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Environmental Effects of Dredging Technical Notes

Influence of Sediment Properties on Bioaccumulation Potential of PCBs: Field Studies at the Calumet Confined Disposal Facility

Purpose

This technical note describes field testing conducted to examine the equilibrium partitioning of polychlorinated biphenyls (PCBs) between sediment and fish, changes in the partitioning over time, and the impact that depuration rates of PCBs can exert on apparent equilibrium observations.

Background

The US Environmental Protection Agency (EPA) is authorized to develop and implement sediment quality criteria (SQC) under Section 304(a) of the Clean Water Act. Under this authority, the EPA is proceeding with development of SQC for nonpolar organic compounds and metals. A major assumption in the current approach to SQC for nonpolar organic compounds such as PCBs is the existence of equilibrium in the sediment.

The US Army Corps of Engineers (USACE) is presently investigating the link between contaminant levels in sediment and sediment geochemistry, as well as the utility of equilibrium partitioning approaches for predicting contaminant levels in aquatic organisms in the field. Knowledge of these interactions will provide the USACE with a means of evaluating the adequacy of proposed SQC approaches for estimating the potential impacts of dredged material placement. The existence of steady-state (no measurable change over time) between sediments and organisms was investigated in the field at the Calumet confined disposal facility in the Chicago District.

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Introduction

The Calumet confined disposal facility (CDF) (Figure 1) is roughly triangular in shape, covers 43 acres, and was designed to hold 1.45 million cu yd of dredged material. The CDF was formed by a stone-filled dike with a core of prepared limestone. A synthetic membrane lines the entire interior face with a blanket of silty sand overlying the liner to create a barrier of low permeability (Dorkin and others 1988). Since its creation at the mouth of the Calumet River on the shore of Lake Michigan in 1983-1984, the CDF has received five separate lots of dredged material totalling approximately 300,000 cu yd. The most recent dredging operation included a large amount of debris (pilings, concrete, and rock) that was placed in area 5. Low levels of polychlorinated biphenyls (PCBs) have been reported and an endemic population of animals has developed inside the CDF (Dorkin and others 1988).

The Calumet CDF is relatively isolated from outside sources of water and contaminants because the sand and synthetic liner limits interchange between the CDF and Lake Michigan. The limited water interchange provides a good test of equilibrium partitioning between sediment and organisms in the field by localizing fish populations and providing consistent contaminant exposure conditions. The objective of this study was to determine whether steady-state conditions exist between sediment and organisms under optimum field conditions in the Calumet CDF and its immediate surroundings.

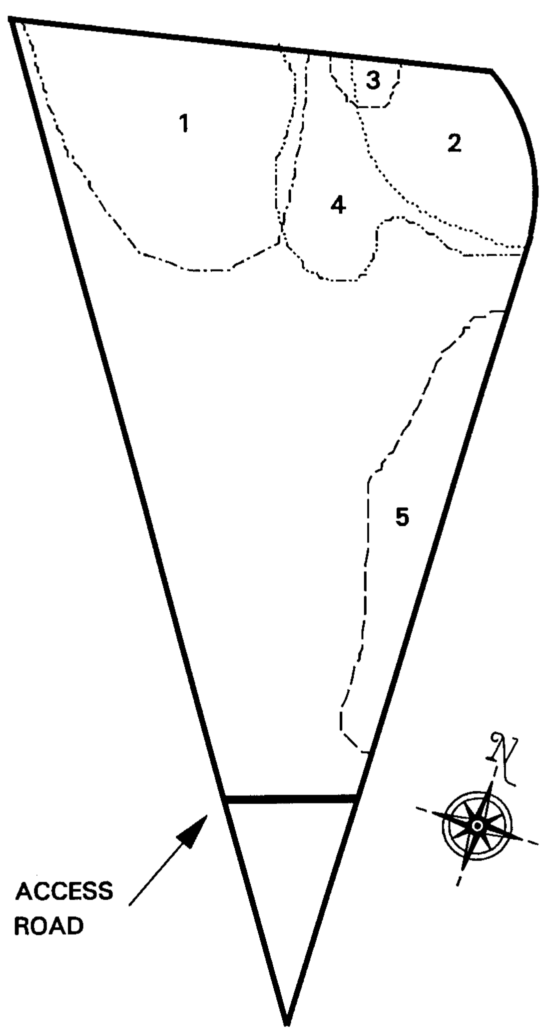

Figure 1. Calumet CDF and approximate location of the five disposal events

Materials and Methods

Thirty-six box cores in transects across the CDF were taken in early May and mid October 1990. At each sampling time, the top 2 cm of sediment were composited into 12 samples and analyzed for PCB, total organic carbon (TOC), humic and fulvic acid organic matter fractions, and grain size. The top 2 cm of sediment was analyzed to characterize the material most frequently contacted by bottom-dwelling organisms. Physical data (temperature, dissolved oxygen, light attenuation, and suspended sediments) were obtained in the water column.

Black bullhead (*Ameiurus (=Ictalurus) melas*) was collected on three occasions during the study (June 14, July 10, and July 28, 1990). This animal was selected because of its abundance in the CDF, its bottom foraging behavior, and its sufficient size (5-8 in.). Fish were stunned using standard fish-shocking techniques, netted, placed in buckets of water, and quickly transferred to a large (500-gal) tank for transport to the laboratory. The fish were treated for parasites by dipping in a weak formalin solution and placed into 4-ft-diameter circular tanks approximately 2 ft deep for depuration. The tanks were maintained in a flow-through mode at 25° C under natural daylight conditions. Commercial catfish chow was fed. Five fish (replicates) were removed from the aquaria and frozen at day 0, 2, 7, 14, 28, and 56. Animals were shipped to the WES where PCB concentrations and percent lipids were determined in standard fillets taken from the fish.

Results and Discussion

Existing data from the Calumet CDF and adjacent areas were reanalyzed (Dorkin and others 1988, Clarke, McFarland, and Dorkin 1988). Dorkin and others (1988) determined total PCB concentrations in many aquatic organisms including crayfish, alewife, yellow perch, bluntnose minnow, channel catfish, orangespot sunfish, green sunfish, gizzard shad, carp, goldfish, rainbow trout, brown trout, worms/leeches, and pumpkinseed. Not all organisms were found at every site investigated. Four sites were studied, including the pond inside the CDF, the area outside the CDF, in the Chicago River, and at the breakwater area near the CDF. The breakwater area is a high-energy environment, outside the CDF is intermediate, and inside the CDF is a pond with minimal interchanges with the outside water body.

Preference factors ((organism concentration ÷ decimal fraction lipids) ÷ (sediment concentration ÷ fraction TOC)) derived from the data in Clarke, McFarland, and Dorkin (1988) are presented in Figure 2 for crayfish, bullhead, and the mean of all other species. The mean of all other species was used because these fish are not associated with the sediment to the same extent as black bullhead and crayfish. Marked differences were observed in preference factors between sampling locations for crayfish, bullhead, and the mean of all other species. Results within a sampling location, however, were similar. Preference factors inside the CDF ranged from 3.44 for bullhead to 2.95 for all species, very close to the values reported for other laboratory and field situations (Brannon and others 1991a,b). Steady-state conditions between sediment and organism contamination appeared

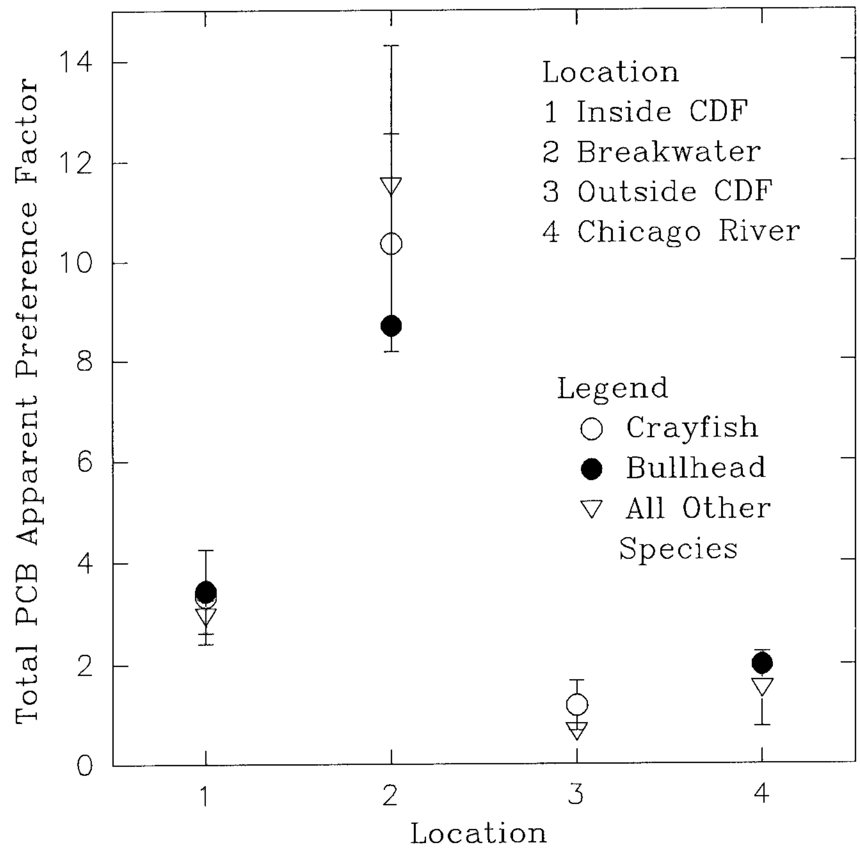

Figure 2. Apparent preference factors from the Calumet CDF and environs (Dorkin and others 1988, Clarke, McFarland, and Dorkin 1988)

to exist within the CDF for all organisms analyzed, including fish not thought to have direct contact with the sediment (Clarke, McFarland, and Dorkin 1988). Preference factors in organisms from the breakwater area were from two to three times higher than expected based on sediment PCB concentrations normalized to TOC; this indicated exposure to other sources (sediment or water) of PCB with higher bioaccumulation potential (Clarke, McFarland, and Dorkin 1988).

Preference factors within a location agreed closely in spite of differences in feeding (organism trophic level) and migratory habits of organisms, indicating that exposures were similar. Preference factors for organisms such as crayfish, closely identified with specific sediment locales, were much higher in the breakwater area than the range of 1.73 to 4.0 typically observed in laboratory and field studies (Brannon and others 1991b). PCB bioaccumulation outside the CDF, as indicated by preference factors, was lower than expected for all species tested (crayfish = 1.18 compared to 0.64 for all other species combined), indicating less exposure from the sediment or other sources. Deviations from the normal range of preference factors may indicate that steady-state conditions between sediment and organisms did not exist at the breakwater area or in other locales, even for crayfish.

These results imply that steady-state does not exist between sediment and aquatic organisms in relatively high-energy aquatic environments, even for organisms that are closely associated with the sediment. Application of equilibrium concepts in such areas may lead to incorrect sediment categorizations.

Field data collected in 1990 provide additional information on PCB partitioning between sediment and aquatic organisms. Concentrations of total PCBs, Aroclor 1254, and TOC in sediment from the Calumet CDF are presented in Table 1. Concentrations of total PCB and TOC are lower than the 1.1 mg/kg and 4.9 percent, respectively, reported by Dorkin and others (1988) for sediment inside the CDF.

Table 1
Sediment Data from Calumet Harbor CDF

Parameter	Value	
	Mean	Standard Error
Total PCB, µg/g	0.29	0.045
Aroclor 1254, µg/g	0.26	0.025
TOC, percent	2.85	0.17
Humic + fulvic, percent	0.32	0.014
Fraction Solids	0.445	0.006
Sand, percent	16.04	3.6
Silt, percent	58.96	2.56
Clay, percent	27.00	4.13

Preference factors normalized on both a TOC and humic + fulvic acid organic matter basis using the 1990 samplings (time 0 data) are presented in Figure 3 for total PCB and Aroclor 1254. Results show that no significant difference existed between preference factors at any of the sampling times. This result indicates that steady-state conditions between sediment and organism concentrations of PCB existed within the CDF. The TOC preference factor values did not significantly differ from the preference factor of 3.44 derived from the data of Dorkin and others (1988) for the black bullhead. These data indicate that preference factors between sediment and organisms within the CDF did not significantly change over either the short term (months and weeks) or long term (years). Preference factors computed using the humic + fulvic acid fraction, although exhibiting different absolute values, showed the same trends as those computed using TOC. There was no apparent improvement, however, over the use of TOC to normalize sediment PCB concentrations.

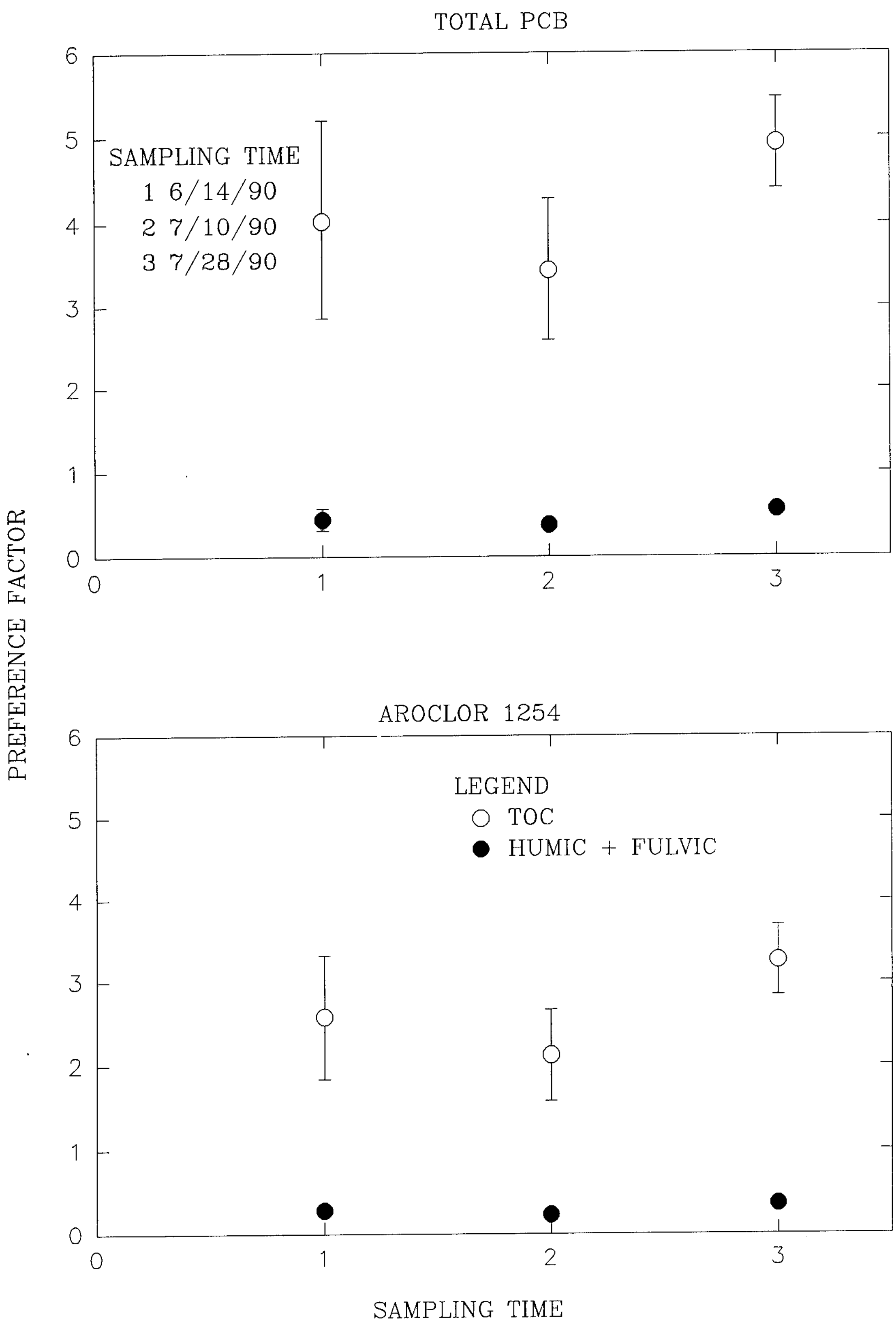

Figure 3. Preference factors for total PCB and Aroclor 1254 (TOC and humic + fulvic acid basis) for black bullhead in the Calumet CDF

Depuration of total PCB and Aroclor 1254, as reflected by changes in the preference factor computed using initial PCB and TOC exposure conditions, proceeded very slowly for total PCB and only marginally faster for Aroclor 1254 (Figure 4). Removal of PCB from the black bullhead does not follow any type of elimination rate constant for the time period studied (8 weeks). This lack of a pattern could be due to the fact that non-normalized PCB concentrations in the fish tissue were low, ranging from less than the detection limit to 1.4 μg/g for total PCB, and 0.74 μg/g for Aroclor 1254. However, these depuration results agree with findings of others (DeFoe, Veith, and Carlson 1978, Lieb, Bills, and Sinnhuber 1974) for fathead minnows and rainbow trout.

Depuration results indicate that attainment of steady-state will be slow when aquatic animals move from areas of high contamination to areas of low contamination. This may account for the much higher preference factors in the breakwater area than would be expected from sediment concentrations of PCB and TOC.

The equilibrium partitioning SQC approach currently under development is based on interstitial water exposure of benthic organisms. Results of this study indicate that attainment of steady-state exposure between benthic organisms such as worms (assuming that depuration rates are similar) moving into clean sediment after encountering contaminated sediment microzones would be slow. Previous results (Brannon and others 1989, 1991a,b) have shown that attainment of steady-state preference factors is rapid when "clean" animals are exposed to contaminated sediment. The reverse may not be true when contaminated animals are exposed to a clean environment.

Summary of Findings

Preference factors for total PCB in the Calumet CDF did not change significantly over the short term (months and weeks) or long term (years), indicating that steady-state conditions existed. Preference factors computed using the sediment humic + fulvic acid fraction, although exhibiting different absolute values, showed the same trends as those computed using TOC, but did not confer any apparent advantages.

Results also indicated that steady-state did not exist between sediment and aquatic organisms in higher energy environments outside the Calumet CDF. This was true even for organisms such as crayfish and black bullhead that are closely associated with the sediment. Application of equilibrium concepts for examining the partitioning of contaminants between sediment and aquatic organisms in such areas may not be warranted.

Depuration studies for black bullhead indicated that elimination of PCB proceeds very slowly. When aquatic animals move from areas of high contamination to areas of low contamination, attainment of steady-state with sediment can be slow, the opposite of what happens when clean animals are exposed to contaminated sediment. If contaminated microzones and localized contamination

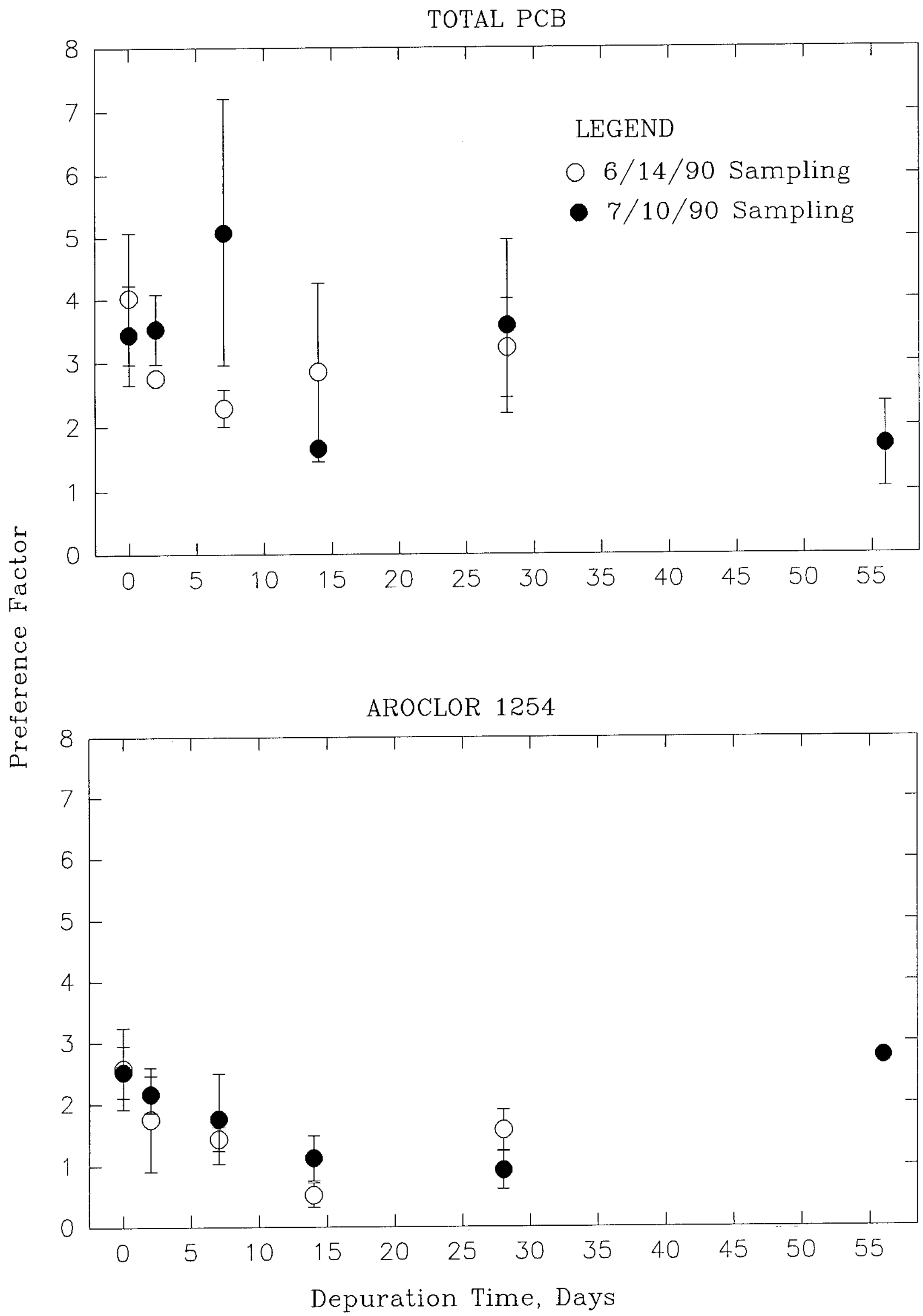

Figure 4. Effect of depuration time on total PCB and Aroclor 1254 preference factors in black bullhead

exist in sediment, the rate of attainment of steady-state between clean sediment and benthic organisms may be affected.

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