Application of Passive Sampling to Predict PCB Microbial Dechlorination Kinetics in Sediment

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Background

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, New Series, Vol. 236, No. 4802 (May 8, 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

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Reductive Dechlorination of Polychlorinated Biphenyls: Threshold Concentration and Dechlorination Kinetics of Individual Congeners in Aroclor 1248

YOUNG-CHEOL CHO,[†] ROGER C. SOKOL,[‡,§] ROBERT C. FROHNHOEFER,[†] AND G-YULL RHEE*[,†,§]

Environ. Sci. Technol. **2003**, *37*, 5651–5656

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[⊥]

Environ. Sci. Technol. **2005**, *39*, 3538–3547

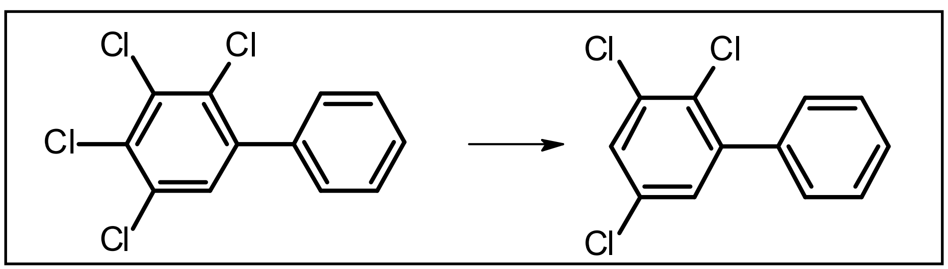
***In situ* treatment of PCBs by anaerobic microbial dechlorination in aquatic sediment: are we there yet?**

Kevin R Sowers[1] and Harold D May[2]

Current Opinion in Biotechnology 2013, **24**:482–488

Dehalobium chlorocoeria

- Sediment free co-culture containing *Desulovibrio*
- Capable of halorespiration of chlorinated organics: PCB, PCP, PCE, and Dioxin
- Can be grown to high cell densities (~1x10^8 cells/mL) on PCE
- Dechlorinate double flanked meta and para chlorines



Passive Sampling

- Low Density Polyethylene (PE) sheets
- Well established partitioning coefficients for a range of hydrophobic contaminants

$$K_{PE} = \frac{C_{PE}}{C_{water}}$$

- K_{PE} ranges from 10^4-10^8 for PCBs based on hydrophobicity
- PE sampling enables accurate measurements of the freely dissolved PCB concentration at < 1 nM concentrations

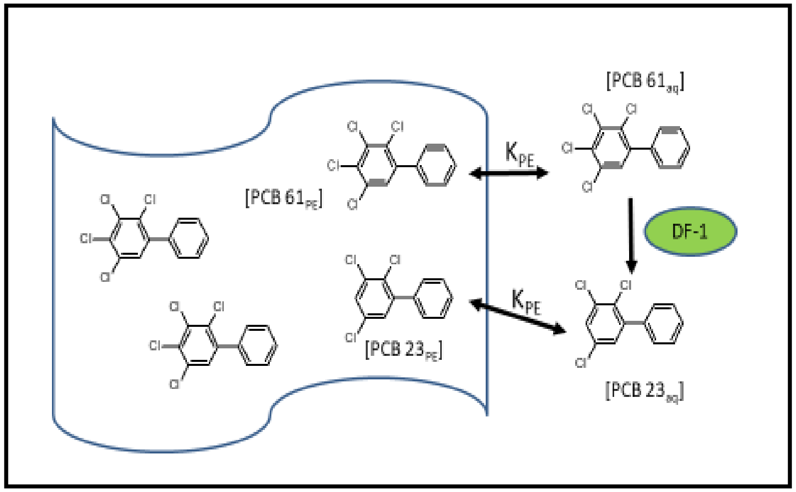
Validating work by Lombard et al. (2014)

Defining Buffering Capacity:

$$\frac{dC_w}{dt} * \left(\frac{V_w * +m_{PE} * K_{PE}}{V_w}\right) = C_w * k_b$$

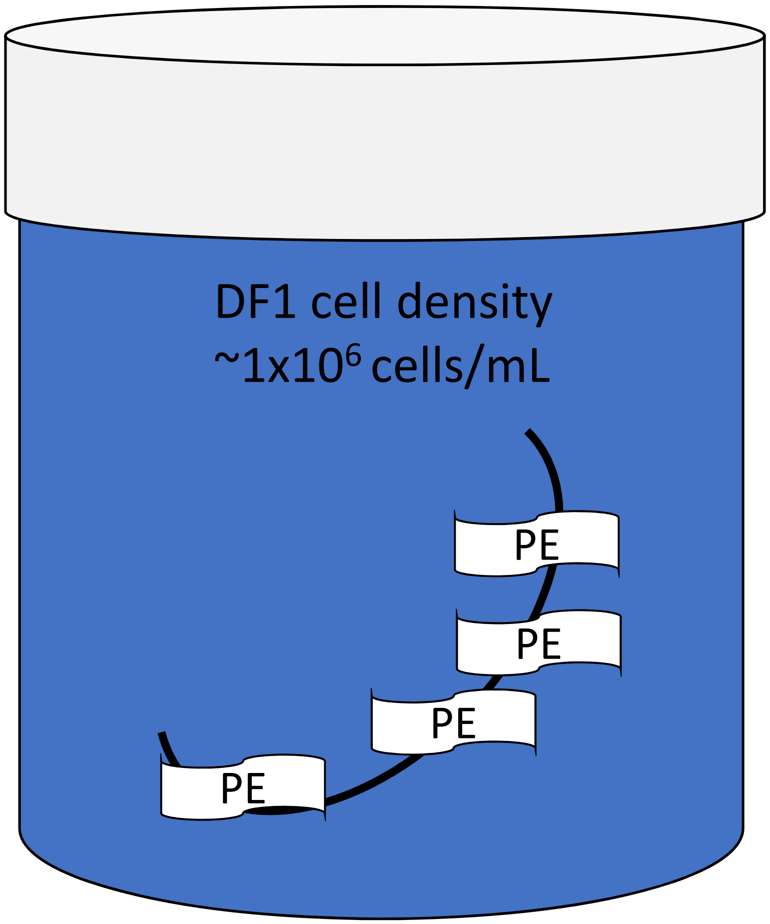
$$k_b' = k_b * \left(\frac{V_w}{V_w * +m_{PE} * K_{PE}}\right)$$

$$\frac{C_w}{C_{w\,o}} = e^{-k_b' t}$$



- Assume all phases are at equilibrium
- Assume that mass transfer is faster than the microbial rate

Experimental Design



Materials:

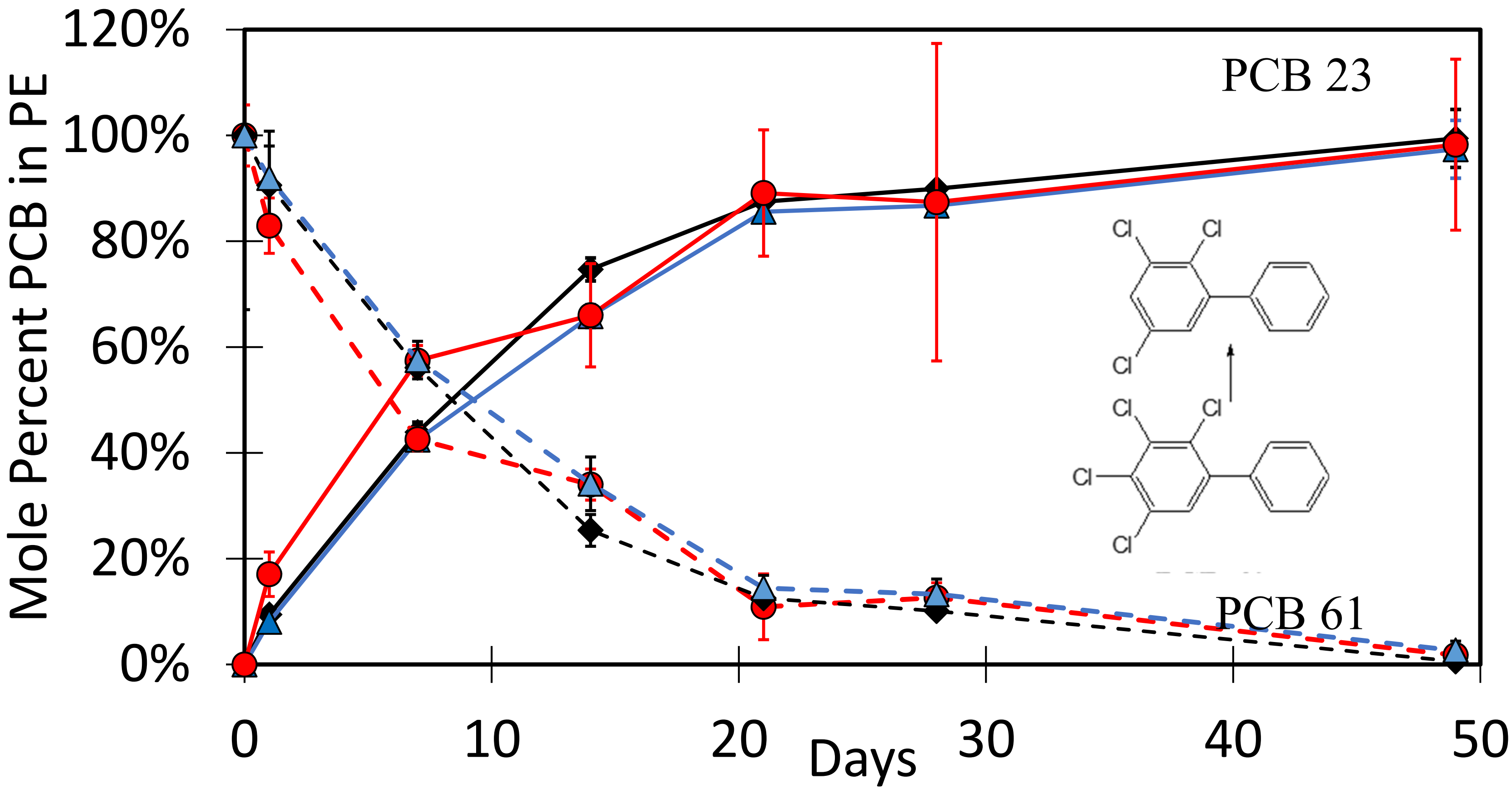
- 90 mL medium salt media (Berkaw et al 1996)
- 10 mM sodium formate
- 0.15 g PE sampler
- 10 mL DF1 inoculum (~1×10^7 cells/mL)

Sampling:

PE Removed at days 0, 1, 7, 14, 21, 28, and 42

Cell density qPCR at days 0, 7, and 42

First order Kinetics



Initial aqueous concentrations of PCB 61:

- 0.41 nM blue triangle
- 0.11 nM red circle
- 0.0043 nM black diamond

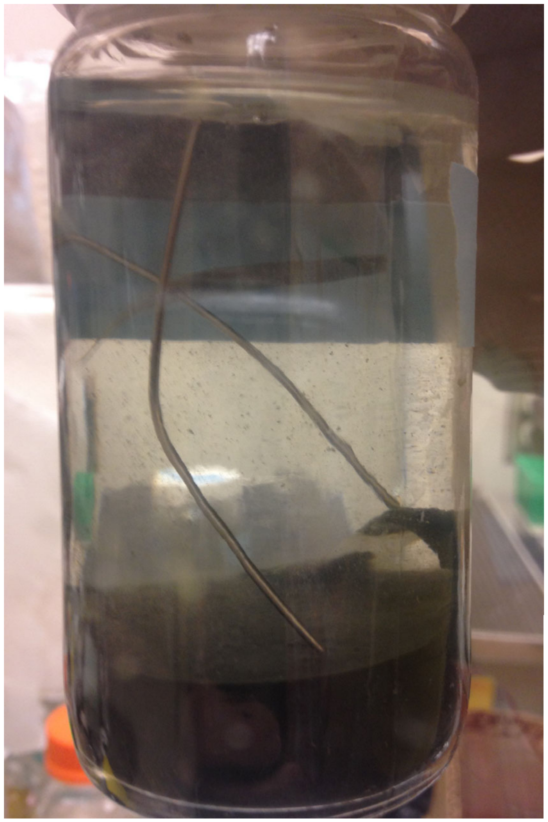
Comparing Results

Matrix	Cell Density	PCB 61$_{aq}$ initial (nM)	PCB 23$_{aq}$ accum rate (nM/d^{-1})	Std Error	r^2	k_b' (d^{-1})	CF	k_b (d^{-1})	k_b (d^{-1}) (10^6 cell/mL)
POM*	1.20E+06	**3.23E-01**	9.19E-03	4.0E-05	0.89	0.029	960	27	**23**
POM*	1.20E+06	**9.01E-02**	3.08E-03	8.5E-05	0.97	0.034	960	33	**27**
POM*	1.20E+06	**3.33E-02**	1.20E-03	3.3E-05	0.98	0.036	960	35	**29**
POM*	1.20E+06	**8.56E-03**	2.78E-04	3.0E-05	0.84	0.032	960	31	**26**
PE	1.60E+06	**4.10E-01**	9.30E-02	5.3E-02	0.98	0.23	309	70	**44**
PE	1.60E+06	**1.10E-01**	2.38E-02	1.3E-02	0.93	0.22	309	67	**42**
PE	1.60E+06	**4.30E-03**	8.00E-04	5.8E-05	0.87	0.19	309	57	**36**

* Results reported by Lombard et al. (2014)

Do the rates apply in sediments?

Sediment Experimental Design

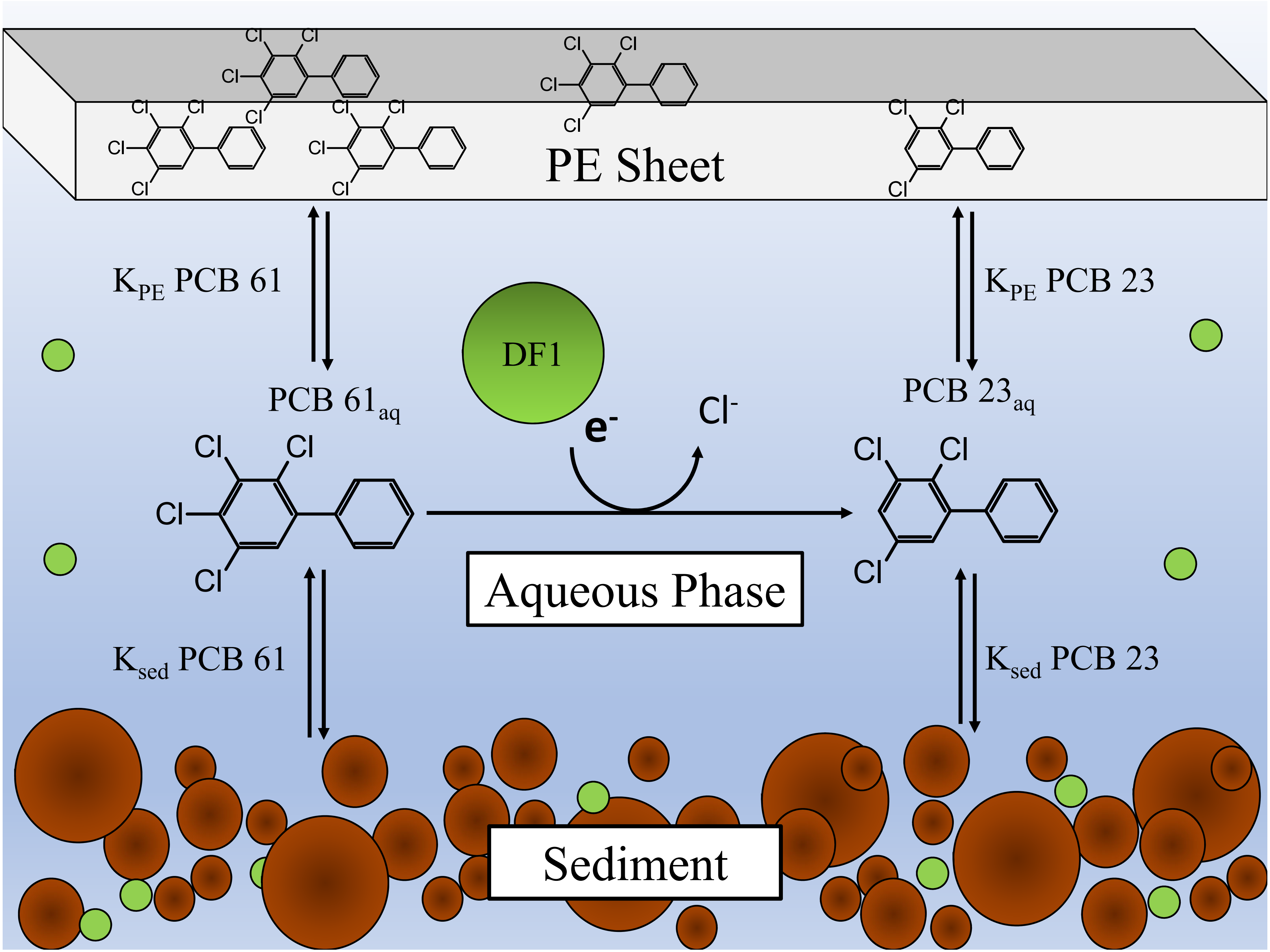


Materials:
- 10 g wet sediment
- 0.15 g of PE
- 80 mL E-CL media
- 10mM sodium formate
- 10 mL DF1 inoculum (~$1x10^7$ cells/mL)

Sampling:
PE Removed at days 0, 1, 7, 14, 21, 28, and 42

Sediment at day 0 and 42
Cell density qPCR at days 0, 7, and 42

PCB 61_o
$1.3x10^{-1}$,$1.6x10^{-2}$, and $5.1x10^{-3}$ nM



PE Sheet
K_PE PCB 61
K_PE PCB 23
PCB 61aq
PCB 23aq
DF1
e-
Cl-
Aqueous Phase
K_sed PCB 61
K_sed PCB 23
Sediment

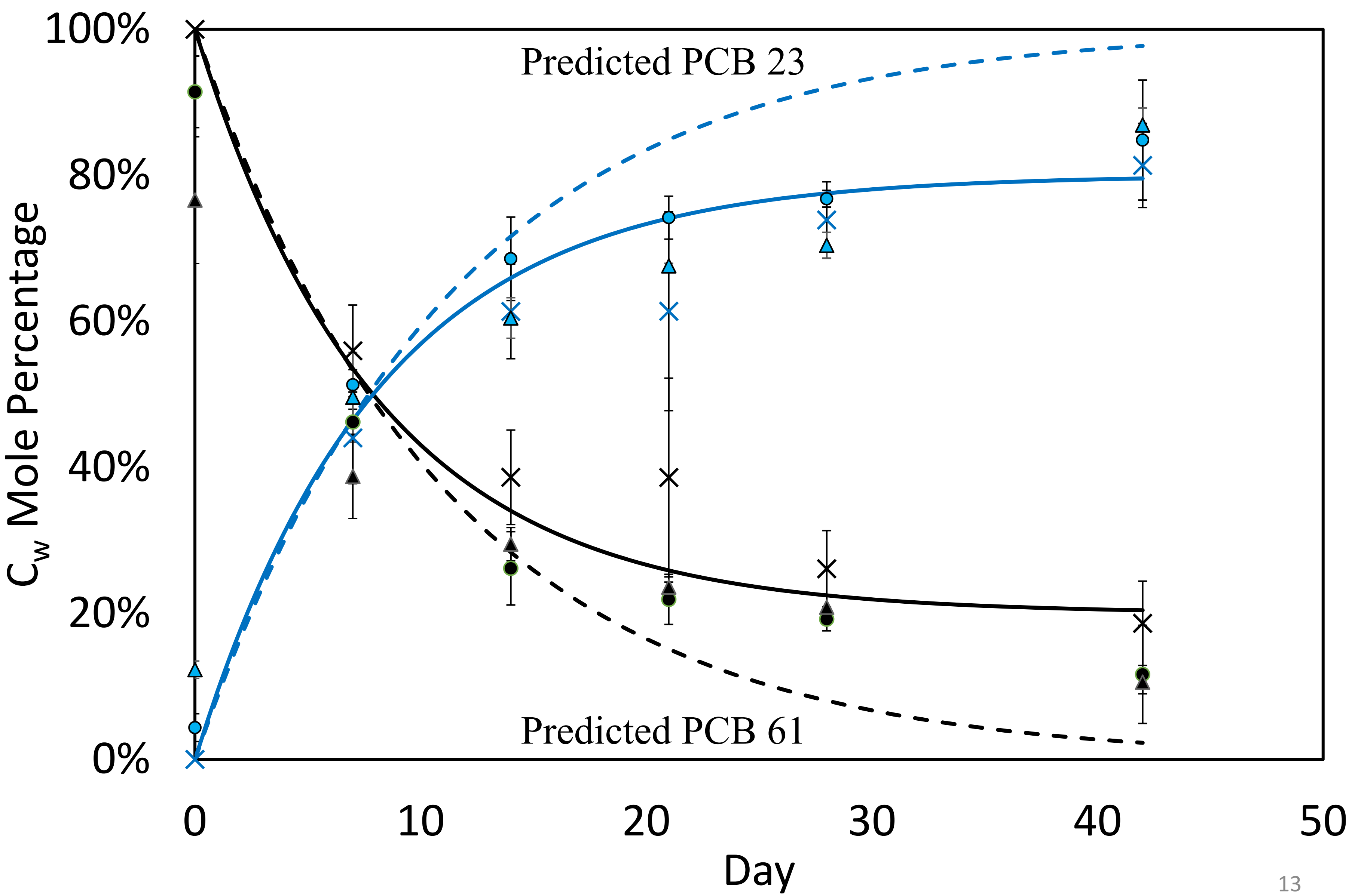
Incorporating Sediment into Buffering Capacity

$$\frac{dC_w}{dt} * (\frac{V_w * + m_{PE} * K_{PE} + m_{sed} * K_{sed}}{V_w}) = C_w * k_b$$

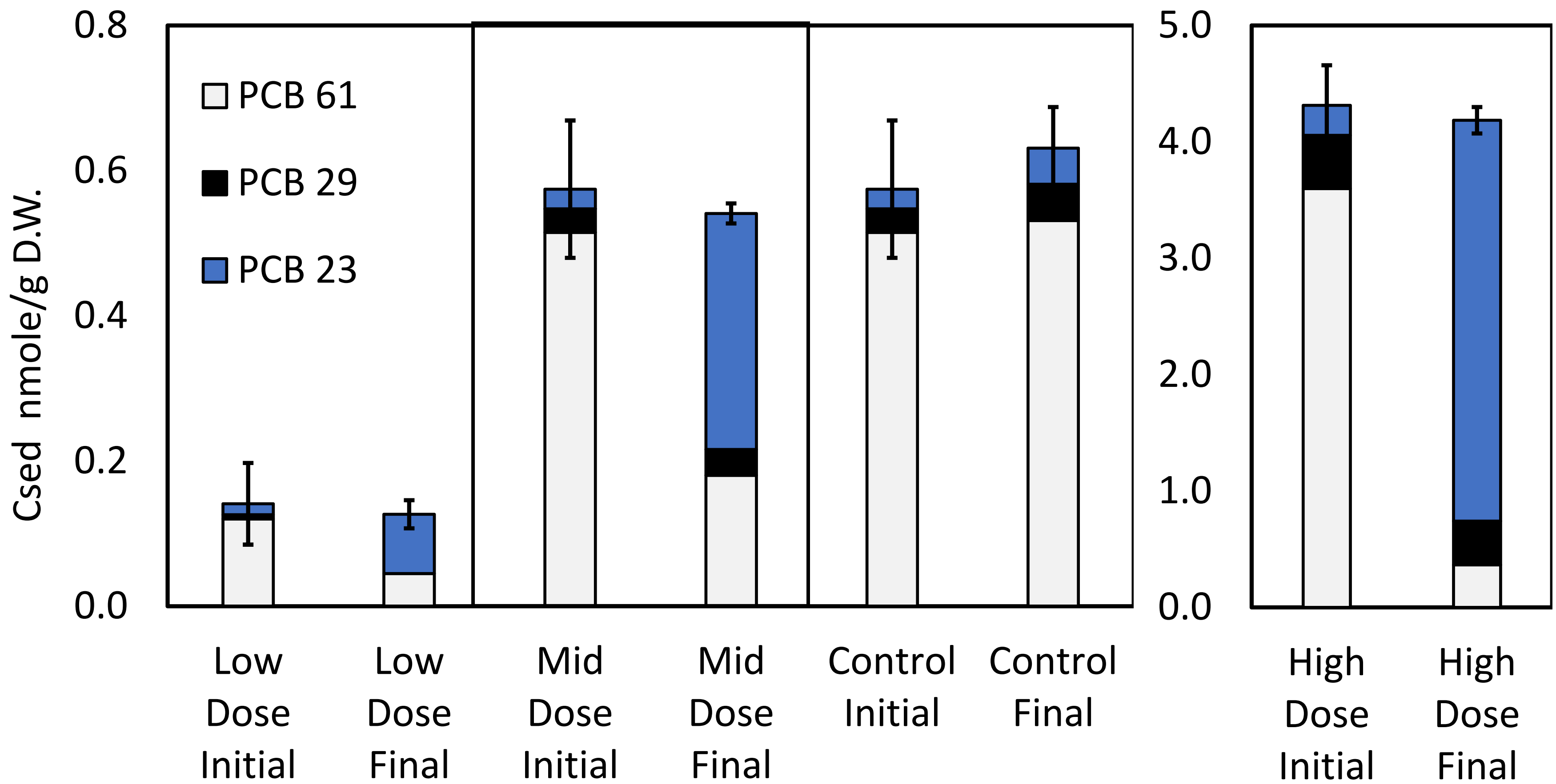
$$k_b' = k_b * \left(\frac{V_w}{V_w * + m_{PE} * K_{PE} + m_{sed} * K_{sed}} \right)$$

$$\frac{C_w}{C_{w\ o}} = e^{-k_b' t}$$

Predicting Dechlorination in Sediment Slurries



Sediment Concentrations

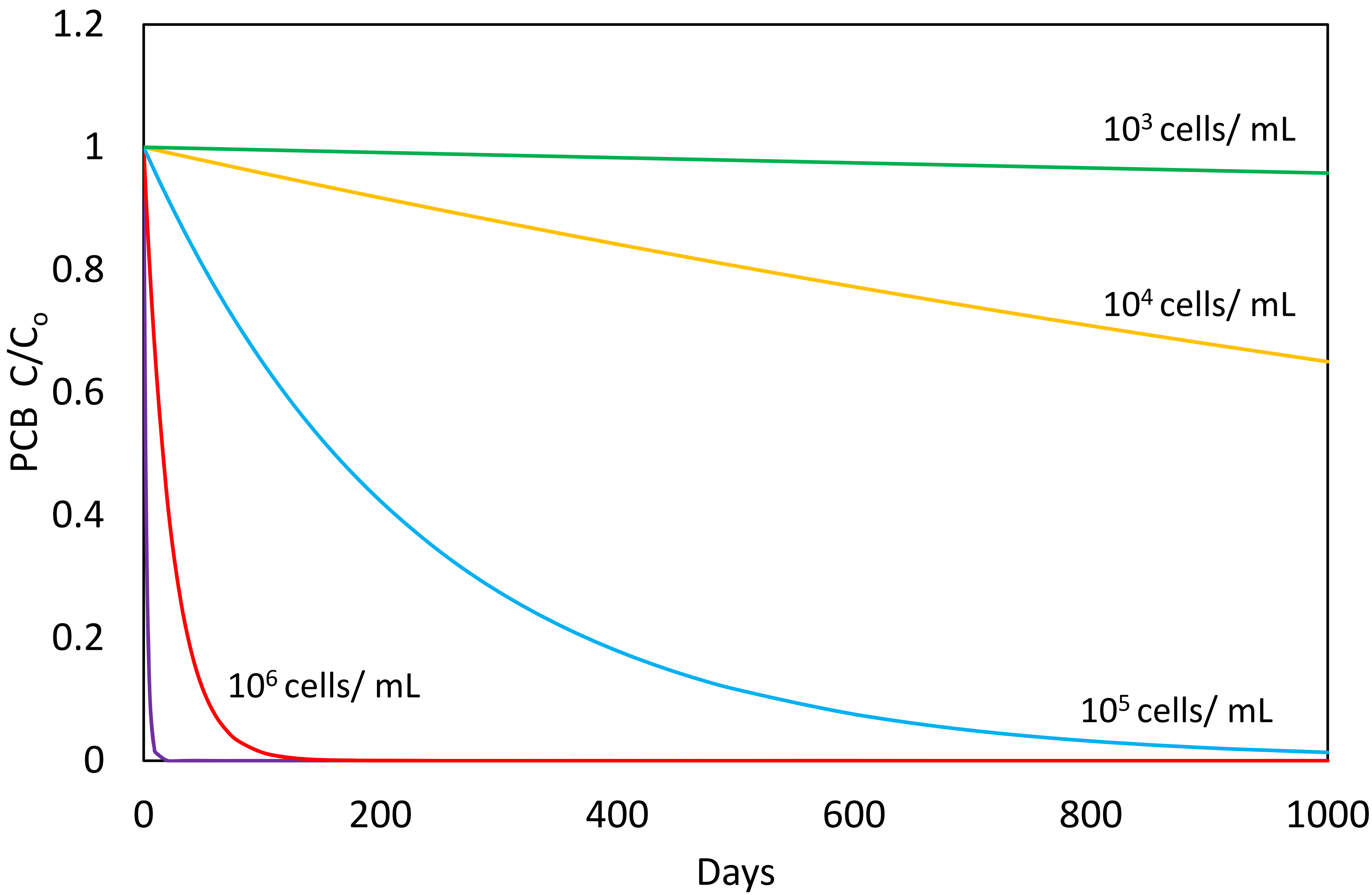


PE vs. Sediment Microcosm

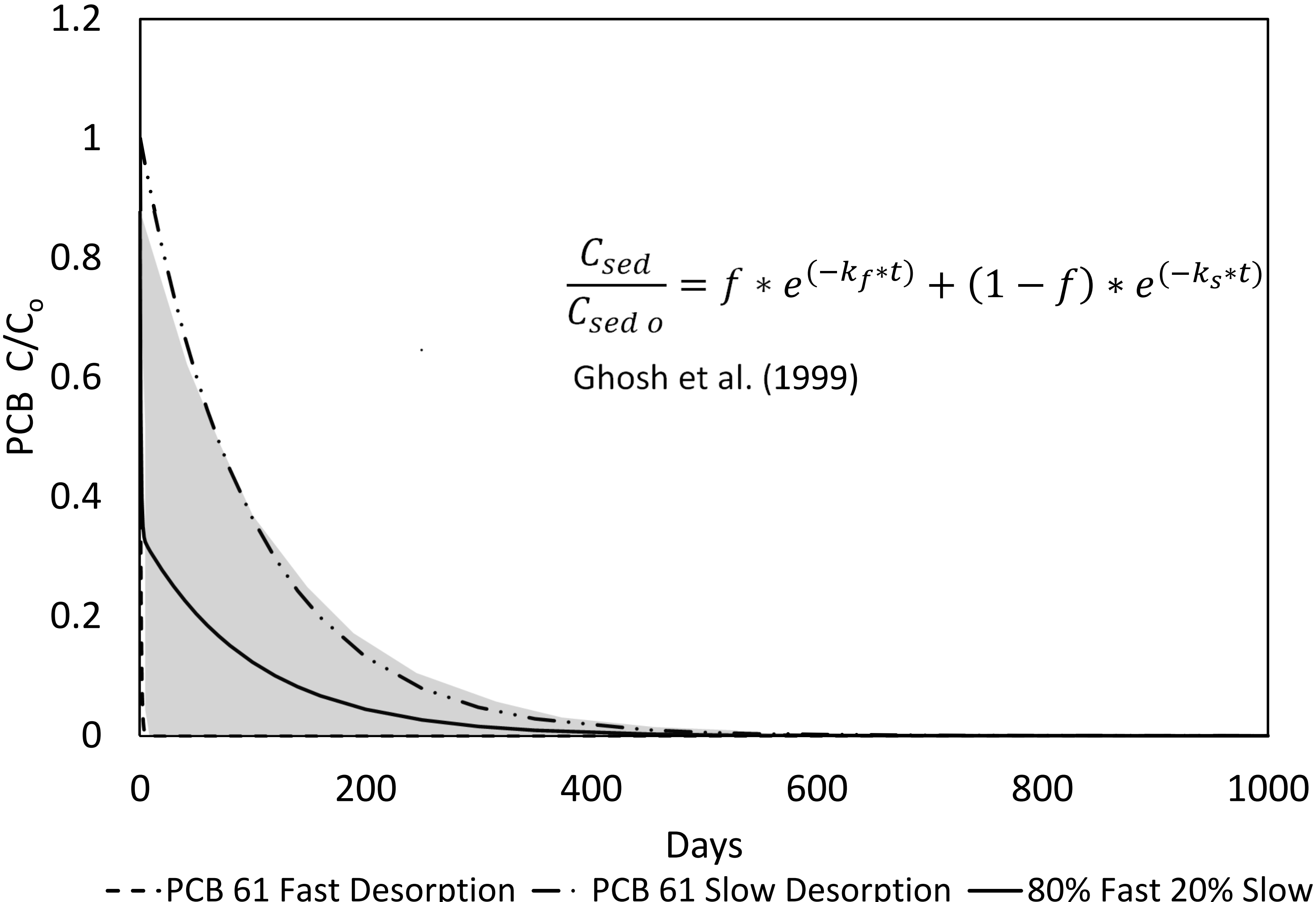
Matrix	Cell Density	PCB 61_{aq} initial (nM)	PCB 23_{aq} accum rate (nM/d^{-1})	Std Error	r^2	k_b' ** (d^{-1})	CF	k_b (d^{-1})	k_b (d^{-1}) (10^6 cell/mL)
PE	1.60E+06	**4.10E-01**	9.30E-02	5.3E-02	0.98	0.23	309	70	**44**
PE	1.60E+06	**1.10E-01**	2.38E-02	1.3E-02	0.93	0.22	309	67	**42**
PE	1.60E+06	**4.30E-03**	8.00E-04	5.8E-05	0.87	0.19	309	57	**36**
PE+Sed.	5.60E+06	**1.34E-01**	1.50E-02	4.6E-03	0.84	0.14	1830	256	**46**
PE+Sed.	5.60E+06	**1.70E-02**	1.70E-03	5.6E-04	0.93	0.14	1830	249	**45**
PE+Sed.	5.60E+06	**5.10E-03**	3.00E-04	1.0E-04	0.92	0.07	1830	134	**24**

** Incorporating 20% slow desorbing fraction not bioavailable

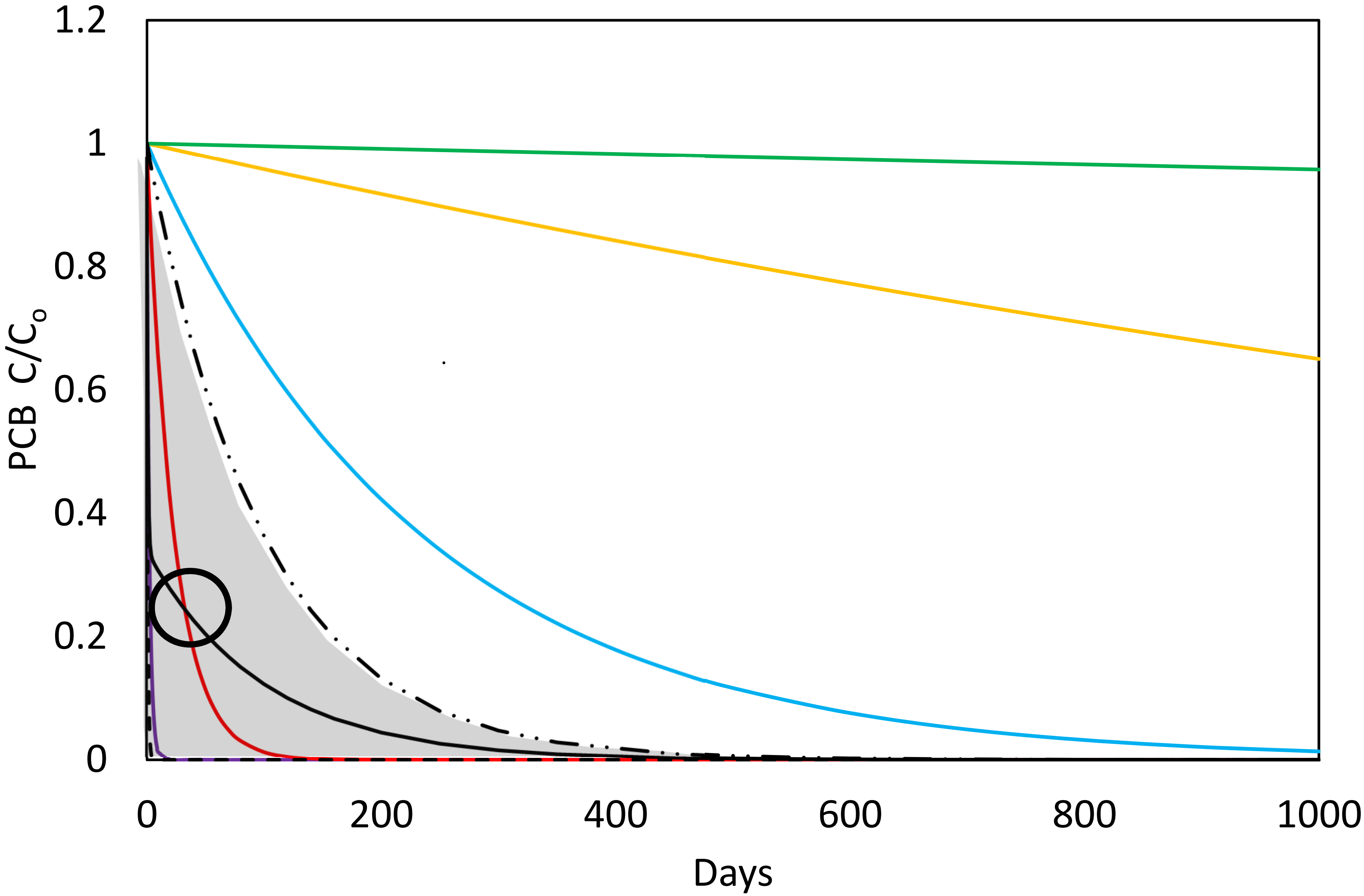
Implications for Bioremediation



Implications for Bioremediation



Implications for Bioremediation



Summary of Results

- Lombard et al. (2014) report k_b using POM to be 26 d^{-1}
- Observe similar first order rate kinetics with PE k_b = 41 d^{-1}
- Accounting for 20% fraction not bioavailable in sediment slurries, k_b = 39 d^{-1}
- In both sediment slurry and PE system, microbial kinetics determined by freely dissolved phase

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Questions?

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