15. Biological Processes Affecting Remedial Design and Performance

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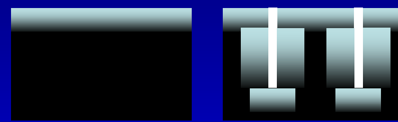
15a. Microbial Degradation Processes

- Organic Contaminant Biodegradation & Bioturbation
- Methodology
- PAH Degradation Rates
- PCB Degradation Processes
- Metal Sequestration
- Sediments as Sources Verses Sinks

Organic Contaminant Biodegradation & Bioturbation

Organic contaminant biodegradation occurs most rapidly in sediments that have a lot of transition & mixing zones (macrofaunal bioturbation > physical mixing > no mixing)

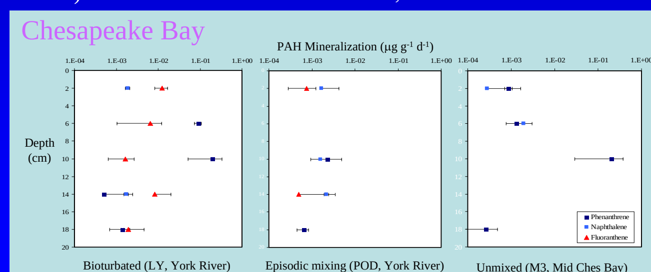
- Increase contaminant flux into sediment.
- Increase contaminant flux out of sediment (particle resuspension, removal of 'volatiles').
- Different infauna types can have different net effects of contaminant flux.



- Mixing can reduce VOCs and increase HMW hydrocarbon degradation (reduce organotoxicity).
- Can add stimulants (O^2, nutrients) but if transition zones aren't created, stimulation will be short lived.

	Turnover Time (days)		
Station	Naph	Phen	Fluor
F	242	58	408
L	2498	1581	>5000

PAH mineralization rate & turnover increases with depth of bioturbation.



Methodology

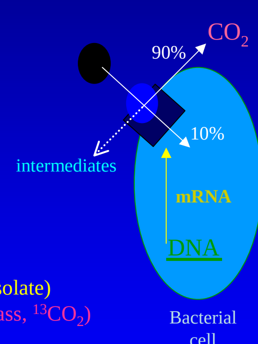
Measuring contaminant degradation -- Gather as many lines of evidence as possible to determine rate of contaminant degradation

NRC 1993 guidelines for in situ bioremediation (lines of evidence)

- Contaminant mass loss (can be abiotic)
- Bacterial abundance (plate counts, microscopy)
- Grazer abundance (relates to bacterial growth rate)
- Intermediates (unless degradation is within cell)

- Flask studies (spiking)* (assemblage changes)

- Bacterial metabolism* (^{3}H-leucine incorporation)
- Radiotracer mineralization* (^{14}C-contaminants to $^{14}CO_2$)
- Presence of degrading assemblage (PLFA, DNA; may not be active)
- Production of catalytic enzymes for degradation (mRNA; difficult to isolate)
- Stable isotopes monitoring* (^{13}C-contaminant to DNA, bacterial biomass, $^{13}CO_2$)
- Natural abundance radioisotope monitoring* (^{14}C dating; expensive)*



*rate

National Research Council. 1993. In Situ Bioremediation: When does it work? National Academy Press, Washington, DC, 207 pp.

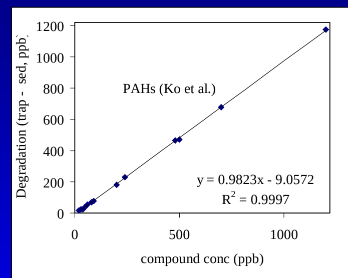
PAH Degradation Rates

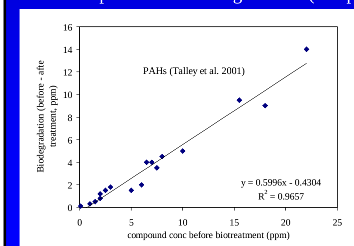
PAH degradation rates by natural bacterial assemblages are often a function of ambient concentration and PAH flux and not necessarily ‘biodegradability, bioavailability or molecular structure’.

<ins>Bioremediation</ins>: HMW PAHs are harder to degrade than LMW PAHs
<ins>Microbial Ecology</ins>: Differences in assimilation efficiency among individual PAHs are subtle compared with differences in ambient concentration.

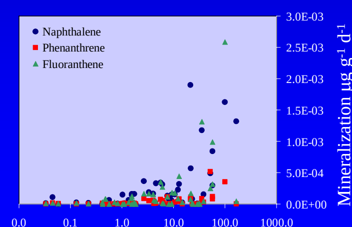
<ins>Bioremediation</ins>: HMW PAHs bind to organic matter becoming less bioavailable.
<ins>Microbial Ecology</ins>: Organic matter is a competing C source.

<ins>Bioremediation</ins>: Low concn of PAHs are recalcitrant because they are weathered.
<ins>Microbial Ecology:</ins> Low concn of any C source will provide little selective pressure for its degradation (competing C; low encounter rate)





EPA505 on solid PAH

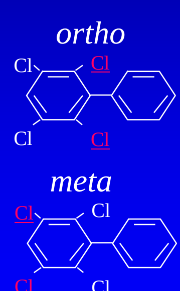


PAH in sediment (ppm)

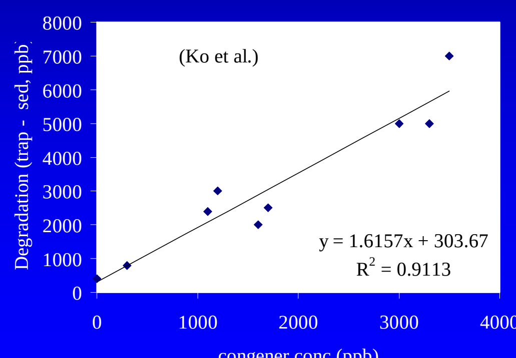
PCB Degradation Processes

PCB degradation rates are usually slower than those for PAHs but so is their ambient concentration and flux in most sediment. Evidence for biodegradation is more cumbersome to acquire.

- Degradation of PCB congeners can also be a function of ambient concentration (< 8 ppm).
- Biologically induced congener ratio change
- Chlorine isotope monitoring
- Dredging can move PCBs into water column on particles



PCB-Dechlorinating bacteria can selectively remove the chlorines noted in red



Metal Sequestration

Metals can be sequestered or changed to a less toxic form but are usually not totally eliminated from the system.

- Metals change form (and media) or can be bound up in organic to be less toxic but are generally not completely degraded.
- Bacteria can reduce metals directly or indirectly by creating a reducing environment.
- Recent use of *Spartina alterniflora* for metals bioremediation of intertidal sediments (biomass can be harvested and physically removed from ecosystem; phytoaccumulation)[1].
- Form of metals can be impacted by dredging (oxidation of reduced local microenvironment, resuspension of particles).

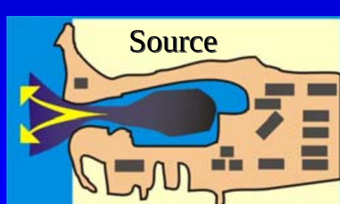

Creosote-impacted *Spartina* marsh

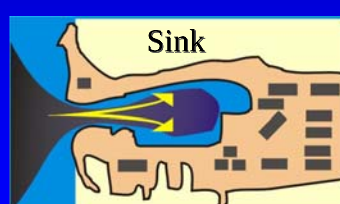
[1]http://aesop.rutgers.edu/~haggblom/sediments.html

Sediment as Sources verses Sinks

Sediments as contaminant SOURCES verses SINKS: compare contaminant degradation with transport (flux). Capping or dredging impacted sediments that are actually contaminant sinks can have unintended consequences for the ecosystem.

- If your ambient contaminant concentrations are a balance between flux from water column particles and biodegradation, then you can inadvertently shift the balance towards higher ambient contaminant levels.
- Puget Sound cap: significantly depressed PAH biodegradation by reducing O_2 & SO_4 supply (UW).
- Can set up engineering criteria to appear successful but are not ecologically protective.
- Tempting to try and trump lack of mixing (cap, geotextile) with amendments. Solid oxygenating compounds can dramatically raise pH and virtually shut down bacterial metabolism in sediments.



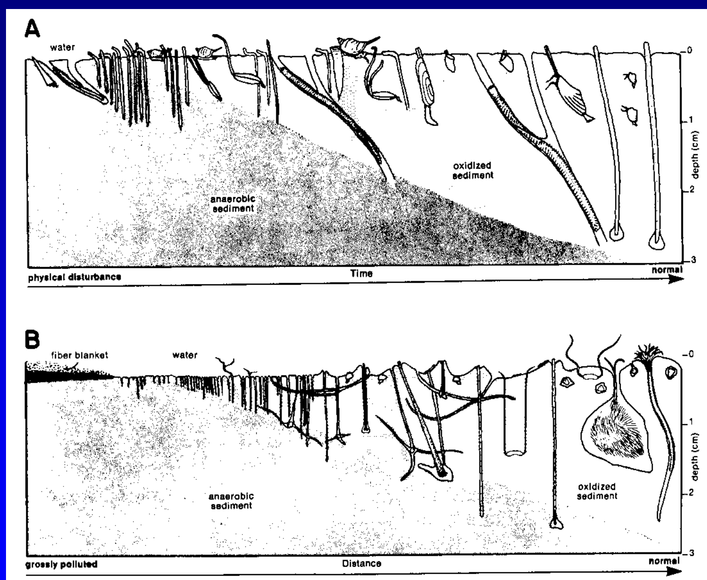


Pohlman, J. W., Coffin, R. B., Mitchell, C. S., Montgomery, M. T., Spargo, B. J., Steele, J. K., and T. J. Boyd. 2002. Transport, deposition, and biodegradation of particle bound polycyclic aromatic hydrocarbons in a tidal basin of an industrial watershed. Environ. Monitor. Assess. 75: 155-167.

15b. Role of Sediment Bioturbation in Contaminant Remediation

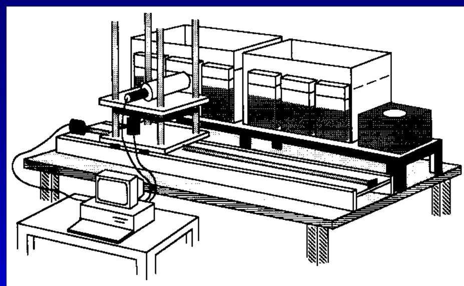
- Bioturbation and sediment mixing
- Mathematical models of particle mixing
- Bioturbation and sediment-water exchange
- Mathematical models of solute transport
- Bioturbation affects microbial degradation
- Biogeochemical models of sediments

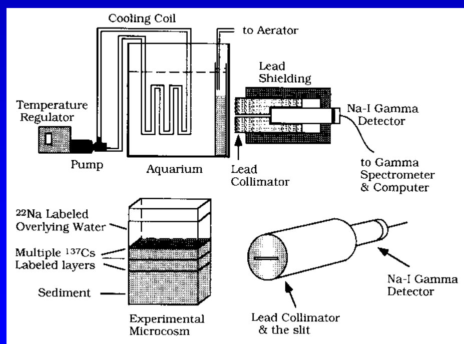
Bioturbation and sediment mixing

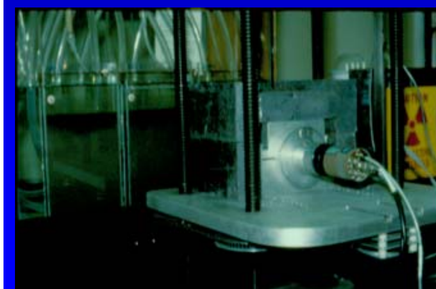


Modified from Rhoads and Boyer 1982

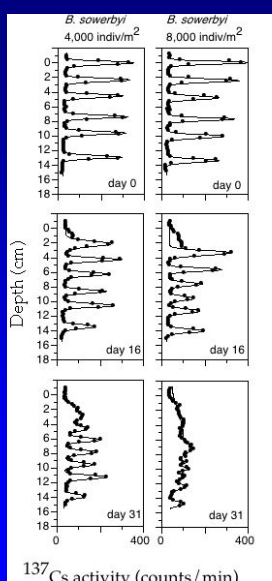
Bioturbation and sediment mixing (con't)







Bioturbation and sediment mixing (con't)



Mathematical models of particle mixing

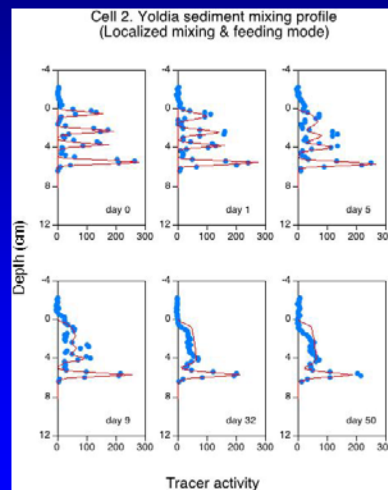
Enhanced Diffusion

$$\frac{\partial C_i}{\partial t} = D_B \frac{\partial^2 C_i}{\partial x^2} - \omega \frac{\partial C_i}{\partial x} - \lambda C_i$$

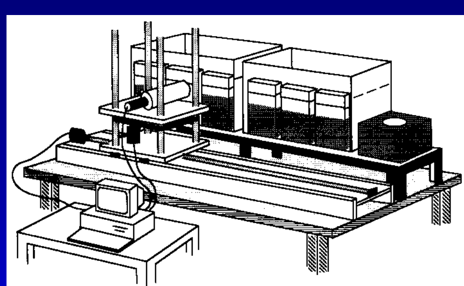
Non-local Mixing

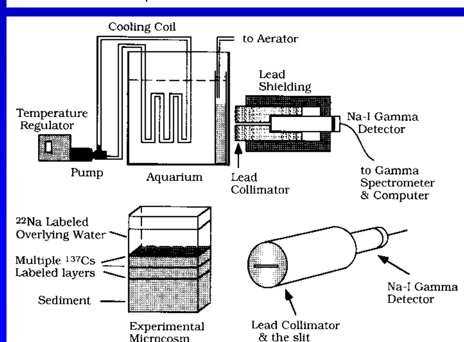
$$\frac{\partial C_i}{\partial t} = \frac{\partial}{\partial x}\left[D_B \frac{\partial C_i}{\partial x} + \phi D_M \frac{\partial}{\partial x}(\alpha C_i) \right]$$

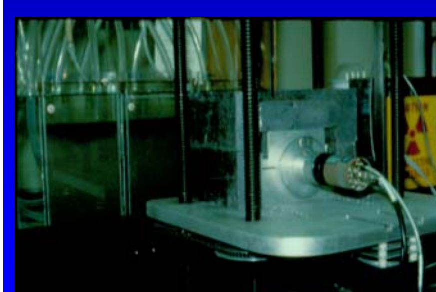
$$- \frac{\partial}{\partial x}\left[\omega C_i + \phi(\nu - \omega)\alpha C_i\right] - \left[\lambda + \eta\gamma(x)\right]C_i$$



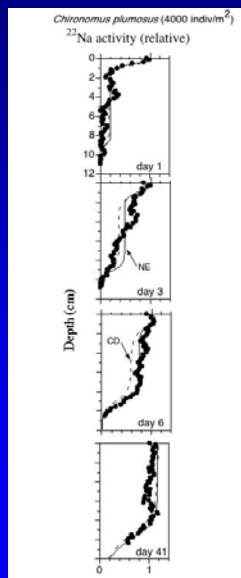
Bioturbation and sediment-water exchange

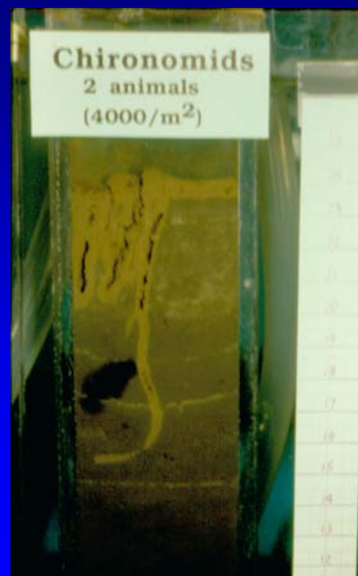






Bioturbation and sediment-water exchange (con't)





Mathematical models of solute transport

Enhanced Diffusion

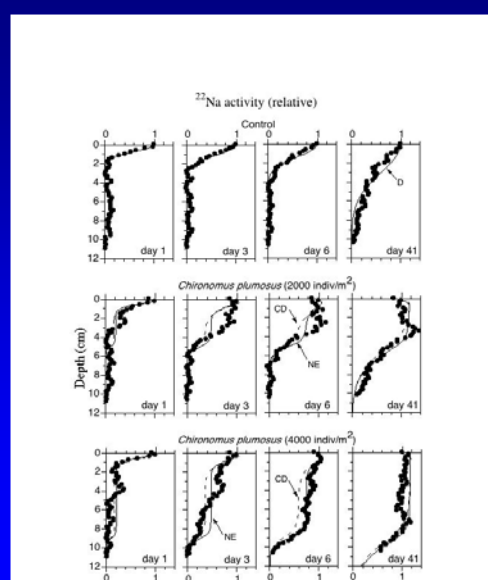
$$\frac{\partial C_i}{\partial t} = D_e \frac{\partial^2 C_i}{\partial x^2} - \omega \frac{\partial C_i}{\partial x} - \lambda C_i$$

Cylindrical Burrow

$$\frac{\partial C_i}{\partial t} = D_s \frac{\partial^2 C_i}{\partial x^2} - \omega \frac{\partial C_i}{\partial x} + \frac{D_s}{r} \frac{\partial}{\partial r}\left(r \frac{\partial C_i}{\partial r}\right) - \lambda C_i$$

Non-local Exchange

$$\frac{\partial C_i}{\partial t} = D_s \frac{\partial^2 C_i}{\partial x^2} - \omega \frac{\partial C_i}{\partial x} - \alpha (C_i - C_o) - \lambda C_i$$

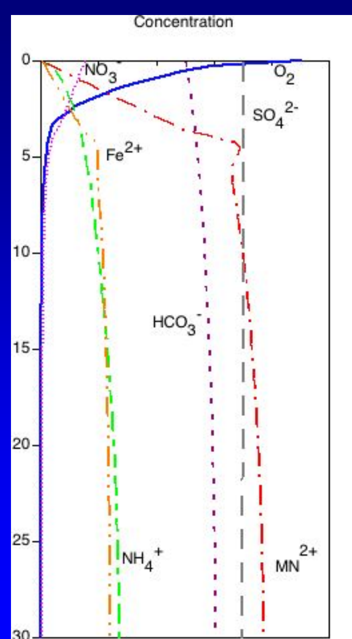


Biogeochemical models of organic carbon oxidation

Microbial degradation reaction sequence:

- Oxygen (Aerobic Respiration)
- Nitrate (Denitrification)
- Manganate (Oxyhydroxide Reduction)
- Ferric Iron (Oxyhydroxide Reduction)
- Sulfate (Reduction)
- Carbon (Methanogenesis)

Biogeochemical Model



Summary

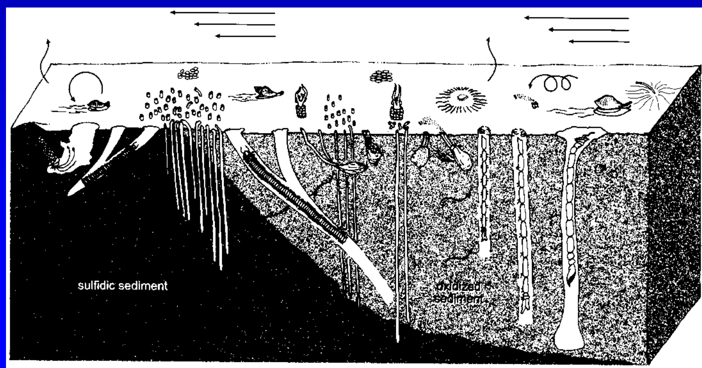
Bioturbation - particle mixing

Bioturbation - solute transport

Organic carbon degradation

Experimentally measure processes

Mathematically model processes



15c. What about plants?

- Role in Contaminant Transport
- Role in Degradation Processes

Role in Contaminant Transport

Sediment entrainment and stability (phytostabilization)

- Generally form barriers to direct mixing between sediment and water column (less resuspension).
- Confluent beds can armor sediments which can also reduce accumulation of sediments and contaminant flux from water column (sedimentation).
- Excellent at removing nutrients from surface runoff.

Role in Degradation Processes

Zones of transition

- Difficult to sample and study role of contaminant degradation process *in situ* but we know from how the rhizosphere has been studied in terrestrial system that it is an microbially active area.
- Do see enhanced biodegradation of hydrocarbons associated with rhizosphere in soil and in intertidal and dredged sediments? Different infauna types can have different net effects of contaminant flux to & from sediment.
- PCB degradation in sediments reported for Lake Hartwell.
- Phytoremediation of metals in intertidal sediments by cordgrass (*S. alterniflora*).
- Unlike macrofaunal bioturbation, not likely to have as great a role in biodegradation of PAH fluxing in from water column.
- Difficult to imagine removing significant plant biomass will have positive impact on intrinsic biodegradation.