PCB Bioremediation finally coming of age?

Upal Ghosh, Kevin Sowers, Trevor Needham, and Ray Payne

University of Maryland Baltimore County

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Chemical Biochemical and Environmental Engineering

Microbial Biodegradation

- PCB aerobic degradation and anaerobic dechlorination observed 3 decades ago
- Aerobic transformation pathways reasonably well understood
- Dechlorination pathways identified; dechlorinators isolated and grown in the absence of sediments
- Biology reasonably well understood
- Anticipation of natural attenuation and engineering for remediation challenged by:
  - poor mechanistic understanding of biotransformation kinetics
  - issue of residuals after partial degradation

Polychlorinated Biphenyl Dechlorination in Aquatic Sediments

John F. Brown, Jr., Donna L. Bedard, Michael J. Brennan, James C. Carnahan, Helen Feng, Robert E. Wagner

Science, 1987

In Situ Stimulation of Aerobic PCB Biodegradation in Hudson River Sediments

M. R. Harkness, J. B. McDermott, D. A. Abramowicz,* J. J. Salvo, W. P. Flanagan, M. L. Stephens, F. J. Mondello, R. J. May, J. H. Lobos, K. M. Carroll, M. J. Brennan, A. A. Bracco, K. M. Fish, G. L. Warner, P. R. Wilson, D. K. Dietrich, D. T. Lin, C. B. Morgan, W. L. Gately

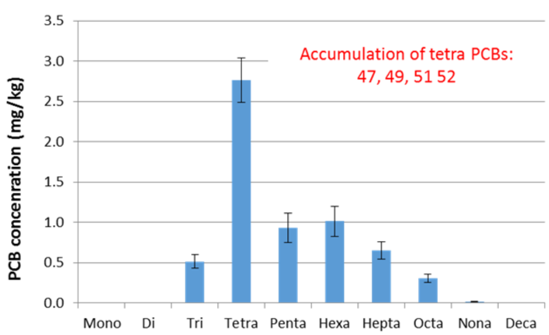
Science, 1993

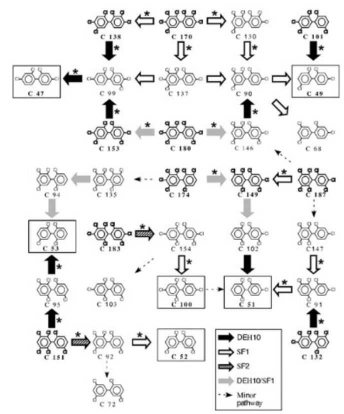
Long-Term Recovery of PCB-Contaminated Sediments at the Lake Hartwell Superfund Site: PCB Dechlorination. 1. End-Member Characterization

VICTOR S. MAGAR,*,† GLENN W. JOHNSON,‡ RICHARD C. BRENNER,§ JOHN F. QUENSEN, III,‖ ERIC A. FOOTE,† GREG DURELL,⊥ JENNIFER A. ICKES,†,# AND CAROLE PEVEN-MCCARTHY⊥

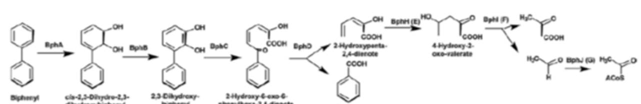
U.S. Environmental Protection Agency, National Risk Management Research Laboratory, 26 West Martin Luther King Drive, Cincinnati, Ohio 45268, and Battelle Memorial Institute, 505 King Avenue, Columbus, Ohio 43201

ES&T 2005





anaerobic pathways



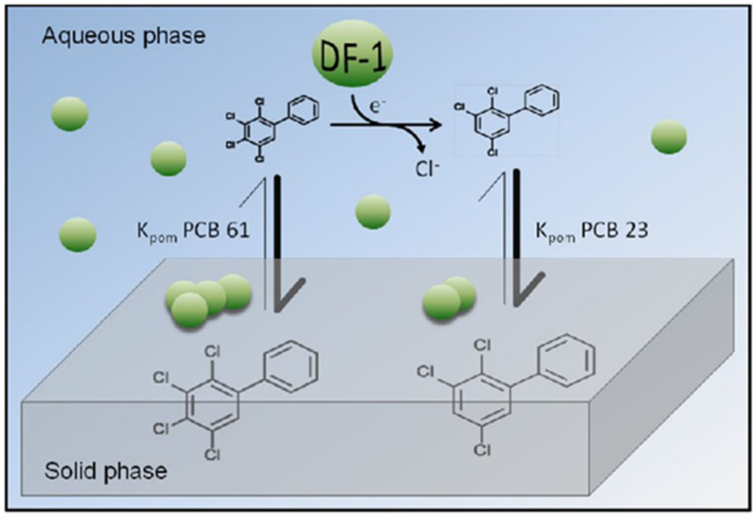
Aerobic pathway

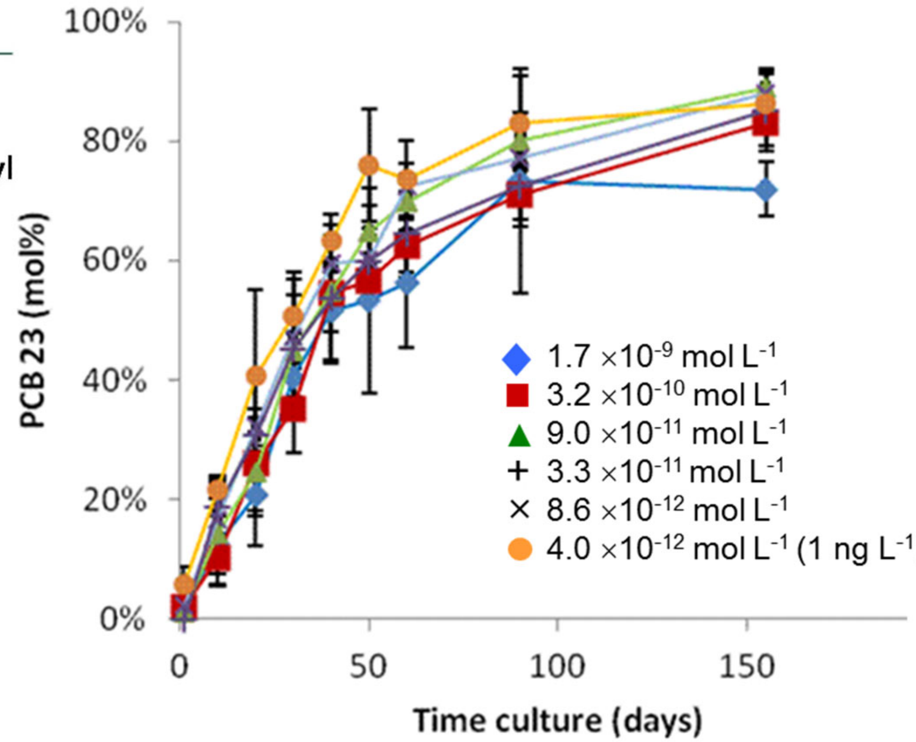
New Understanding of PCB dechlorination kinetics

Environmental Science & Technology

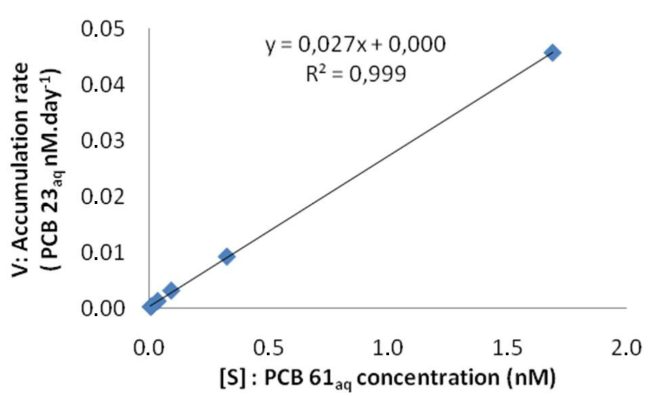
Kinetics and Threshold Level of 2,3,4,5-Tetrachlorobiphenyl Dechlorination by an Organohalide Respiring Bacterium

Nathalie J. Lombard,[†] Upal Ghosh,[‡] Birthe V. Kjellerup,[§] and Kevin R. Sowers[*,†]





(a)



- PCB dechlorination rate can be measured using passive dosing/sampling
- Rate of dechlorination linear function of PCB concentration
- Dechlorination observed down to 1 ng/L PCB concentration in water
- Rate constant same across 4 orders of magnitude

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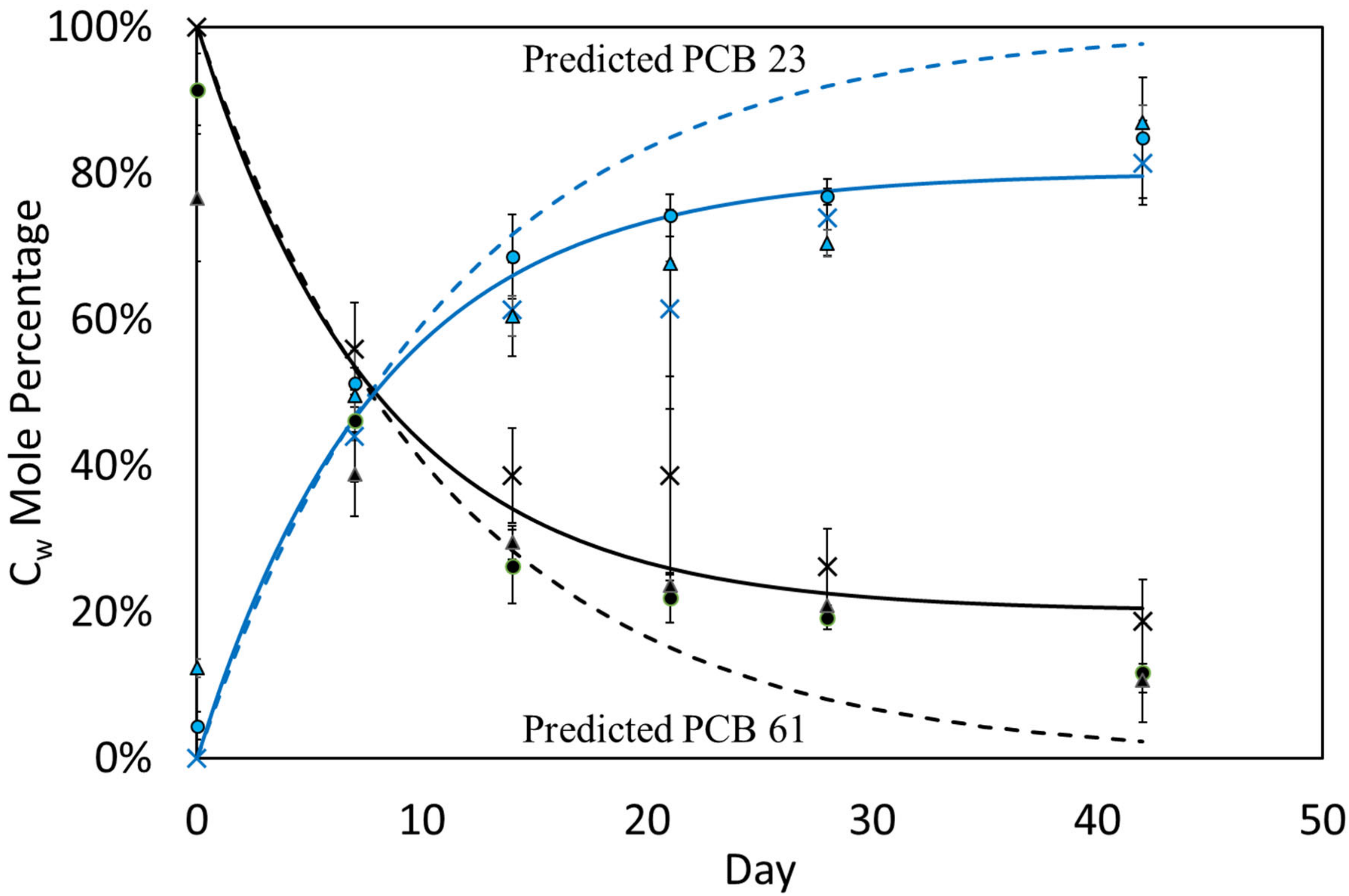
Predicting Dechlorination in Sediment Slurries



- Dechlorination in sediment explained by kinetics measured in sediment-free system
- About 20% residual PCB desorbs slower than microbial dechlorination

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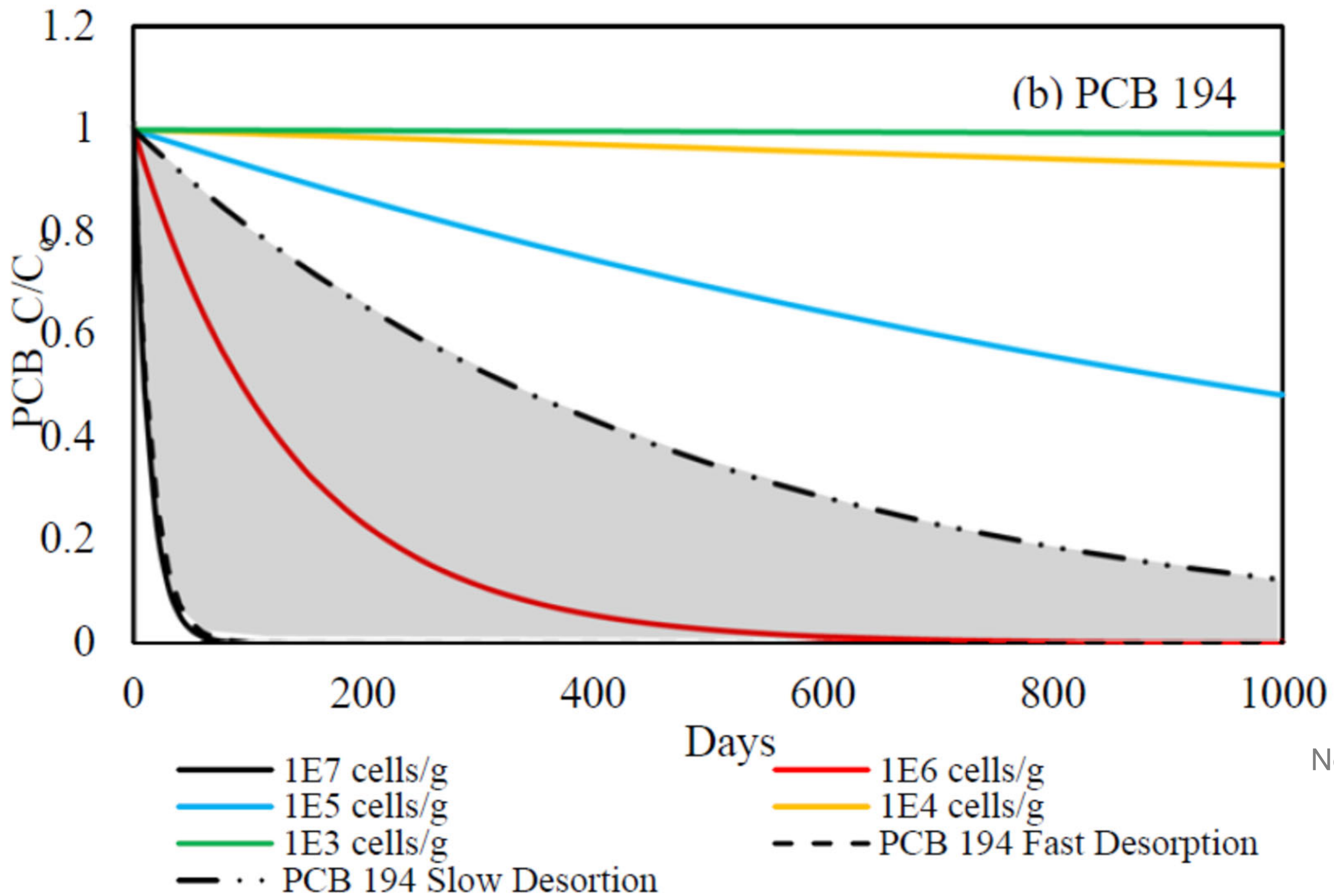
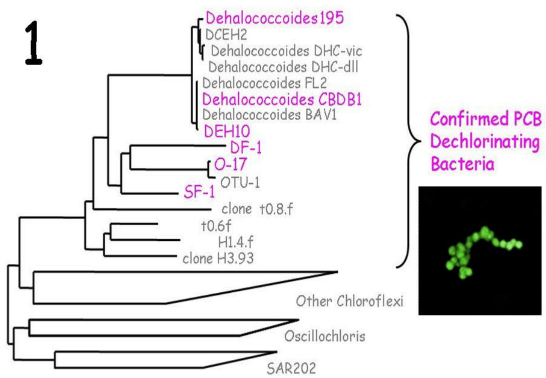
Predicting native dechlorination rates in sediment



Needham *et al., submitted*

- Dechlorination rate at native organism abundance in sediments is too slow
- Rate increases with bioamendment to sediments
- At optimal dose, dechlorination rate limited by desorption rate from sediment

Technology Scaleup and Translation

1


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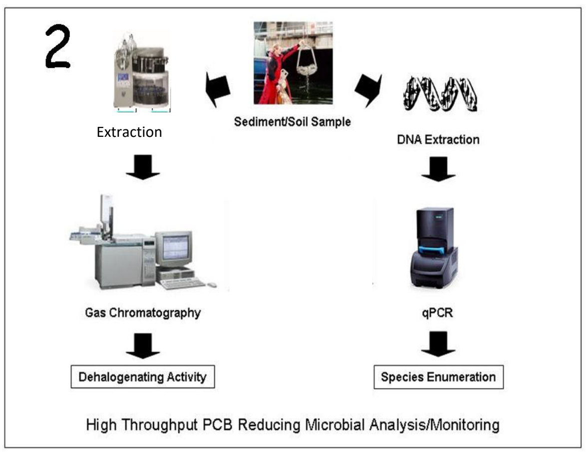


3


4

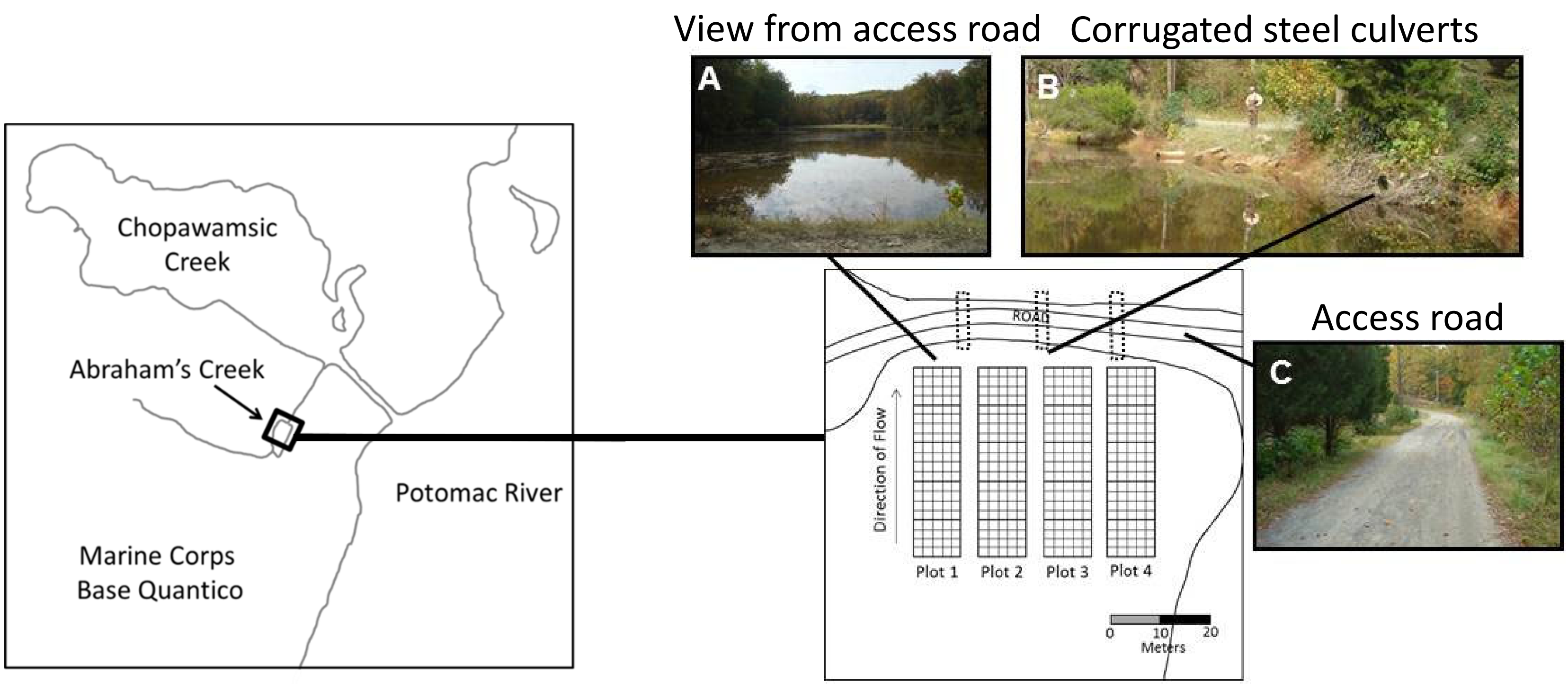

1) PCB anaerobic halorespirer and aerobic degrader available

2) Assays developed for monitoring treatment and bioamendments

3) Methods developed for biomass scale-up of bioamendments w/o PCB

4) System developed for *in situ* deployment of bioamendments on activated carbon agglomerate (SediMite)

Abraham's Creek VA – April 2015



- Abraham's Creek MCBQ is an 8 acre/32,000 m^2 watershed outflow
- Original contaminant likely A1260
- Currently contaminated with an average 5 ppm PCB
- Treatments in four 400 sq. m plots
- Load rate = 1 ton SediMite + 10^{12} cells/400 m^2

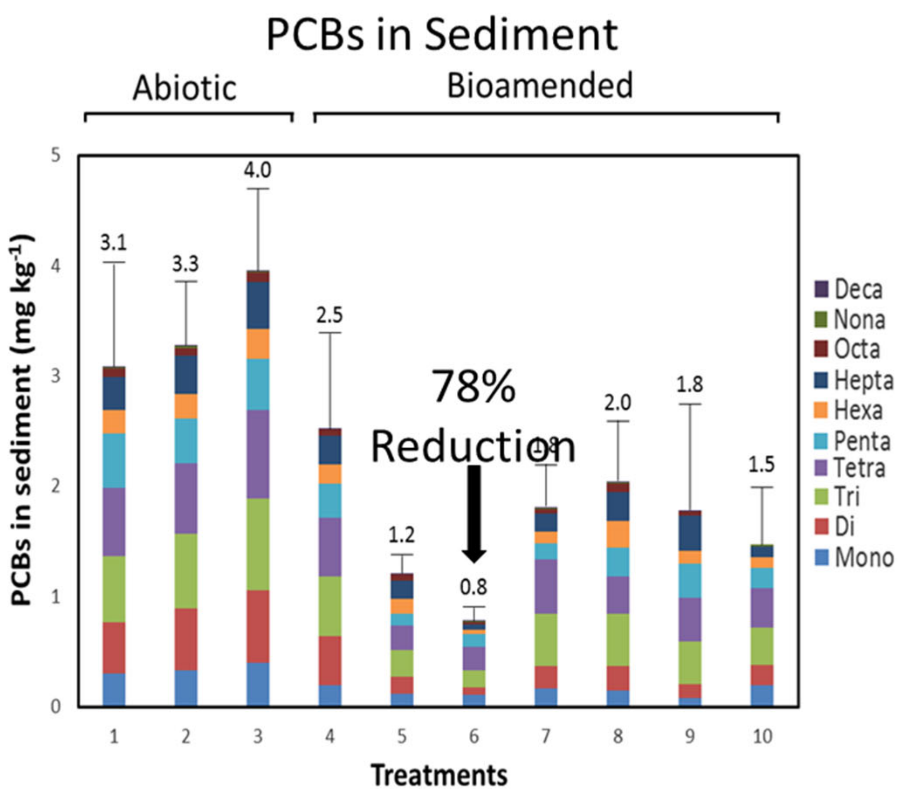
Treatability Study-Experimental Design

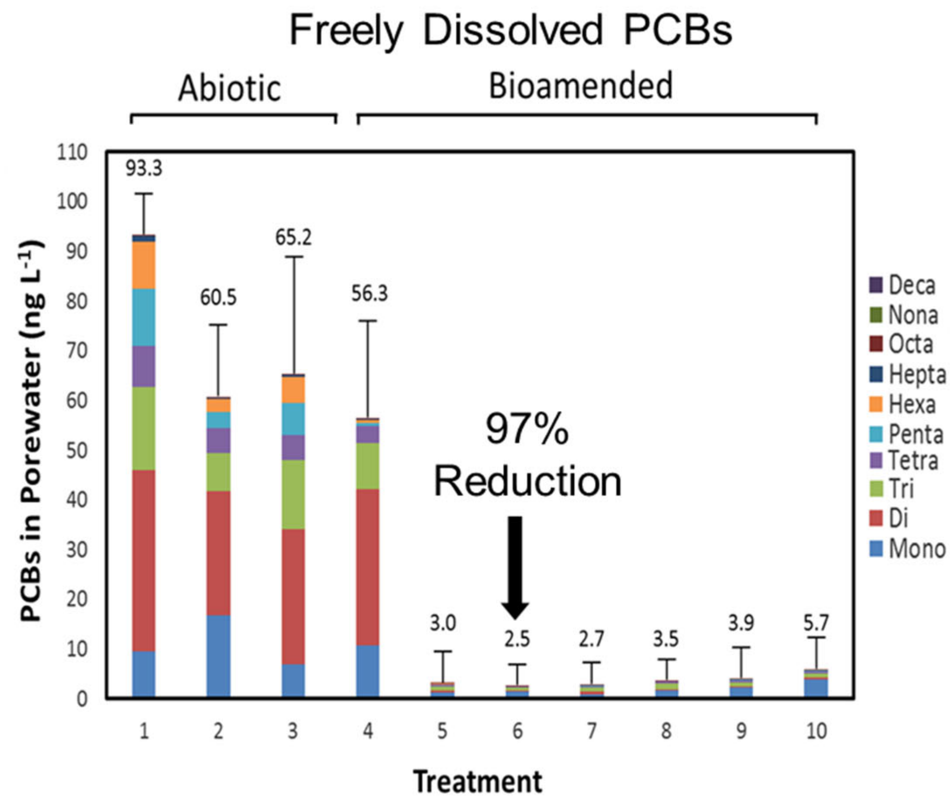
Treatment	SediMite™	Cellulose	Cells g^{-1} sediment	Anaerobic Dechlorinator	Aerobic Degrader
1	-	-	-	-	-
2	3%	-	-	-	-
3	3%	0.03%	-	-	-
4	3%	0.03%	5×10^3	DF-1	LB400
5	3%	0.03%	5×10^4	DF-1	LB400
6	3%	0.03%	5×10^5	DF-1	LB400
7	3%	-	5×10^5	DF-1	LB400
8	3%	0.03%	5×10^5	SF1+DEH10	LB400
9	3%	0.03%	5×10^5	o-17	LB400
10	3%	0.03%	5×10^5	DF1+SF1+DEH 10+ o-17	LB400

- Abiotic controls
- Bioamendment titer
- Bioamendment, no cellulose
- Different halorespirers

- 2 L recirculating mesocosms mimic *in situ* conditions
- Water is aerated to 6.8 mg/L and returned to system
- Tops sealed to minimize loss of PCBs from vapor phase
- XAD-2 resin to prevent build up of PCB products in water

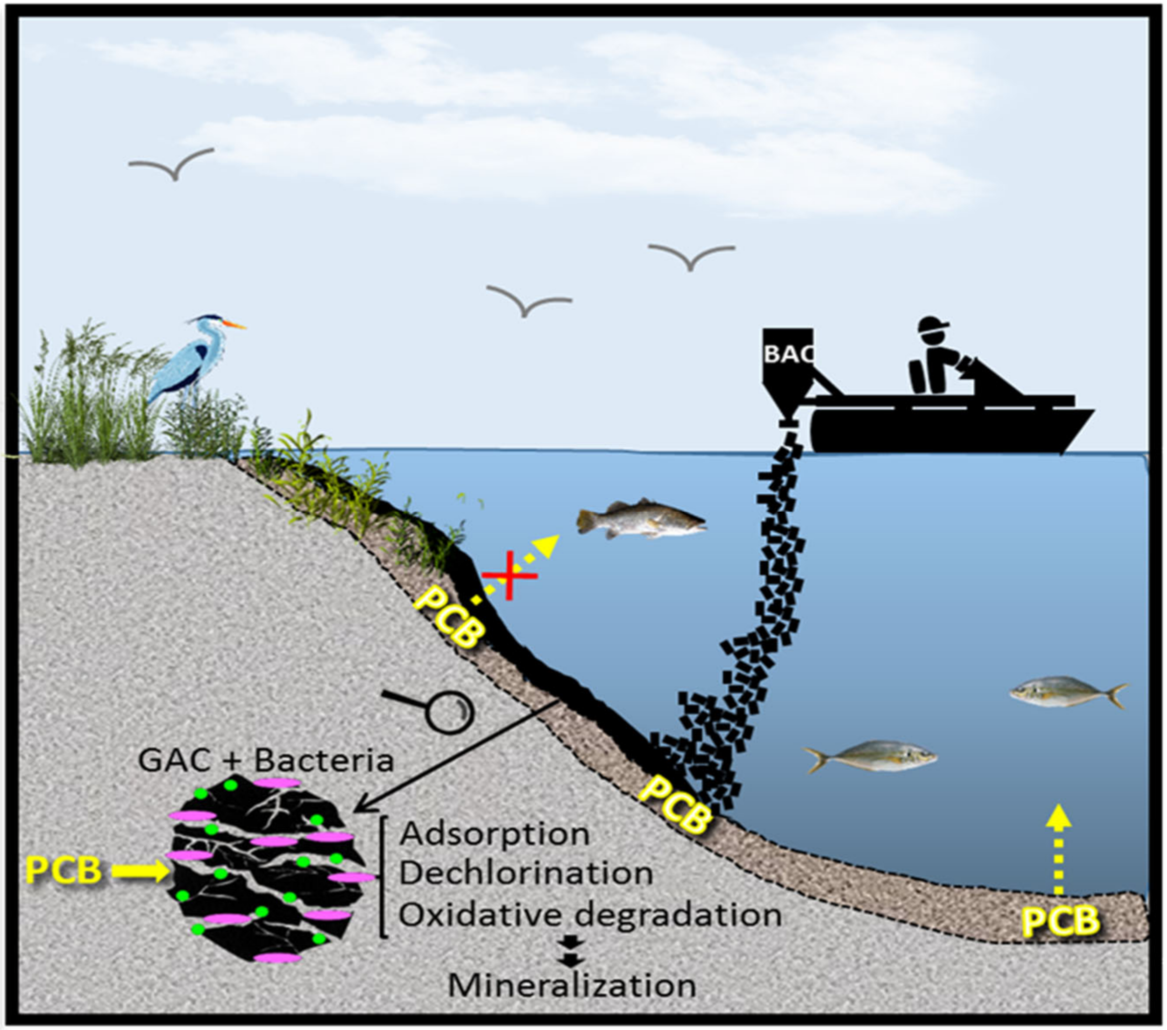
Treatability Study-Results





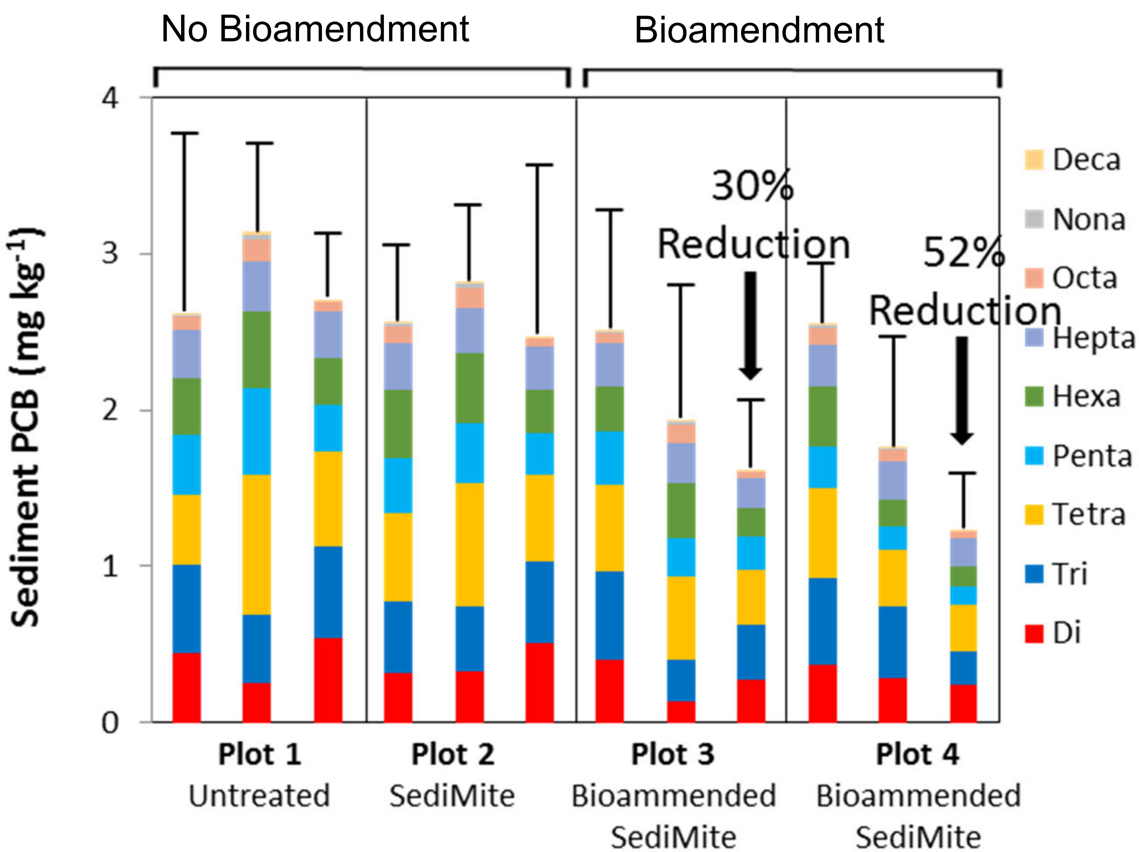
- Bioamending with 10^5 cell/g yielded greatest reduction of PCBs after 375 days
- DF1 and LB400 were most robust bioamendments
- Addition of carbon source only slightly stimulated PCB degradation
- Mono- to nona-chlorobiphenyls were reduced = anaerobic & aerobic activity

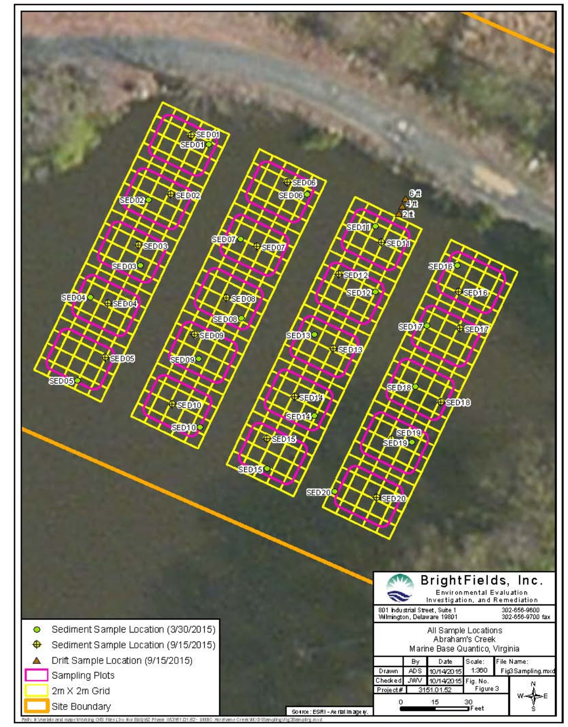
Field Application of Bioamended AC



- 3000 kg bioamended SediMite deployed with air horn
- Final SediMite concentration = 0.3g/10 g sediment
- Final bioamendment concentration = 10^6 cells/10 g sediment

Performance Assessment-Total PCBs





- Decrease in bioamended plots after *409* days
- 80% reduction in total mass of coplanar PCBs
- No significant change in untreated plots and below benthic zone
- Difference observed between Plots 3 & 4

Environmental Science & Technology
Article
Cite This: Environ. Sci. Technol. XXXX, XXX, XXX−XXX
pubs.acs.org/est

A Pilot-Scale Field Study: In Situ Treatment of PCB-Impacted Sediments with Bioamended Activated Carbon

Rayford B. Payne,† Upal Ghosh,‡ Harold D. May,§ Christopher W. Marshall,∥,⊥ and Kevin R. Sowers*,†

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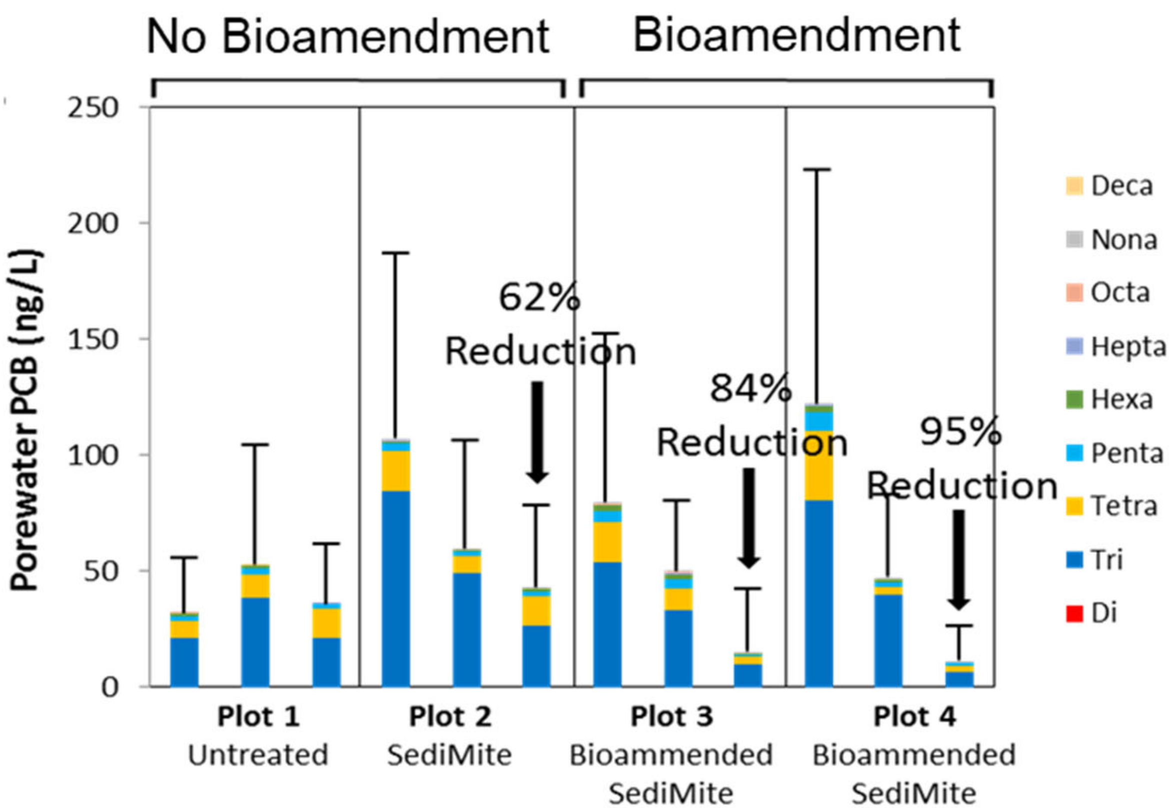
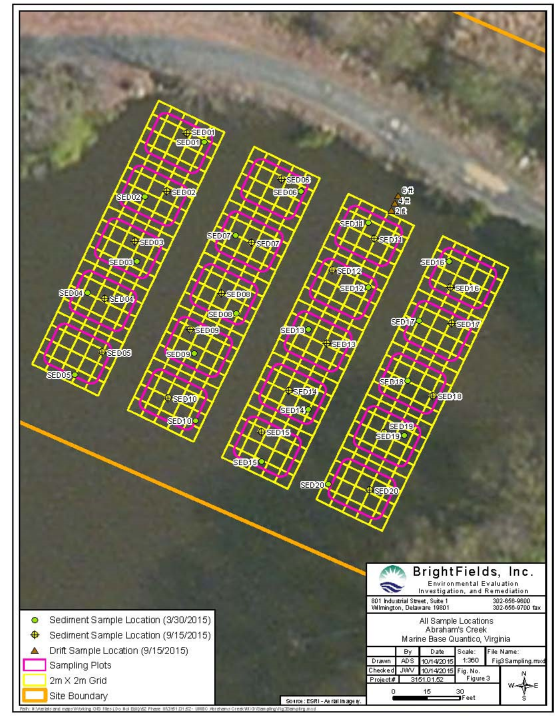
Performance Assessment-Dissolved PCBs





- Decrease in bioamended plots after *409* days
- Some decrease with AC due to adsorption, but significantly less decrease than bioamended plots
- No significant change in untreated plot and below benthic zone

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Performance Summary

- The bioamended effectively reduces both the total mass and bioavailability of PCBs
- There was a direct relationship between the extent of degradation and the amount of bioamended AC applied
- The treatment rapidly degrades the soluble and rapidly desorbing PCBs, then the process continues at a slower rate for the remaining slow desorbing PCBs
- The bioamendment was stable and did not migrate downstream of application in a stream with intermittent flow during rains and spring melts
- The treatment is well suited for environmentally sensitive sites, difficult to reach areas such as under piers, water margins, and dredged materials

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Contributors, Collaborators, Funding Source

- **Kevin R. Sowers & Ray Payne**

  University of Maryland Baltimore County, IMET

- **Upal Ghosh and Trevor Needham**

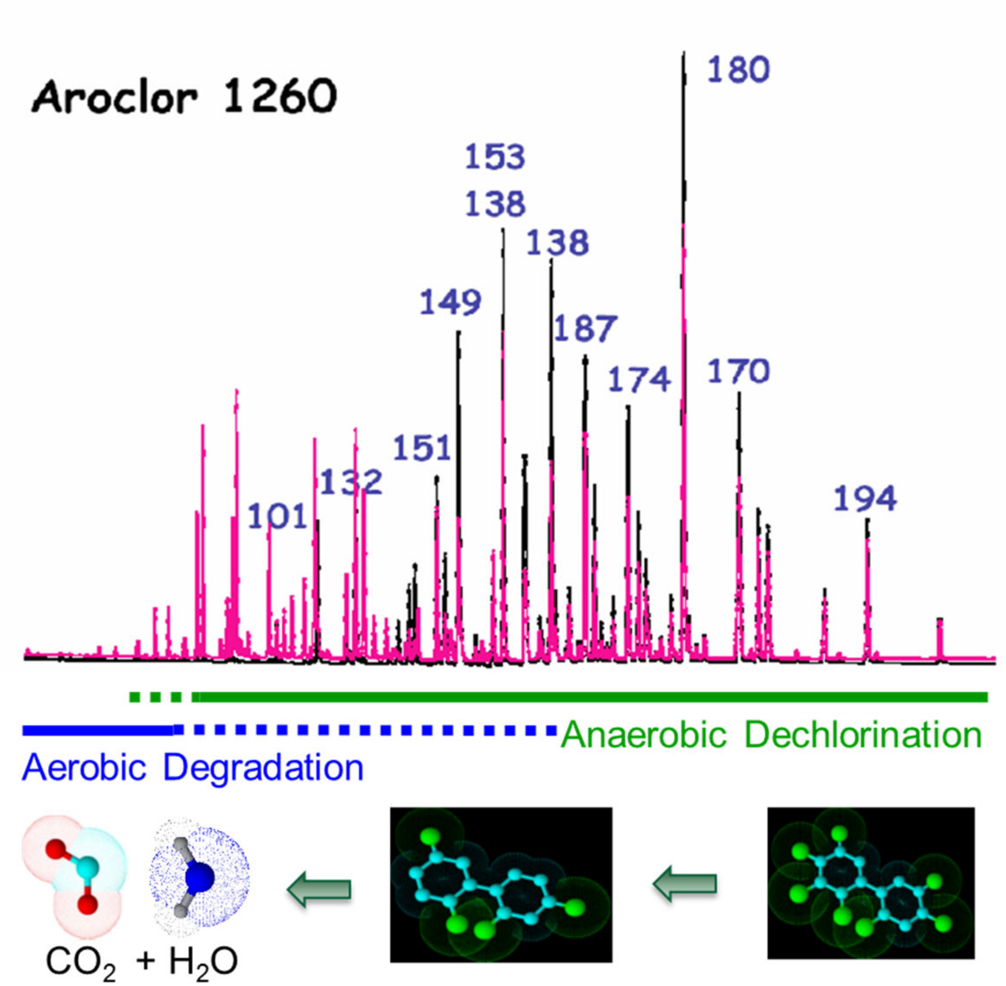
  University of Maryland Baltimore County, CBEE

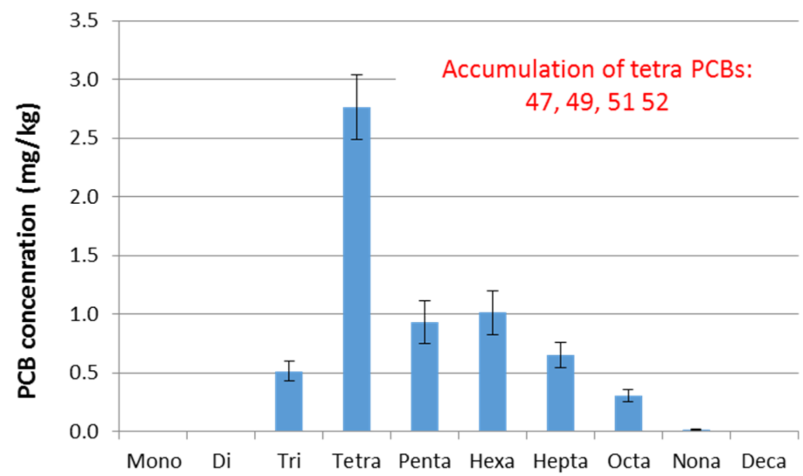
- **Hal May**

  Medical University of So. Carolina

Funding: SERDP, ESTCP, NIEHS, ONR

How PCB Bioremediation Works

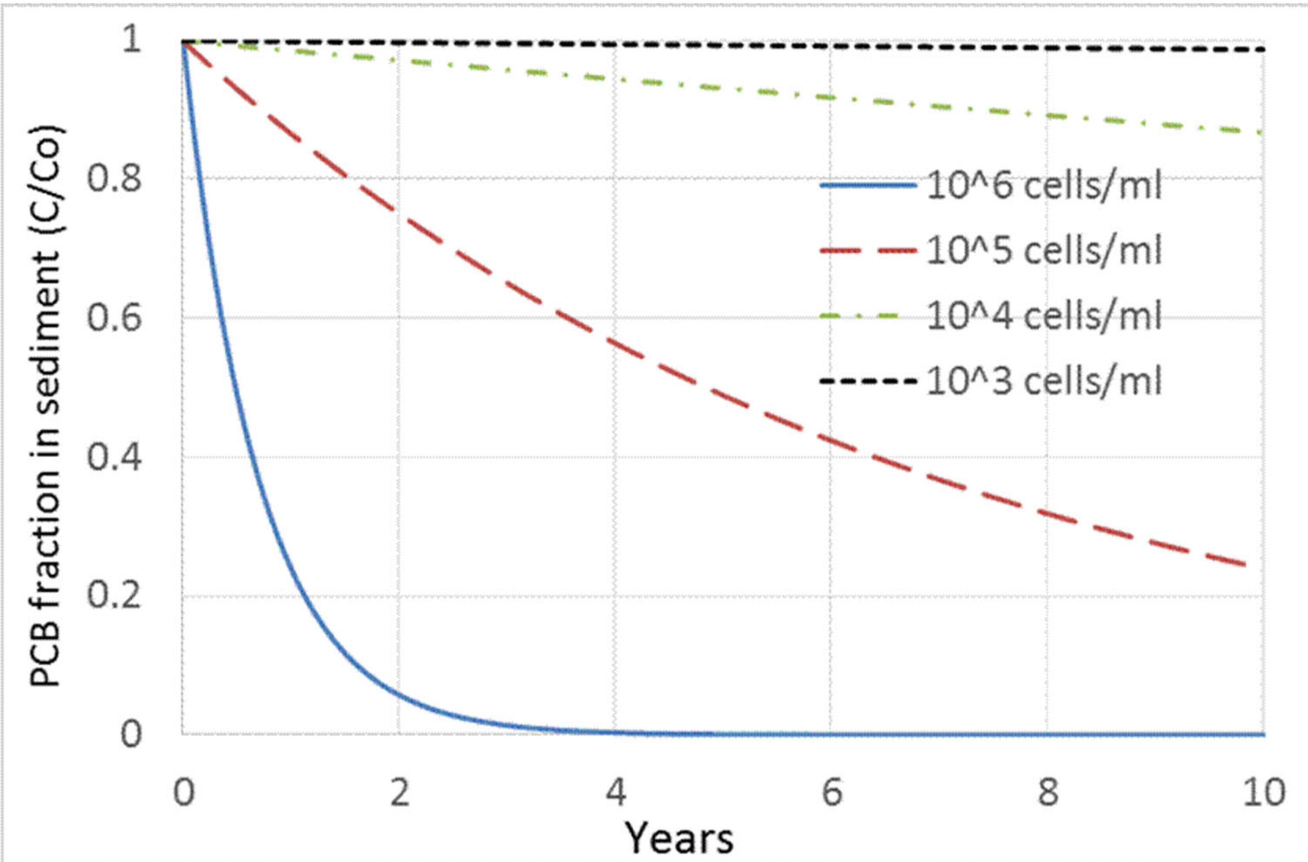




Complementary activities of:

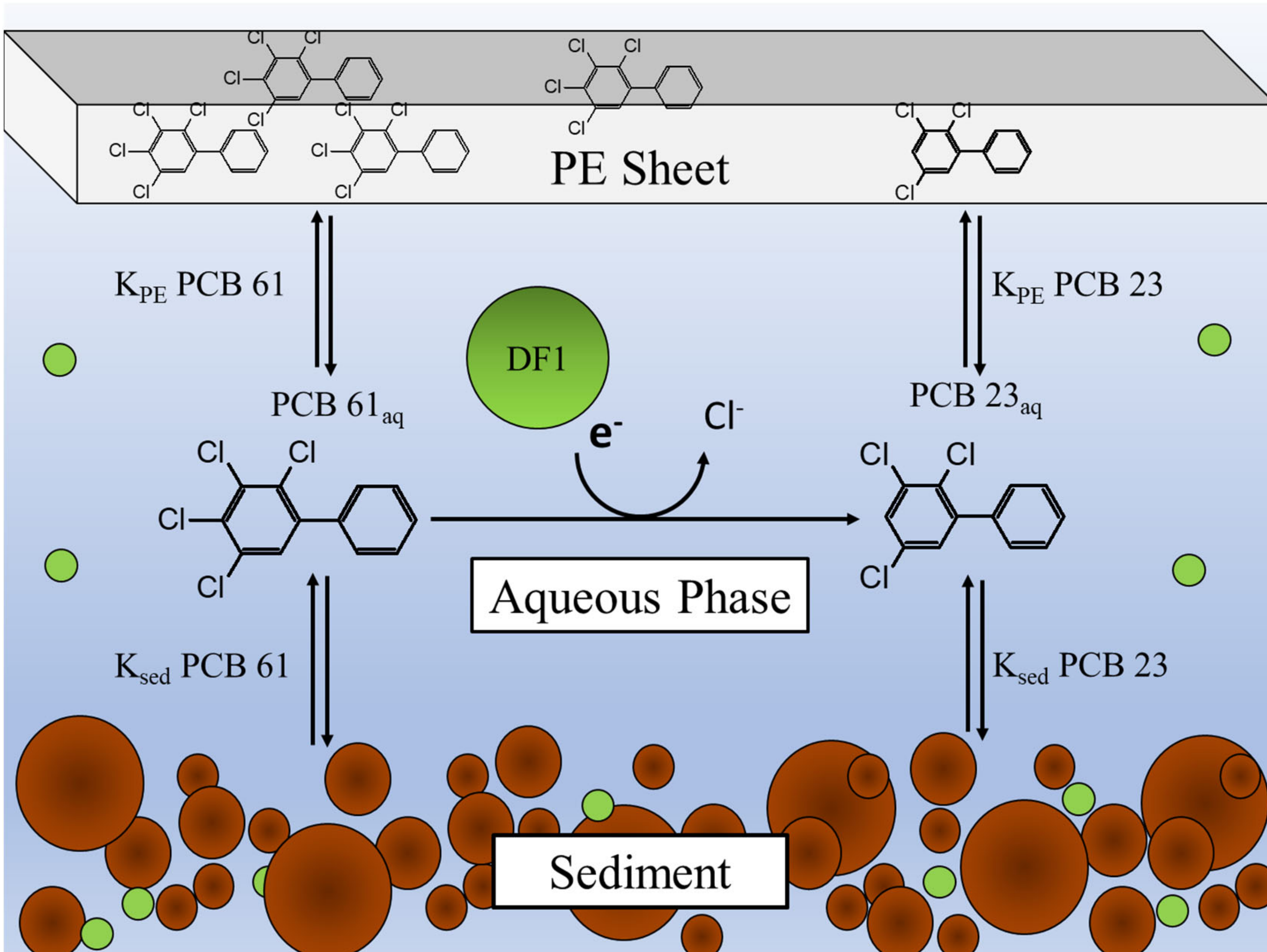
1) anaerobic halorespiring bacterium
2) aerobic oxidizing/dechlorinating bacterium

Explanation of slow PCB dechlorination kinetics in sediments

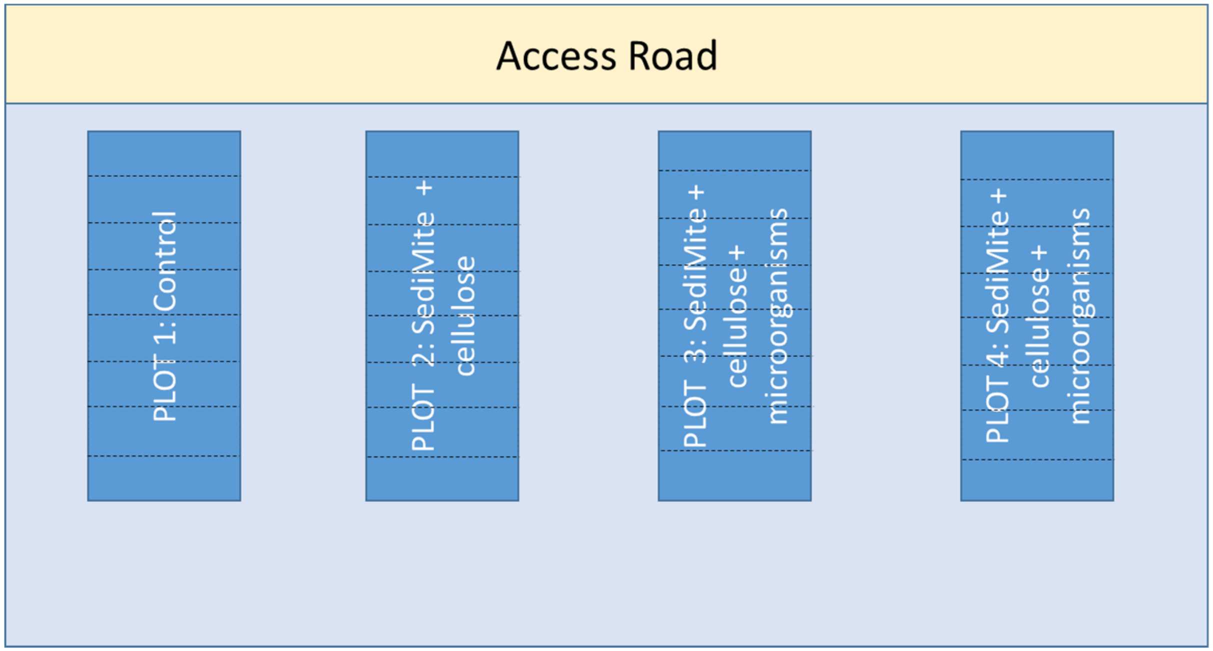


- Low rates in environment due to low cell numbers, not bioavailability thresholds
- Bioaugmentation increases rate of degradation
- Predictive models possible based on PCB porewater concentration and number of dechlorinating microorganisms

Buffering due to sorption to solids



Field Test Design

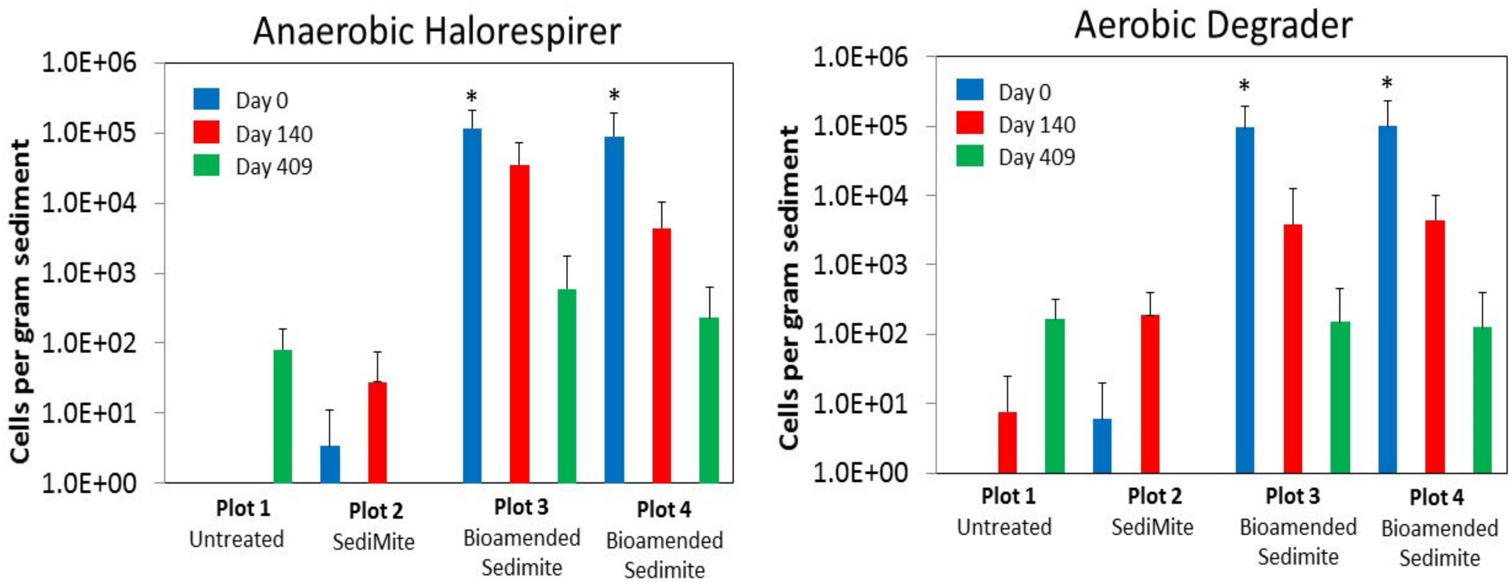


- Layout of four treatment plots each 400 m^2 in area
- Plot 1 – no treatment
- Plot 2 – SediMite containing cellulose as a slow release carbon source
- Plot 3/4 – SediMite/cellulose amended with anaerobic PCB dechlorinating DF1 and aerobic dechlorinating/oxidizing LB400

Field Test-Deployment




Fate of Bioamendments



- Halorespirer and aerobic degrader decreased by 2 to 3 orders of magnitude after 409 days in plots 3 and 4
- Similar decrease in cell numbers observed in the mesocosm treatability study after a similar period of time
- Despite the decrease the titer was 2-3 orders of magnitude greater than background levels after 409 days

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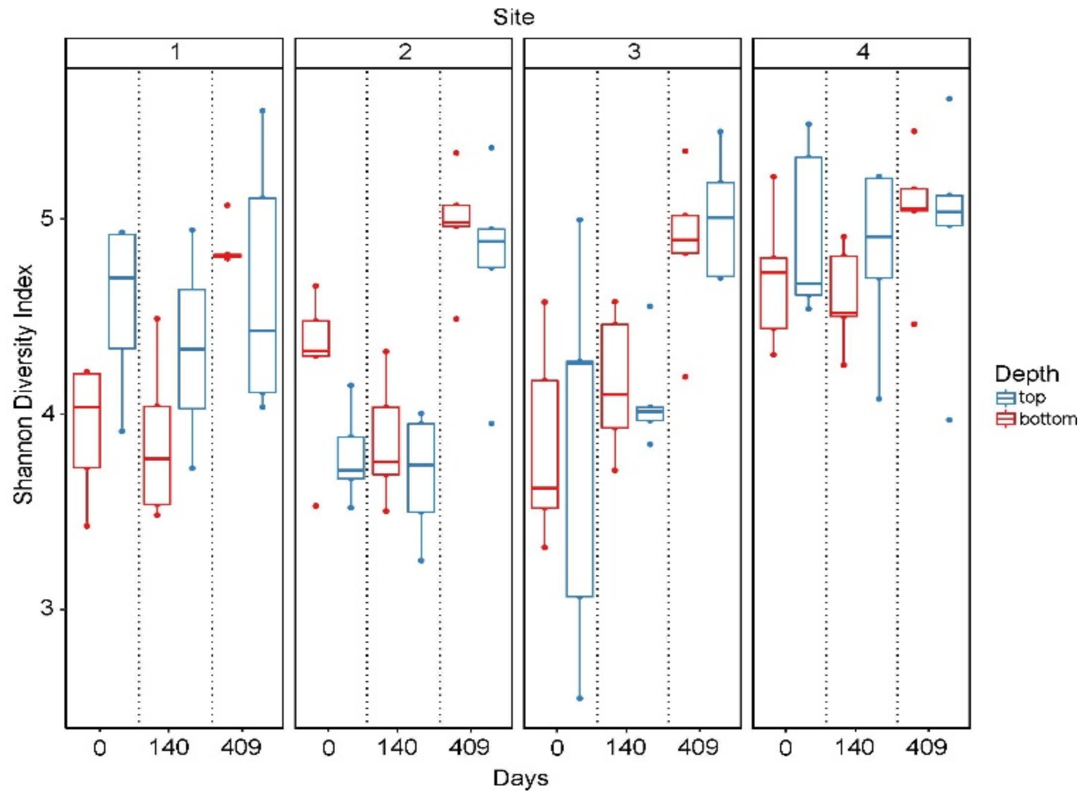
Effect of Treatments on Indigenous Bacteria



- Plot 4 began the experiment significantly more diverse than all other sites and remained significantly more diverse over 140 days
- The microbial diversity was not significantly different between any other sites, time points, or depths.
- Therefore, bioaugmentation and the addition of activated carbon did not significantly alter total microbial diversity on a macroscale.

Cost Comparison of Remediation Technologies

Treatment Alternative	Total Capital Cost (2017 dollars)	O&M Cost	Total Annualized cost ($/acre)
Alt 1: No further action	0	0	0
Alt 2: Monitored Natural Attenuation	130,000	520,000	83,333
Alt 3: Isolation cap	4,030,000	910,000	633,333
Alt 4: Excavation & on-site CDF	17,030,000	910,000	2,300,000
Alt 5: Excavate & off-site disposal	25,090,000	0	3,216,000
Alt 6: Partial excavation & off-site disposal	11,570,000	260,000	1,516,666
Alt 7: Capping and wetland creation	5,850,000	910,000	866,666
Alt 8: Reactive cap	4,030,000	910,000	633,333
Alt 9: SediMite™ only	1,096720	910,000	250,640
Alt 10: Bioamended SediMite™ (present study)	**1,767,920**	**910,000**	**343,323**

Comparison of implementation of remediation technologies for 7.8 acre pond in Abraham's Creek. Costs for Alt 1-8 are based on 2008 Feasibility Study for the site (Battelle 2008).

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Upcoming Full-Scale Applications

South Wilmington Wetland Park
Mouth of drainage outlet (14,150 sf)
Scheduled Apr 2019

Anne Arundel Co. former Formica plant cooling pond (32,336 sf)
Tentatively Scheduled June 2019