Upper Hudson Unremediated PCBs: Impacts on the Recovery Time of Lower Hudson Fish

Jay Field[1], John Kern[2], Lisa Rosman[3]

[1] NOAA Office of Response and Restoration, Seattle, Washington, USA
[2] Kern Statistical Services, Inc., Sauk Rapids, Minnesota, USA
[3] NOAA Office of Response and Restoration, New York City, New York, USA

Introduction

Remediation decisions at large sediment sites with bioaccumulative contaminants often rely on complex models to make projections for comparison of natural recovery and active remedial alternatives. Projections of biota concentrations to estimate the time to reach risk-based thresholds provide a basis for evaluating remedial alternatives. We use recently collected remedial design sediment data from the Hudson River PCBs Superfund Site to evaluate model projections of the estimated time to achieve risk thresholds in fish.

The Hudson River PCBs Superfund Site extends approximately 200 miles from two General Electric (GE) plants in the Upper Hudson River (UHR) to New York Harbor. EPA's Record of Decision in 2002 [1] called for dredging and natural recovery of PCB contaminated sediments in the UHR, the 40 miles of river above the Federal Dam at Troy. EPA developed models to predict future levels of PCBs in UHR sediment, water, and fish [2,3]. The models also were linked to Lower Hudson River (LHR) models [4] to predict PCBs in four species of fish at four locations in the LHR [5].

PCB concentrations in surface sediment collected during remedial design sampling (2002-2005) exceeded upper bound model projections under Monitored Natural Attenuation (MNA) and were estimated to be 5-fold higher than expected after completion of the selected remedial alternative in River Sections 2 and 3 in the UHR (Figure 1) [6,7]. These findings imply that the rate of natural recovery (decline in surface sediment concentrations) was significantly overestimated by the original models. We applied a simplified modeling approach to evaluate the impact of these higher sediment concentrations and slower rate of natural recovery on the time to reach risk-target thresholds in fish in the LHR under the selected remedy.

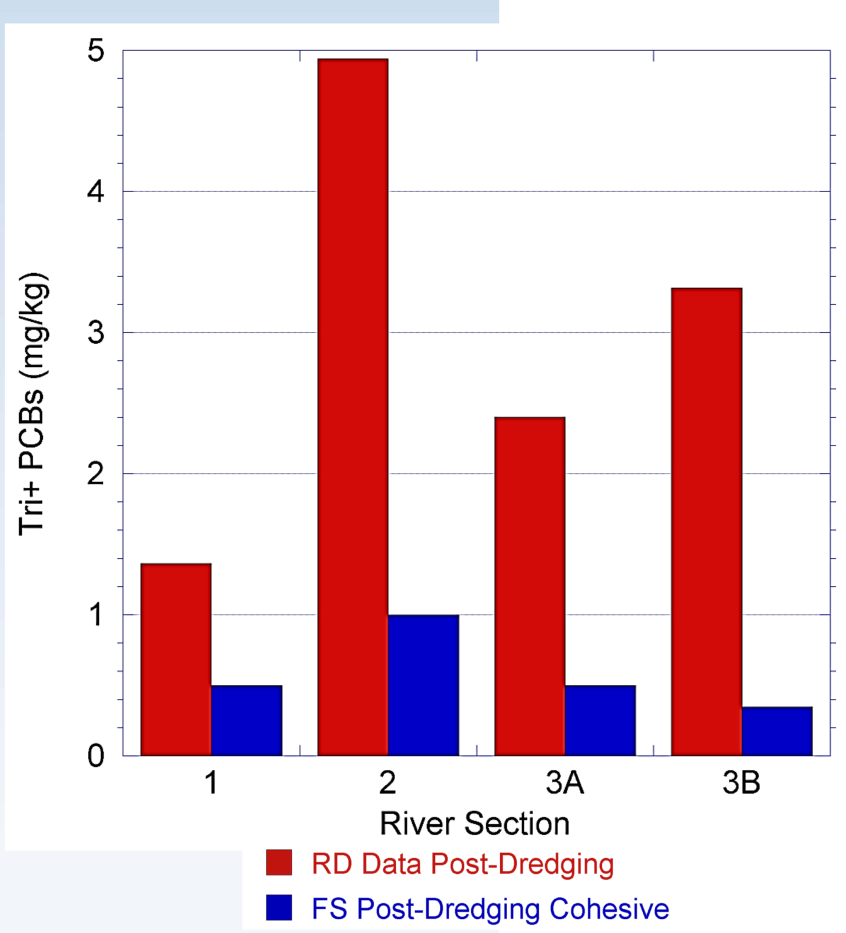

Figure 1. EPA model predictions for post-dredging surface Tri+ PCB concentrations (blue bars) compared to estimated concentrations from data collected during remedial design sampling (red bars).

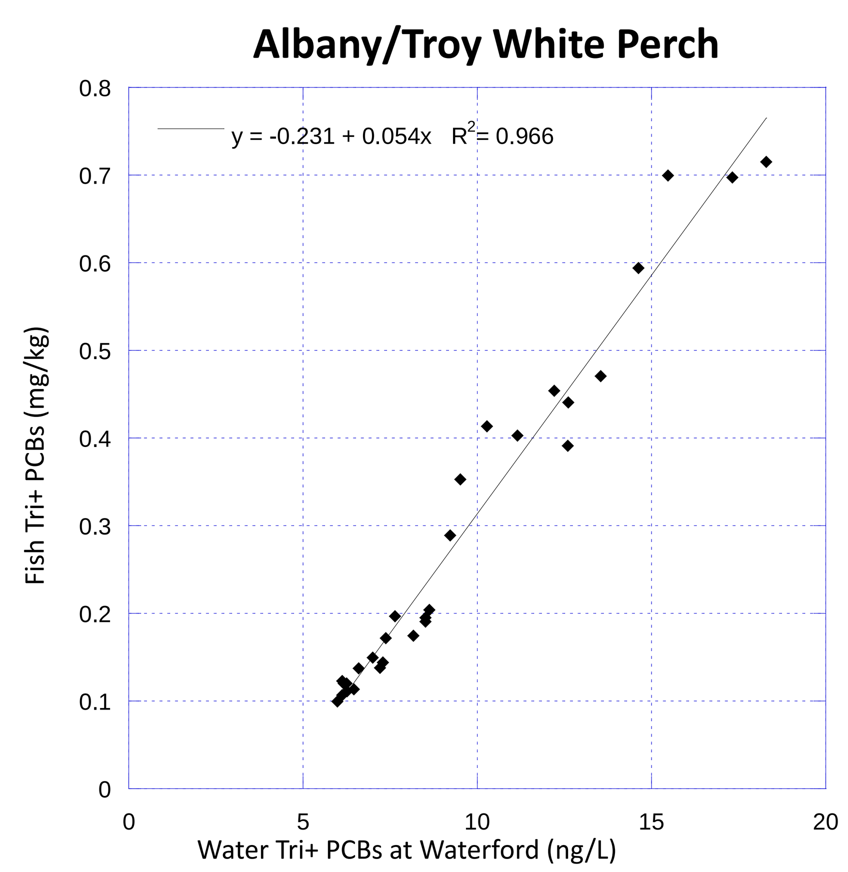

Figure 2. The relationship between EPA model projections for water concentrations at Waterford and EPA model projections of PCBs in white perch at Albany/Troy.

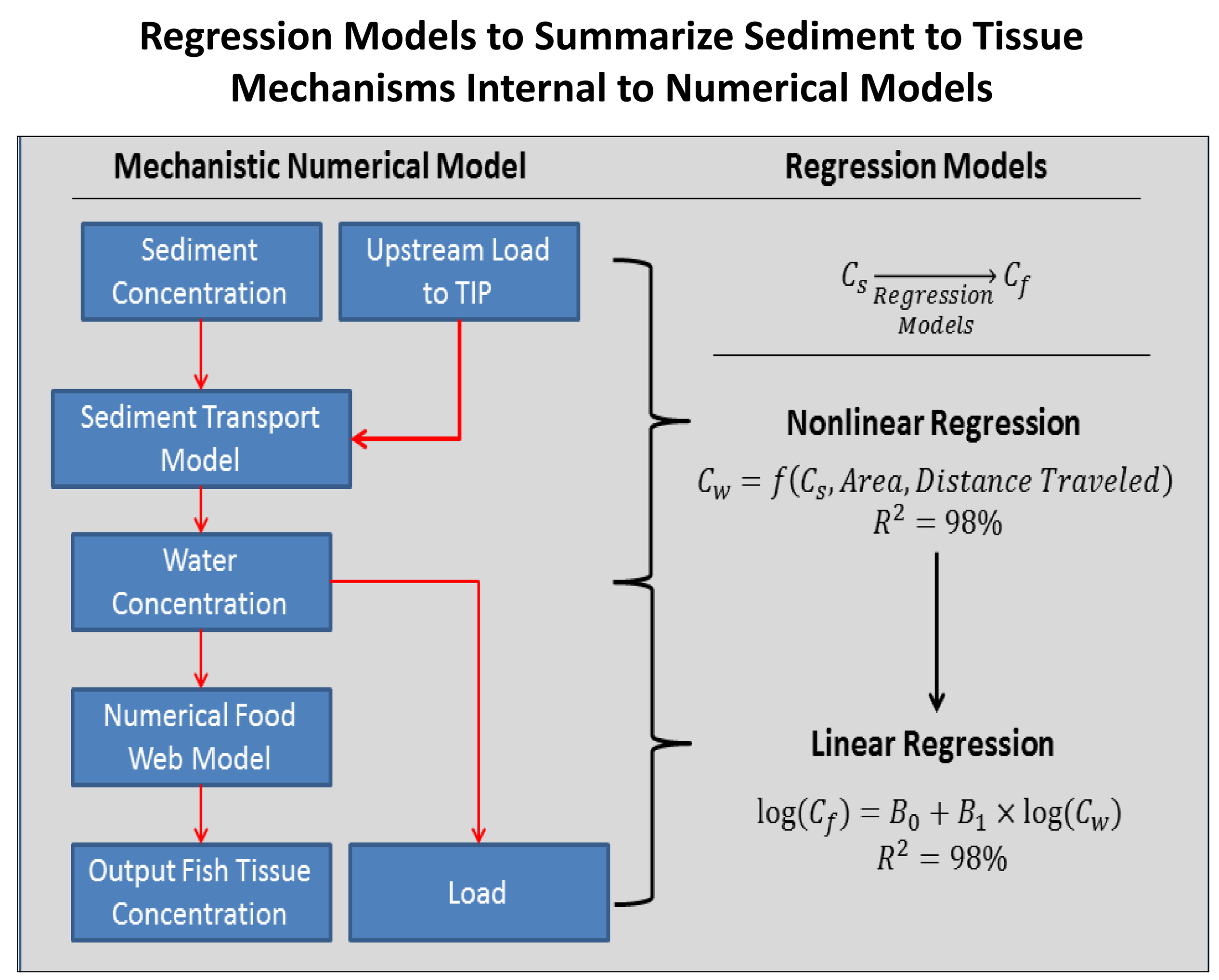

Figure 3. Regression model approach to predicting fish concentrations in the LHR.

Approach

EPA model projections of PCB concentrations in sediment, water, and fish all showed approximately exponential declines over time during natural recovery. Model projections of water concentrations at Waterford under the MNA scenario were observed to be directly related to modeled fish concentrations (Figure 2). Other LHR resident fish species and locations had similar relationships. We used the inputs and outputs from the original models to reverse engineer a set of nonlinear and linear regression models that provide a computationally simple means to reproduce the EPA model results (Figure 3).

Surface sediment PCBs in 4 model subsections for MNA or post-remediation were projected over 30 years. Nonlinear regression models were used to estimate water concentrations (c_w) in each model subsection as a function of sediment PCBs (c_s), upstream source input (10 ng/L or 0 ng/L), area of subsection, and distance from the dam at Waterford. Regression model output closely matched the original model projections for water concentrations in the model subsections (Figure 4). The output water column PCB concentrations from the model at Waterford were used in a log-log linear regression model to predict LHR fish PCBs (c_f).

These reverse-engineered models were used to evaluate the effect of changes in initial sediment PCBs, rate of natural recovery, and magnitude of upstream source input on model projections for PCBs in fish in the LHR. Remedial design sediment with greater spatial coverage was substituted for the initial sediment surface and a lower natural recovery rate was selected based on prior analysis [6].

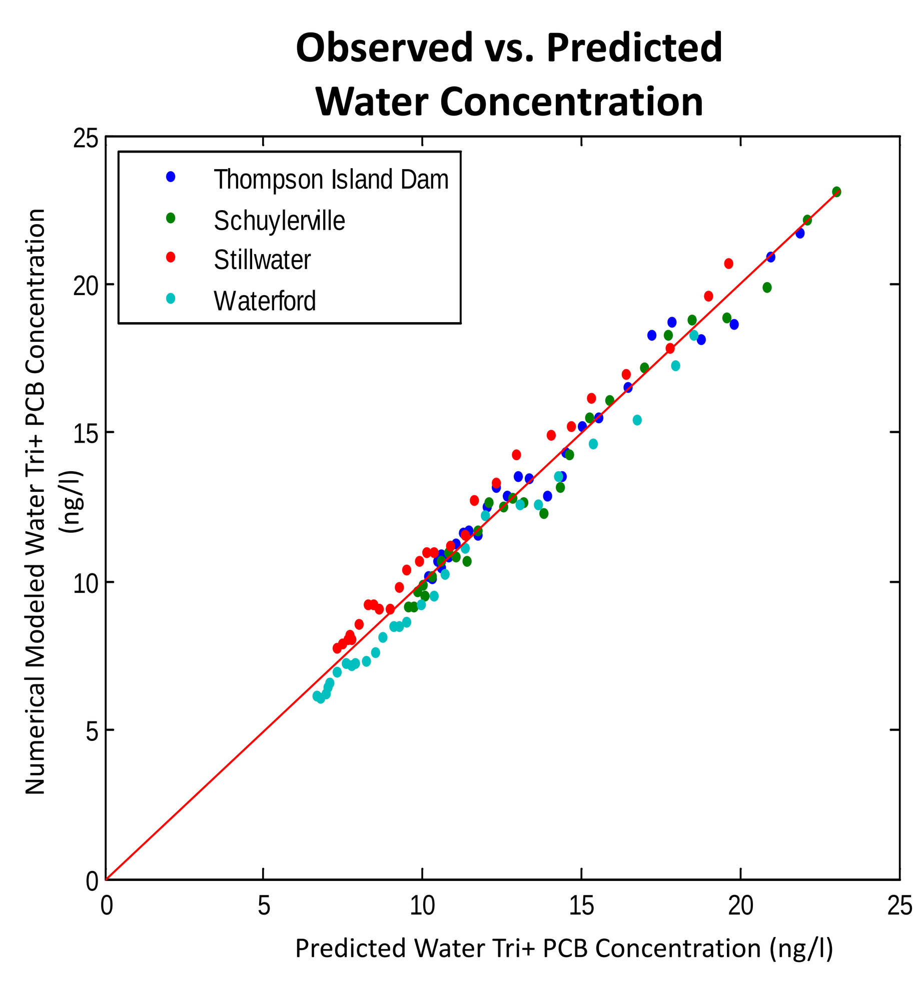

Figure 4. Comparison of regression model estimated water concentrations in 4 model subsections with EPA mechanistic model output under the MNA alternative.

Results and Discussion

Reverse engineering of the EPA models successfully reproduced model projections of sediment and water concentrations in the UHR and fish concentrations in the LHR. Figure 4 shows the strong correlation between original model outputs and reverse engineered nonlinear model estimates for MNA. Figure 2 shows that PCB concentrations in fish from the food web model can be accurately predicted from the regression on water column PCB concentrations. Together, these results demonstrate that the reverse engineering approach accurately captures the essential elements of the numerical mass balance model and that predictions of fish tissue concentrations associated with changes in bed sediment PCB concentrations can be developed without recourse to the expensive and time-consuming process of recalibration and computation of the original model.

Revising the estimates of pre- and post-removal surface sediment concentrations based on the extensive sediment dataset collected under remedial design provides a more accurate picture of current concentrations and predicted increased time to achieve target thresholds under MNA and the selected remedy (dredging followed by natural recovery) to original model predictions. The predicted times to target thresholds were sensitive to the magnitude of the upstream source and the rate of natural recovery.

Figure 5 compares the estimated number of years to reach EPA risk thresholds in white perch from Albany/Troy from the reverse-engineered models for the selected remedy under original projected sediment concentrations (REM310A) and adjusted sediment concentrations (REM310B) using two exponential sediment decay rates: ~8.5% (original model) and 3%, and two estimates of upstream source input: 10 ng/L (Fig. 5A) and 0 ng/L (Fig. 5B). For all scenarios, the time to reach thresholds using the updated sediment concentrations is estimated to be much longer than the original model projections.

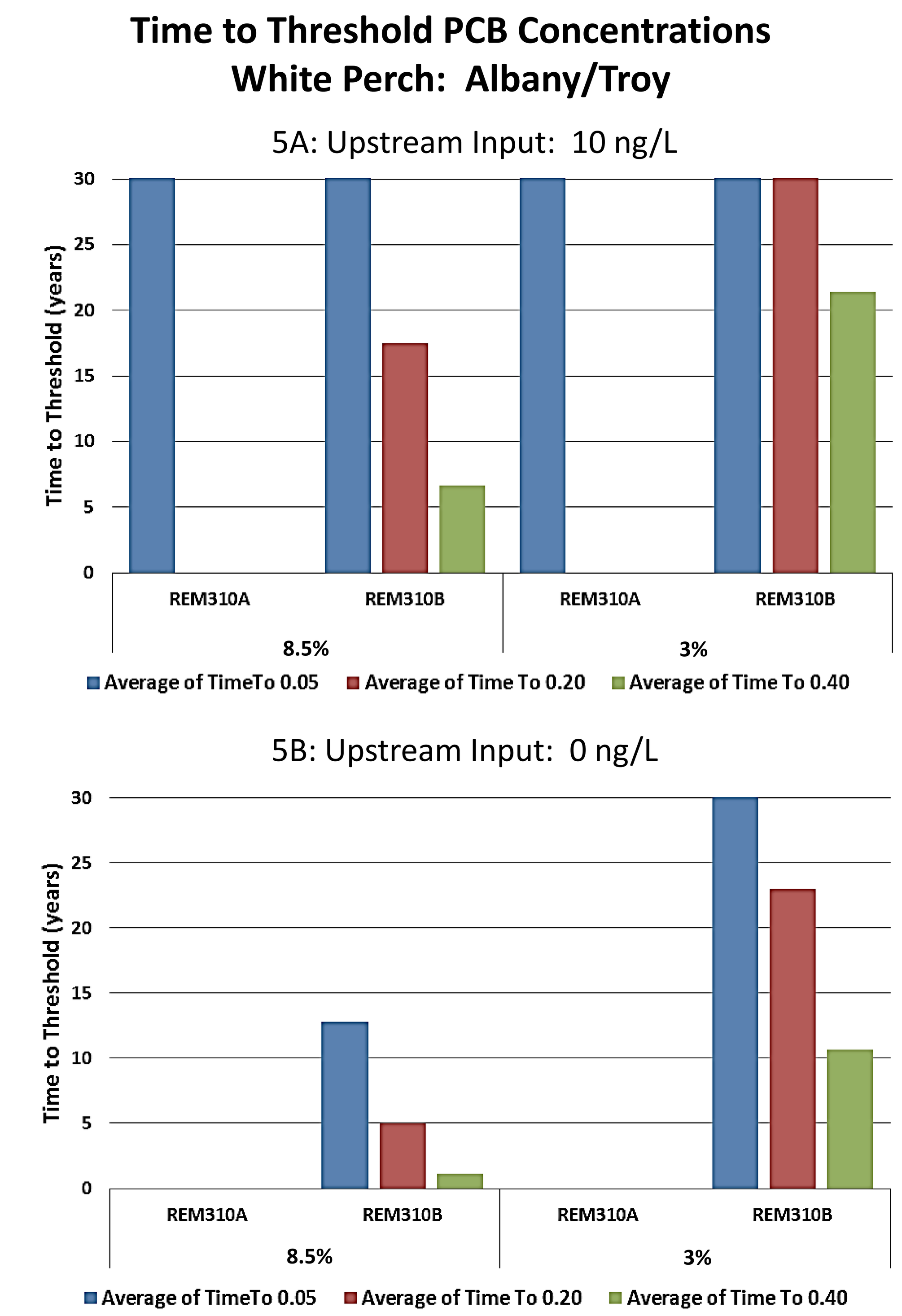

Figure 5. Estimated time (number of years) to reach EPA risk thresholds in white perch from Albany/Troy under the selected alternative using original predictions of post-dredging surface sediment concentrations (REM310A) and updated estimates of post-dredging sediment concentrations (REM310B). The projections in each panel are shown for two rates of exponential decay of sediment concentrations: 8.5% (original model) and 3% (revised estimate). Panel 5A shows the predictions assuming an upstream source input of 10 ng/L and Panel 5B shows the predictions assuming an upstream source input of 0 ng/L.

Summary

Reverse engineering of EPA models using a combination of nonlinear and linear regressions successfully reproduced model results for MNA projections of sediment and water concentrations in the UHR and fish concentrations in LHR.

Predicted time to threshold concentrations is sensitive to assumptions:
- Initial surface sediment PCB concentrations
- Exponential rate of annual decay in sediment concentrations under natural recovery
- Magnitude of upstream source load into the Thompson Island Pool

Recent data suggest some original model assumptions need to be changed:
- Surface sediment concentrations were higher and more widespread prior to remediation than anticipated during mechanistic model development
- Exponential annual decay closer to 3% than 8.5%
- Upstream load between 0 and 10 ng/L PCBs (recent load approximately 2-5 ng/L

Best estimates of PCB concentrations were obtained using updated sediment concentrations for the selected remedy modeled scenarios. These updated sediment models suggest fish in the LHR will take longer than expected to reach EPA risk thresholds. For example, white perch at Albany/Troy:
- Time to 0.2 ppm and 0.05 ppm PCB threshold 2 to 3+ decades, respectively
- Time to 0.4 ppm PCB threshold on the order of 1 to 2 decades

References

[1] USEPA. 2002. Hudson River PCBs Site Record of Decision. January 2002. http://www.epa.gov/hudson/d_rod.htm#record

[2] USEPA2000a. Hudson River PCBs Reassessment RI/FS Phase 2 Report: Revised Baseline Modeling Report. January 2000. http://epa.gov/hudson/reports.htm

[3] [USEPA] U.S. Environmental Protection Agency. 2000b. Hudson River PCBs Reassessment RI/FS, Phase 3 Report: Feasibility Study. December 2000. http://epa.gov/hudson/study.htm

[4] Farley KJ, Thomann RV, Cooney TF, Damiani DR, Wand JR. 1999. An Integrated Model of Organic Chemical Fate and Bioaccumulation in the Hudson River Estuary. Prepared for the Hudson River Foundation. Manhattan College, Riverdale, NY.

[5] [USEPA] U.S. Environmental Protection Agency. 1999. Phase 2:. Further Site Characterization and Analysis, Volume 2E-A Baseline Ecological Risk Assessment for Future Risks in the Lower Hudson River, Hudson River PCBs Reassessment RI/FS. December 1999. http://www.epa.gov/hudson/low-hud-future-era.pdf

[6] Field LJ,, Kern JW, Rosman LB. 2009. Evaluation of Natural Recovery Models for Sediment in the Upper Hudson River.. February 2009. http://www.darrp.noaa.gov/northeast/hudson/pdf/Battelle09_Field_NatRecovery_508.pdf

[7] Field LJ, Rosman LB, Brosnan T, Foley R. 2011. Hudson River Remedy: Unremediated PCBs and the Implications for Restoration. February 2011. http://www.darrp.noaa.gov/northeast/hudson/pdf/Battelle1_Field.final1.pdf