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ACCUMULATION OF PCBs, MERCURY, AND CADMIUM BY *NEREIS VIRENS*, *MERCENARIA MERCENARIA*, AND *PALAEMONETES PUGIO* FROM CONTAMINATED HARBOR SEDIMENTS

by

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Accumulation of polychlorinated biphenyls (PCBs), mercury, and cadmium by sandworms (Nereis virens), hard clams (Mercenaria mercenaria), and grass shrimp (Palaemonetes pugio) exposed to contaminated sediments from four sites in New York Harbor was studied for a 100-day period. Of the three contaminants monitored, only PCBs were found to bioaccumulate above background (control) concentrations. Small increases in PCB body burden were detected in M. mercenaria and P. pugio, whereas higher concentrations were measured in

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N. virens. Uptake was affected by the organic content of the sediment. Bioaccumulation factors (concentration in tissue/concentration in sediment) for N. virens ranged from 1.59 in a low organic sediment to 0.15 in a high organic sediment. Comparison of 10-day and steady-state concentrations of PCBs in N. virens indicates that a 10-day exposure underestimates equilibrium concentration; however, 10 days is sufficient to detect the potential for PCB accumulation. Results from this study support the contention that sediment concentration alone does not reflect bioavailability and that toxicity tests (bioassays) and field monitoring remain the most direct methods for estimating bioaccumulation potential of sediment-bound contaminants.

PREFACE

This study was conducted by the U. S. Environmental Protection Agency, Environmental Research Laboratory, Gulf Breeze, Fla. (ERLGB), which provided partial funding support. Financial sponsorship was primarily from the U. S. Army Engineer District, New York, through the Environmental Laboratory (EL) of the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss. The WES also contributed financial support under the Long-Term Effects of Dredging Operations (LEDO) research program, which it is conducting under sponsorship of the Office, Chief of Engineers (OCE), Washington, D. C.

The authors gratefully acknowledge the assistance of ERLGB personnel: Mrs. V. Bersabal and Ms. J. Small for technical assistance, Mr. T. Gates and Dr. C. Deans for programming and statistical assistance, and Mr. S. Foss for the illustrations. The study was conducted under the general supervision of Dr. Al Bourquin, Chief, Processes and Effects Branch. The Director of ERLGB during this study was Dr. Henry Enos.

The WES project manager was Dr. R. Peddicord, under the general supervision of Dr. R. Engler, Chief, Contaminant Mobility and Regulatory Criteria Group; Mr. D. Robey, Chief, Ecosystem Research and Simulation Division; and Dr. J. Harrison, Chief, EL. LEDO is managed in EL through the Office of Environmental Effects of Dredging Programs (EEDP), Mr. C. Calhoun, Manager, and Mr. R. Logov EEDP LEDO Program Coordinator. The New York District project manager was Mr. J. Mansky. Technical monitors of the LEDO program were Dr. J. Hall, Operations Division, OCE; Dr. W. Klesch, Planning Division, OCE; and Mr. C. Hummer, Dredging Division, Water Resources Support Center.

Commanders and Directors of the WES during conduct of the study and preparation of the report were COL Nelson P. Conover, CE, and COL Tilford C. Creel, CE. Technical Director was Mr. F. R. Brown.

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ACCUMULATION OF PCBs, MERCURY, AND CADMIUM BY NEREIS VIRENS, MERCENARIA MERCENARIA, AND PALAEMONETES PUGIO FROM CONTAMINATED HARBOR SEDIMENTS

I. INTRODUCTION

Dredging and the subsequent disposal of dredged material are necessary for maintaining the waterways and harbors of this country. In 1980, approximately 45 million cubic meters of dredged material was disposed of in the coastal waters of the United States (Letzkus, 1982). To ensure that disposal operations are conducted with a minimal degree of environmental risk, dredged material destined for ocean disposal must be evaluated on the basis of criteria established by the U.S. Environmental Protection Agency (Section 103, Public Law 92-532).

Disposal evaluations currently utilize toxicity tests (bioassays) to determine the biological availability of contaminants associated with dredged sediments. Test procedures (U.S. Environmental Protection Agency/Corps of Engineers (EPA/CE), 1977) consist of a 10-day acute phase, followed by bioaccumulation analyses (whole-body residues) for those organisms that survive the 10-day exposure. Laboratory results from tests conducted on a variety of New York Harbor bottom sediments (Suszkowski and Mansky, 1981) indicate that acute toxicity is rarely encountered; however, bioaccumulation of certain xenobiotics (i.e., polychlorinated biphenyls [PCBs], mercury [Hg], cadmium [Cd], and polycyclic aromatic hydrocarbons [PAHs]) by test organisms has been observed. Thus, a major problem in evaluating disposal options is the

difficulty in relating short-term laboratory results to actual conditions at the disposal site.

Biota indigenous to the disposal site will eventually attain a steady-state or equilibrium condition with contaminants available from deposited dredged material. Therefore, if a 10-day exposure period is to have predictive value, its relationship to long-term exposure must be evaluated.

The objective of this study was to compare whole-body residues that exist after 10 days of exposure with steady-state concentrations in three routinely used test species (Nereis virens, Mercenaria mercenaria, and Palaemonetes pugio) and three contaminants (PCBs, Hg, and Cd) commonly associated with bottom sediments of urbanized and industrialized areas. An additional objective was to examine the relationships of organic content, particle size, and sediment moisture content to bioaccumulation potential.

II. MATERIALS AND METHODS

A. Sediments

Test sediments collected from four sites in New York Harbor were selected to represent a range in concentrations of PCBs, Hg, Cd, organic content, particle size, and moisture content. Fifty liters of each sediment type (designated A through D) were collected by the New York District, U.S. Army Corps of Engineers, and shipped to the Gulf Breeze Laboratory by refrigerated truck (4° C). Prior to testing (July through November 1981), sediments were sieved (5-mm mesh) to remove

large debris and macrofauna, thoroughly mixed to ensure uniformity, and analyzed for the three contaminants and sediment parameters (Holme and McIntyre, 1971). In addition, a standard elutriate test (EPA/CE, 1981) for PCBs was conducted for each sediment type. Sediments were stored at 4° C and tested within two weeks of acquisition.

B. Organisms

Species selected for testing have been used routinely for dredged material evaluation in the northeast and are representative of the infaunal, epibenthic, and water-column habitats. Sandworms (N. virens) were obtained from the Maine Bait Co., New Castle, Maine, and hard clams (M. mercenaria) from the Blue Point Hatchery, Long Island, New York; grass shrimp (P. pugio) were collected in northwest Florida. All animals were acclimated to test conditions in the laboratory for at least one week prior to testing. Subsets (N=3) of each organism were analyzed for PCBs, Hg, and Cd. Grass shrimp were pooled to provide at least 1 g of tissue for each analysis.

C. Exposure Systems

Organisms were exposed to contaminated sediments by the method of Rubinstein et al. (1980) (Fig. 1). Forty-liter aquaria (50 cm x 25 cm x 30 cm) were used as test vessels (three replicates per sediment type). Unfiltered seawater ($30^{o}/oo$ salinity $\pm$ $2^{o}/oo$) was pumped from Santa Rosa Sound to a headbox in the laboratory. Temperature was maintained at 22° $\pm$ 1° C by water chiller units (Mini-Cool D1-100)

mounted in the headbox and water bath. Water flowed from the headbox to a trough which delivered seawater at a rate of 27 ℓ per hour to the individual aquaria. Flow to the aquaria was adjusted by raising or lowering individual standpipes in the trough. Effluent water drained from the aquaria through openings 25 cm above the substrate on the side of the aquaria opposite the incoming water and was routed through an in-line sediment trap to a holding pond. A flow rate of 27 ℓ per hour per aquarium was selected to meet the nutritional requirements of M. mercenaria (1 ℓ per hour per individual) and is in excess of minimum recommended exchange rates (Ameuran Public Health Association, 1981).

Test sediments (3.6 ℓ) were poured uniformly over the bottom of the designated aquaria. Several hours were allowed for the sediment to settle before the seawater flow was resumed, leaving approximately a 3.5-cm layer of test material in each aquarium. A control aquarium, set up similar to exposure aquaria, received a 3.5-cm layer of washed beach sand instead of sediment. The control allowed us to monitor the condition of organisms from the original test stock and also served to detect potential problems related to changes in quality of incoming seawater.

Each aquarium received 20 sandworms, 12 clams, and 100 grass shrimp. In addition to the organic material brought in with the incoming seawater, animals were routinely fed a flake food (Tetra SM-80 Tetra Werke, West Germany) at a rate estimated to be two percent of body weight per day. Organisms were collected and analyzed for

whole-body concentrations of PCBs, Hg, and Cd on days 3, 7, 10, 17, 24, 38, 58, and 100. At each sampling interval, triplicate analyses were conducted for each species (N=3) except shrimp; on day 100 grass shrimp were not analyzed due to insufficient numbers. Animals were placed in uncontaminated flowing seawater for 24 hours prior to preparation for analyses to purge residual sediment from the intestinal tract. Organic content (by combustion at 550° C) and moisture content were measured for each sediment type at the beginning and end of the experiment. Incoming seawater was monitored weekly for contaminants.

Dredged material, like natural sediment, is subject to periodic resuspension due to a variety of physical and biological processes (e.g., tidal scour, bioturbation, etc.). To simulate resuspension in the test aquaria, we utilized a suspended-sediment dosing apparatus (Rubinstein et al., 1980) (Fig. 1). For this study we delivered a suspended-solids load of 100 mg/ℓ (dry weight) for each sediment type at six-hour intervals. Sediments remained in suspension for approximately 20 minutes before settling or being slowly flushed out of the aquaria. Preliminary tests conducted with dye markers indicated complete mixing of incoming water with no stratification.

D. Chemical Analyses

Polychlorinated biphenyls. Polytron homogenizers (PCU-2 Brinkman Instruments) were used to extract tissue samples by grinding with acetonitrile. Tissue samples (50% tissue in distilled water, w/w) of 1 to 4 g in 25-mm x 150-mm screw-cap culture tubes were homogenized four

times with 5 mℓ of acetonitrile for 15 to 30 seconds. After each homogenization, the samples were centrifuged and the supernate decanted. Acetonitrile extracts (20 mℓ) were combined with 75 mℓ of 2% Na_2SO_4, then extracted twice with 10 mℓ hexane. The samples were shaken by hand for 1 minute and the phases were allowed to separate (any emulsions were broken by sonicating the samples as necessary). The hexane layer was transfered to 25-mℓ concentrator tubes and concentrated, using a gentle stream of nitrogen to reduce the volume to 0.1 - 0.5 mℓ. The concentrate was then transferred to a Florisil column for cleanup.

PCBs were extracted from sediments by the Soxhlet method of Bellar et al. (1980). Extracts were treated with mercury to remove sulfur and transferred to a Florisil column to remove other organic contaminants.

Kontes Chromoflex columns (9 mm) with a small glass wool plug in the tip were packed with 5 mℓ of Florisil and topped with about 25 mm of anhydrous Na_2SO_4. Florisil, Na_2SO_4, and glass wool were stored in an oven at 130° C. The Florisil column was packed just before use, allowed to cool, and moistened with 10 mℓ of hexane. When the hexane reached the top of the Na_2SO_4, sample extracts were layered on the column along with two 0.5-mℓ hexane rinses of the sample container. The PCBs were then eluted with 10 mℓ of hexane, followed by 10 mℓ of 1% methanol in hexane. The eluate was collected, concentrated to a volume of 0.5 to 1.0 mℓ, and diluted for analysis by gas chromatography.

The sediments contained considerable amounts of sulfur, which can interfere with the chromatography of early eluting peaks. All sediment sample extracts were treated to remove the sulfur by addition of 0.2 to 1 mℓ of elemental mercury after the sample had been passed through Florisil and concentrated to a volume of 0.5 to 1.0 mℓ. The sample was then shaken until all the sulfur had reacted. More mercury was added when needed. The sulfur-free samples were then diluted and analyzed by gas chromatography.

All gas chromatography was carried out on a Hewlett-Packard 5840A gas chromatograph with linear electron-capture detector operated at 300° C and a 1.8-m-long glass column (2 mm ID x 6 mm OD) packed with 5% OV101 on Gas Chrom W-HP 80/100 mesh maintained at 200° C. Injection temperature was 225°C. Carrier gas was 10% methane in argon; the flow rate was 30 mℓ/min.

PCB quantification was done by the method of Webb and McCall (1973). The reference standards, obtained from the Food and Drug Administration, Washington, D. C., were described by Sawyer (1978). Only Aroclor 1242 and 1254 mixtures were quantified. Recoveries from spiked samples ranged from 80 to 90%. Values presented in this report were not corrected for percentage recovery.

Mercury and cadmium. One gram of tissue homogenate in water (from Polytron homogenizer) was weighed into a 40-mℓ reaction vessel. Five milliliters of concentrated nitric acid was added and the sample predigested for 2 to 4 hours at 70° C. Reaction vessels were capped and

digestion continued 48 hours at 70° C. Following digestion, samples were transferred to 25-mℓ volumetric flasks and diluted to 25 mℓ with 1% HCL. Dibasic ammonium phosphate (0.25 mℓ) was added to prevent a matrix effect. The sample was divided for Hg and Cd analyses. Metals analysis was conducted with a Perkin Elmer atomic absorption spectrophotometer (Models 503 and 403). Mercury was measured by cold vapor atomic absorption techniques and cadmium by the heated graphite atomizer method. Atomic absorption operating parameters were in accordance with procedures described in "Methods for Chemical Analysis of Water and Wastes" (EPA, 1979). Mercury and cadmium in sediments were measured by the procedure also described in "Methods for Chemical Analysis of Water and Wastes" (EPA, 1979).

III. RESULTS AND DISCUSSION

Sediment values for contaminant concentration, PCB elutriate concentration, particle size, distribution percentage moisture, and organic content measured prior to testing are summarized in Table 1. Three of the four sediments were distinctly different in sediment characteristics; however, sediments B and D were similar in all but Cd concentrations. Whole-body residues of PCBs, Hg, and Cd are shown in Table 2.

None of the sediments (A-D) were acutely toxic to test species. Mortality throughout 100 days of exposure did not exceed 10% for any of the species tested. Of the three contaminants monitored for uptake, only PCBs accumulated above background (control) concentration.

Results of PCB, Hg, and Cd uptake by the test organisms exposed to sediments A-D are shown in Appendix A; mean whole-body concentrations and replicate concentrations with standard deviation are illustrated.

A. PCB Uptake

Exposure to sediments B, C, and D resulted in similar PCB whole-body residues within each species; sediment A consistently produced lower PCB body burdens. Small increases in PCB concentrations relative to controls ($p \leq 0.05$) were detected in M. mercenaria and P. pugio, whereas higher concentrations were measured in N. virens (Fig. 2-4).

The sandworm is an errantiate species that forages interstitially and on the substrate surface, feeding on detritus and organically rich sediments. Although M. mercenaria is a burrowing bivalve, it is a suspension feeder and relies on the overlying water column for nutrition and respiration. Palaemonetes pugio lives in close association with aquatic plants and occasionally browses on the substrate surface; however, it is more representative of the water column habitat. The grass shrimp and clam are primarily susceptible to water-mediated uptake, whereas the sandworm is subject to uptake via interstitial water, ingestion, and absorption from sediments. Therefore, it is not surprising to find the greatest PCB uptake in the polychaete.

A nonlinear regression program was used to fit the three-parameter uptake model of Bahner and Oglesby (1981):

$$y = \frac{P_1}{1 + P_2 (t-P_3)} \qquad (1)$$

for PCB accumulation by N. virens from sediments A-D: where y is the dependent variable expressed as the natural log of the residue x 10^3 and t is the independent variable expressed in days. Based on this model, the following bioaccumulation factors (BAF)

$$BAF = \frac{\text{Tissue Concentration (wet wt)}}{\text{Sediment Concentration (wet wt)}} \qquad (2)$$

were calculated for N. virens at steady-state: sediment A, 0.53; sediment B, 1.06; sediment C, 0.15; and sediment D, 1.59 (Fig. 5).

Previous studies concerning PCB uptake from sediments by polychaetes (McLeese et al., 1980; Fowler et al., 1978; Courtney and Langston, 1978) reported BAFs of 3 to 10 for Nereis sp. exposed to sediments freshly sorbed with PCBs. A possible explanation for the lower BAFs we calculated is that our test material (recently collected from the field) consisted of fine-grained highly organic sediments. The organic content and particle size of the sediments were not reported in the earlier studies. Wildish et al. (1980) noted that organic contaminant flux between sediment and water depends upon adsorption-desorption phenomena that are influenced by the physical and chemical characteristics of the sediment. It is possible that the quantity and quality of the organic load associated with sediment is a key factor affecting the biological availability of associated xenobiotics. Sediment C contained the highest concentration of PCBs,

(Table 1). Sediment A, high in organic content, also produced a low BAF in the polychaete; sediments B and D, which were similar in sediment characteristics, produced higher BAFs. Measured BAFs for N. virens (N=3) on day 100 were inversely related to the organic content of the sediments. Figure 6 depicts the linear regression (R^2=0.76) for BAF on percentage organics of sediments A-D.

The only comparison that can be made between 10-day and steady-state whole-body residues is with PCBs in N. virens. Concentrations measured on day 10 were from 33 to 45% of the 100-day concentrations. Although there is no clear relationship between whole-body concentration in a 10-day exposure period and steady-state concentrations, by day 10, uptake of PCBs from sediments B, C, and D was apparent. As Bryan (1979) states, "The rate at which accumulation occurs in an organism depends not only on the availability of the pollutant but also on a whole range of biological, chemical and environmental factors." Equilibrium concentration in an organism is governed by its ability to excrete the contaminant or, alternatively, to store it. Therefore, it is possible in some situations that an equilibrium may never be attained. Nereis virens, however, did demonstrate steady-state for PCBs by approximately day 30 for sediments A and B and day 40 for sediments C and D (Fig. 5).

Our results indicate that a 10-day exposure period underestimates steady-state concentration of PCBs accumulated from sediments by N. virens. Although 10 days of exposure is sufficient to detect the

potential for PCB accumulation, it does not reflect actual steady-state concentration and therefore cannot be compared directly to a value intended to represent concentrations in indigenous biota at the disposal site.

To assess the relative contribution of water-mediated uptake of PCBs by N. virens, we conducted elutriate analysis of sediments A through D (Table 1). The elutriate concentration represents the maximum water exposure concentration for each sediment type. Based on these concentrations and a bioconcentration factor (BCF)

$$BCF = \frac{\text{Tissue Concentration}}{\text{Water Concentration}} \qquad (3)$$

of 800 for PCB uptake by Nereis sp. from water, calculated by Fowler et al. (1978), we would expect maximum whole-body residues of 0.007 to 0.034 µg PCB/g (wet wt.) if accumulation were dependent solely on direct partitioning from water. However, measured PCB whole-body residues on day 100 ranged from 0.14 µg/g (sediment A) to 0.63 µg/g (sediment D). Therefore, it appears that pathways in addition to direct uptake from water (e.g., ingestion and sorption) substantially contribute to PCB accumulation by the sandworm.

B. Mercury and Cadmium Uptake

Mercury and cadmium are both known to accumulate in a wide variety of marine biota (Eisler, 1981); however, factors that affect bioavailability of heavy metals from sediments are not well understood (Pequegnat, 1979). Gross (1972) found that only small amounts of the metals in dredged material dumped into the New York Bight could be

leached out with hydrochloric acid and concluded that most of the metal was not available to marine biota.

In our study, exposure to sediments that contained as much as 34 µg Hg/g and 38 µg Cd/g (sediment C) did not produce measureable uptake by test organisms (Figs. 7 and 8) relative to controls. There was no apparent correlation between sediment type, contaminant concentration, and measured body burdens of Hg and Cd by N. virens (Figs. 9 and 10), M. mercenaria (Figs. 11 and 12), and P. pugio (Figs. 13 and 14).

Studies conducted by Sunda et al. (1978), Engel et al. (1981), and Cunningham (1979) demonstrate that toxicity and bioavailability of heavy metals are greatly influenced by their chemical form. Accumulation, in part, is a function of the free metal ion concentration, which is directly affected by the total dissolved concentration and the "degree of metal complexation to both organic and inorganic ligands" (Engel et al., 1981). As noted previously, the sediments examined in our study were highly organic and thus could account for the lack of bioavailability of heavy metals, as evidenced by lack of bioaccumulation. In addition, the sediments contained considerable amounts of sulfur, and the formation of metal sulfides could also account for the low availability of Cd and Hg.

IV. CONCLUSIONS

In the past, attempts have been made to use bulk chemical analysis to determine the potential impact of contaminated sediments on the marine environment. Results from our study support the contention that

sediment concentration alone does not reflect bioavailability. The most highly contaminated sediment (C) produced the lowest PCB bioaccumulation factor and did not result in measurable uptake of Hg and Cd. Results also indicate that elutriate analysis alone does not accurately predict PCB bioaccumulation by N. virens.

Exposure concentrations resulting from ocean disposal of contaminated sediments appear to be related to the physical and chemical properties of the sediment as well as site-specific conditions (i.e., receiving water quality and local hydrography). Therefore, future research should examine the relationship between physicochemical sediment parameters and biological effects, as well as the relative potential for bioaccumulation in a wide variety of benthic species which represents a range of trophic levels and feeding modes. Until we can further our understanding of those processes affecting bioavailability of contaminants in bottom sediment, empirical measurement of body burden (i.e., bioassays and field monitoring) remains the most direct method for determining bioaccumulation potential for dredged material.

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Table 1. Sediment Characterization

Sediment	Sediment Concentration PCBs -- Hg -- Cd (µg/g dry weight)	Elutriate Concentration PCBs (µg/ℓ)	Particle-Size Distribution Sand-Silt-Clay (%)	Organics (%)	Moisture (%)
A	0.46 - 4.13 - 5.32	0.008	0 - 84.6 - 15.4	12.6	44
B	0.71 - 2.85 - 11.49	0.043	0.4 - 93.8 - 5.8	5.5	32
C	7.28 - 34.89 - 38.60	0.023	0 - 88.0 - 12.0	22.3	55
D	0.72 - 2.71 - 5.16	0.035	0.2 - 94.3 - 5.5	6.1	30

Table 2. Whole-body Residue of Contaminants at Each Sampling Interval

Contaminant	Test Organism	Sediment Type	Days of Exposure-Residue, µg/g (wet wt) 3	7	10	17	24	38	58	100
PCB	N. virens	A	0.031	0.088	0.074	0.126	0.170	0.171	0.151	0.230
		B	0.110	0.173	0.231	0.289	0.545	0.411	0.335	0.548
		C	0.212	0.251	0.214	0.423	0.537	0.502	0.508	0.437
		D	0.134	0.156	0.179	0.361	0.295	0.539	0.606	0.452
		Control	0.038	ND	0.014	0.039	0.028	ND	0.026	ND
	M. mercenaria	A	0.010	0.014	0.017	0.020	0.021	0.026	0.025	0.024*
		B	0.037	0.044	0.074	0.103	0.066	0.071	0.059	0.040
		C	0.014	0.134	0.046	0.094	0.087	0.118	0.062	0.059*
		D	0.057	0.031	0.058	0.076	0.054	0.059	0.066	0.046
		Control	0.013	ND	ND	ND	ND	ND	0.030	ND
	P. pugio	A	0.027	0.033	--	0.036	0.060	0.031	0.031	--
		B	0.046	0.086	--	0.057	0.120	0.071	0.057	--
		C	0.059	0.056	--	0.087	0.101	0.070	0.061	--
		D	0.058	0.077	--	0.097	0.116	0.065	0.050	--
		Control	ND	ND	--	0.011	0.047	ND	0.018	--
Mercury	N. virens	A	0.294	0.138	0.103	0.095	0.135	0.035	0.156	0.031*
		B	0.144	0.097	0.087	0.051	0.161	0.042	0.064	0.028
		C	0.234	0.050	0.094	0.036	0.135	0.056	0.266	0.029
		D	0.193	0.054	0.078	0.041	0.059	0.116	0.172	0.061
		Control	0.238	0.128	0.031	ND	ND	0.153	0.236	0.093
	M. mercenaria	A	0.044	0.072	0.047	0.074	0.097	0.134	0.060	0.113
		B	0.188	0.084	0.024	0.069	0.049	0.025	0.219*	0.050
		C	0.152	0.069	0.023	--	0.085	0.026	0.050*	0.044
		D	0.225	0.086	0.050	0.036	0.063	0.087	ND	0.032
		Control	0.060	0.164	--	0.111	--	0.231	--	0.046

(Continued)

Notes: Entry ND indicates level of contaminant not detectable.
N = 3 for all entries except those entries followed by *, where N = 1.

Table 2 (Concluded)

Contaminant	Test Organism	Sediment Type	Days of Exposure-Residue, µg/g (wet wt) 3	7	10	17	24	38	58	100
	P. pugio	A	0.072	0.027	0.029	0.051	0.106	0.146	0.077	--
		B	0.096	0.015	0.026	0.144	0.085	0.098	0.043	--
		C	0.147	0.022	0.042	0.082	0.132	0.077	0.018	--
		D	0.121	0.043	0.012	0.123	0.219	0.021	0.129	--
		Control	0.046	--	0.078	0.021	--	0.192	0.25	--
Cadmium	N. virens	A	0.223	0.338	0.043	0.039	0.041	0.045	0.149	0.487
		B	--	0.349	0.180	0.045	0.094	0.065	0.063	0.466
		C	0.189	0.228	0.051	0.042	0.072	0.112	0.074	0.267
		D	0.242	0.143	0.042	0.024	0.056	0.040	0.064	0.164
		Control	0.242	0.225	0.039	0.036	0.156	0.134	0.079	--
	M. mercenaria	A	0.638	0.270	0.156	0.297	0.526	0.406	0.433	0.324
		B	0.526	0.384	0.153	0.293	0.572	0.430	0.578	0.366
		C	0.881	1.14	0.291	0.300	0.419	0.418	0.355	0.702
		D	0.441	0.852	0.244	0.376	0.341	0.397	0.382	0.671
		Control	0.394	--	0.214	0.254	0.294	0.308	0.313	0.290
	P. pugio	A	0.216	0.032	0.024	0.014	0.060	0.179	0.055	--
		B	0.318	0.032	0.036	0.034	0.052	0.060	0.055	--
		C	0.186	0.028	0.026	0.020	0.057	0.034	0.034	--
		D	0.191	0.035	0.030	0.037	0.050	0.058	0.051	--
		Control	0.102	--	0.028	0.017	0.017	0.014	0.020	--

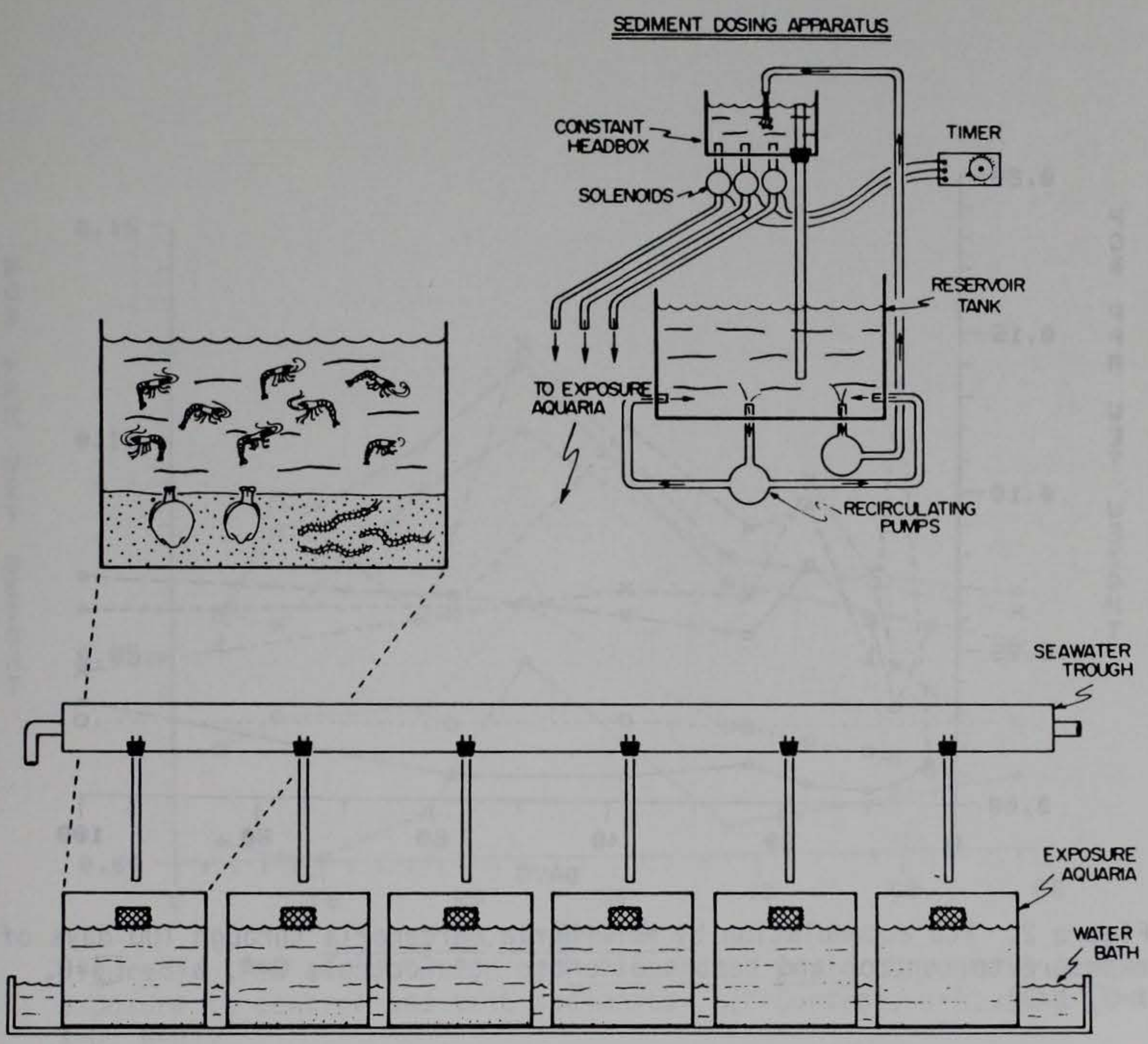

Figure 1. Exposure system consisting of glass aquaria, flowing seawater, temperature bath, and suspended sediment dosing apparatus. An individual dosing system was used for each sediment tested.

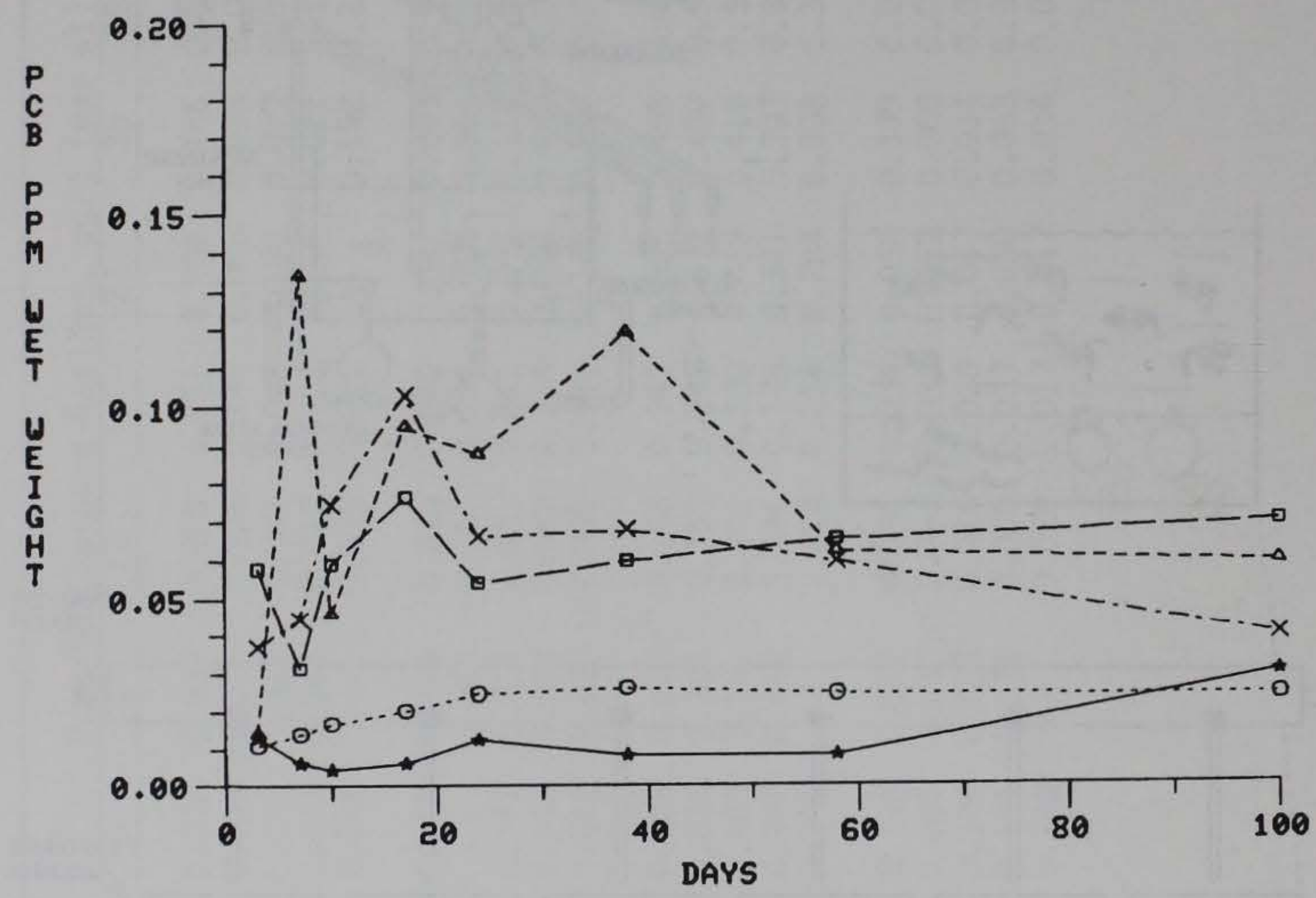

Figure 2. PCB accumulation by Mercenaria mercenaria through 100 days of exposure to control and test sediments (*=Control, O=A, Δ=B, □=C, X=D, N=3).

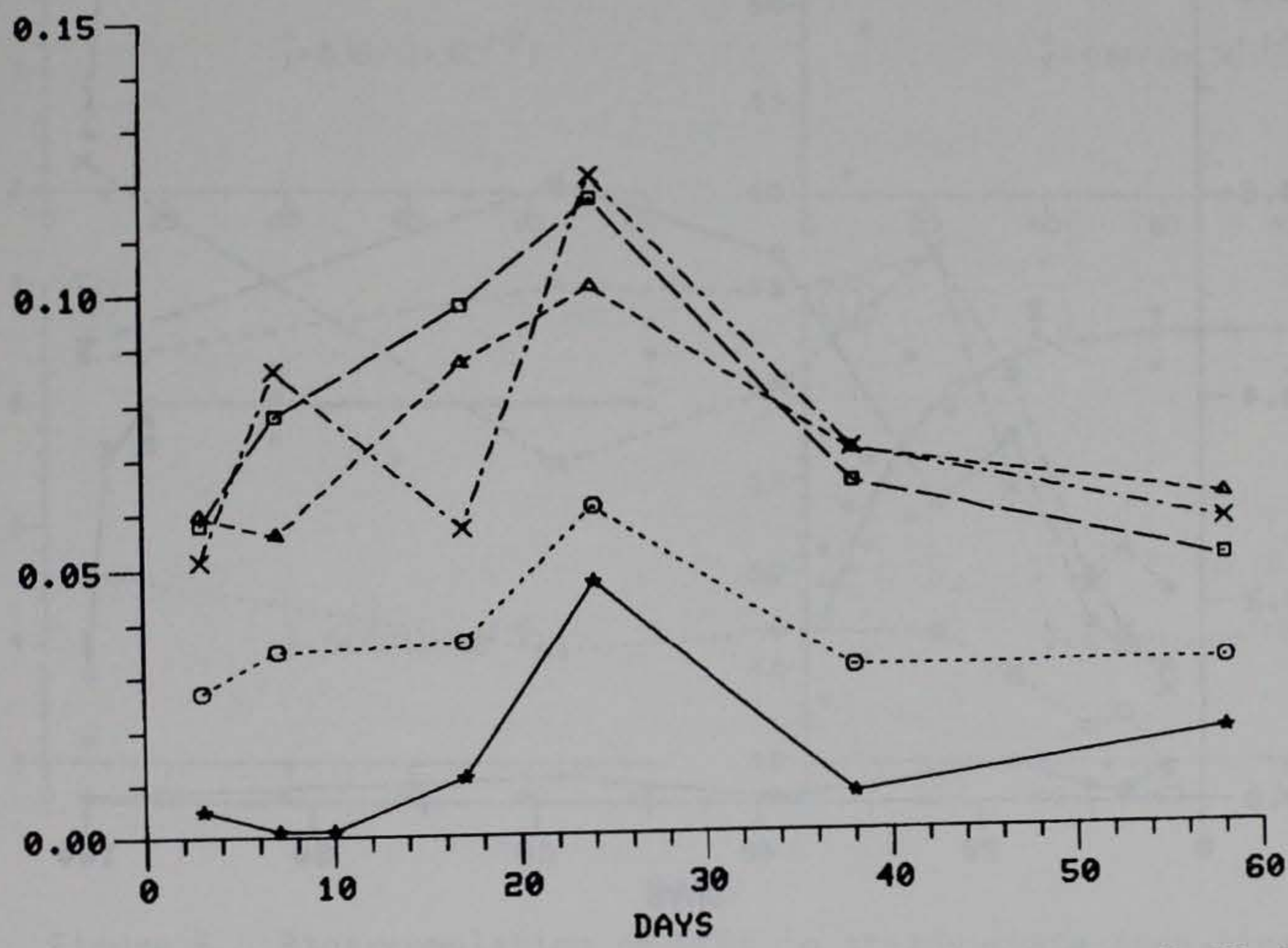

Figure 3. PCB accumulation by Palaemonetes pugio through 58 days of exposure to control and test sediments (*=Control, O=A, Δ=B, □=C, X=D, N=3).

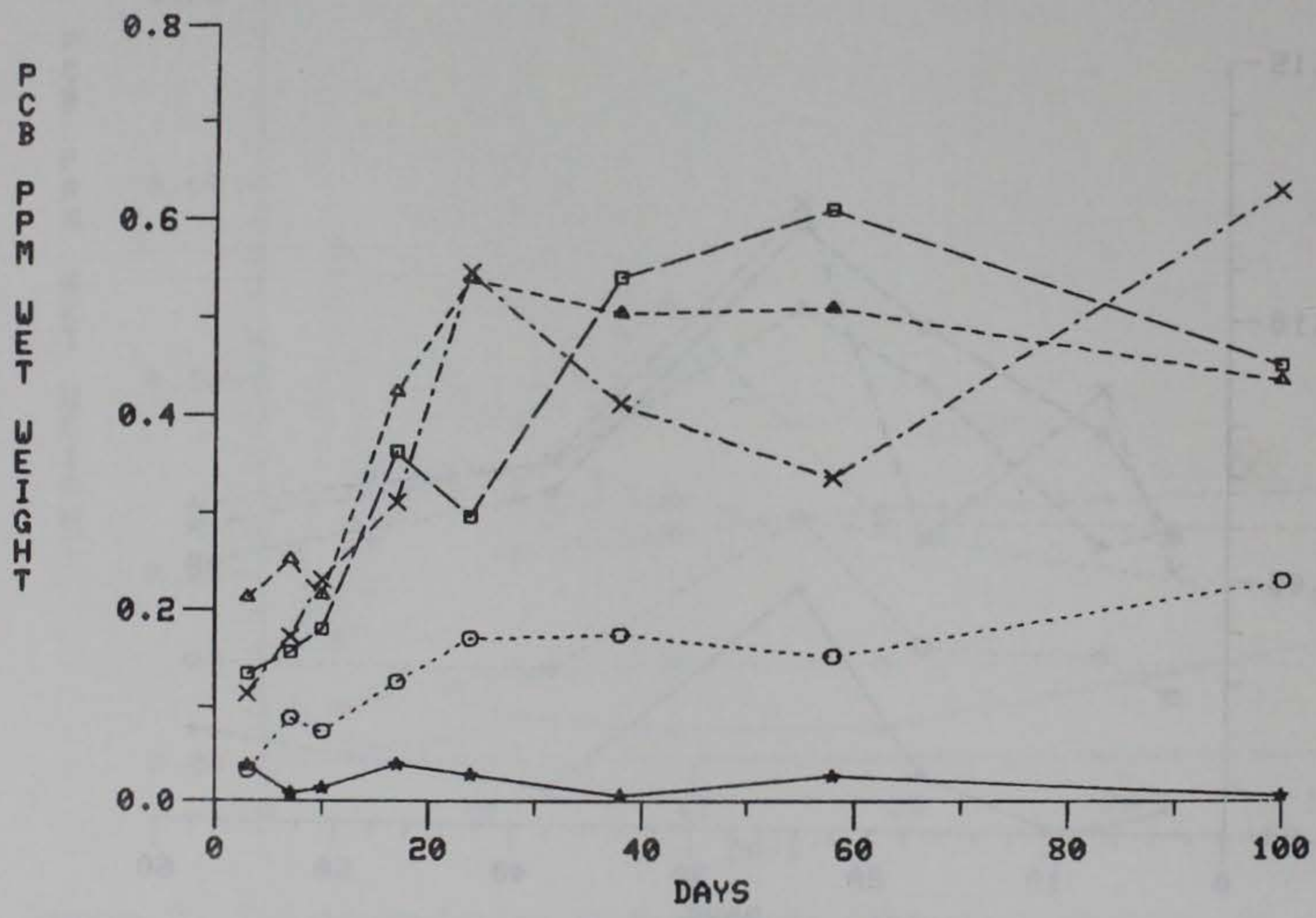

Figure 4. PCB accumulation by Nereis virens through 100 days of exposure to control and test sediments (*=Control, O=A, Δ=B, □=C, X=D, N=3).

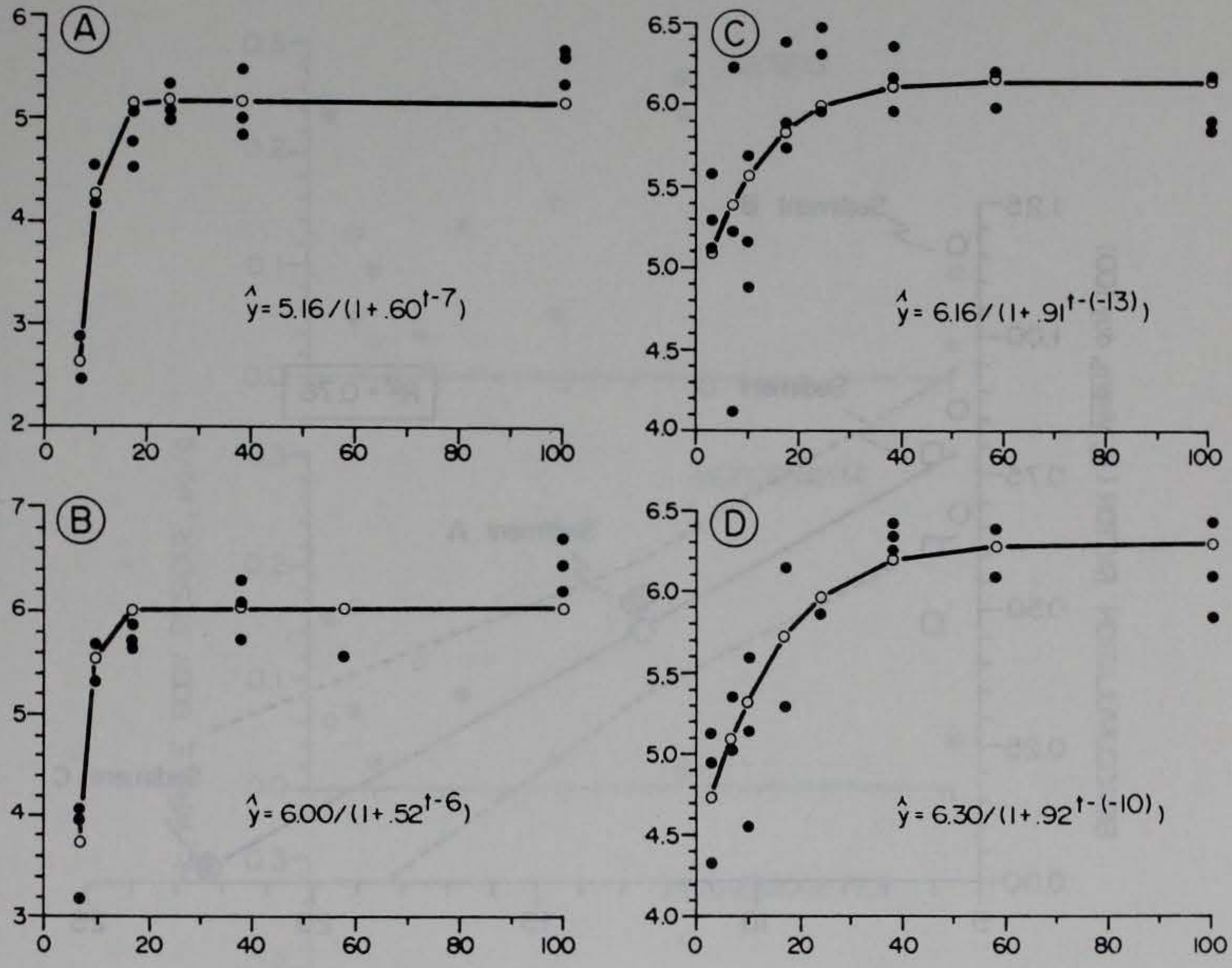

Figure 5. Bioaccumulation of PCBs to steady-state (non-linear regression, Bahner and Oglesby, 1981) for N. virens exposed to sediments A-D.

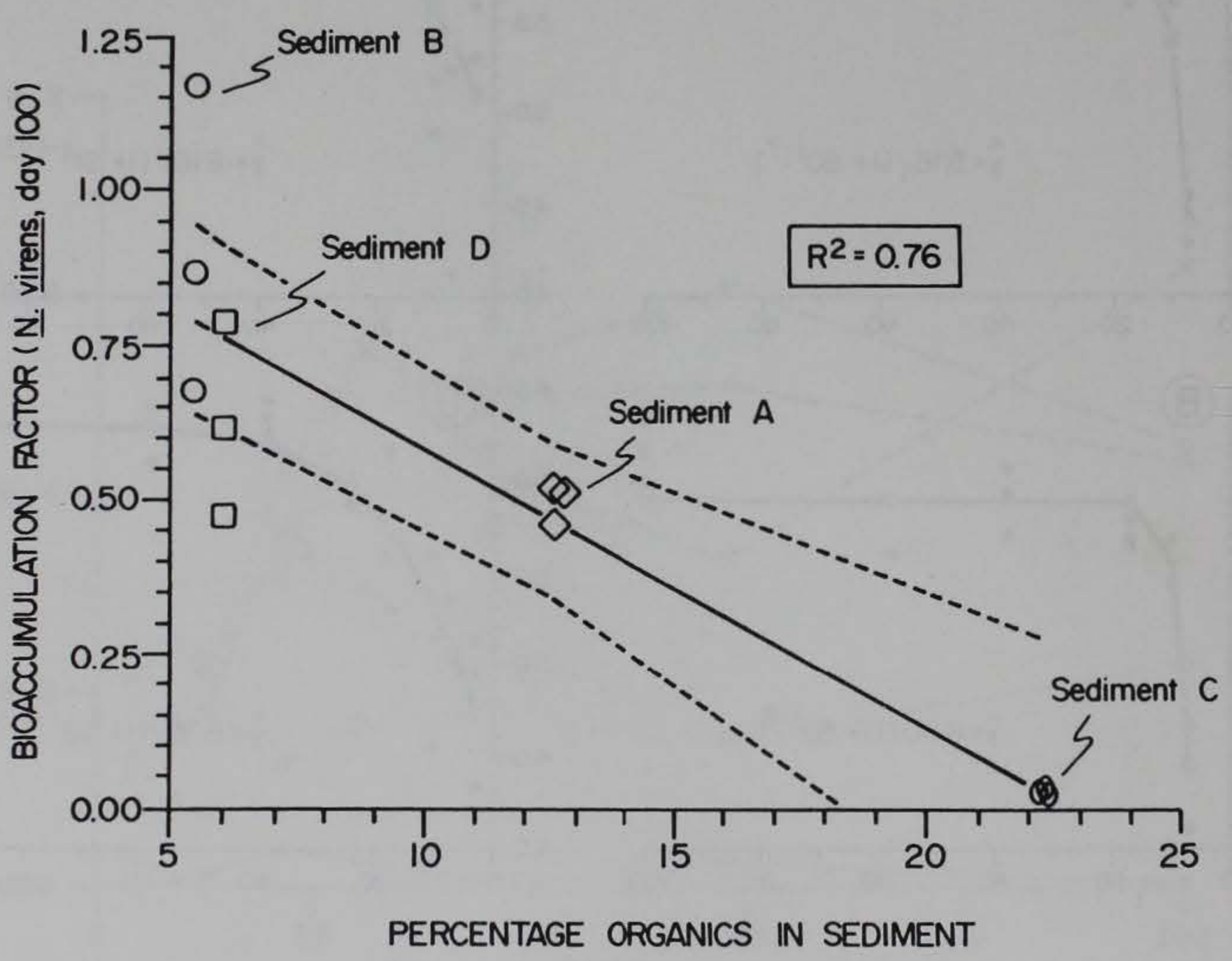

Figure 6. Linear regression with 95% confidence intervals for BAF (N. virens, day 100) on percentage organics in sediments.

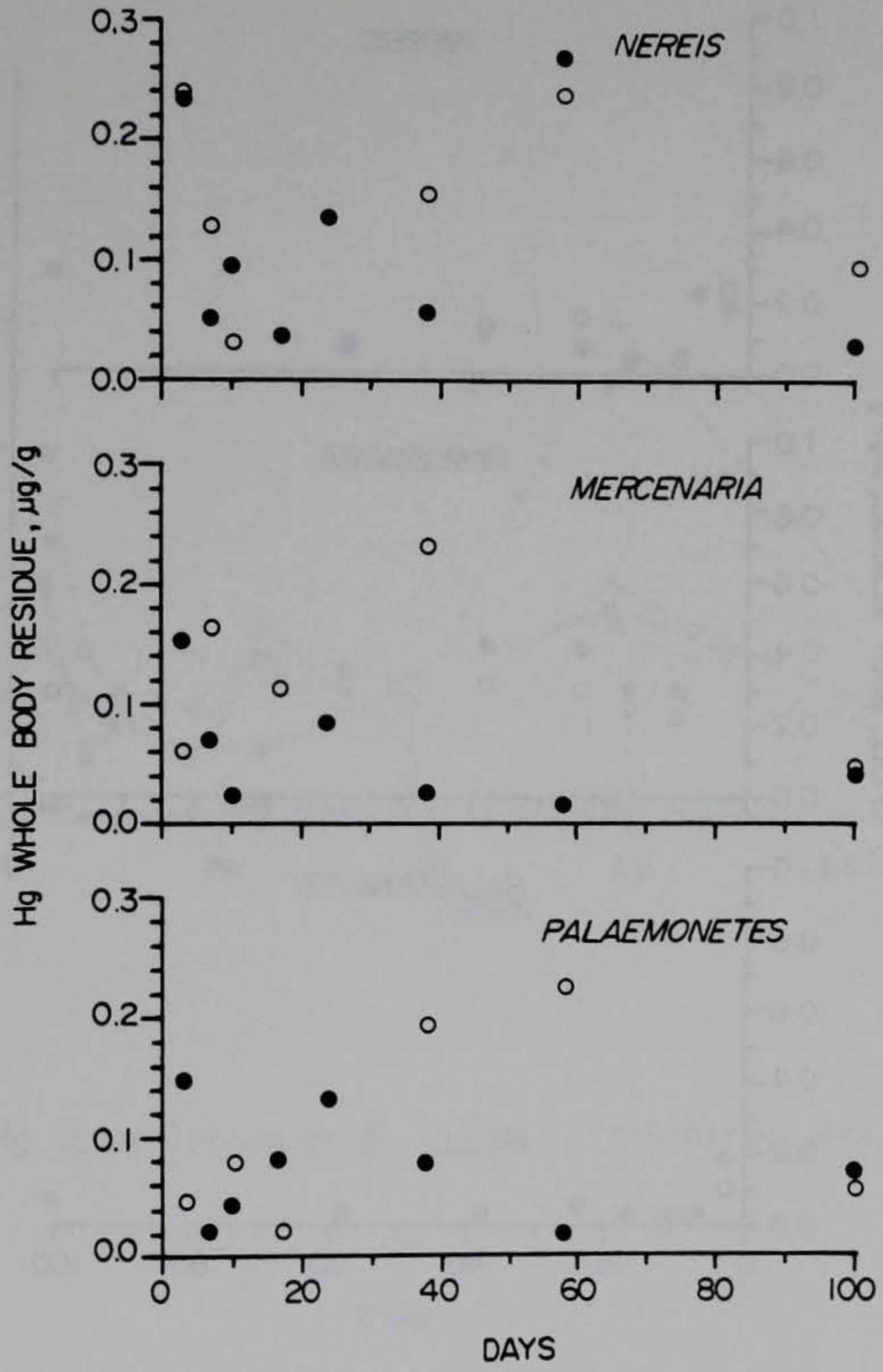

Figure 7. Hg accumulation by test organisms exposed to control sediment (O) and sediment C (●), wet weight.

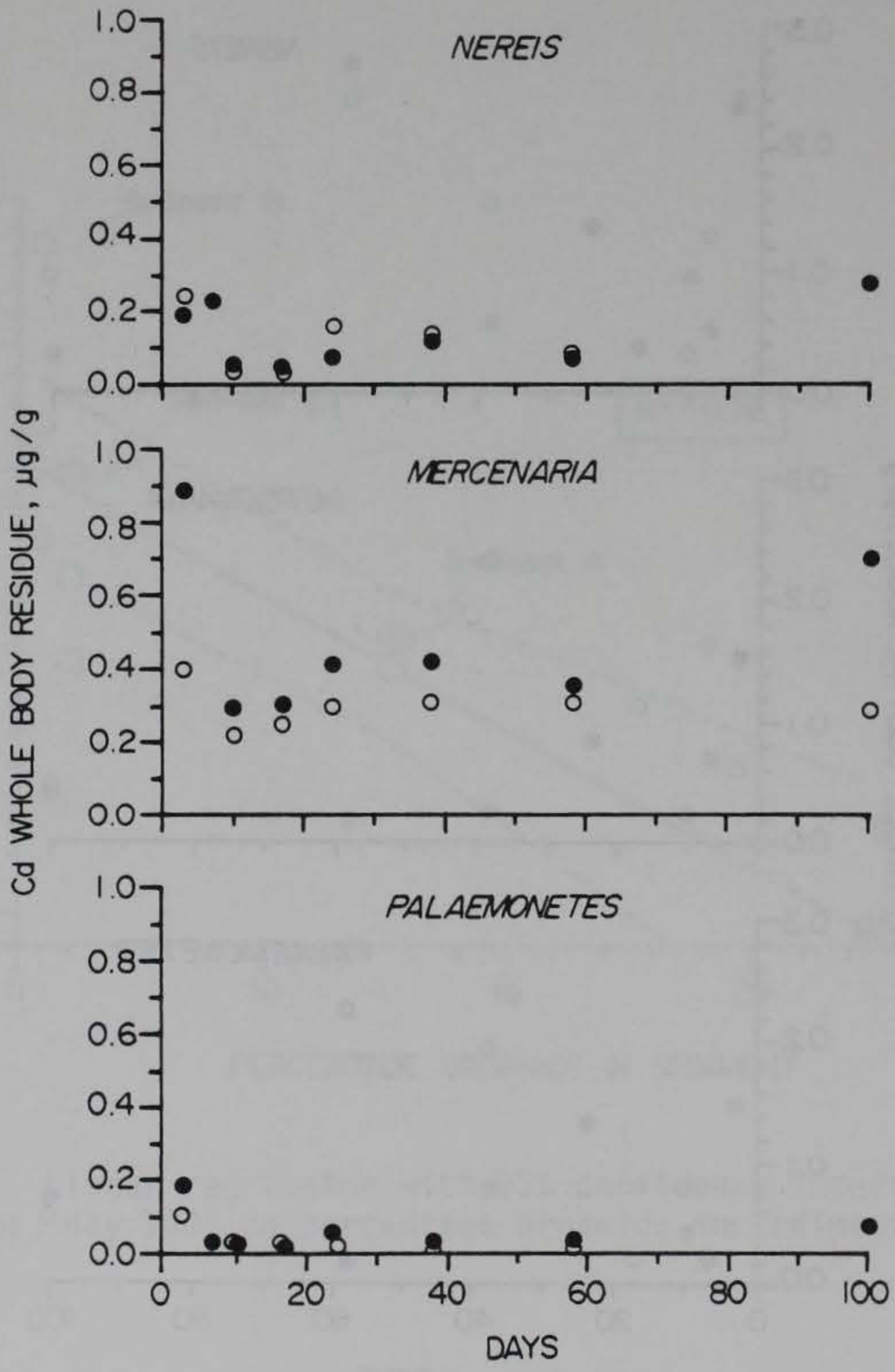

Figure 8. Cd accumulation by test organisms exposed to control sediment (O) and sediment C (●), wet weight.

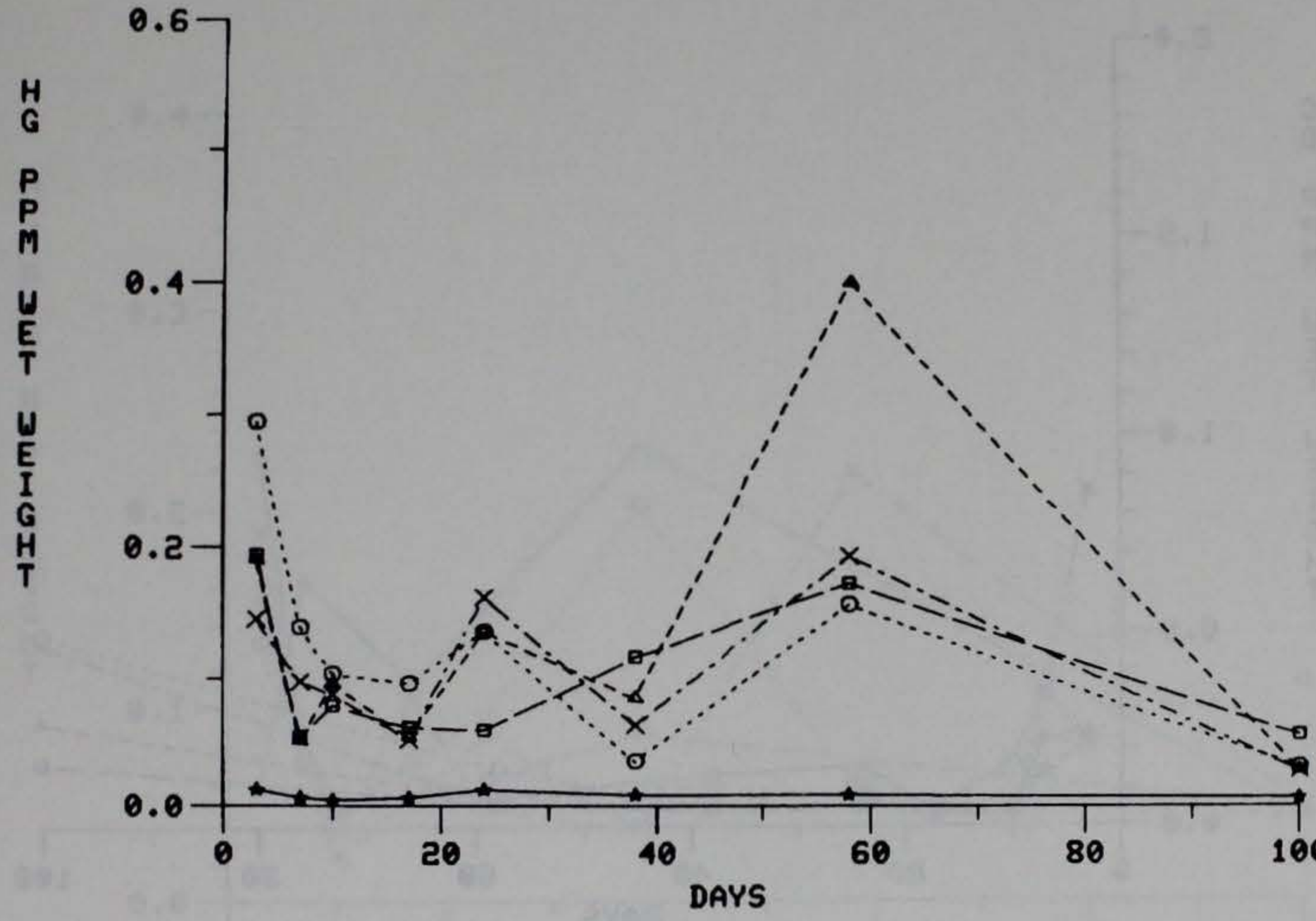

Figure 9. Hg accumulation by N. virens (*=Control, O=A, Δ=B, □=C, X=D, N=3).

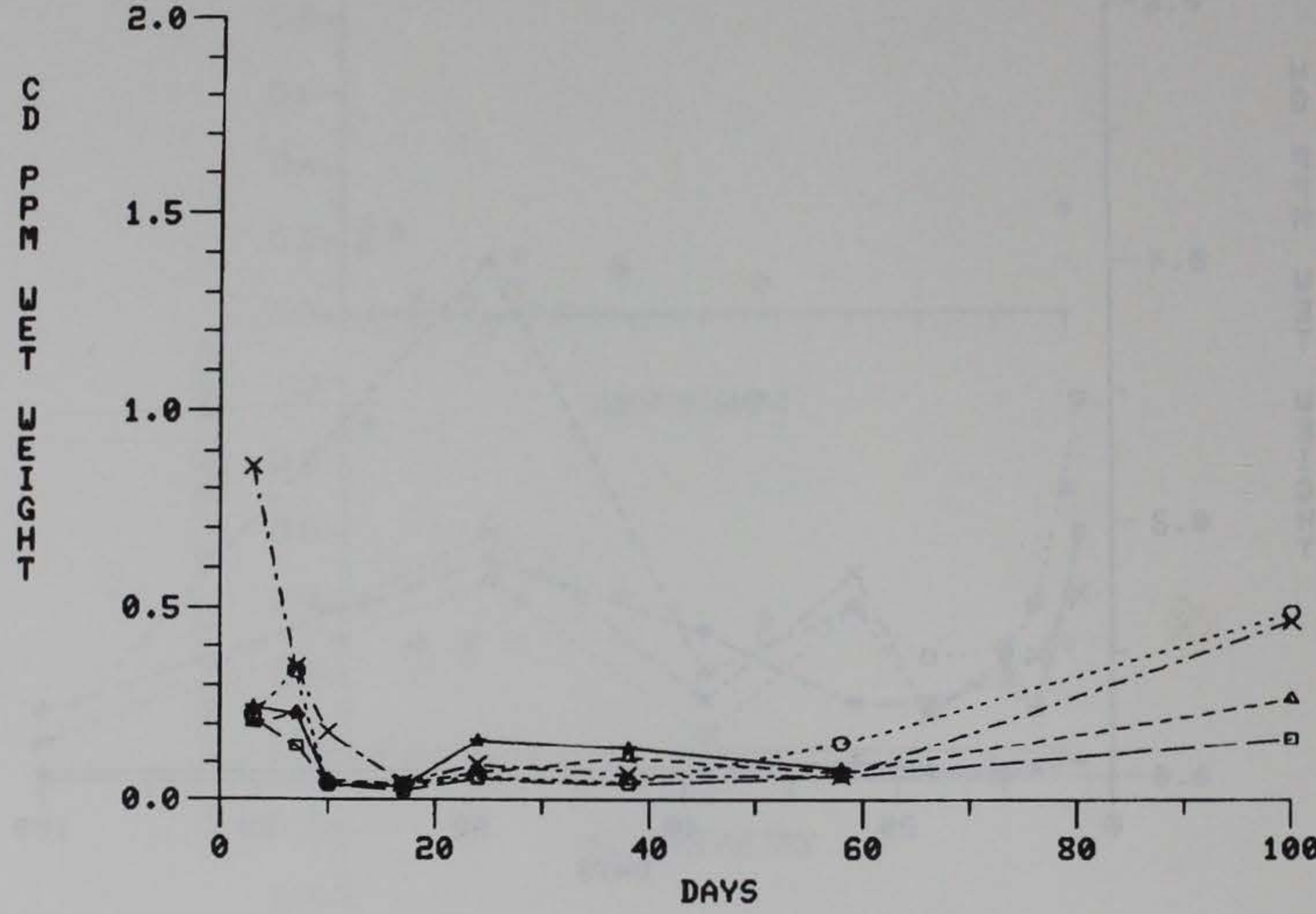

Figure 10. Cd accumulation by N. virens (*=Control, O=A, Δ=B, □=C, X=D, N=3).

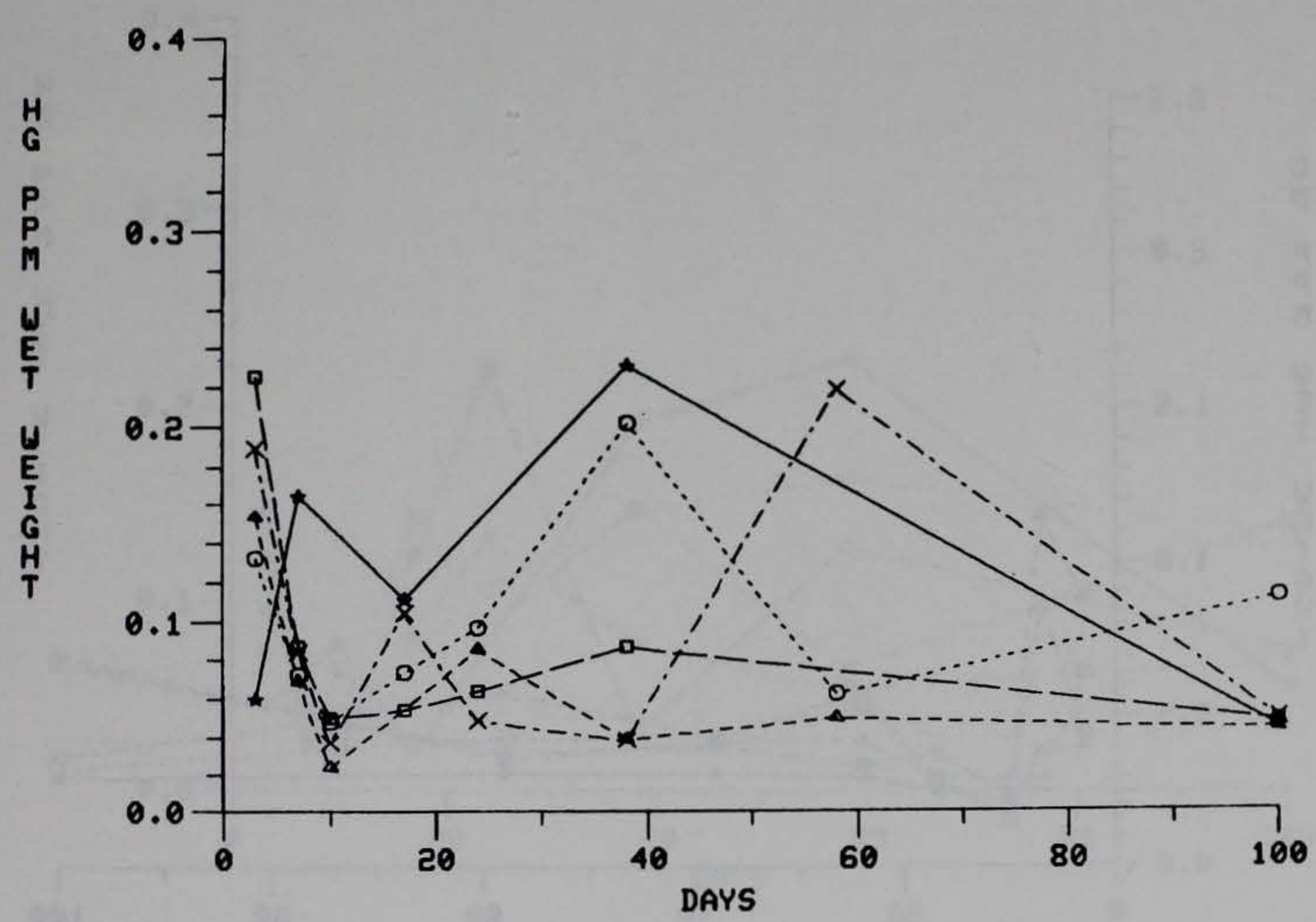

Figure 11. Hg accumulation by M. mercenaria (*=Control, O=A, Δ=B, □=C, X=D, N=3).

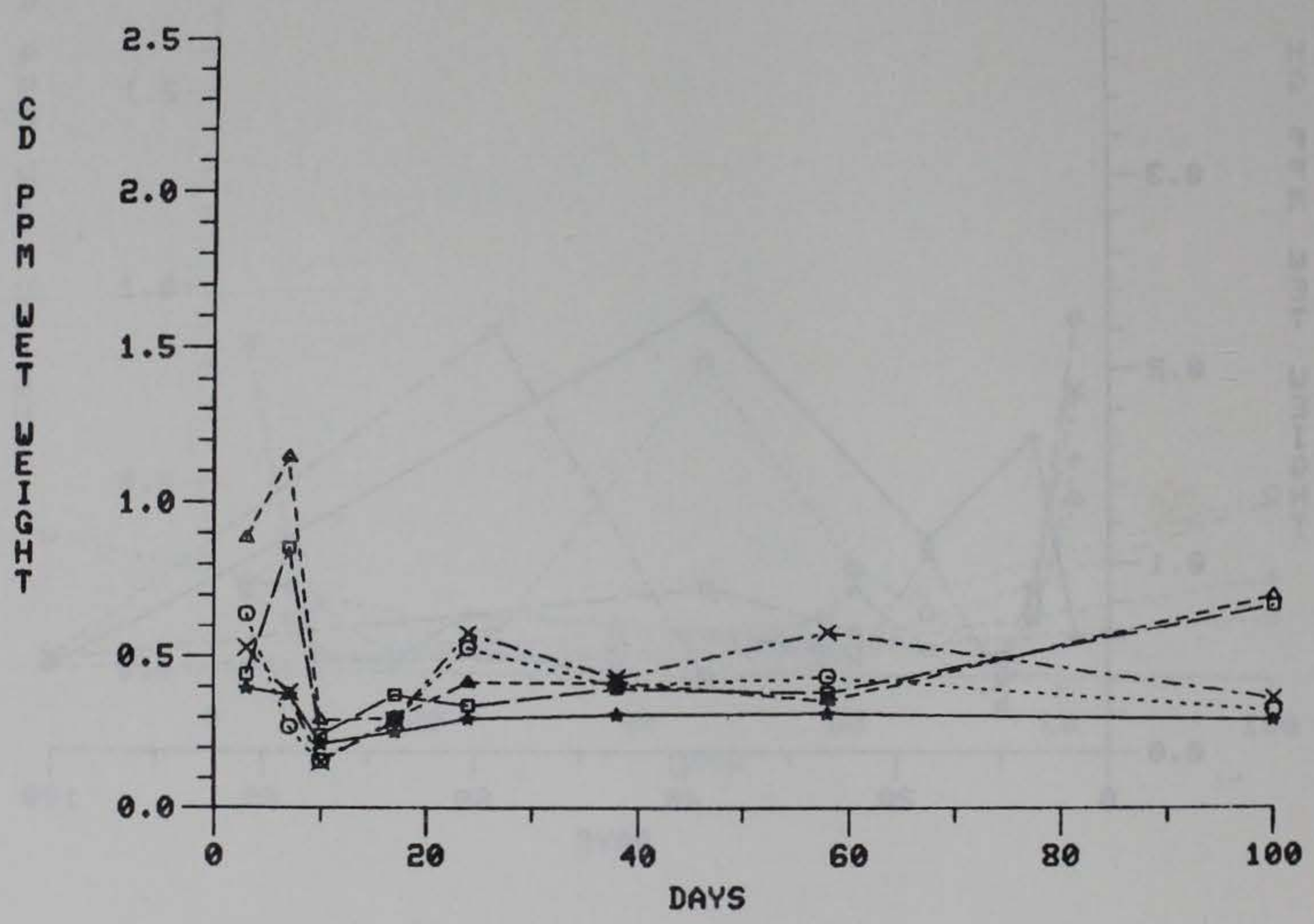

Figure 12. Cd accumulation by M. mercenaria (*=Control, O=A, Δ=B, □=C, X=D, N=3).

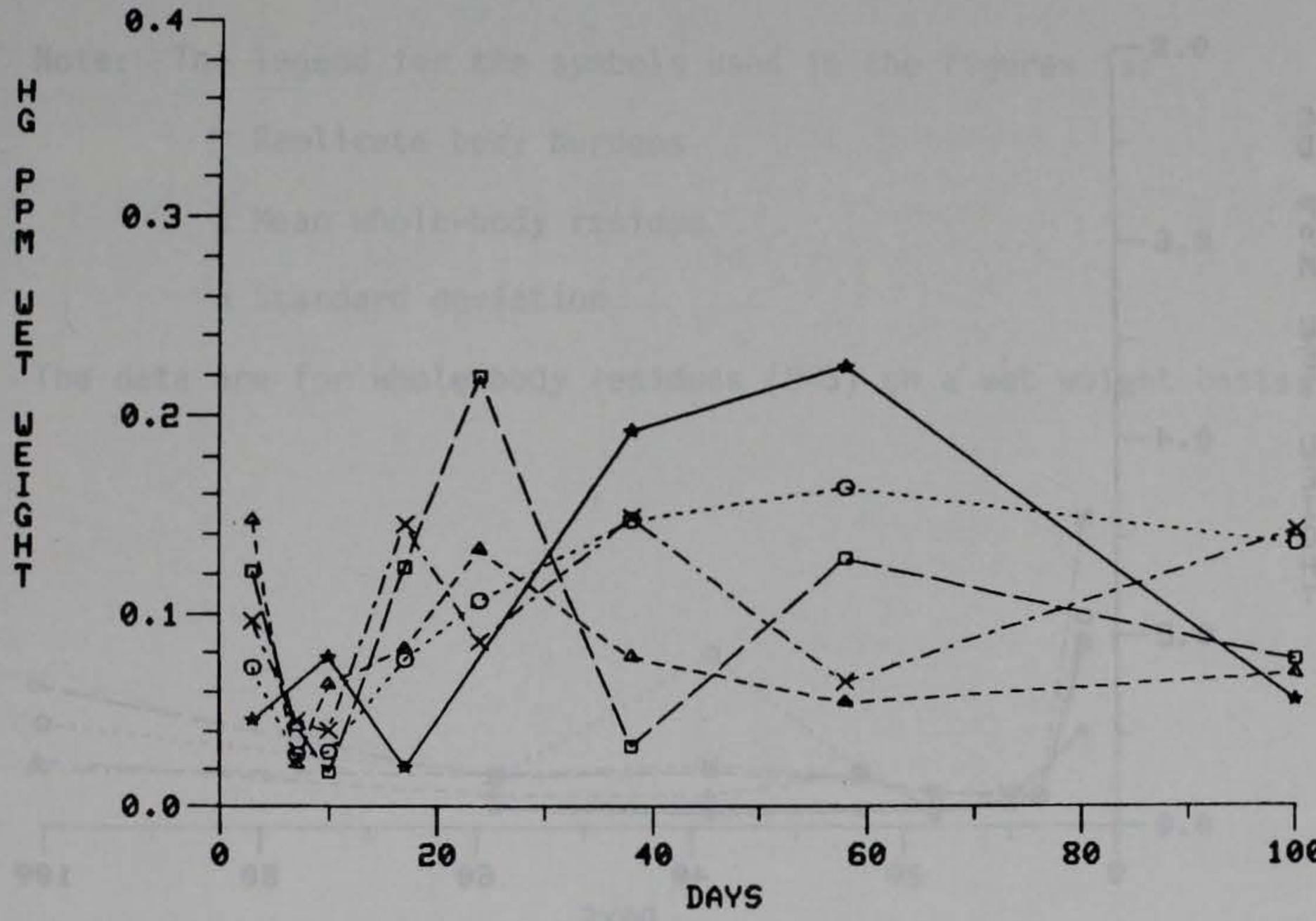

Figure 13. Hg accumulation by P. pugio (*=Control, O=A, Δ=B, □=C, X=D, N=3).

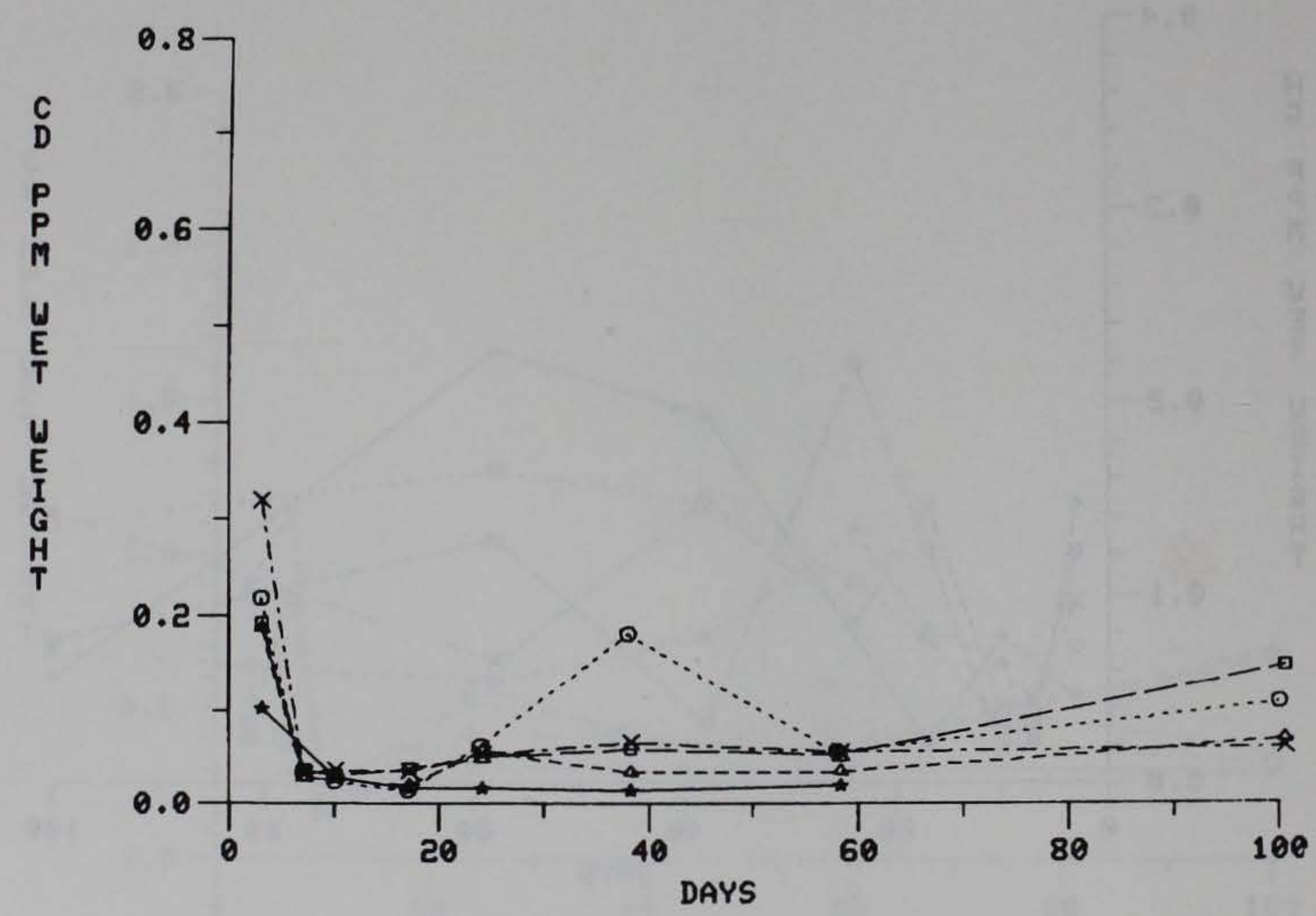

Figure 14. Cd accumulation by P. pugio (*=Control, O=A, Δ=B, □=C, X=D, N=3).

APPENDIX A: ACCUMULATION OF PCBS, MERCURY, AND CADMIUM BY TEST SPECIES.

Note: The legend for the symbols used in the figures is:

* Replicate body burdens

x Mean whole-body residue

Δ Standard deviation

The data are for whole-body residues (N=3) on a wet weight basis.

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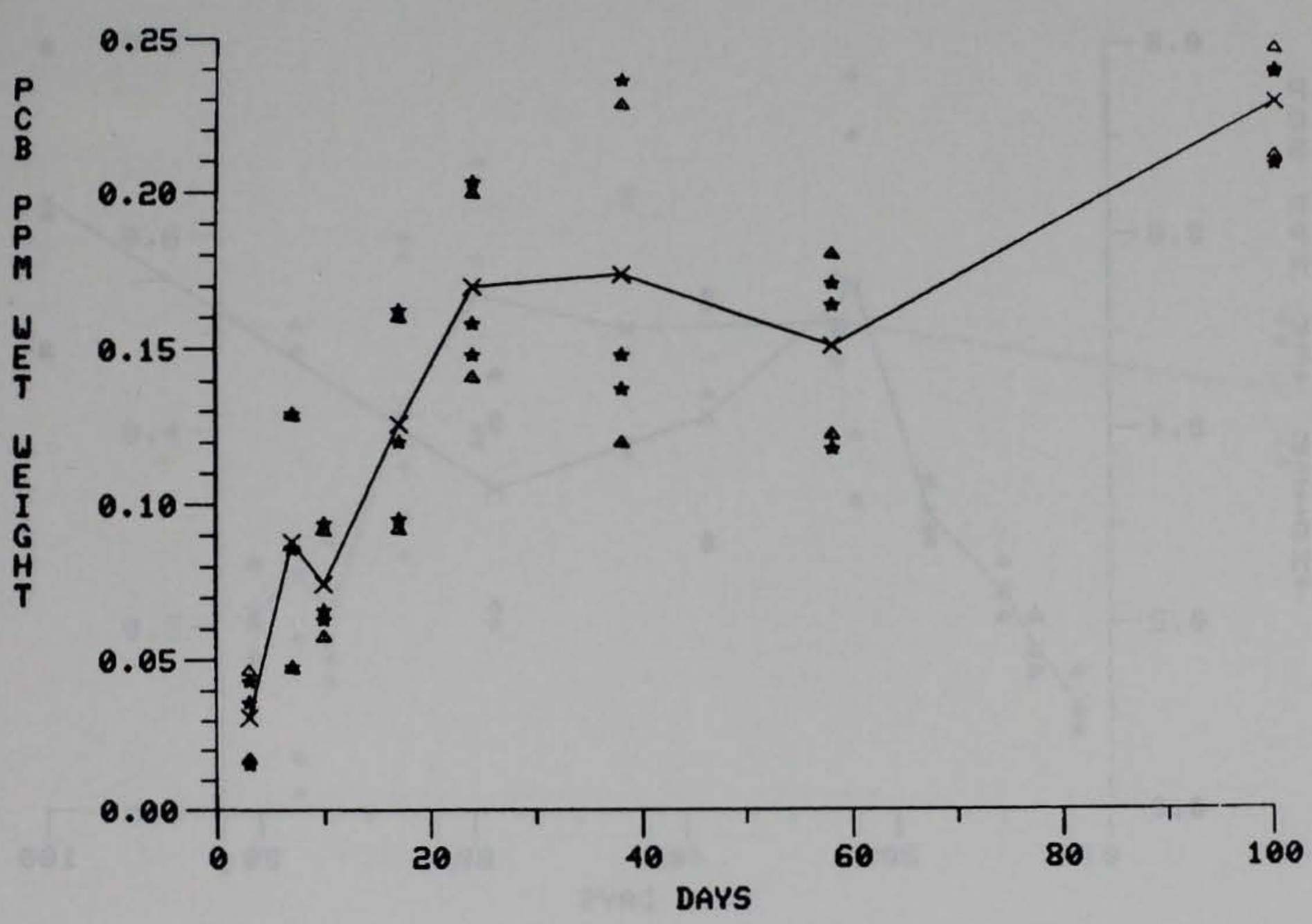

Figure A1. PCB uptake by N. virens from Sediment A.

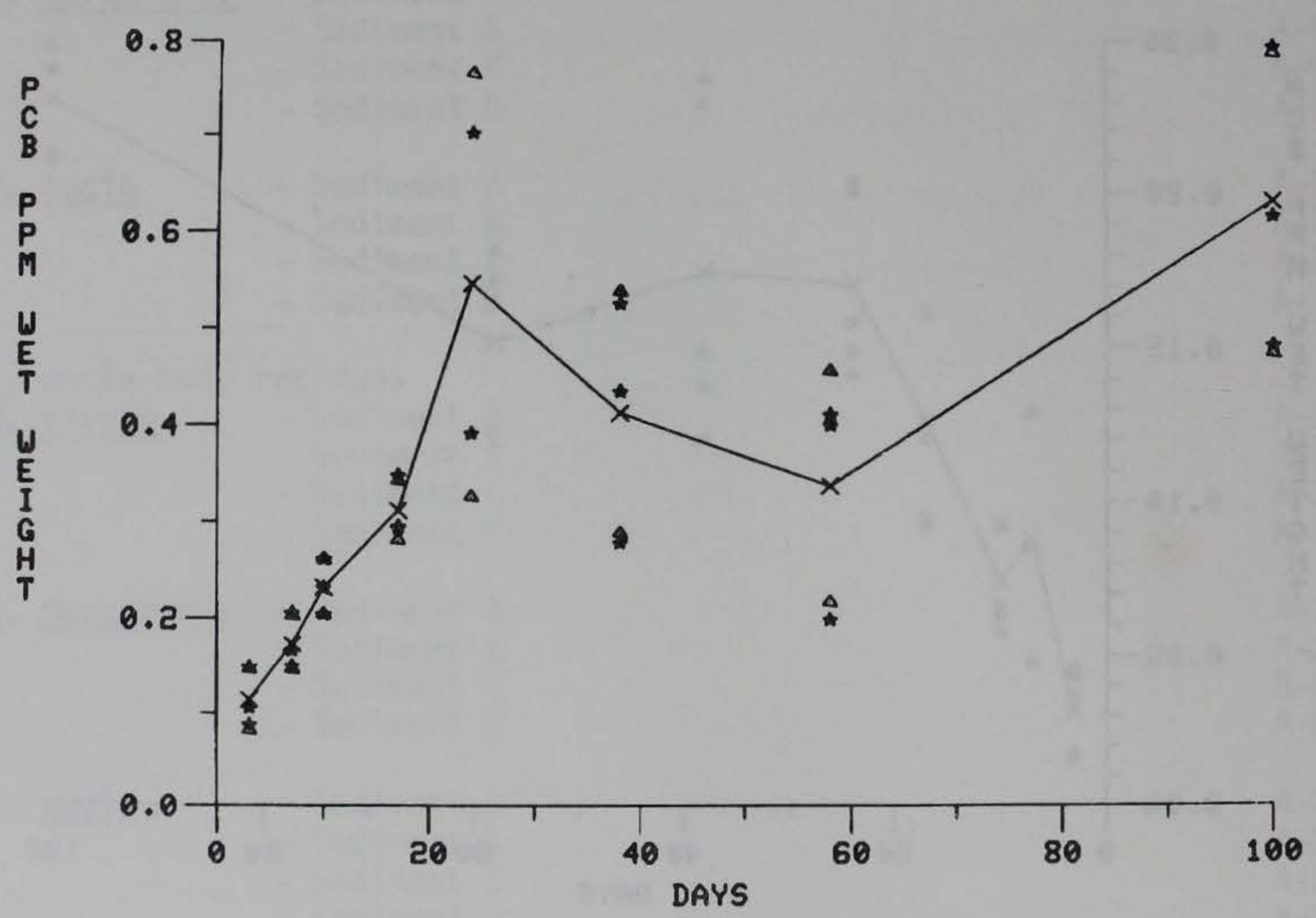

Figure A2. PCB uptake by N. virens from Sediment B.

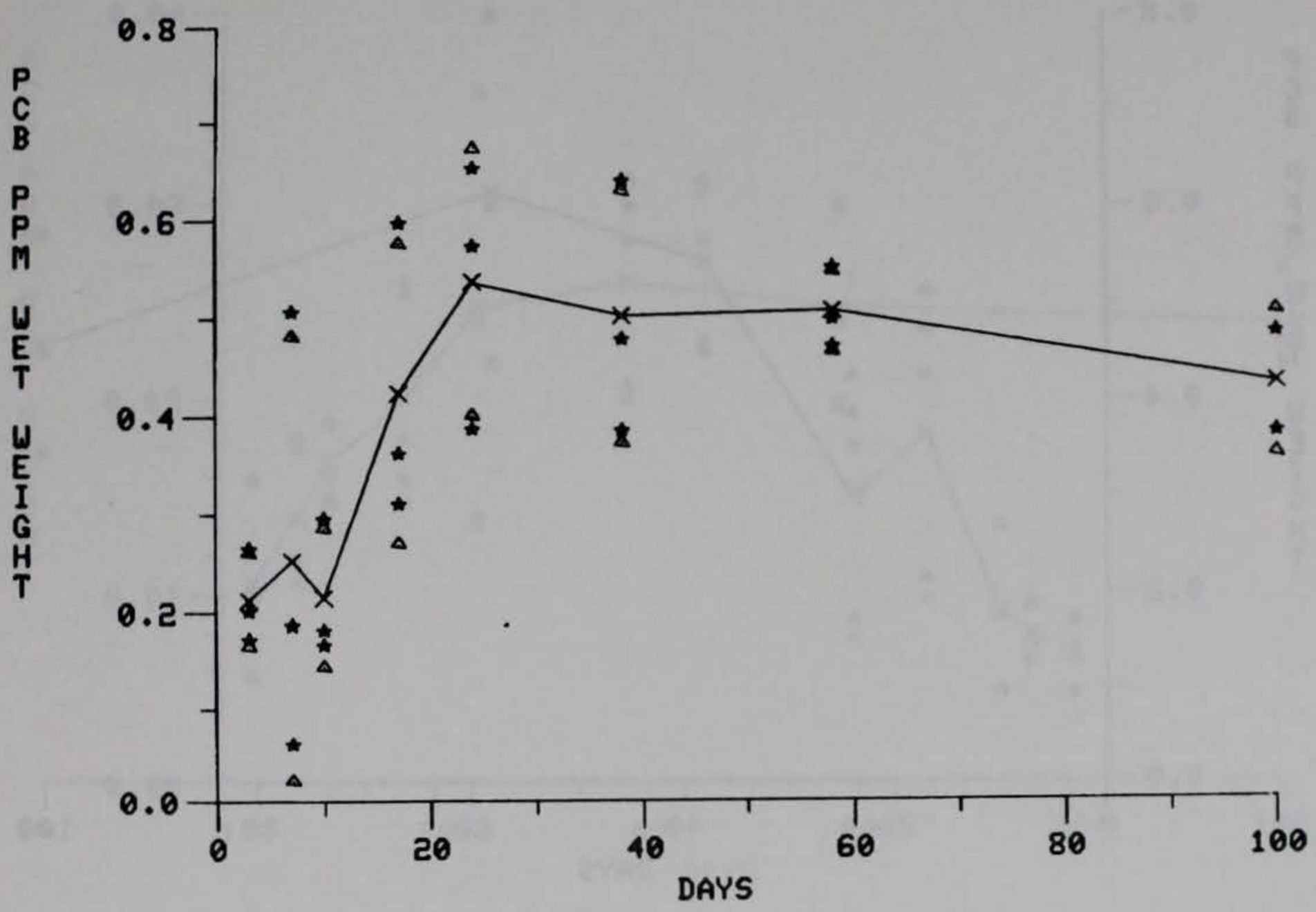

Figure A3. PCB uptake by N. virens from Sediment C.

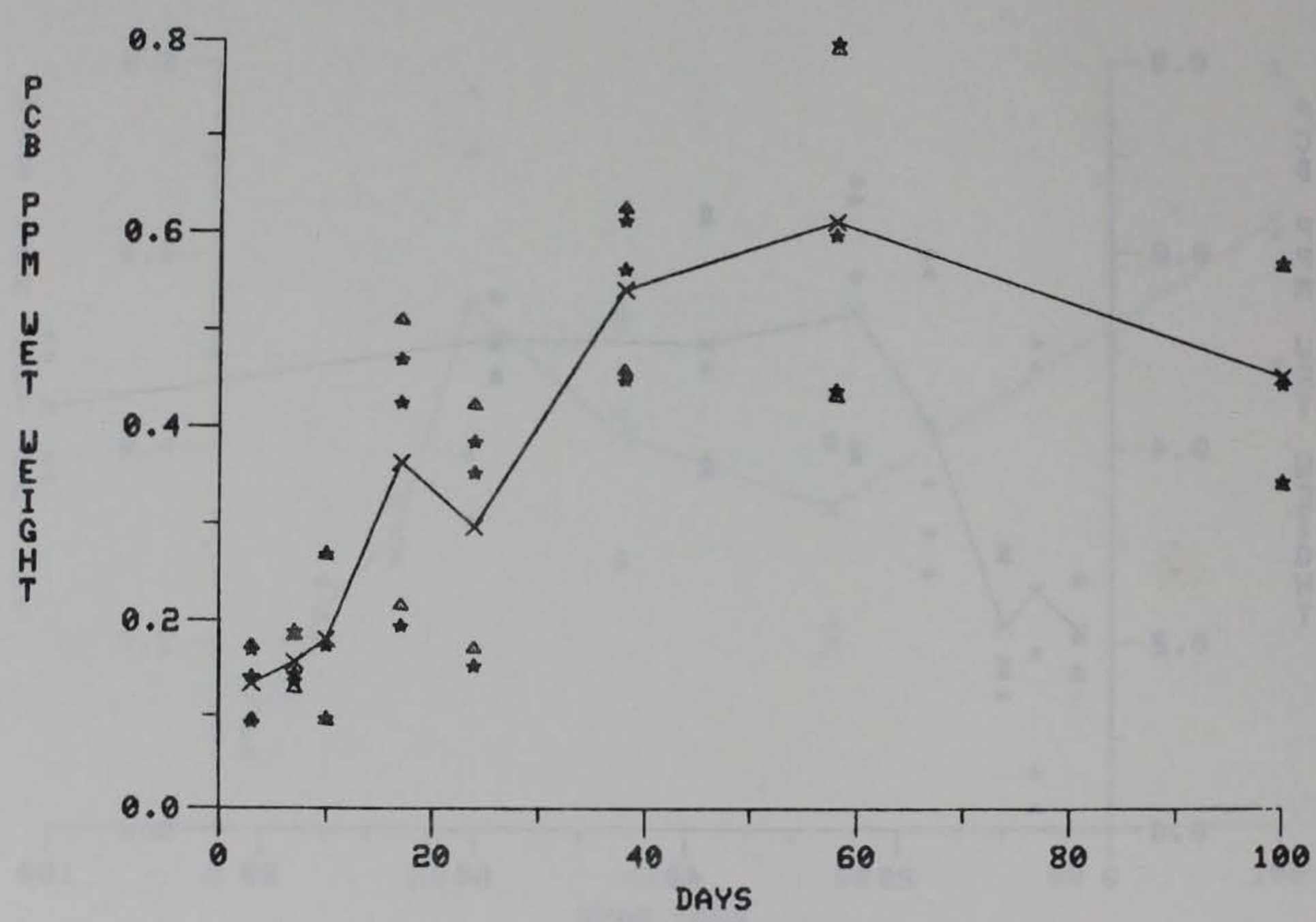

Figure A4. PCB uptake by N. virens from Sediment D.

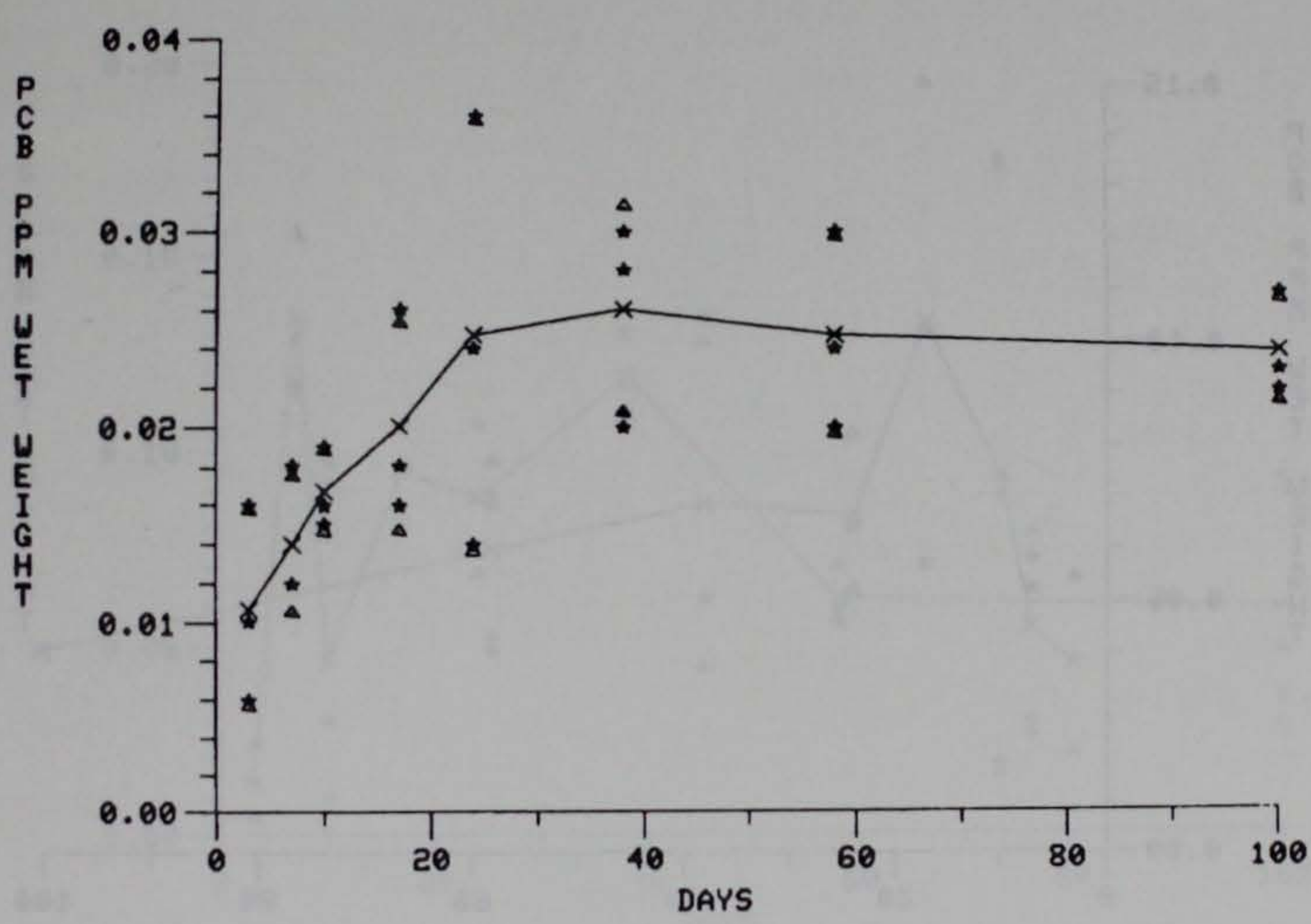

Figure A5. PCB uptake by M. mercenaria from Sediment A.

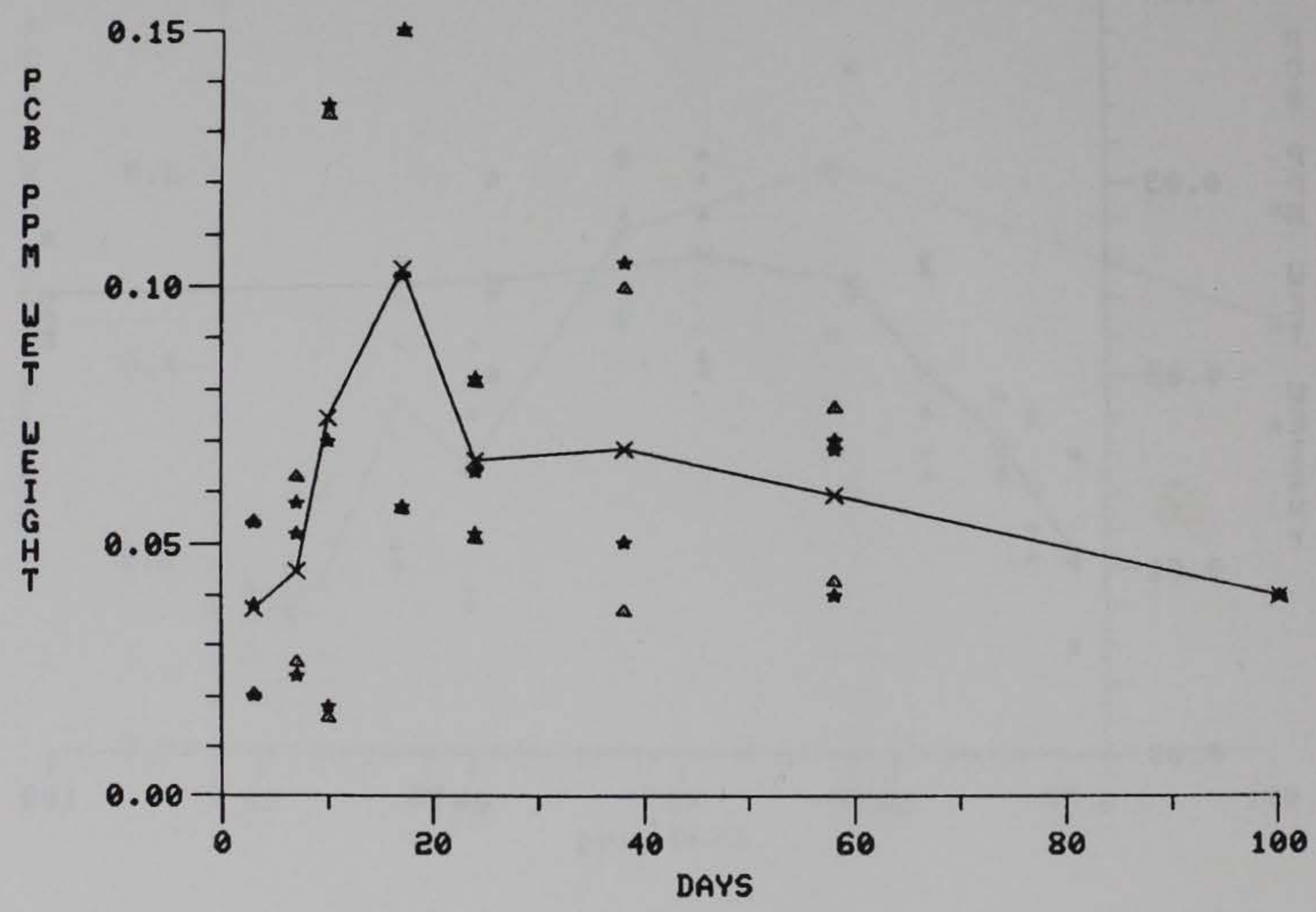

Figure A6. PCB uptake by M. mercenaria from Sediment B.

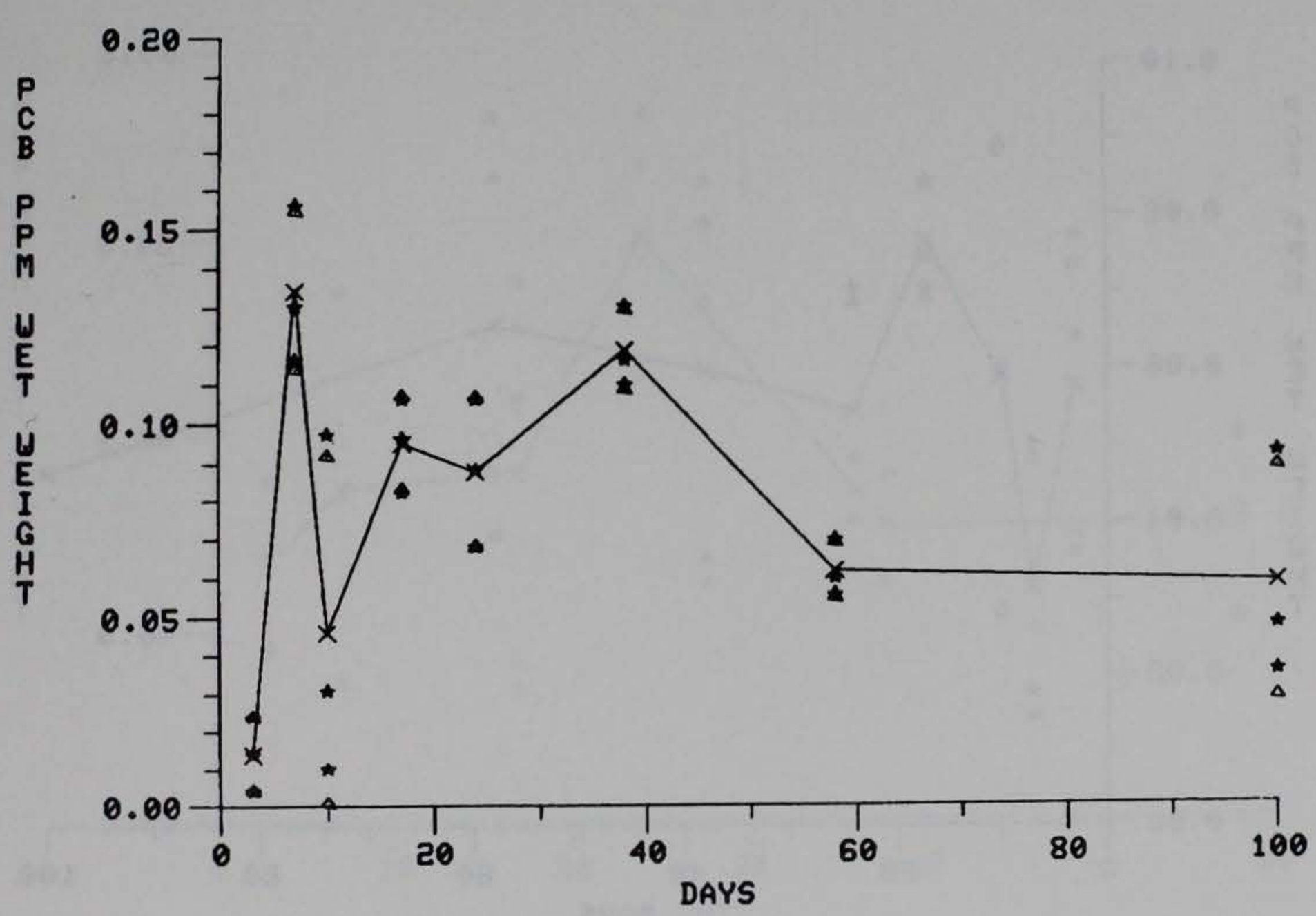

Figure A7. PCB uptake by M. mercenaria from Sediment C.

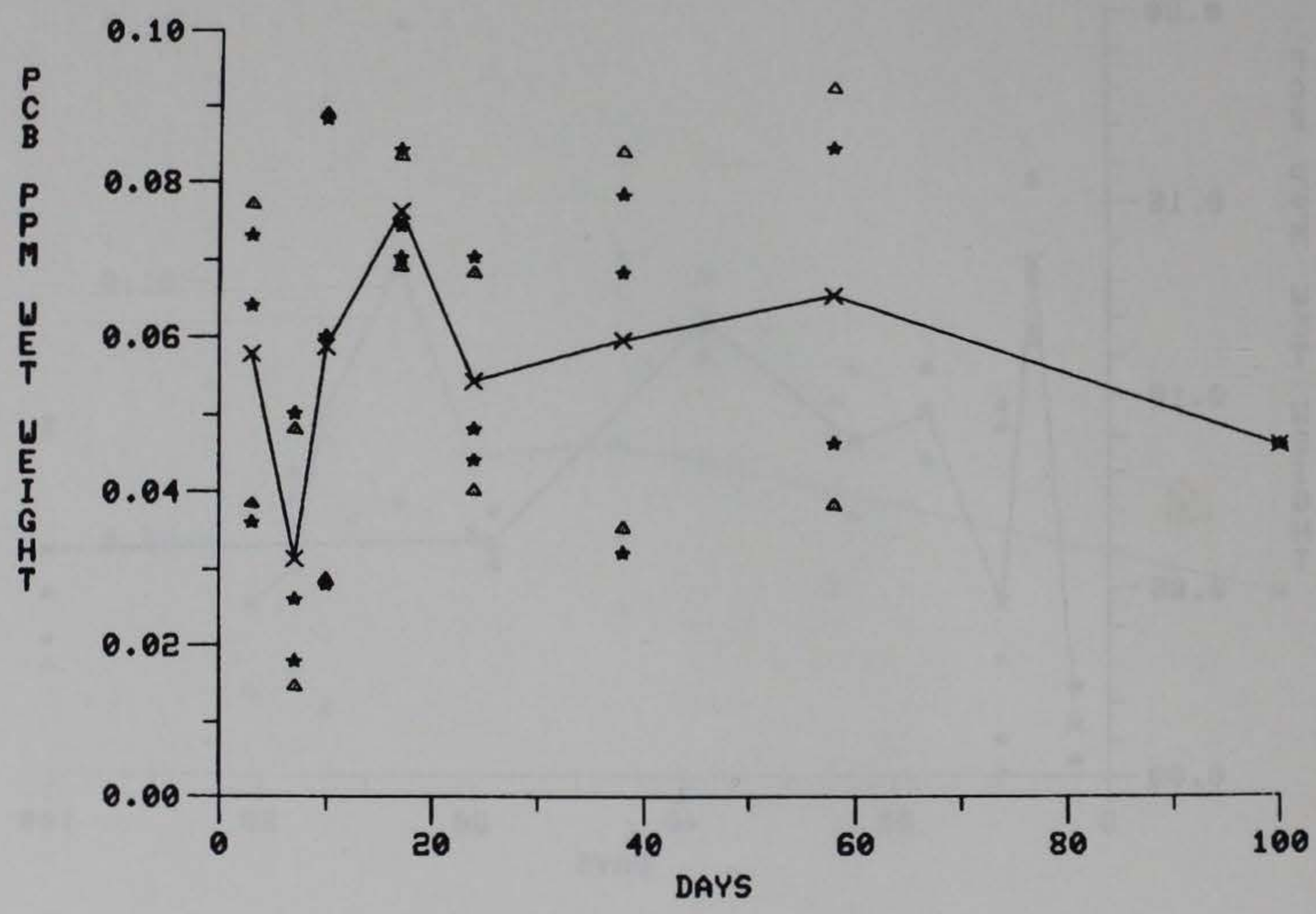

Figure A8. PCB uptake by M. mercenaria from Sediment D.

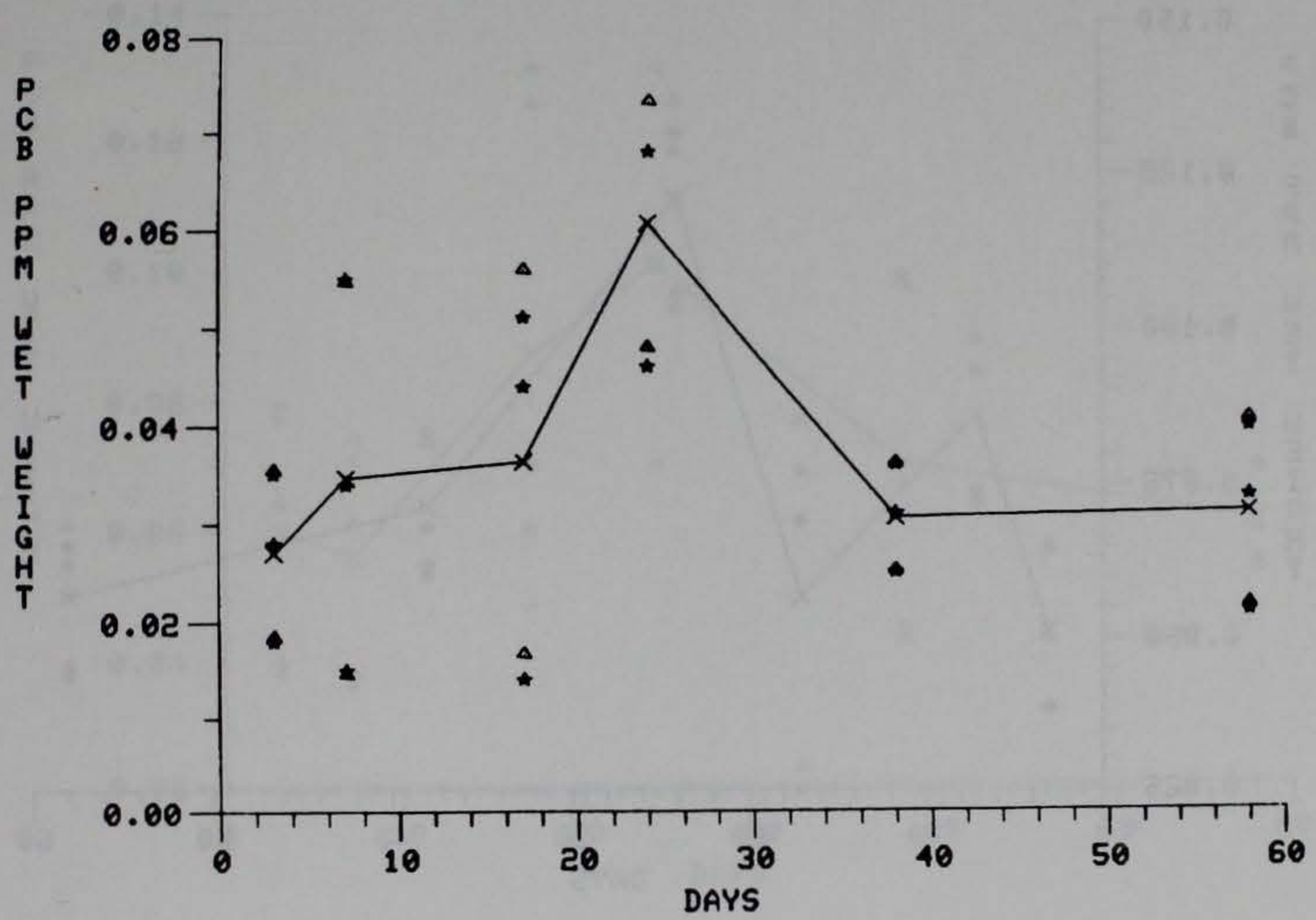

Figure A9. PCB uptake by P. pugio from Sediment A.

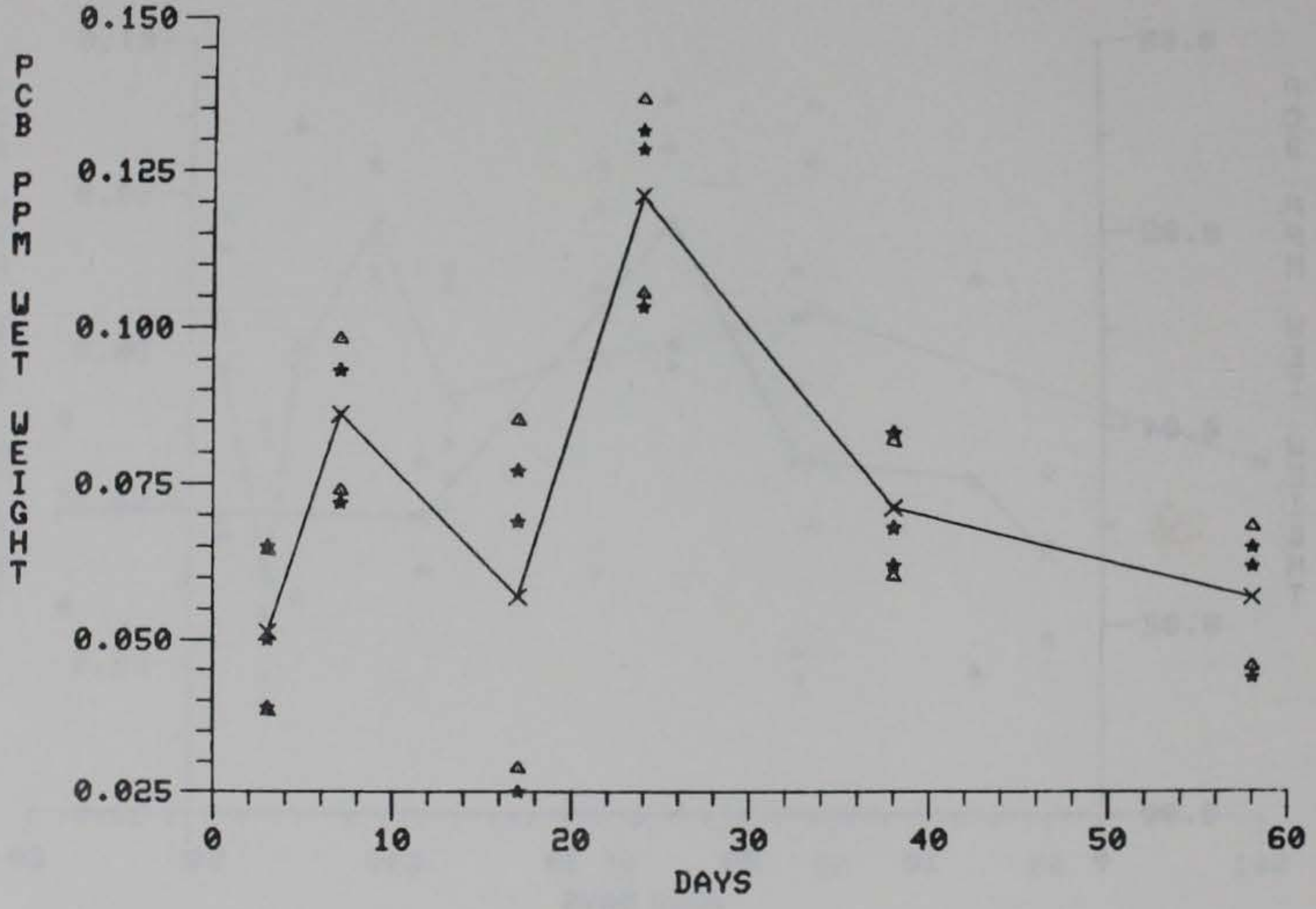

Figure A10. PCB uptake by P. pugio from Sediment B.

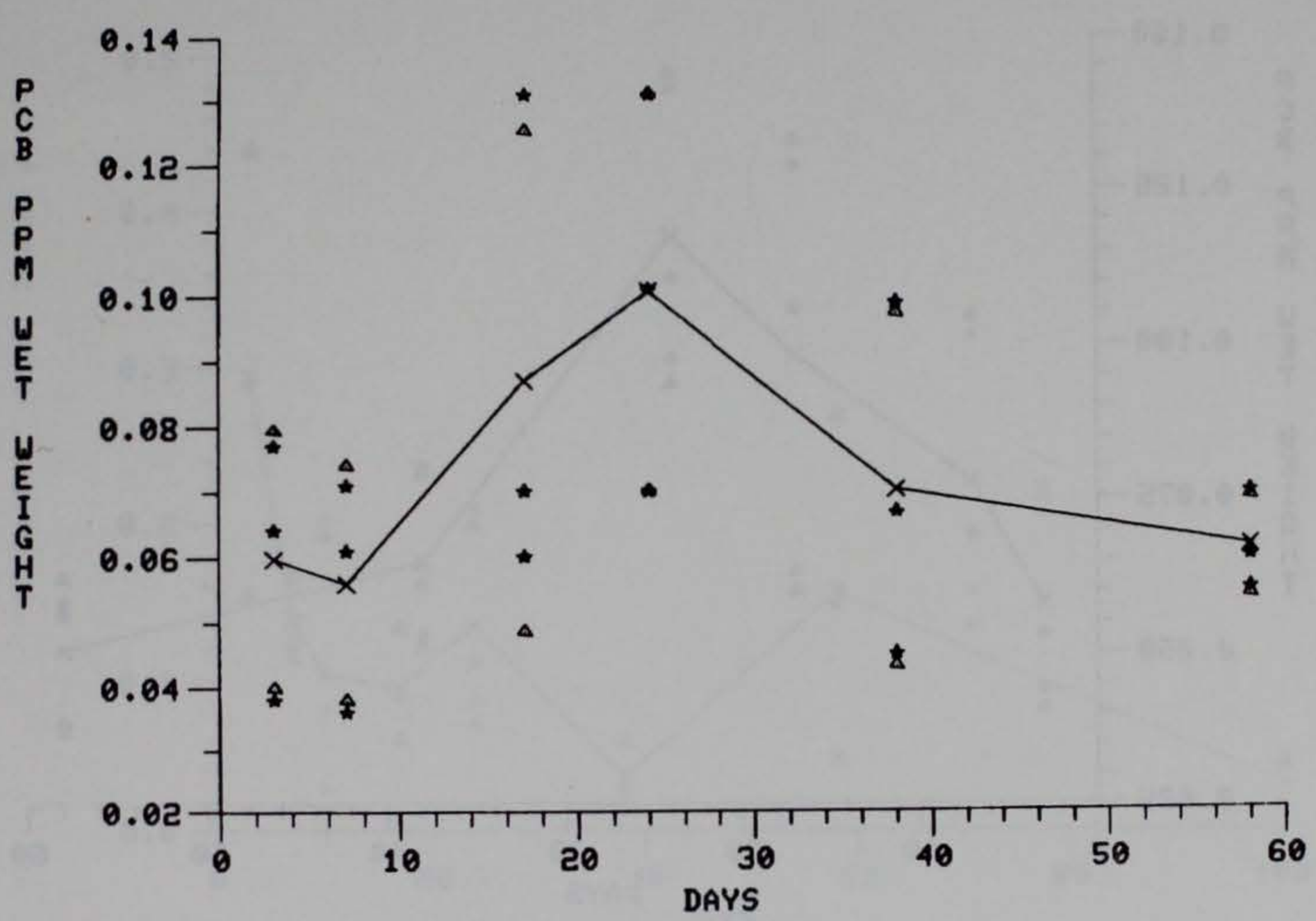

Figure A11. PCB uptake by P. pugio from Sediment C.

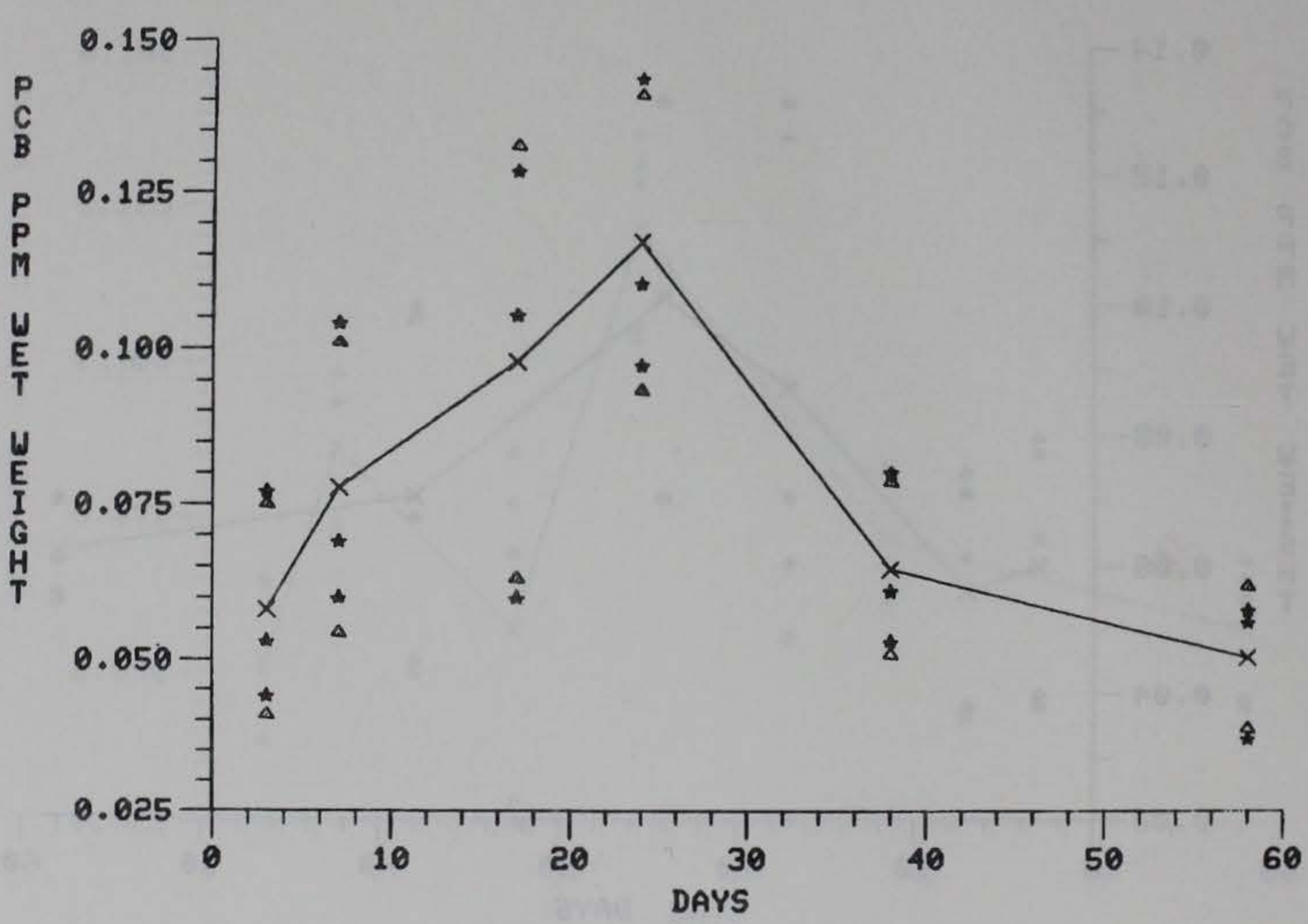

Figure A12. PCB uptake by P. pugio from Sediment D.

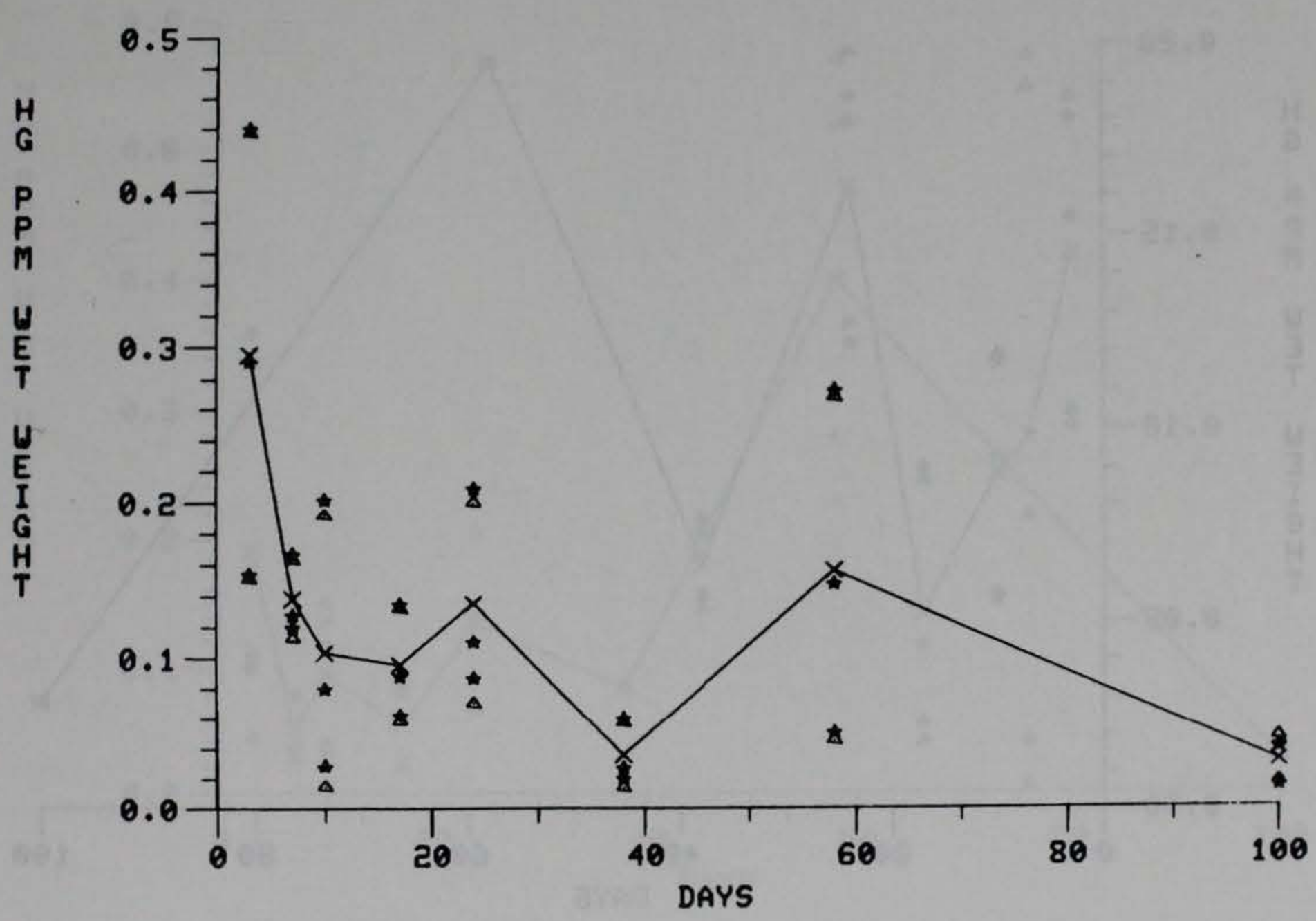

Figure A13. Mercury uptake by N. virens from Sediment A.

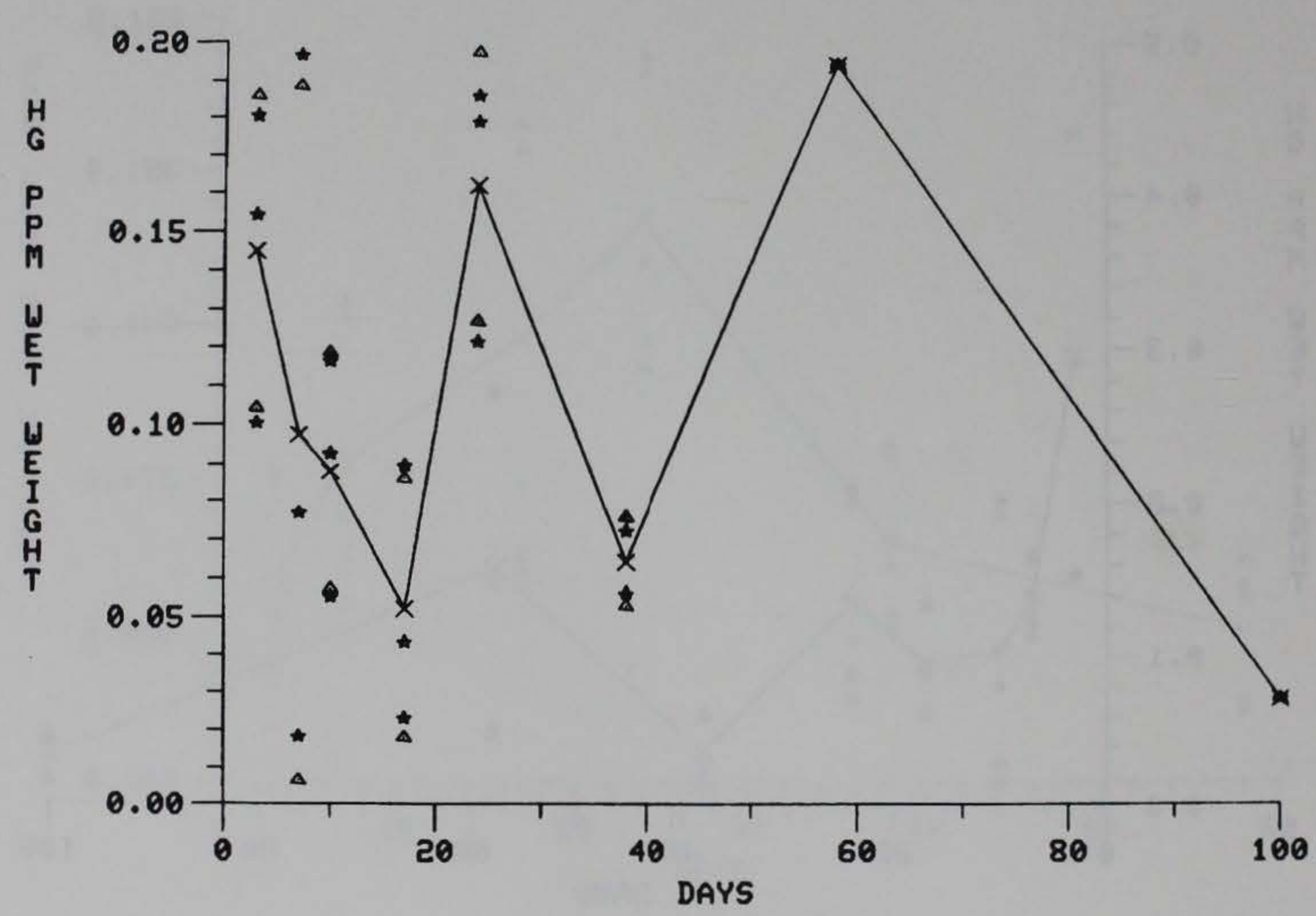

Figure A14. Mercury uptake by N. virens from Sediment B.

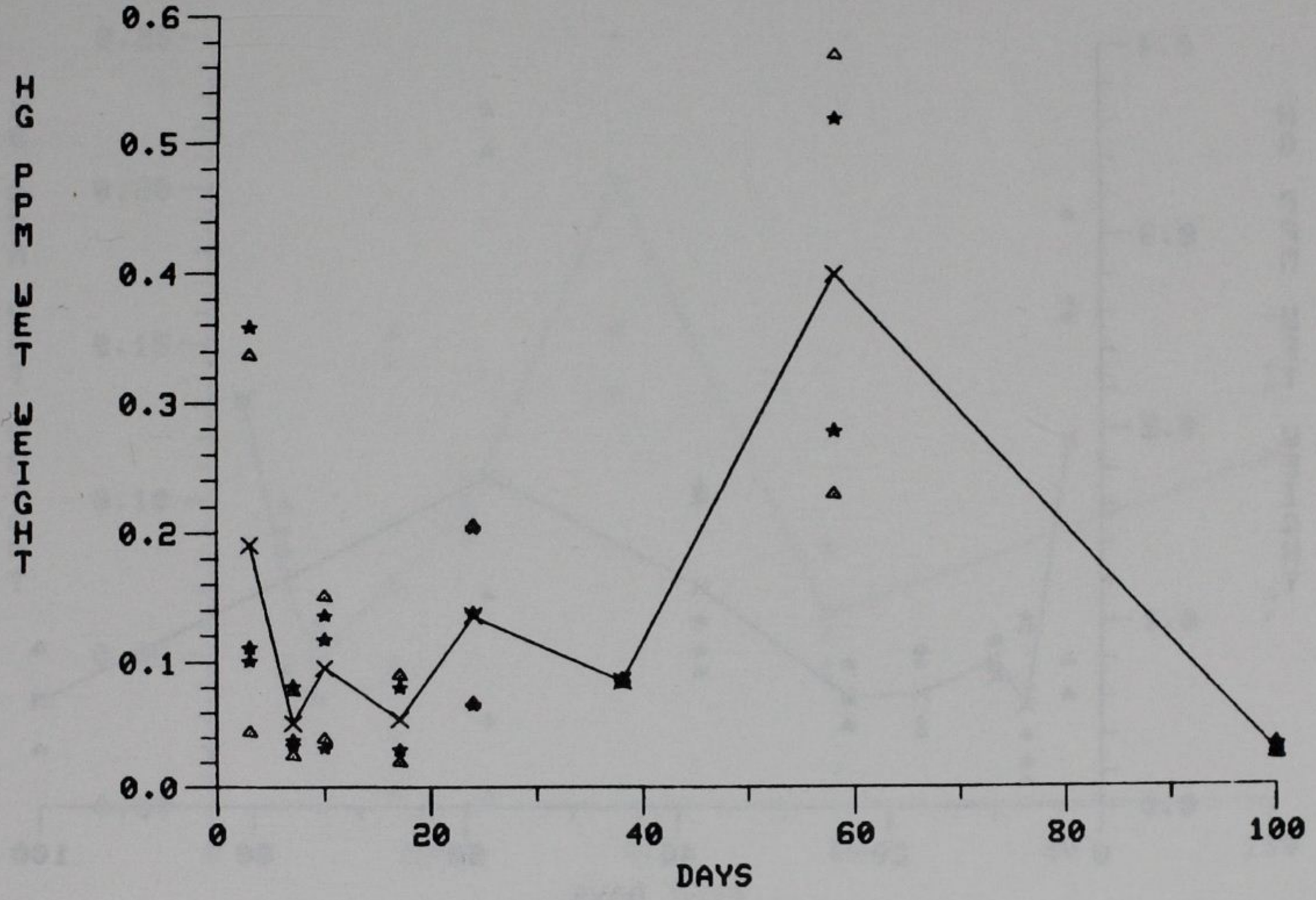

Figure A15. Mercury uptake by N. virens from Sediment C.

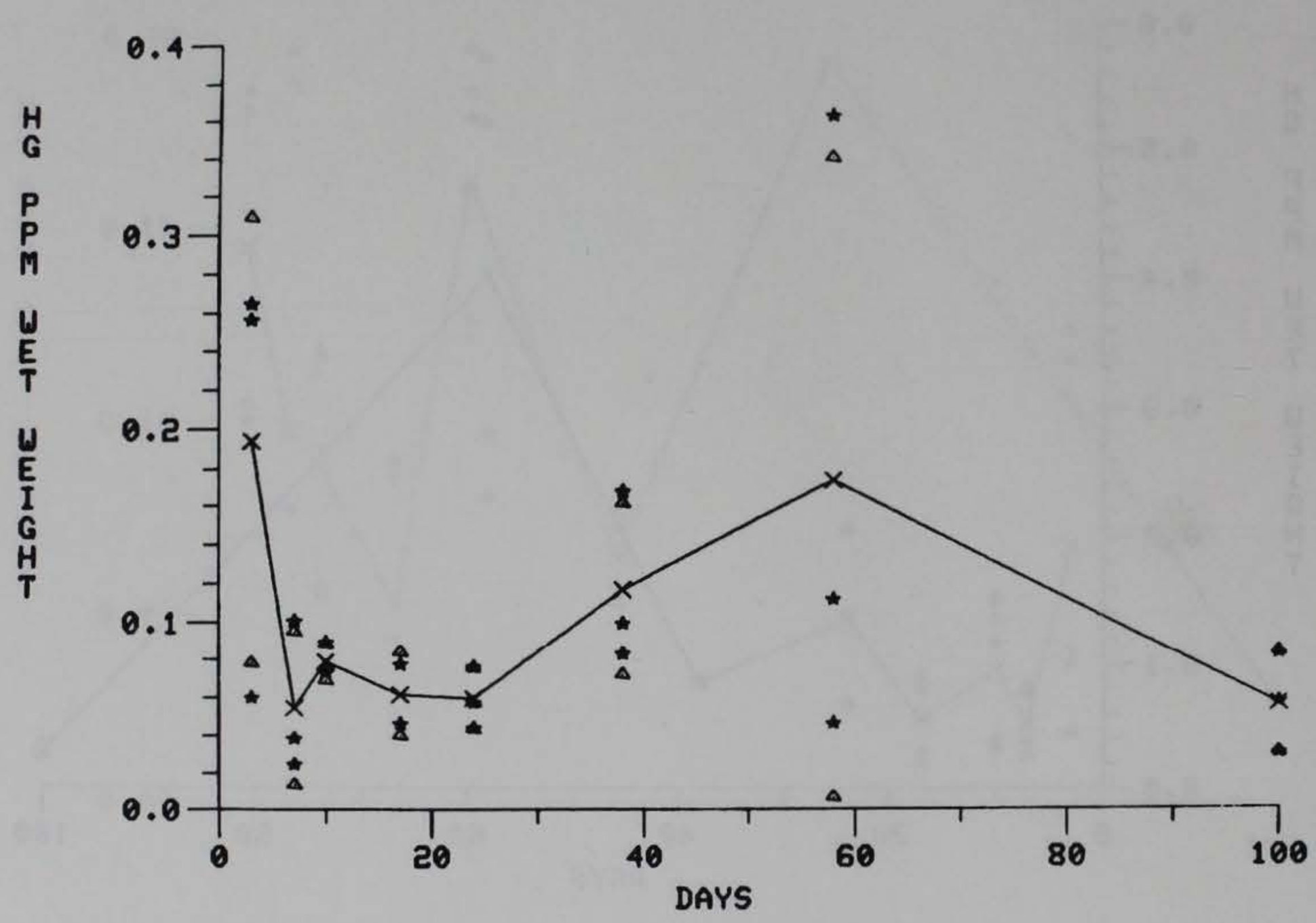

Figure A16. Mercury uptake by N. virens from Sediment D.

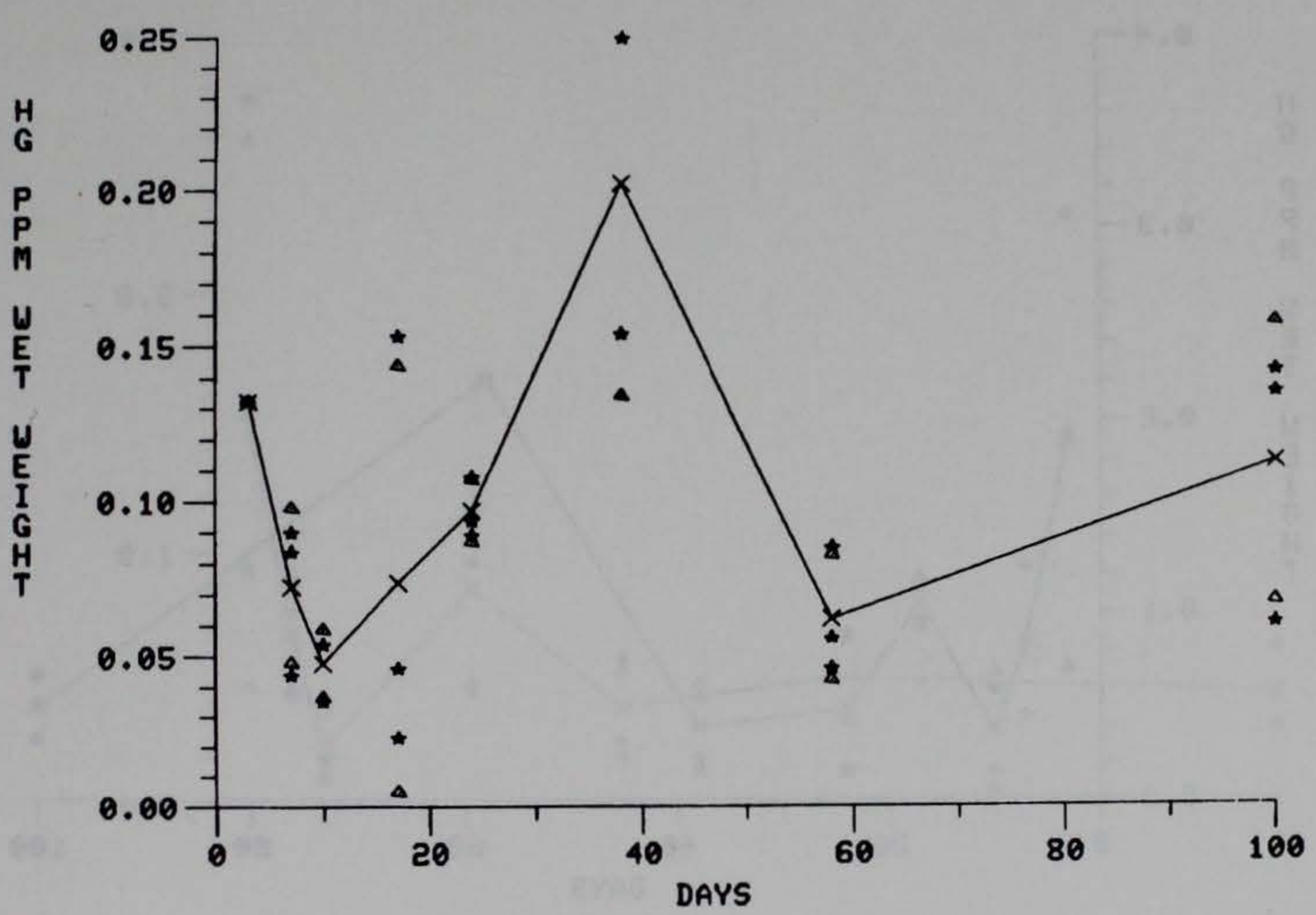

Figure A17. Mercury uptake by M. mercenaria from Sediment A.

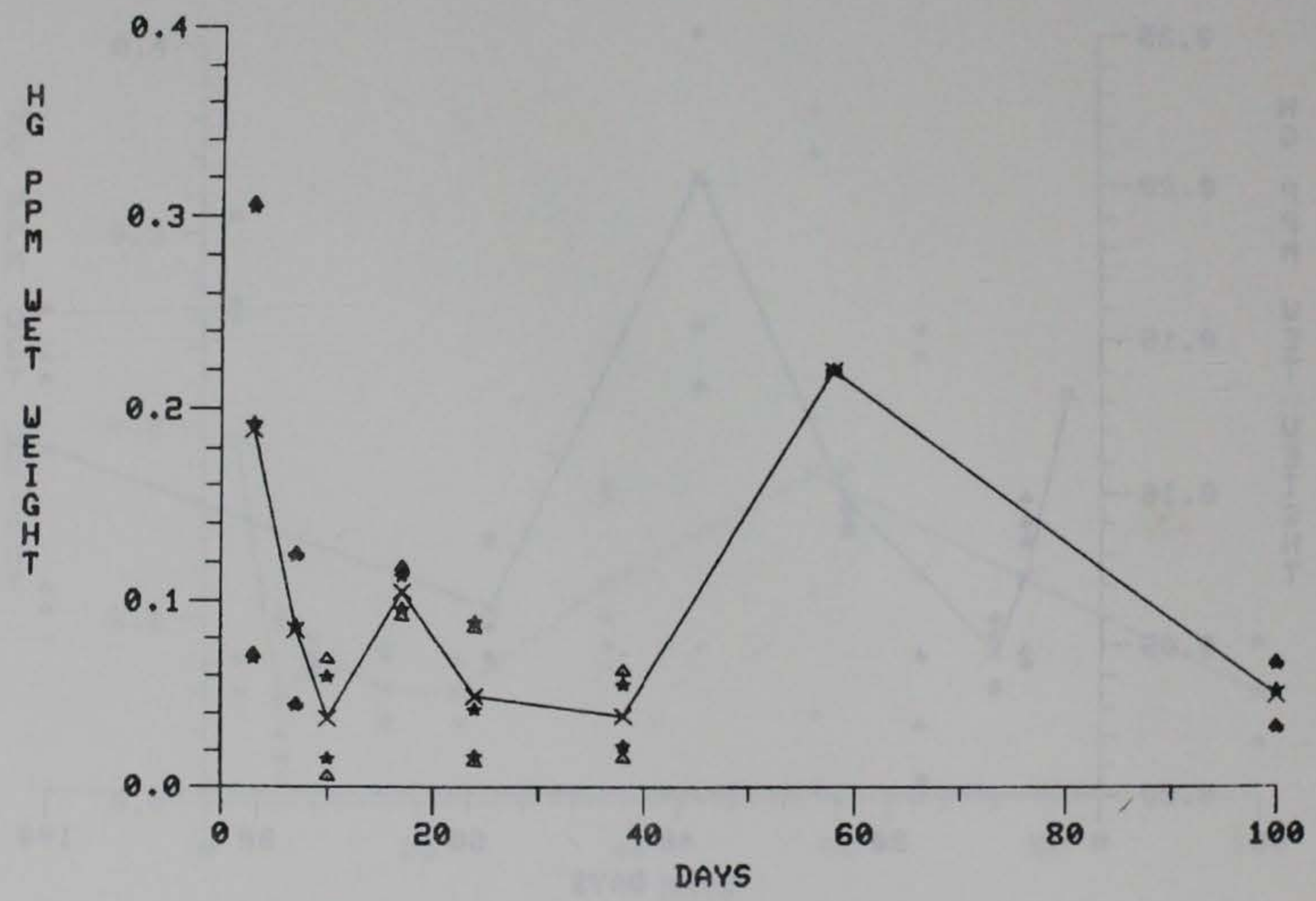

Figure A18. Mercury uptake by M. mercenaria from Sediment B.

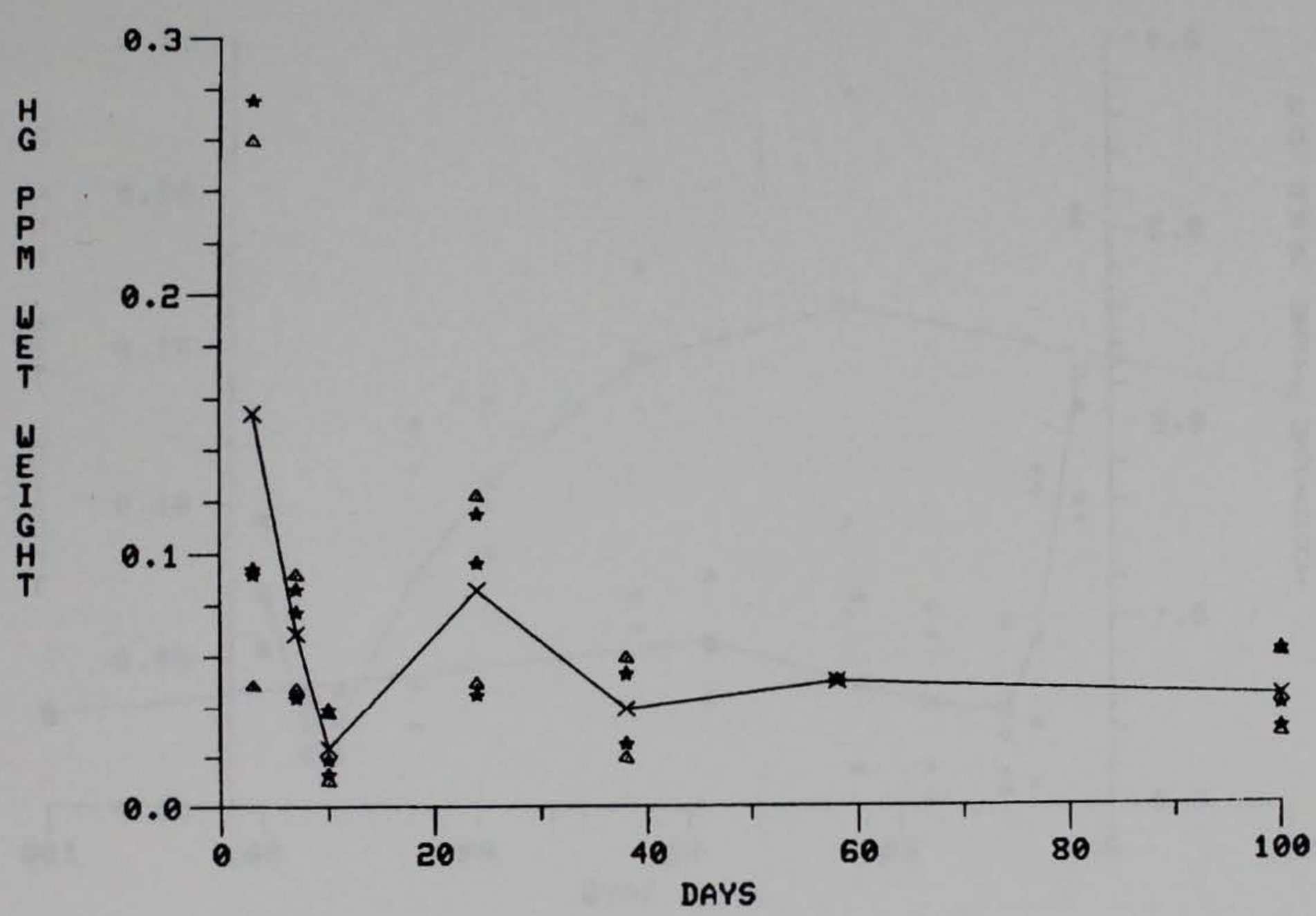

Figure A19. Mercury uptake by M. mercenaria from Sediment C.

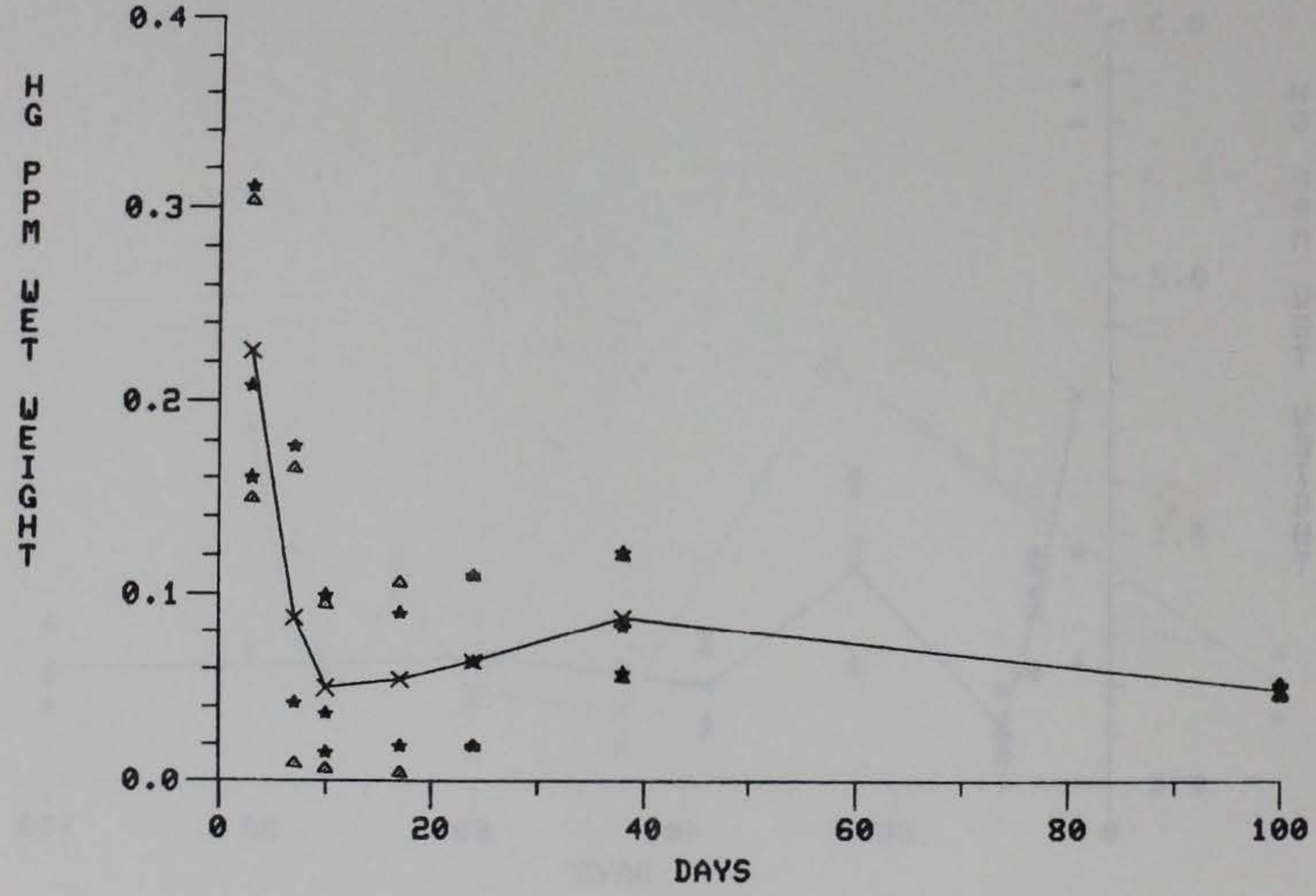

Figure A20. Mercury uptake by M. mercenaria from Sediment D.

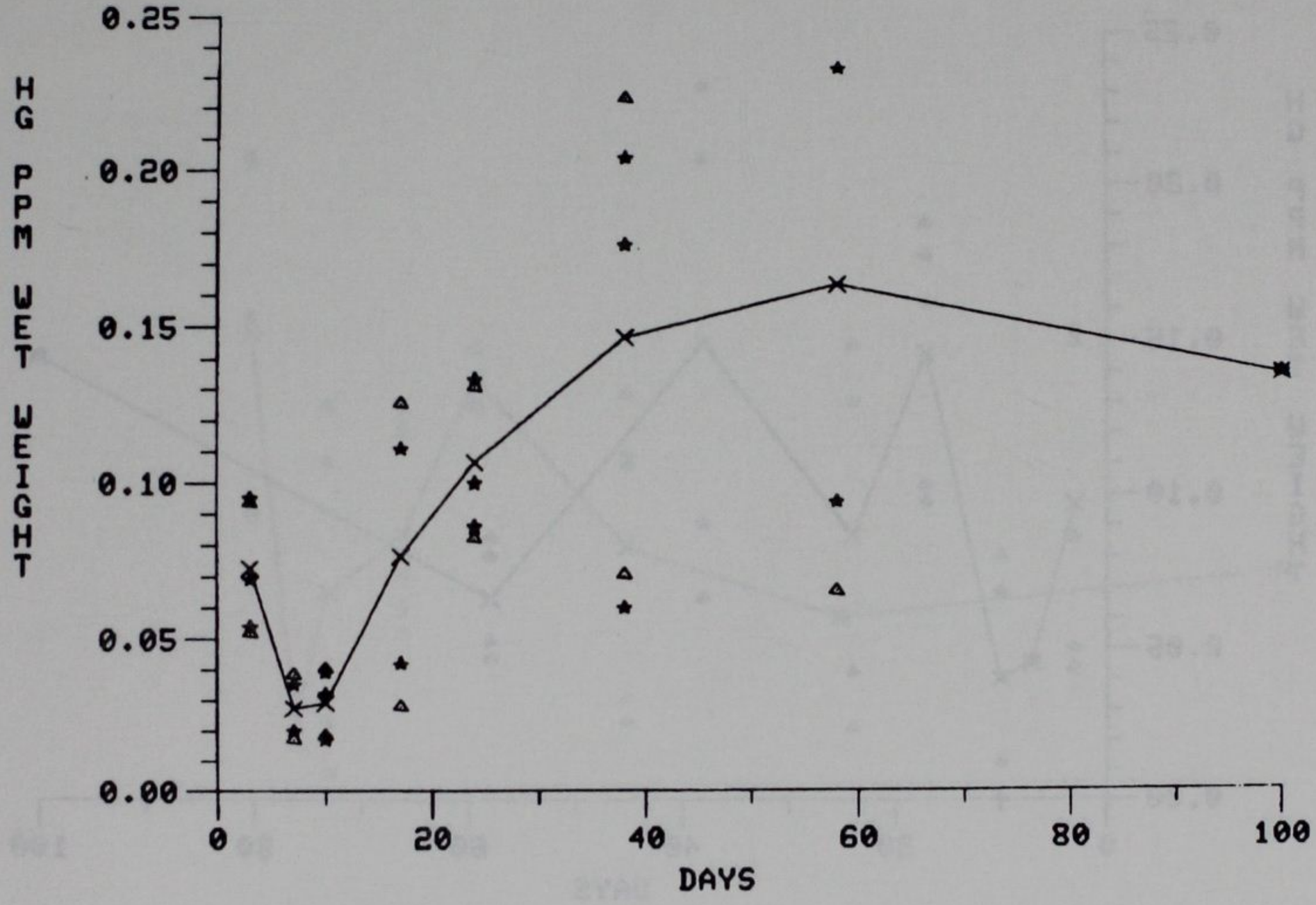

Figure A21. Mercury uptake by P. pugio from Sediment A.

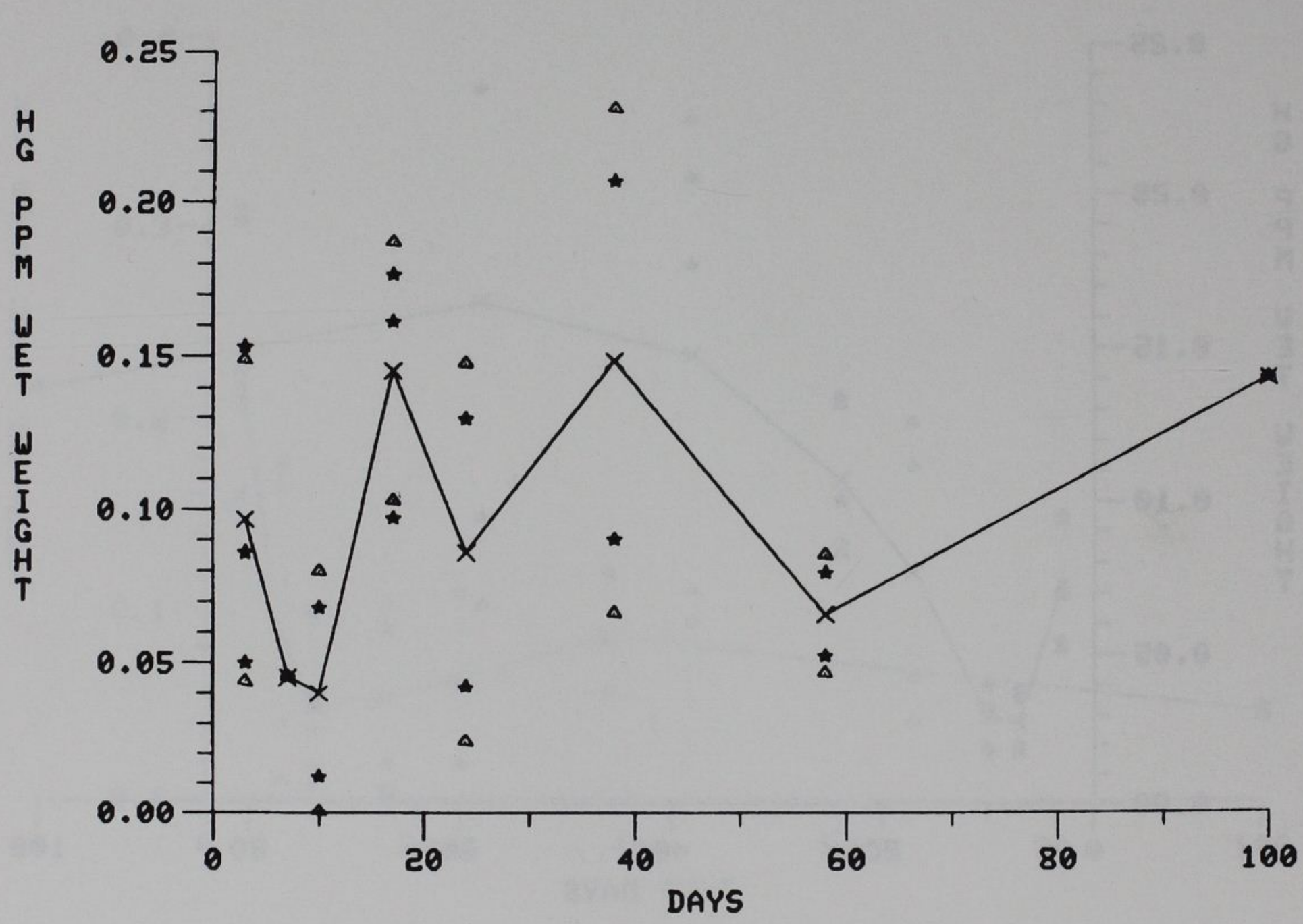

Figure A22. Mercury uptake by P. pugio from Sediment B.

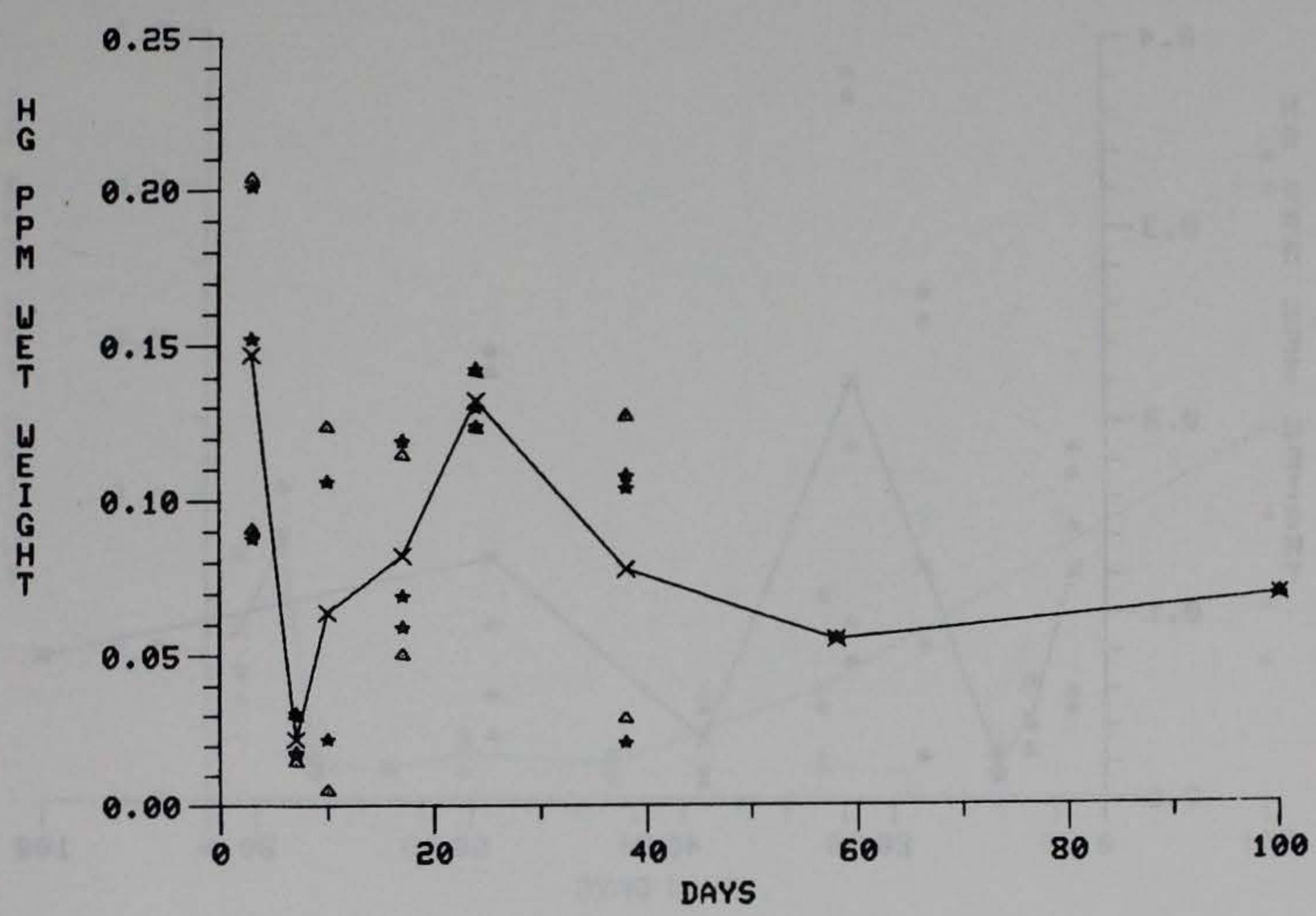

Figure A23. Mercury uptake by P. pugio from Sediment C.

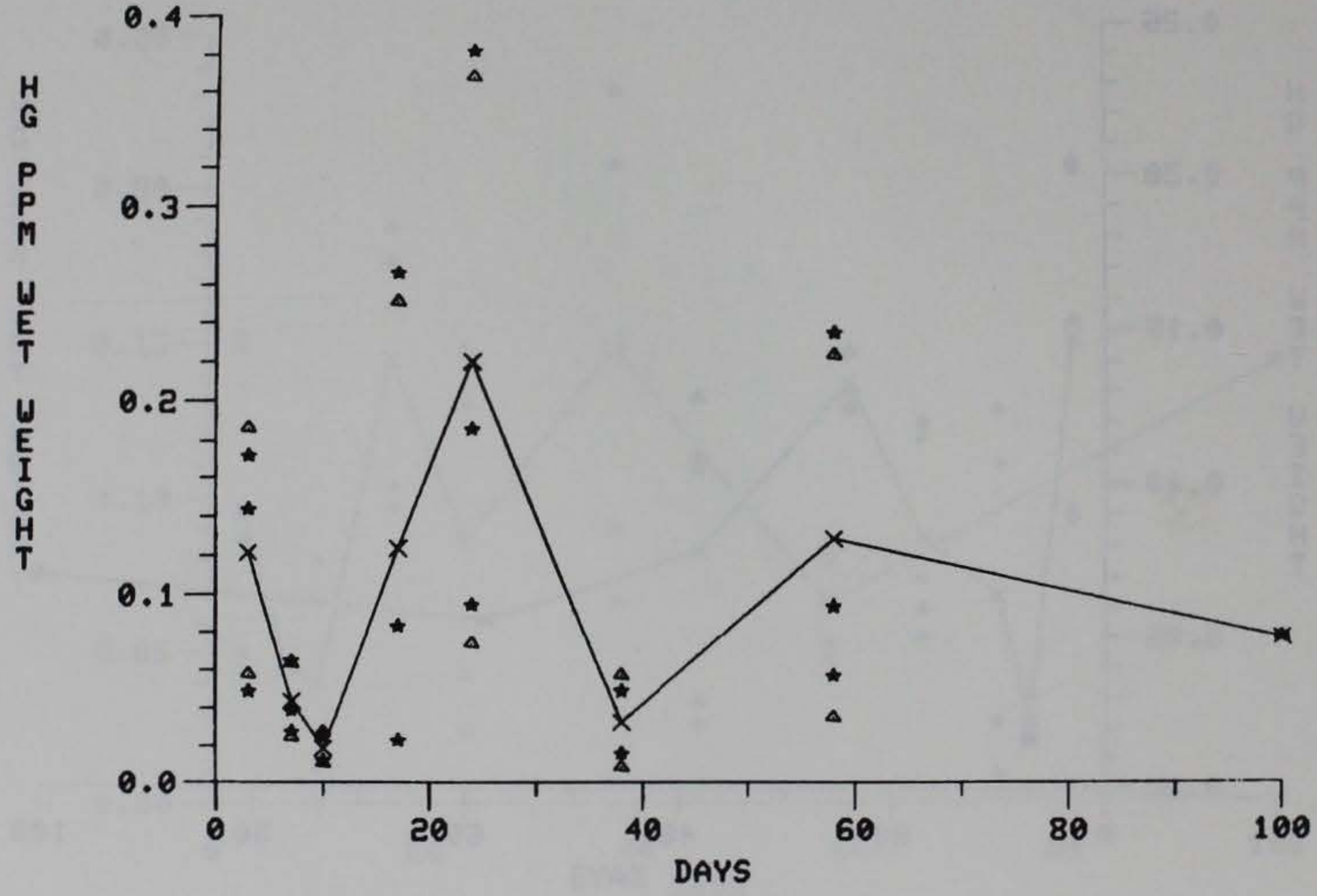

Figure A24. Mercury uptake by P. pugio from Sediment D.

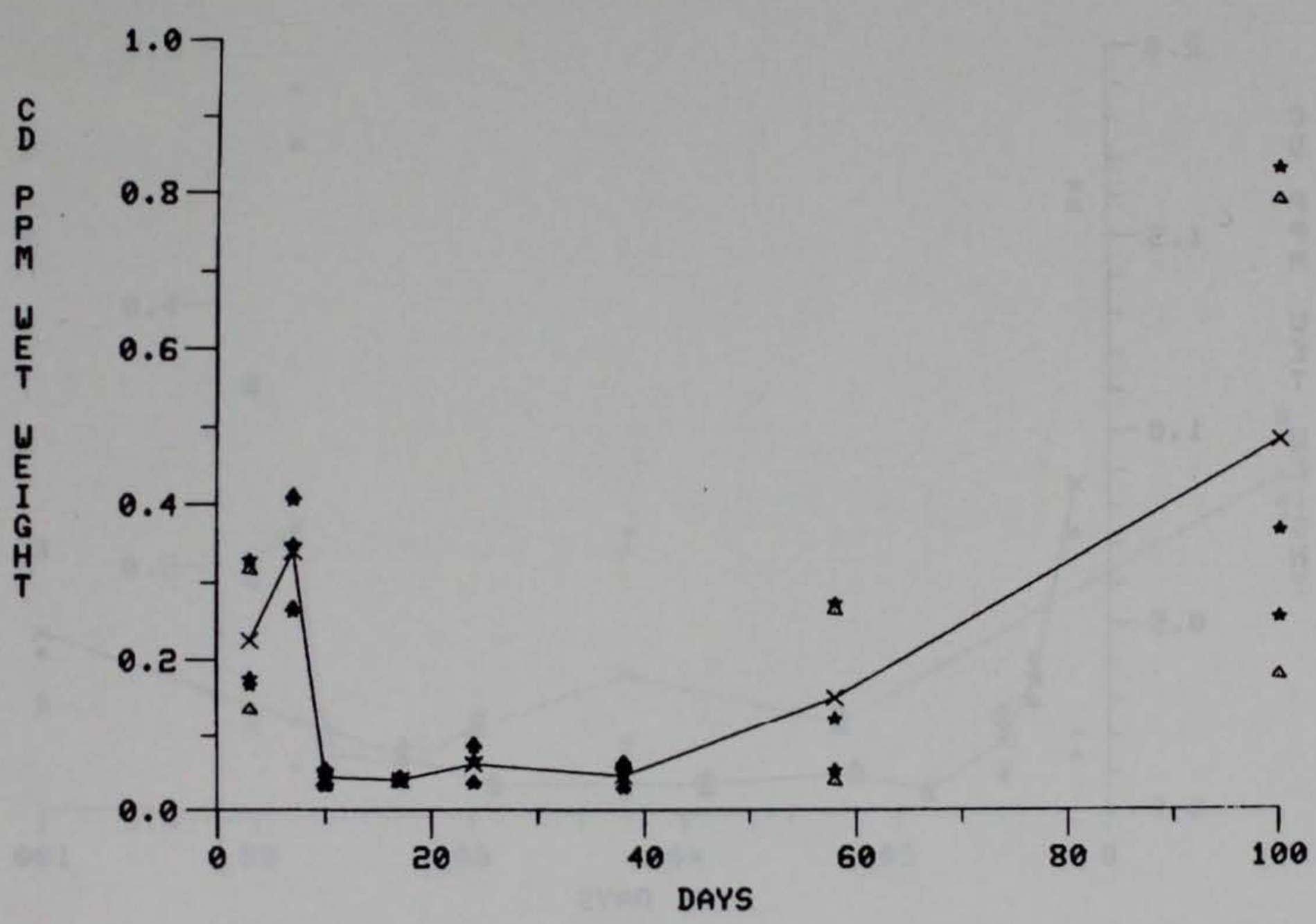

Figure A25. Cadmium uptake by N. virens from Sediment A.

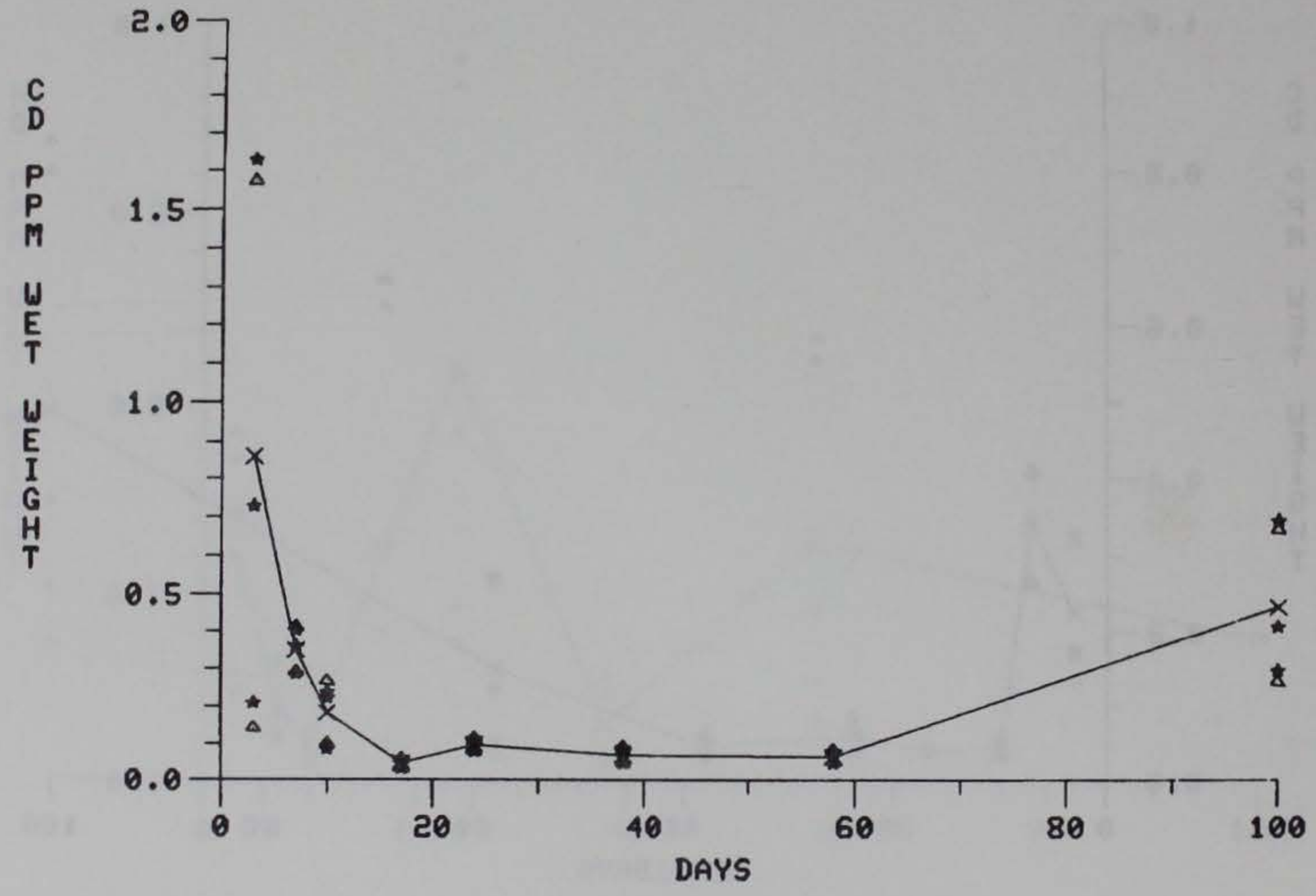

Figure A26. Cadmium uptake by N. virens from Sediment B.

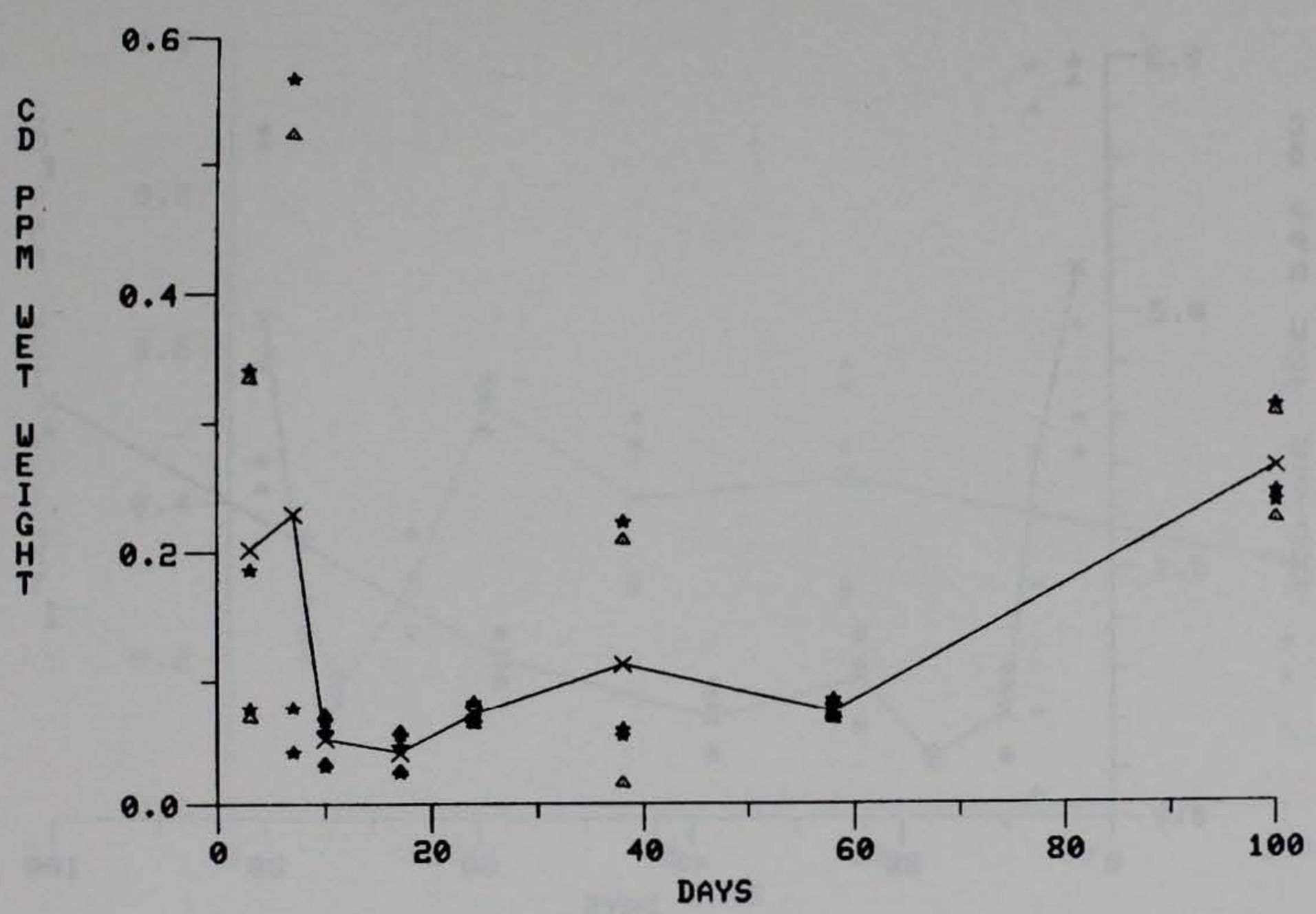

Figure A27. Cadmium uptake by N. virens from Sediment C.

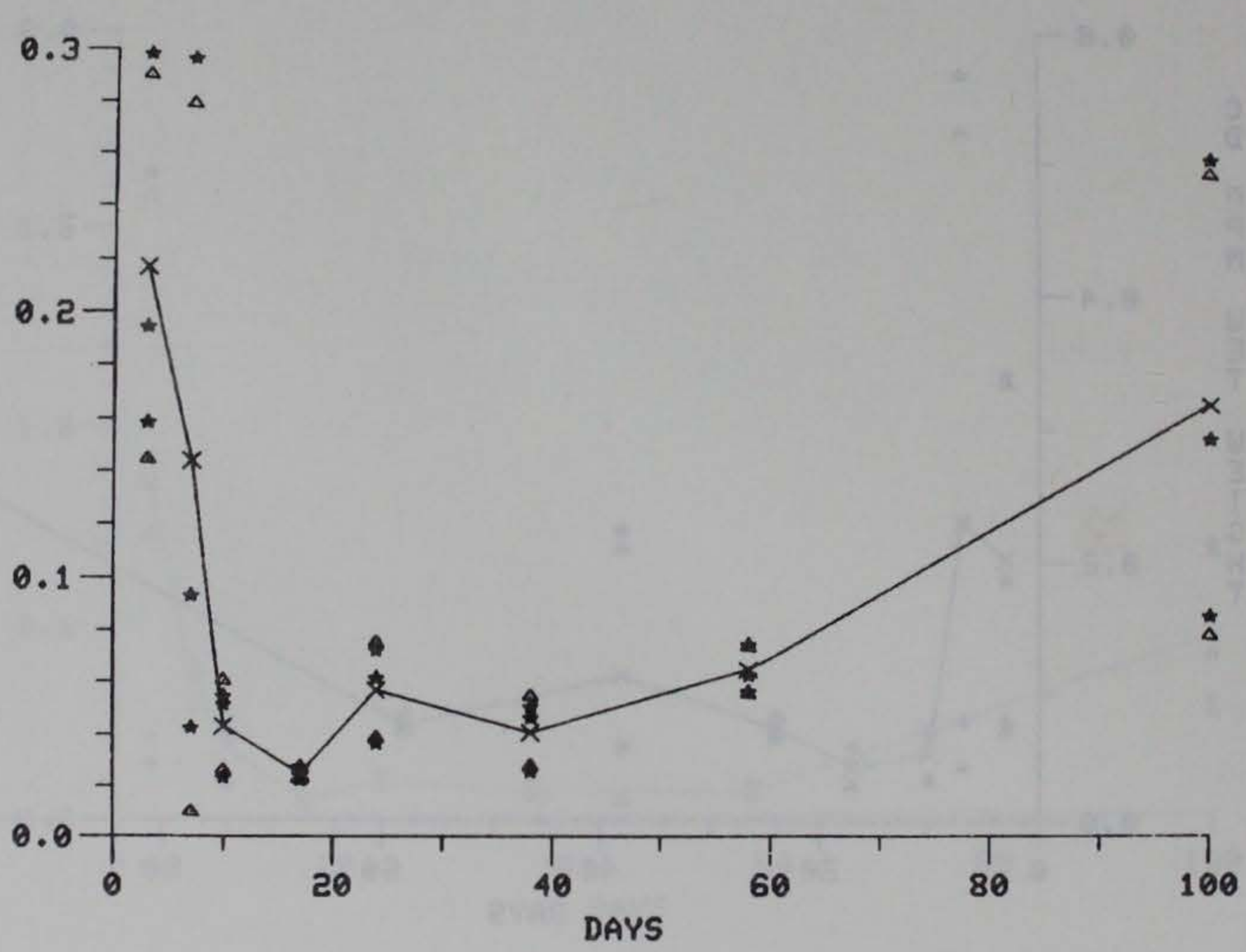

Figure A28. Cadmium uptake by N. virens from Sediment D.

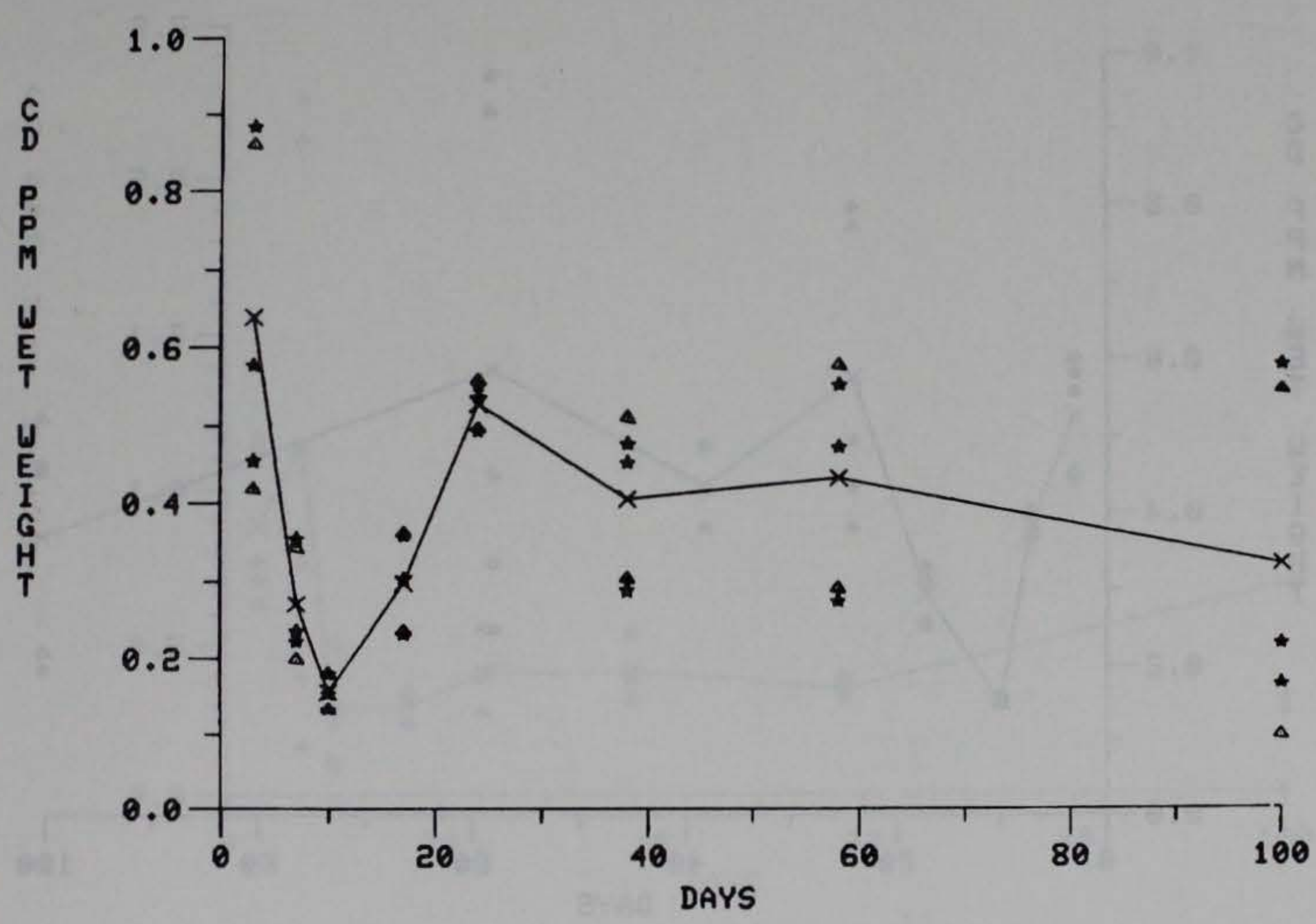

Figure A29. Cadmium uptake by M. mercenaria from Sediment A.

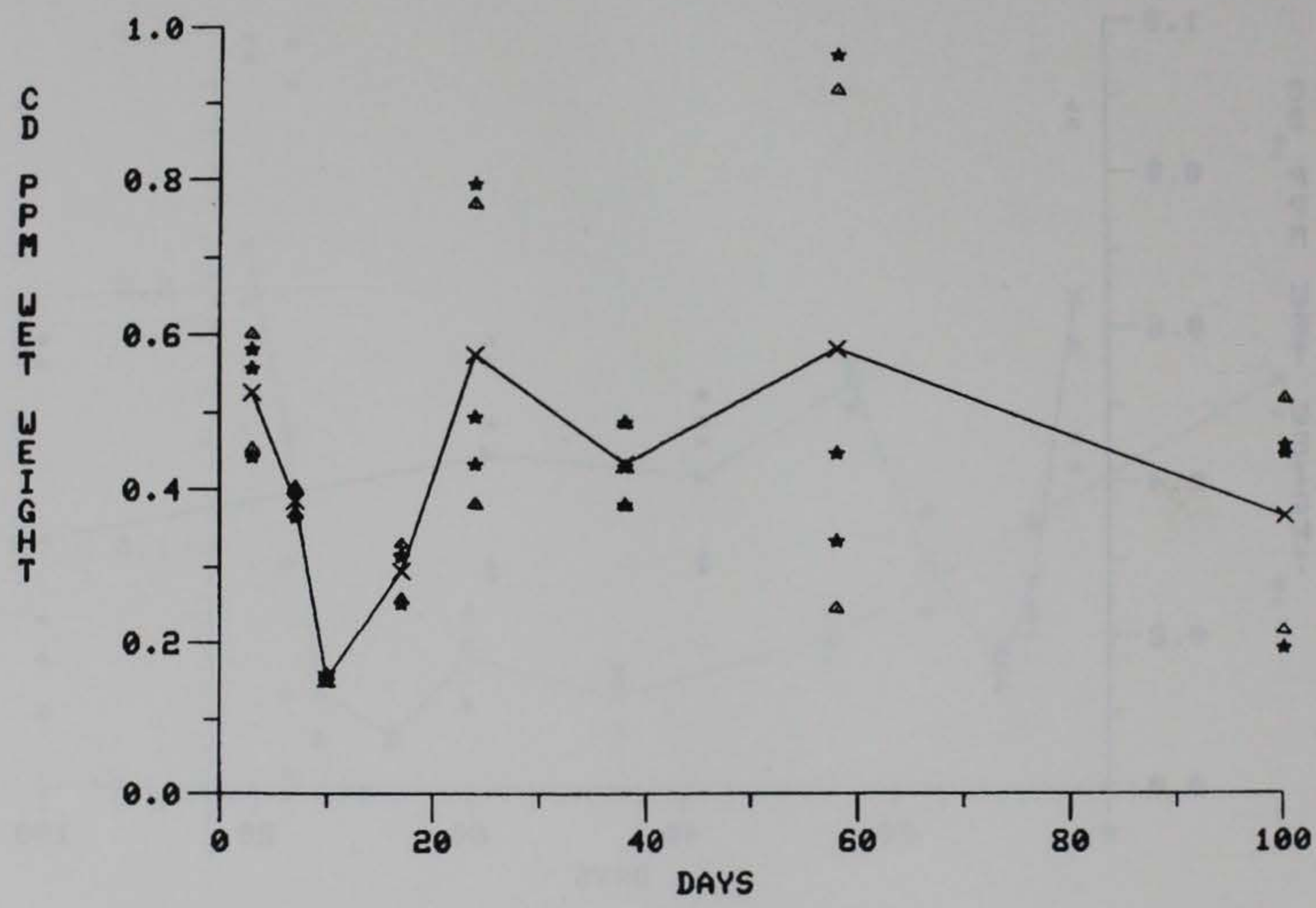

Figure A30. Cadmium uptake by M. mercenaria from Sediment B.

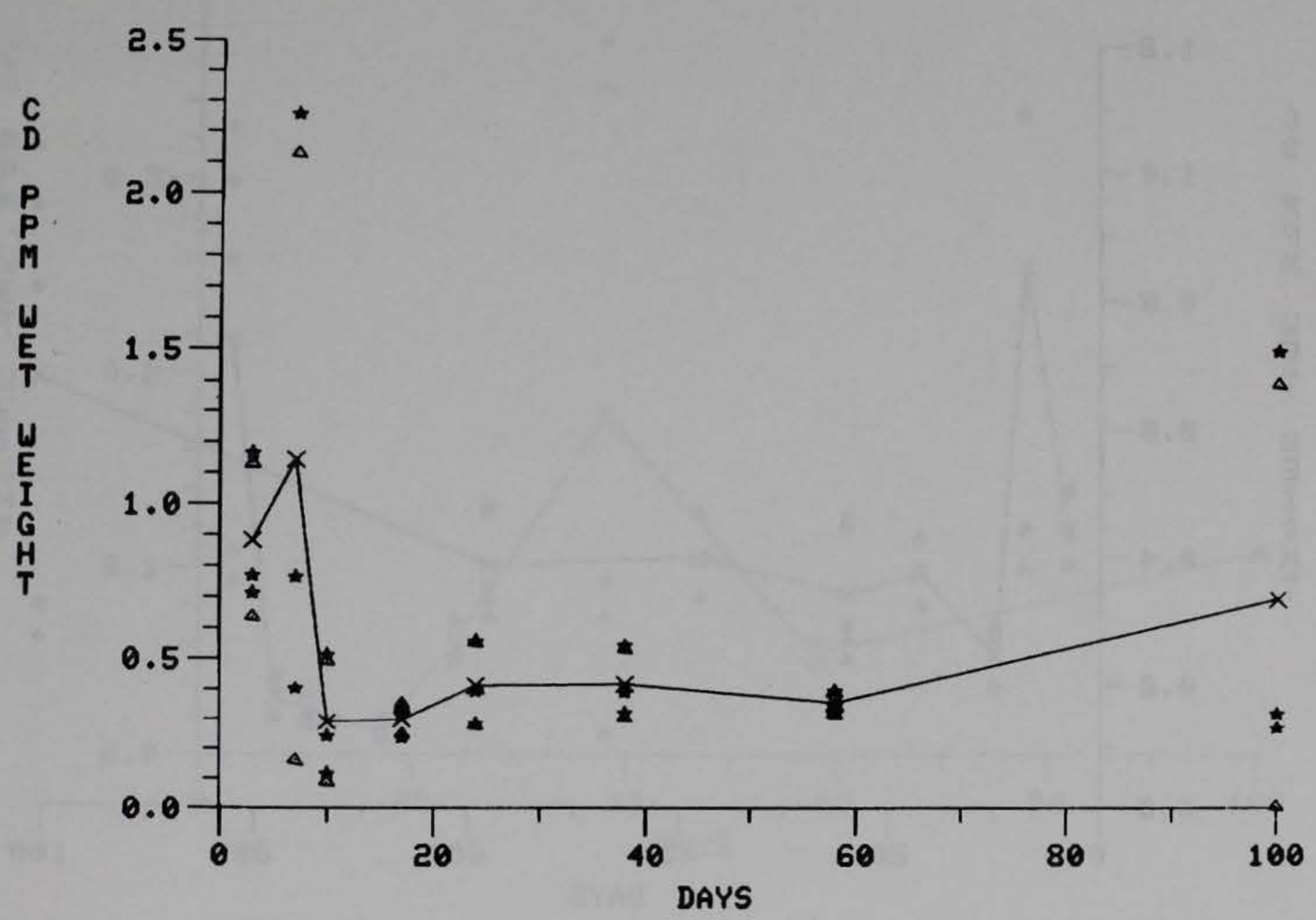

Figure A31. Cadmium uptake by M. mercenaria from Sediment C.

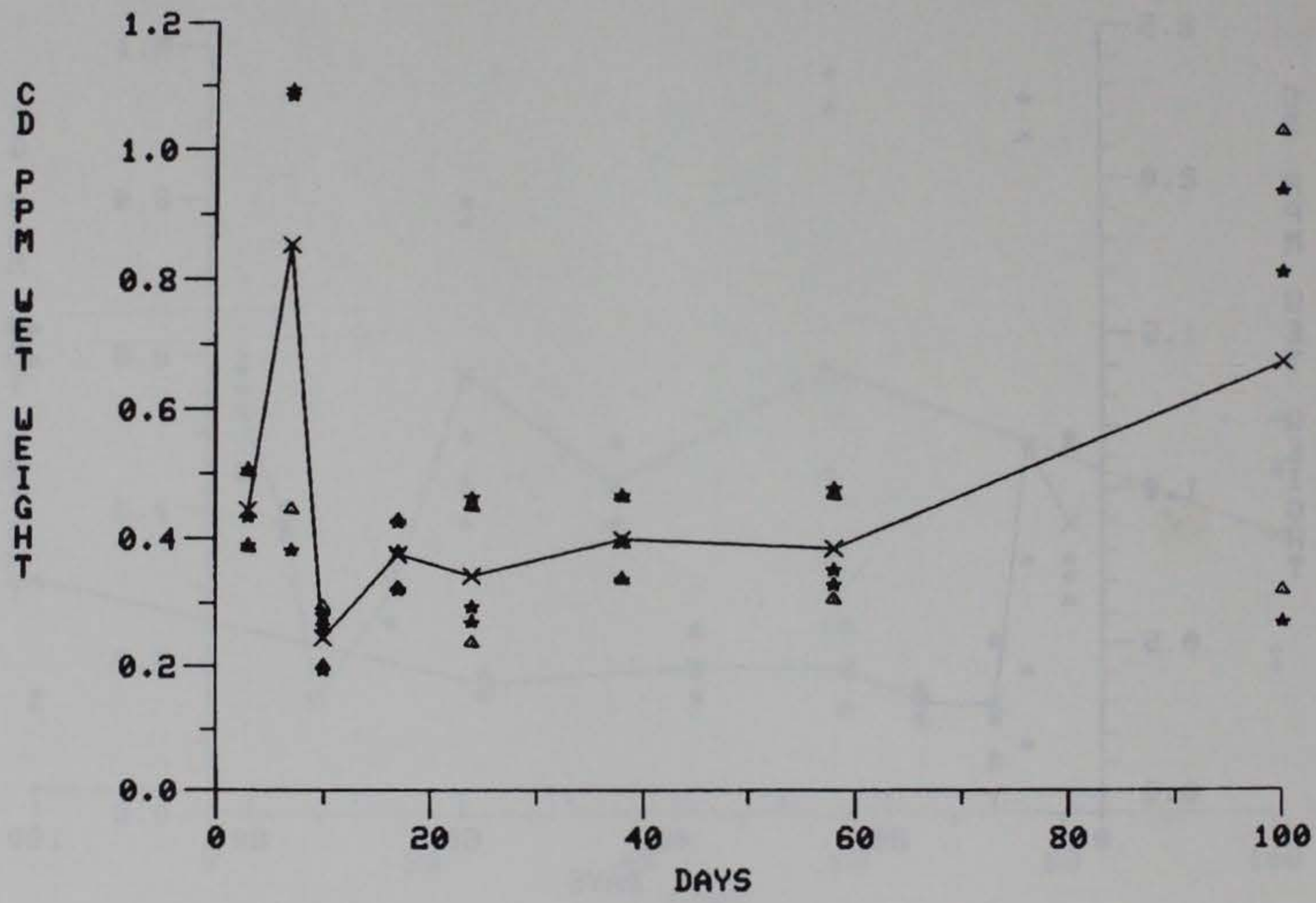

Figure A32. Cadmium uptake by M. mercenaria from Sediment D.

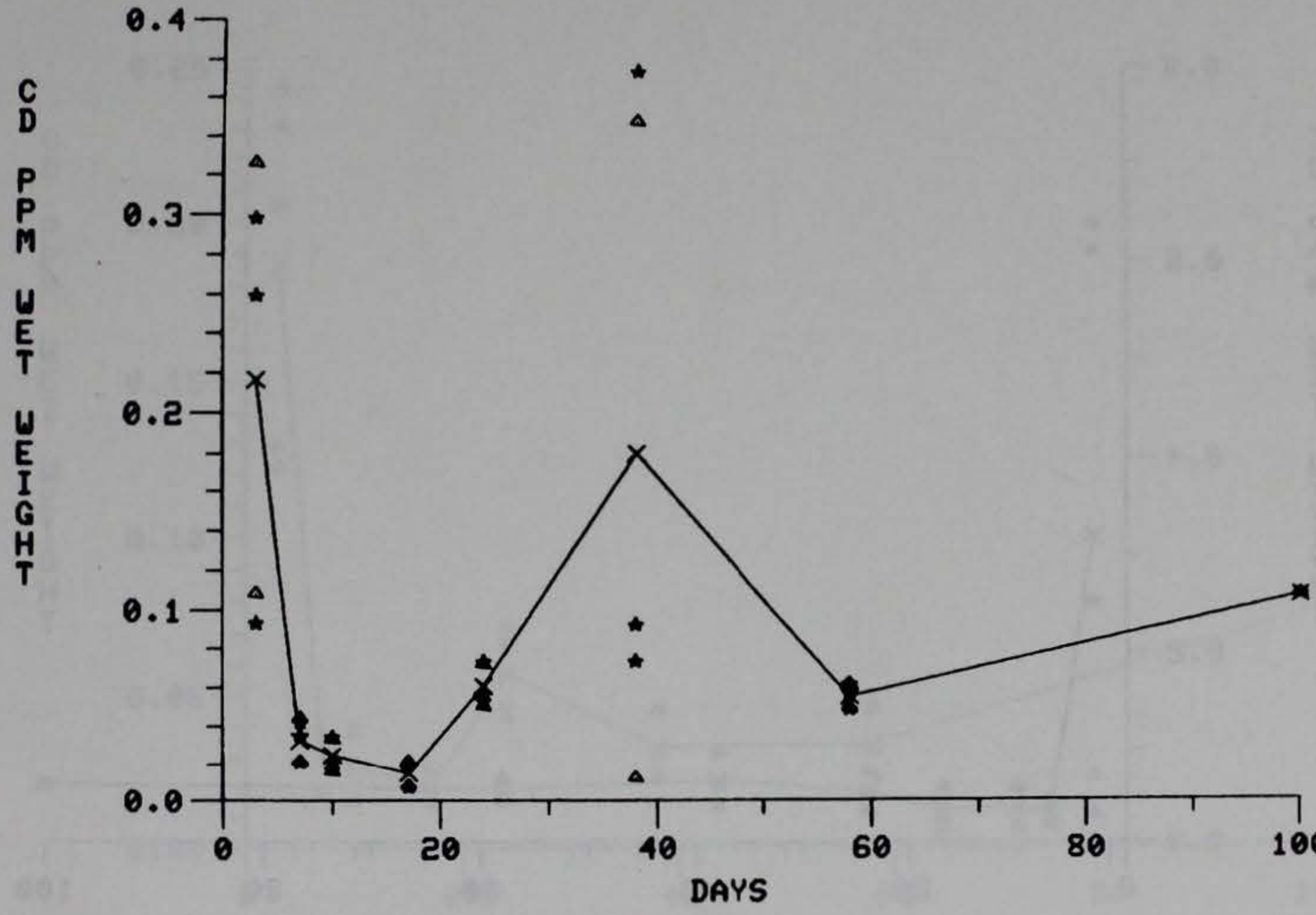

Figure A33. Cadmium uptake by P. pugio from Sediment A.

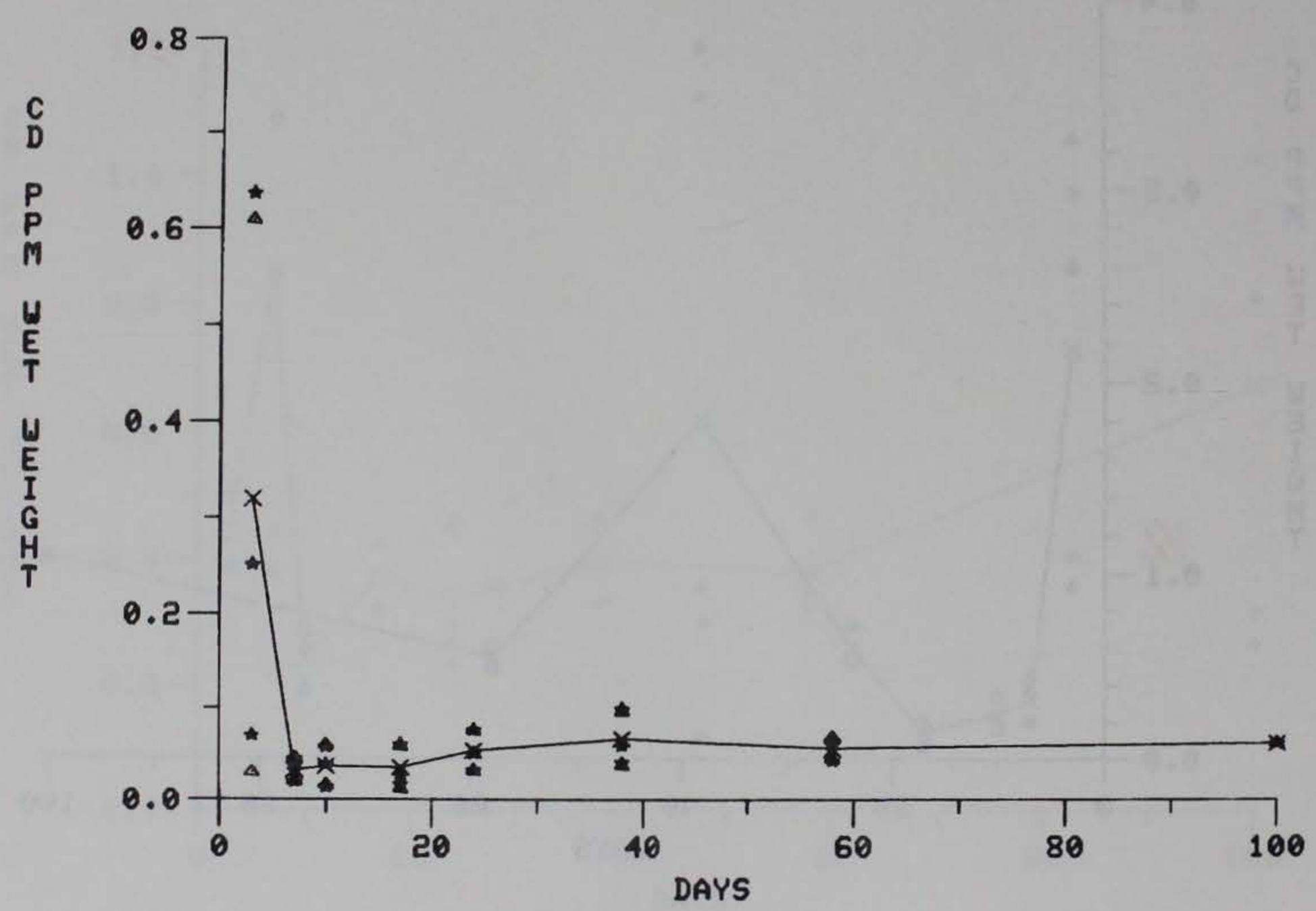

Figure A34. Cadmium uptake by P. pugio from Sediment B.

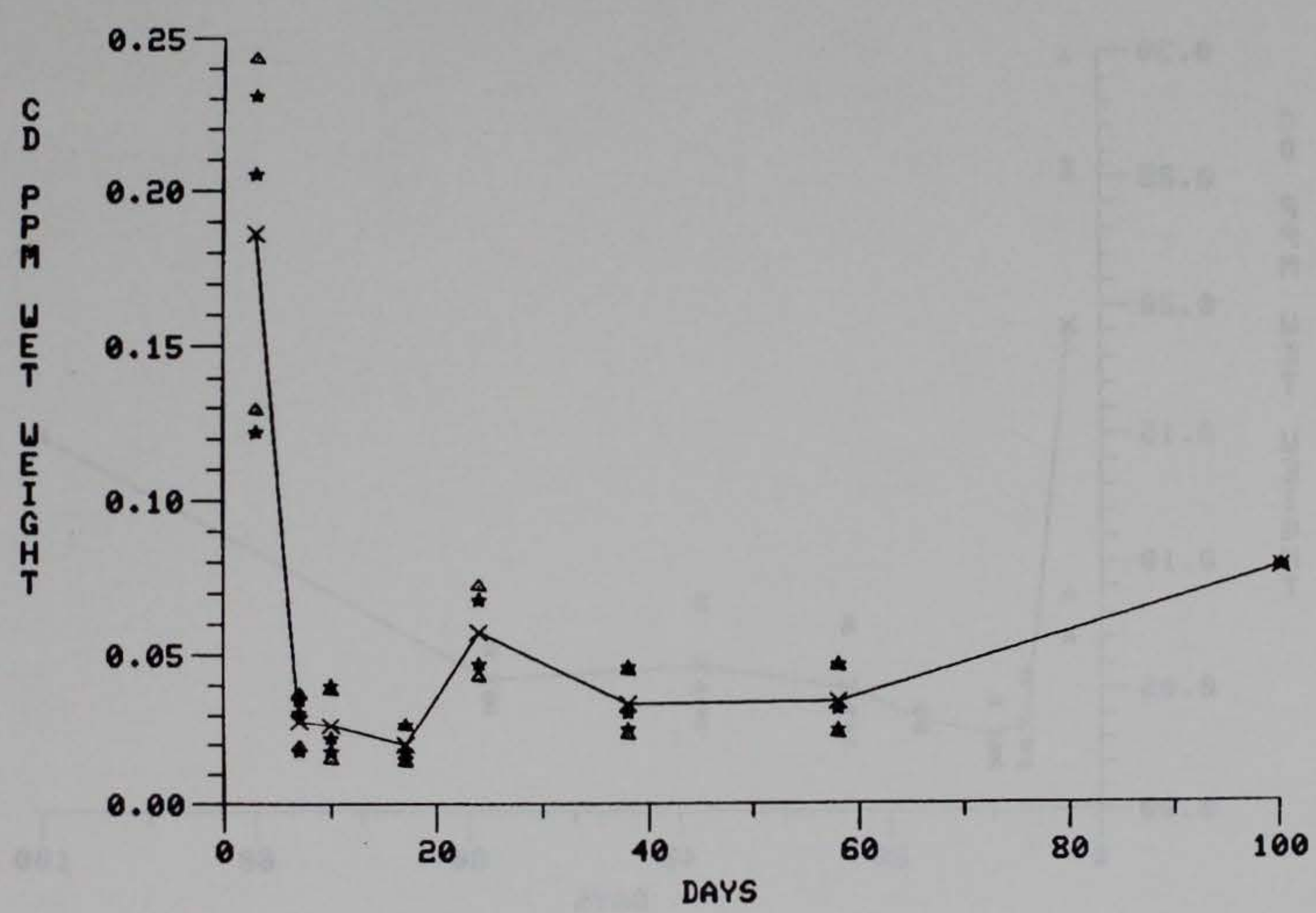

Figure A35. Cadmium uptake by P. pugio from Sediment C.

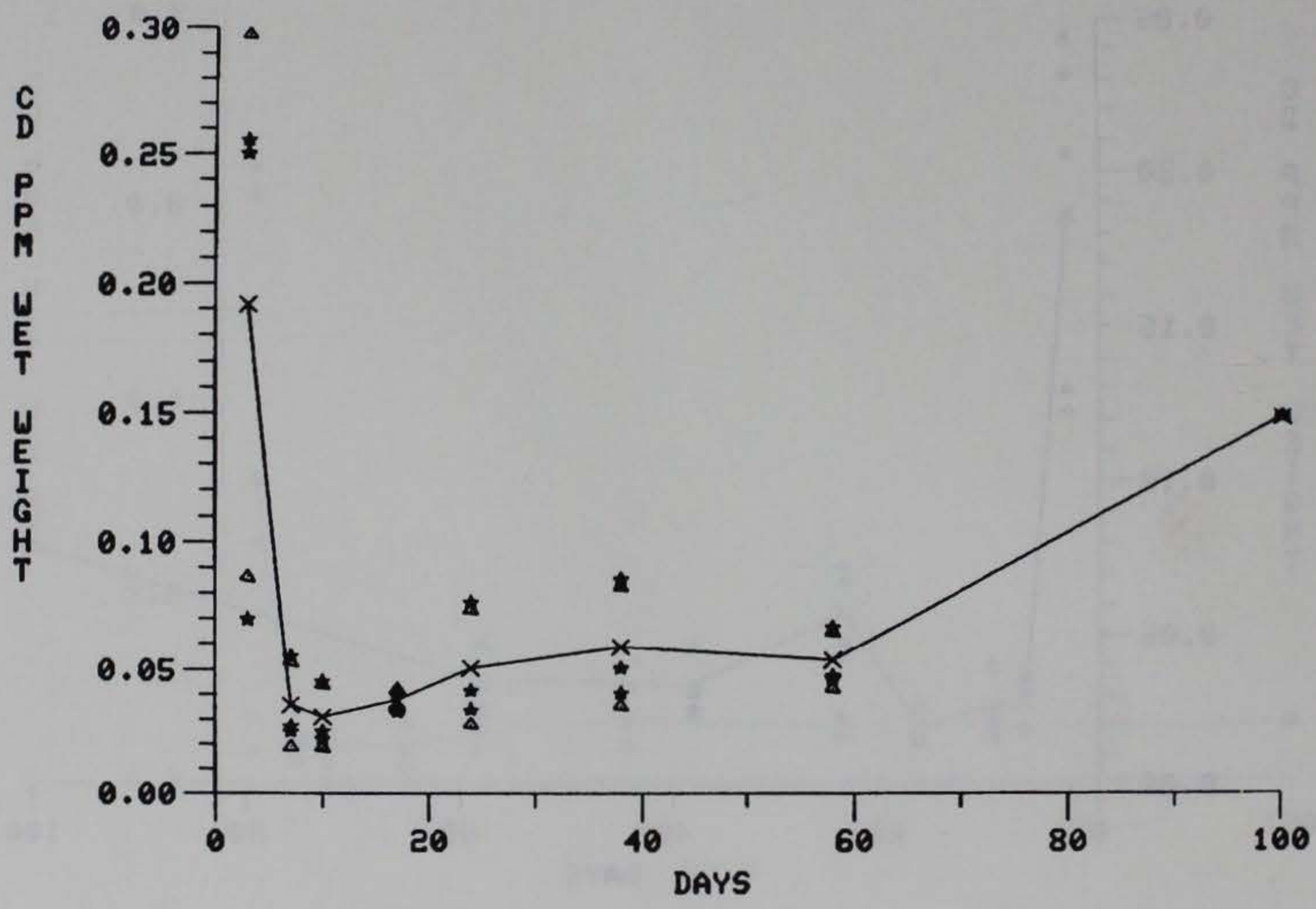

Figure A36. Cadmium uptake by P. pugio from Sediment D.