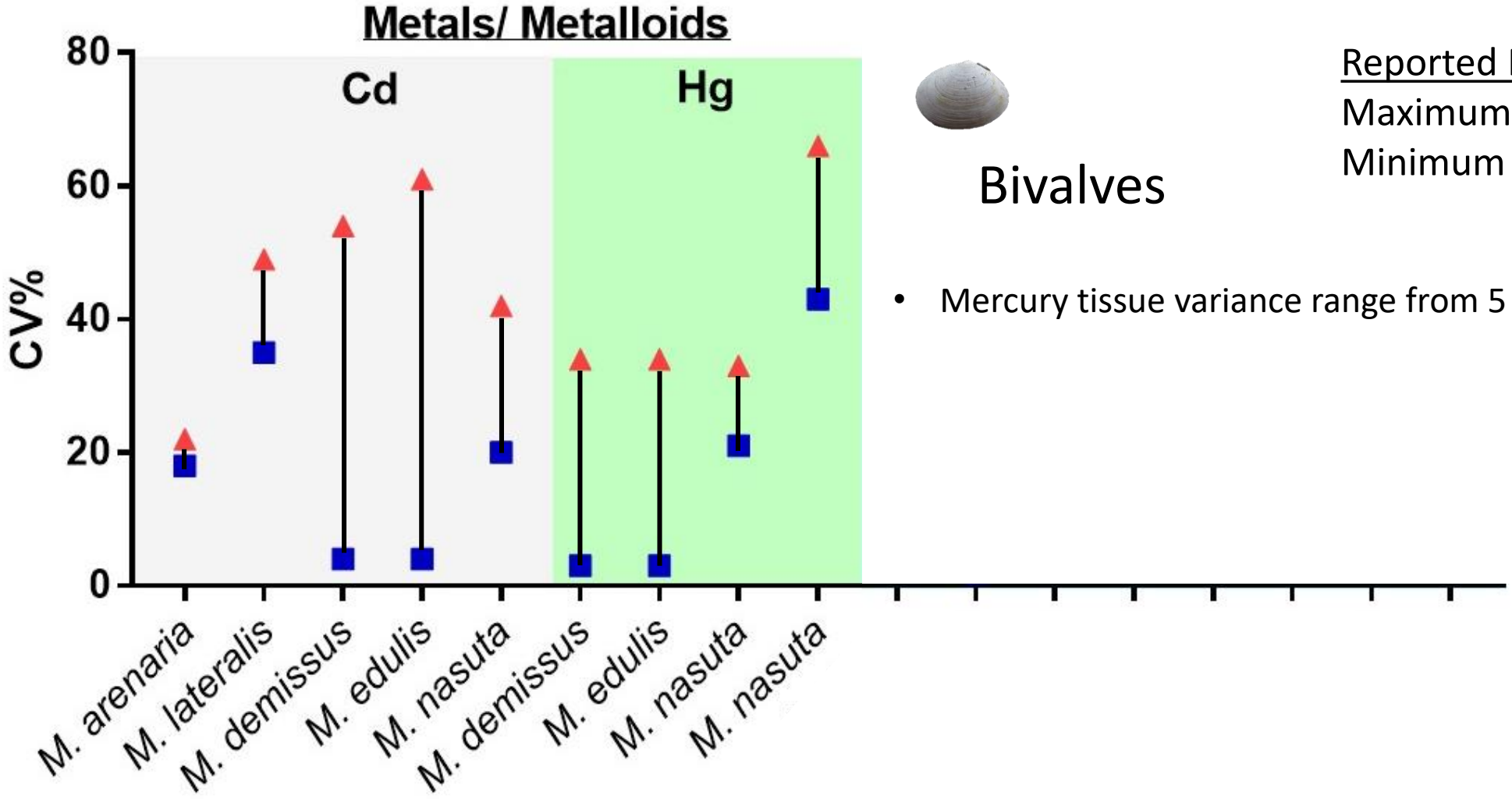
Reported Range

Maximum

Minimum

- Cadmium tissue variance range from 5 to 60% CV

Results: Reported Coefficient of Variations (CVs)

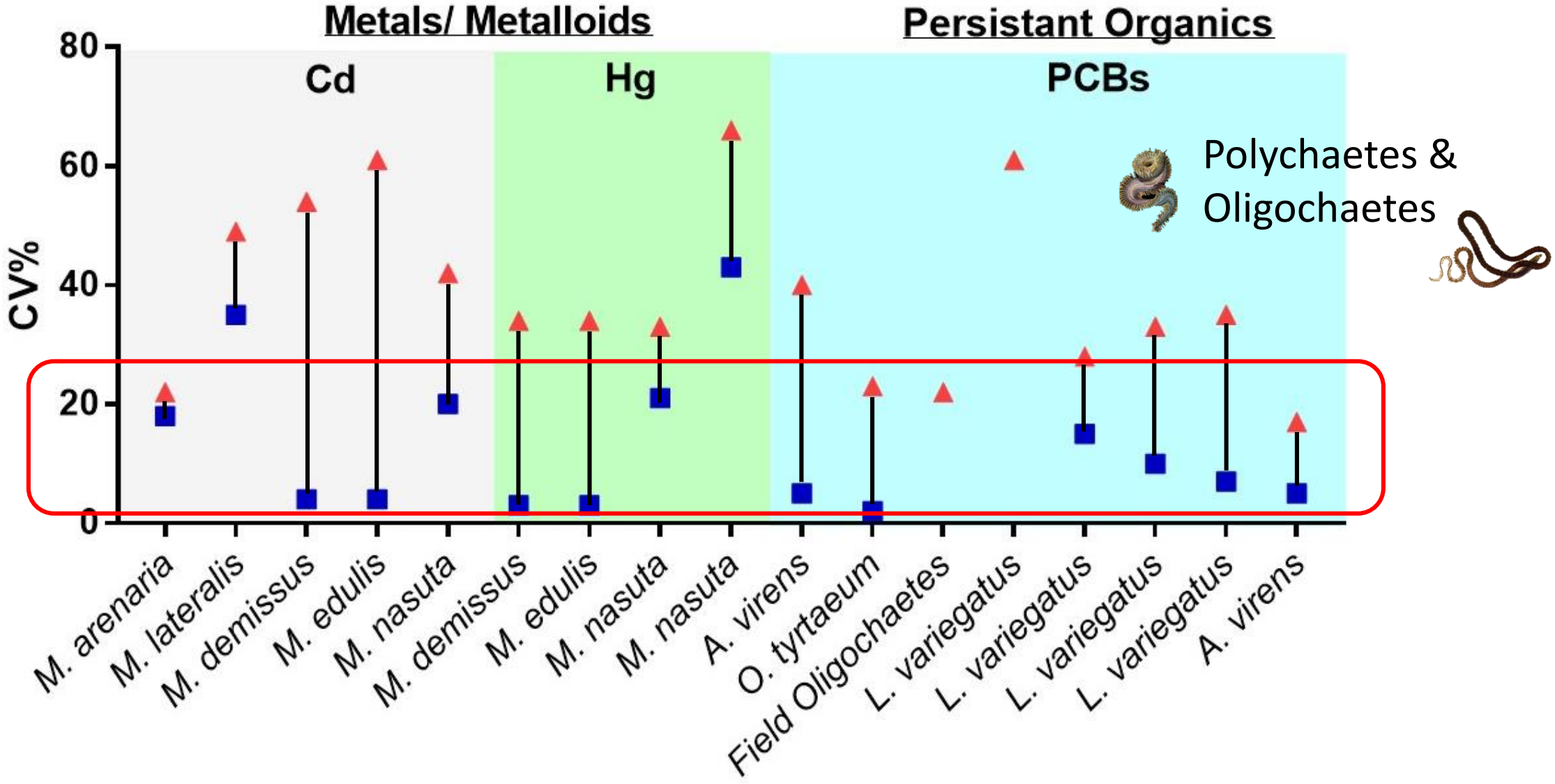


Bivalves

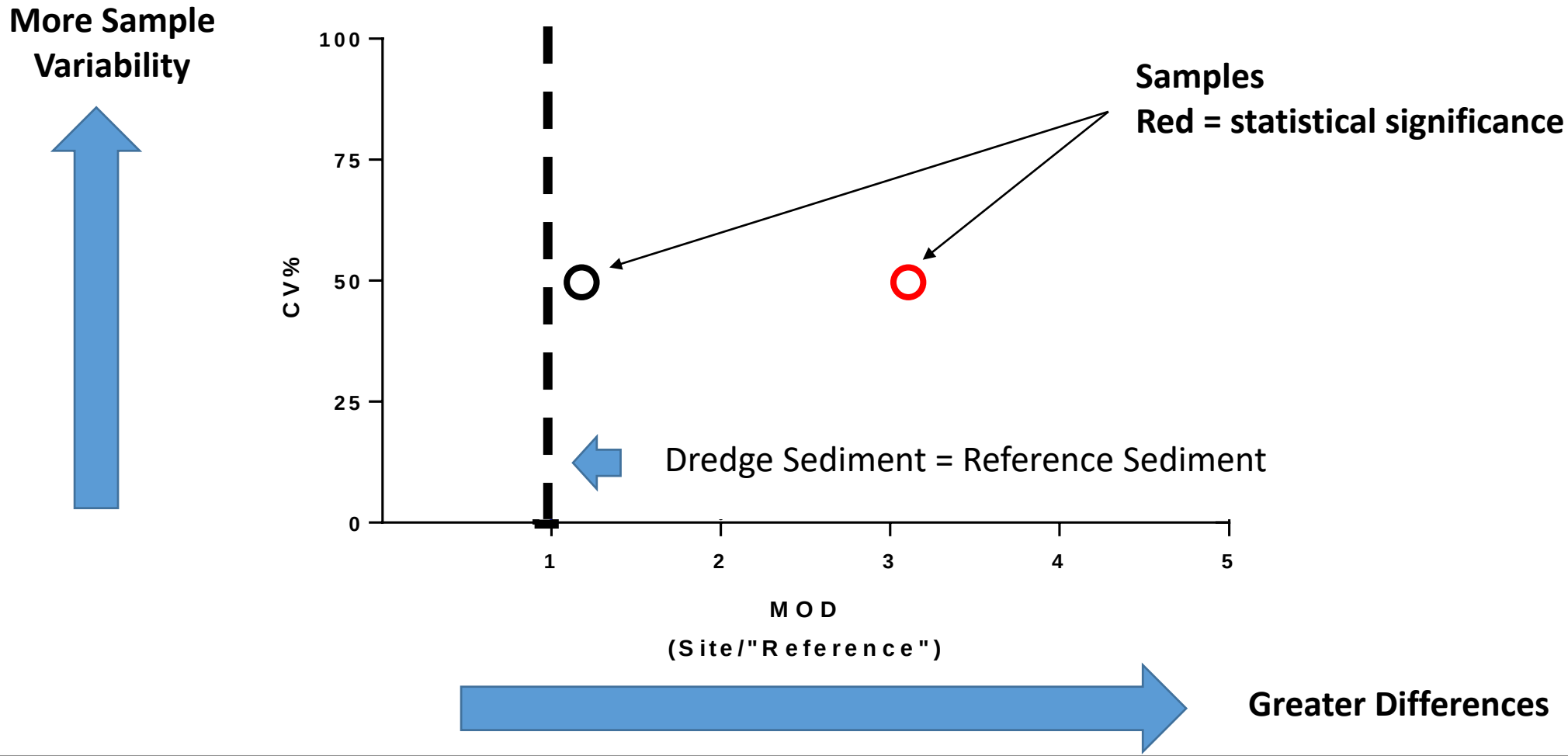
Reported Range
Maximum
Minimum

- Mercury tissue variance range from 5 to 70% CV

Results: Reported Coefficient of Variations (CVs)



Visualizing CVs and MODs



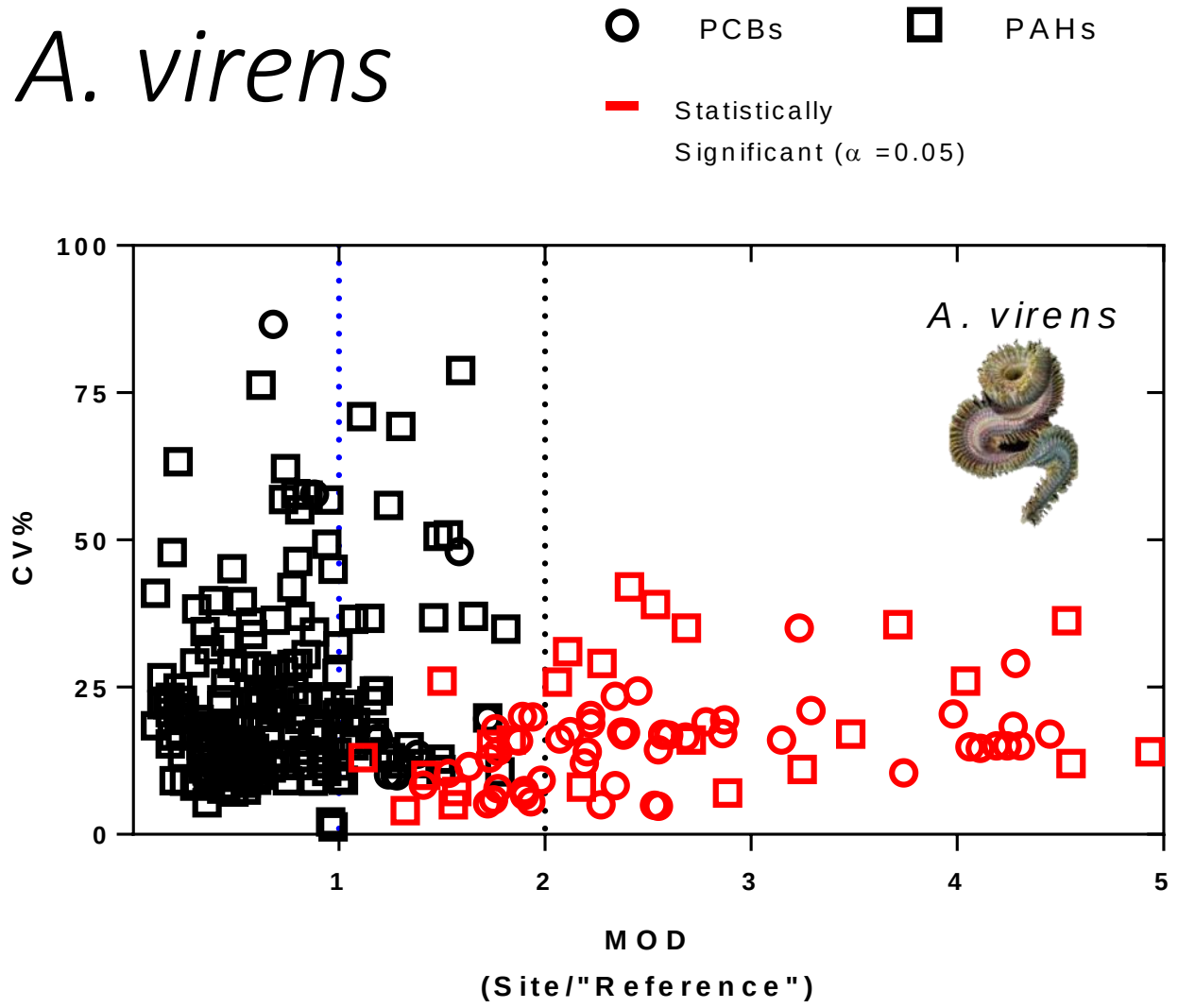
1) New York Harbor; *A. virens*

- Variance compared to MOD

  PCBs (n=12 congeners)

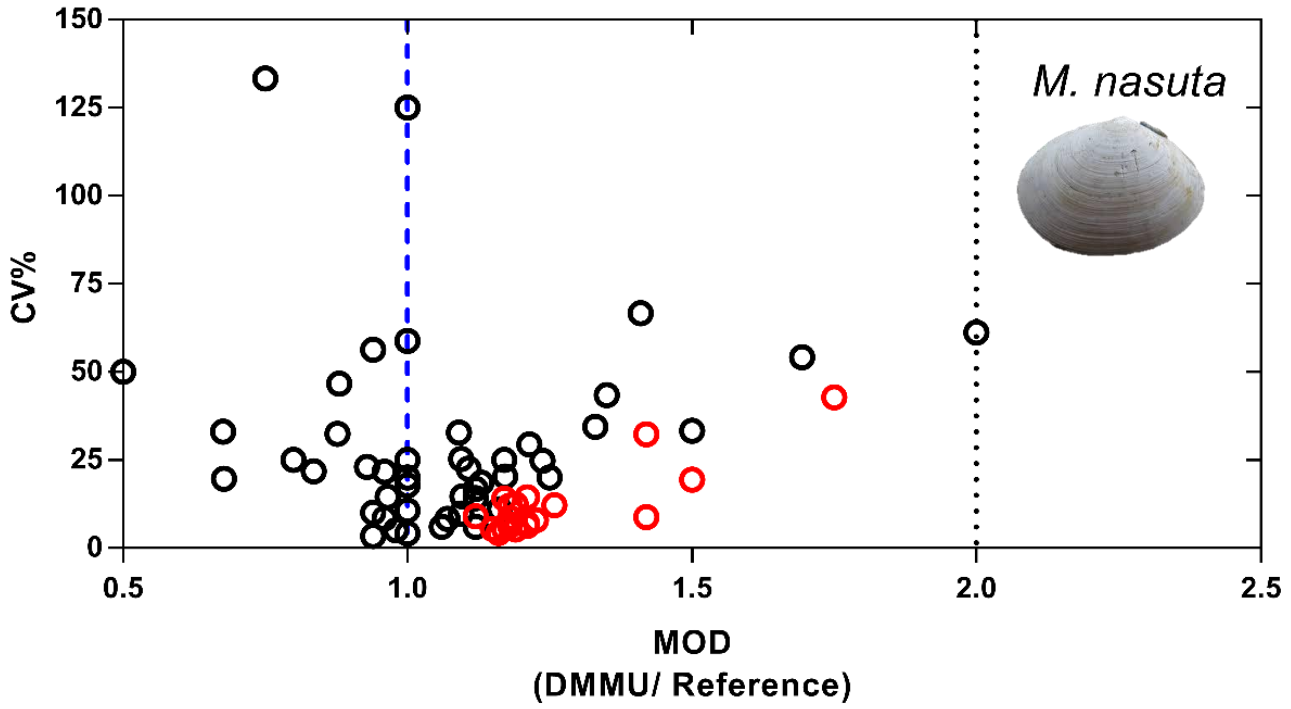
  - Median statistically sig. 16% (n=62)
  - Maximum CV 86% (n=71)

- Overlap between MOD 1 and 2:
  - Indicates potential for false positives (Type I error)



2) Gulf of Mexico; *M. nasuta*

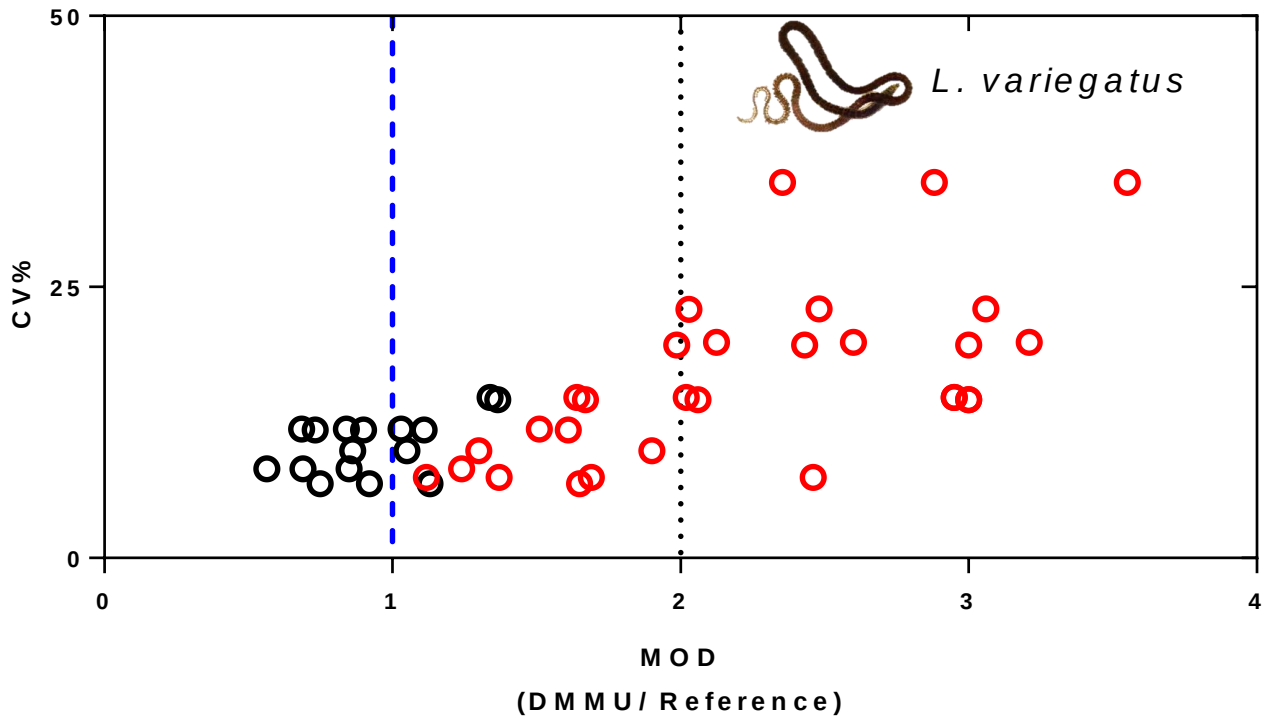
- Variance compared to MOD
  - Metals/ metalloids*
    - Median statistically sig. 9% (n=19)
    - Maximum CV 133%
- Overlap between MOD 1 and 2:
  - Indicates potential for false positives (Type I error)



*(Ag, As, Ba, Cd, Cr, Cu, Ni, Pb, Hg, Sb, Se, Zn)

3) Great Lakes; *L. variegatus*

- Variance compared to MOD
  - PCBs (n=12 congeners)
    - Median statistically sig. 15% (n=44)
    - Maximum CV 35%
- Overlap of statistical significance between MOD 1 and 2:
  - Indicates potential for false positives (Type I error)



Discussion

- Both OTM and ITM identify MODs as an assessment factor, but there is currently limited guidance on the practical application
- Data indicate that precision can be sufficient to detect 2-fold differences (compared to reference) in tissue concentrations
  - ASTM (2016) "…at least a 2-fold difference…"
- Variability within tests indicate that MODs >2 is a benchmark for evaluating statistical differences to minimize false positives (Type I error)
- Inter- and intra-laboratory comparisons are needed to better understand the relative precision and accuracy of bioaccumulation results

Conclusions

- Variability within tests indicate that MODs >2 is a benchmark for evaluating statistical differences to minimize false positives (Type I error)
- MODs can provide a useful benchmark, if laboratory and field variability and uncertainty are considered
- **Assessment of bioaccumulation from dredge material should reflect the best available science to discern bioaccumulative risks**

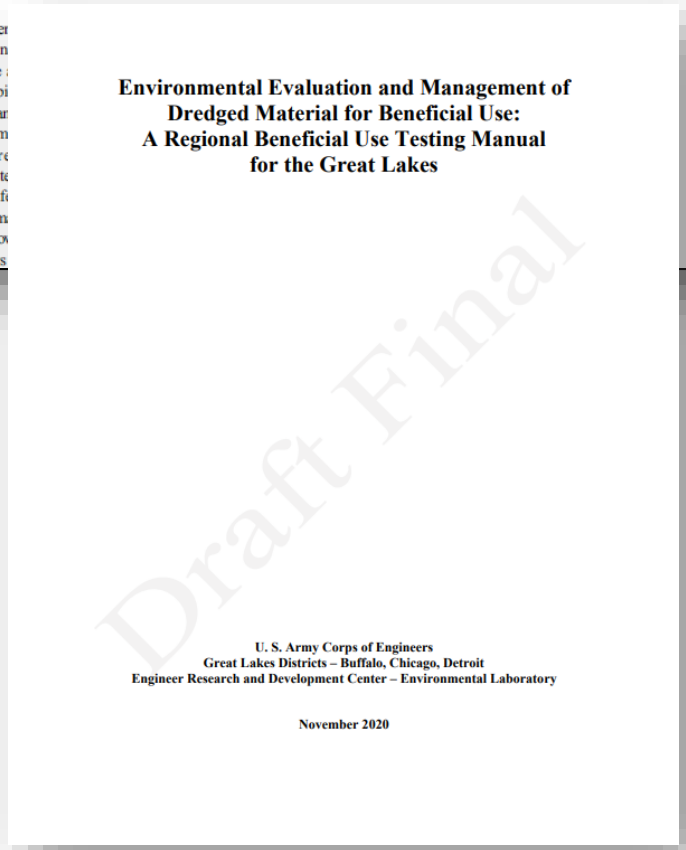
Resources

- Bioaccumulation Evaluation Publication
  - Environmental Monitoring and Assessment (2020):

https://doi.org/10.1007/s10661-020-8236-z

- Regional Testing Manual for the Great Lakes. ‘Draft Final’ available:

https://cdn2.cloud1.cemah.net/wp-content/uploads/sites/38/2020/11/RegionalBeneficialUseManual_Nov2020-draft-final.pdf



THANK YOU!

QUESTIONS?

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