DAMOS
MUSSEL WATCH PROGRAM

EASTERN LONG ISLAND SOUND DISPOSAL SITE AND PORTLAND DISPOSAL SITE MONITORING PROJECTS; 1979 - 1981

CONTRIBUTION #43

SCIENCE APPLICATIONS, INC.

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Acknowledgements

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I am also indebted to Mr. Christopher J. Lindsay, Project Manager, U.S. Army Corps of Engineers, New England Division, for supplying me with records of disposal activities in New England coastal waters. Without this data the reports would not have been written.

Finally, I should like to thank Mrs. Joyce Lorensen for her devoted and competent clerical assistance.

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1.0 INTRODUCTION

1.1 Eastern Long Island Sound Disposal Site

The Eastern Long Island Sound Disposal Site (or New London Disposal Site) is one of two active disposal sites in Long Island Sound and is located two miles south of the mouth of the Thames River (Fig. 1-1). During 1977-1979, more than 1.6 million cubic yards of dredge material from the Thames River were deposited at this site; the bulk of which was dumped from September 1977 to May 1978.

During the present monitoring project, a further 3.6 million cubic yards of dredge materials were placed at this site from March 1979 to November 1981. Figure 1-2 summarizes disposal activities at the site. As can be seen, approximately 400,000 cubic yards of materials were dumped during the period from May 29, 1979 to December 27, 1980. This disposal operation overlapped another major disposal activity at New London Disposal Site. This second operation was initiated on December 12, 1979 and temporarily halted on January 10, 1980 after approximately 2 million cubic yards of materials were deposited. The project was resumed on October 10, 1980 and terminated on January 15, 1981 when an additional 900,000 cubic yards of materials were deposited at the site. The remaining 400,000 cubic yards were contributed by miscellaneous small dredging projects from adjacent areas of New London Harbor.

1.2 Portland Disposal Site

This site, located approximately two miles north of the Portland Lightship, is situated in the center of an old disposal site (Fig. 1-3). The site is in 60 meters of water and

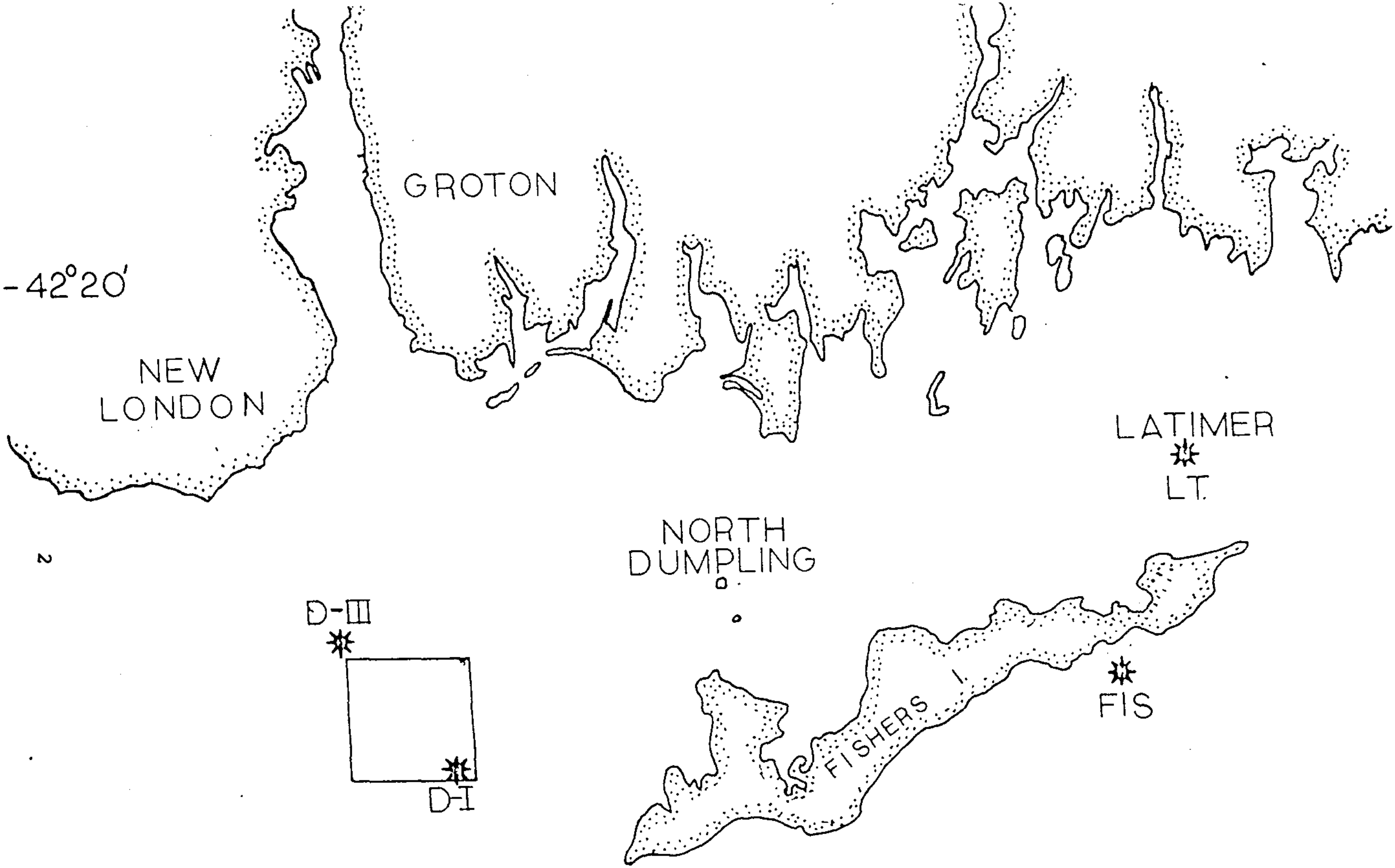

Figure 1-1. DAMOS Eastern Long Island Sound disposal site (New London) and mussel monitoring stations: D1 and D3. The reference stations located farther east at Latimer's Light (LLp) and Fishers Island Sound (FIS) are shown.

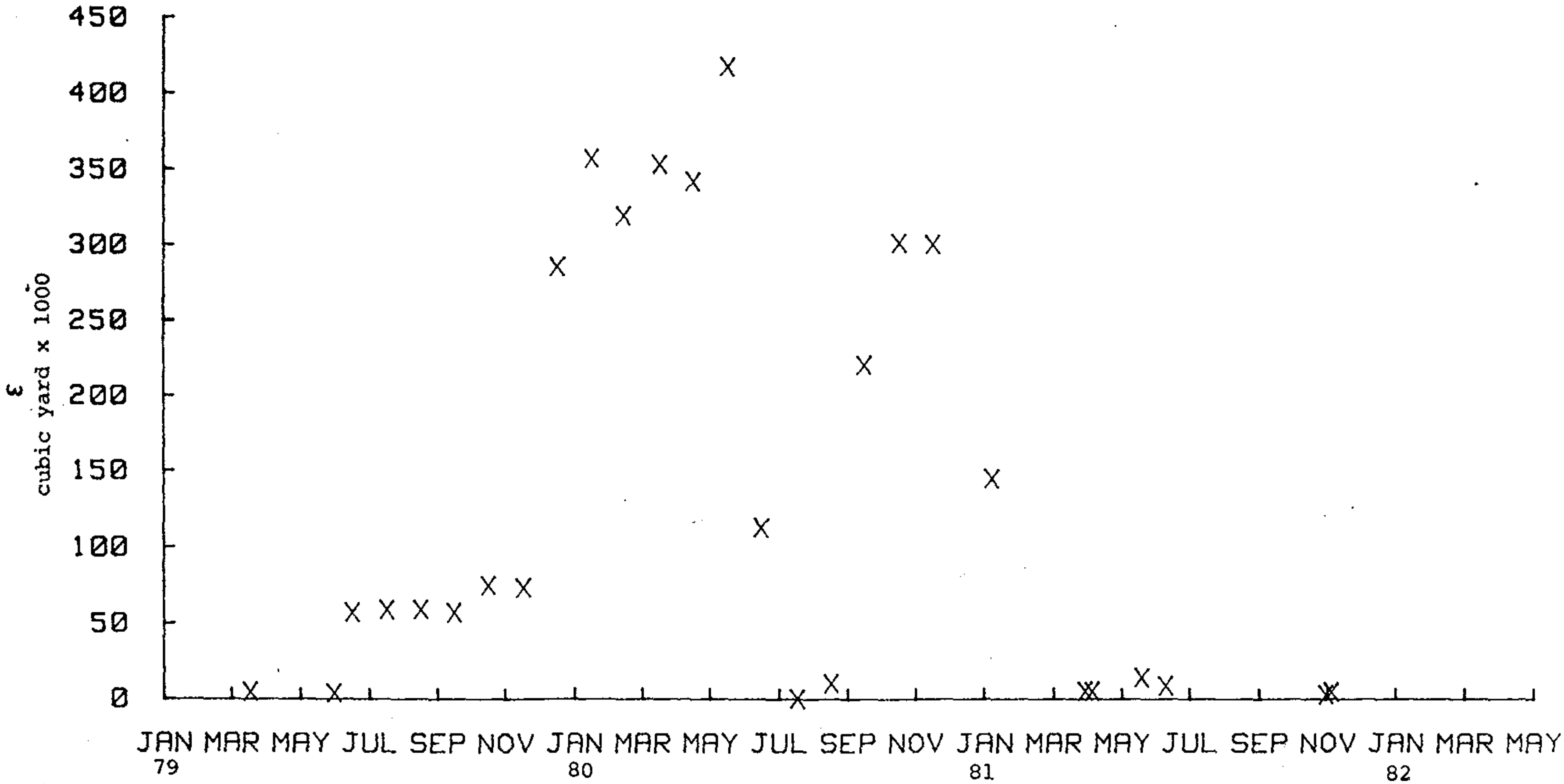

Figure 1-2. Temporal variations of dredge materials (volumes) deposited at the Eastern Long Island Sound Disposal Site from January 1979 to November 1981.

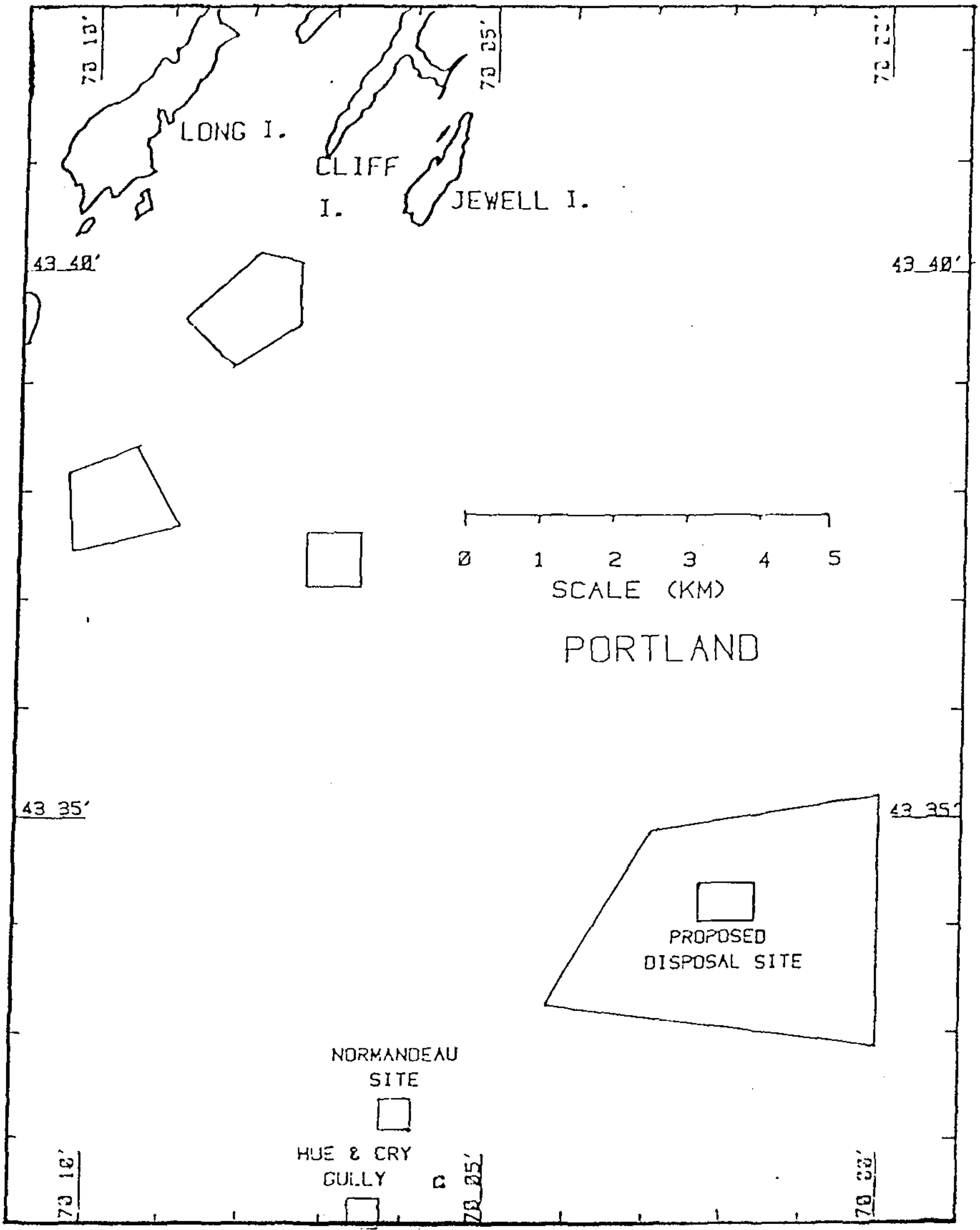

Figure 1-3. DAMOS Portland Disposal Site in Maine.

characterized by a flat sandy bottom ringed with rock outcrops. The area is known to have "very weak tidal currents," although wind generated wave action is possible due mainly to unlimited fetch to the south and southwest (Morton, 1979).

Disposal operations began at this site in September 1979 and were completed in May 1982. According to the records maintained by the U.S. Army Corps of Engineers, New England Division, a total of 1.4 million cubic yards of dredge materials, contributed from 11 permits, were dumped at the site. Among them, the federal project from September 29, 1979 to April 28, 1981, totaling 1.08 million cubic yards, was by far the largest disposal project to date. The dumping of a smaller project estimated at 143,000 cubic yards was completed from November 19, 1981 to May 1982. A summary of all disposal activities at this site is depicted in Figure 1-4.

2.0 PROJECT OBJECTIVES

The major objective of the DAMOS mussel monitoring project was to ascertain whether the disposal of dredge materials would affect the levels of trace metals in mussels experimentally deployed on or near the dumpsite. The second goal was to determine whether elevated levels of trace metals would affect the well being of the organism using the wet/dry tissue weight ratio and/or mortality as indicators. Investigations of other extrinsic factors which could account for the variance observed in trace metal concentrations, constitutes a third objective.

The DAMOS Mussel Watch project is based on the assumption that the trace metal residues in mussel tissue are

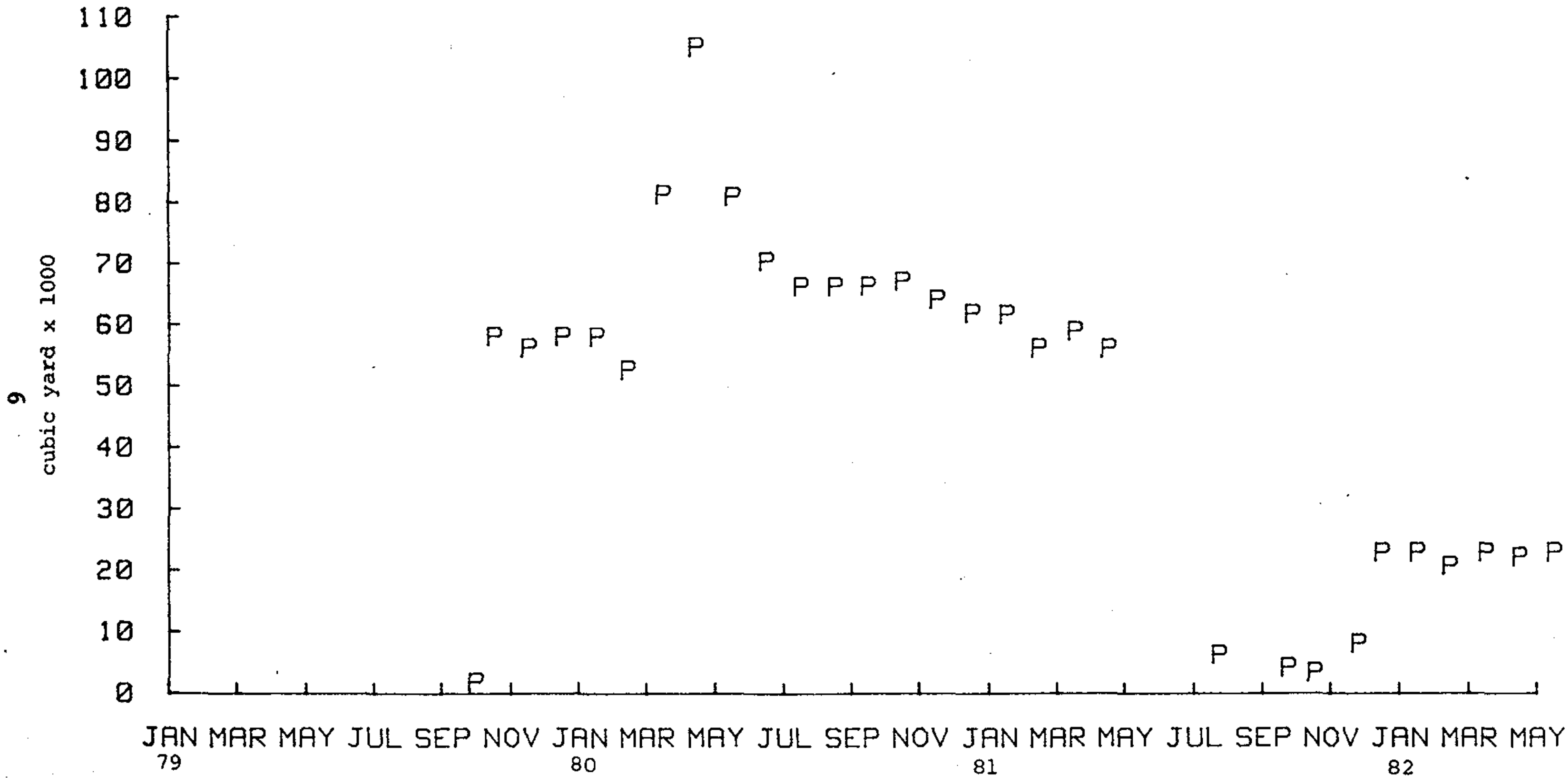

Figure 1-4. Temporal variations of dredge materials (volumes) deposited at the Portland Disposal Site (Maine) from September 1979 to May 1982.

influenced by a sundry of intrinsic and extrinsic factors. The intrinsic factors are innate, and physiological in nature, and dictate the uptake, accumulation, and attrition or depuration of the trace metals, while the extrinsic factors are abiotic and physical in character, and determine the availability of trace metals in the environment in which the organism dwells. As confirmed by our previous studies, this assumption is, indeed, reasonable.

2.1 Experimental

2.1.1 Field Procedures

The blue mussel, Mytilus edulis was used to establish four monitoring stations at the Eastern Long Island Sound Disposal Site. A single population from Latimer's Light was sampled to obtain the experimental animals in order to reduce variations due to possible genetic diversities that may exist in local mussel populations. Groups of 50 mussels were placed in polypropylene mesh bags and placed on a PVC platform, and deployed in the field as described in our previous report (Feng, 1982a). The platforms were deployed at stations D1 and D3 near the disposal site. Two reference stations designated as Fishers Island South (FIS) and Latimers Light (LLp) were also established (Figure 1-1). In addition, paired sampling of mussels maintained at Latimer's Light platform (LLp) and on the rock substrate (LLr) were carried out. This procedure was to determine whether there was any difference in trace metal concentrations in mussels held on the platform and living naturally on the natural bottom. Mussels were sampled by divers on a monthly basis whenever feasible. Sampling was initiated in September 1979, and continued in most cases through May 1981.

At the Portland Disposal Site (P), the horse mussel, *Modiolus modiolus* collected from the reference site Bulwark Shoals (B) was bagged (20 per bag) and deployed at the Disposal Site. The depth of this site (60 m) has limited the accessibility of mussel sampling by divers. During the early stages of this project, an underwater release (Model 431, Innerspace Technology, Inc.) was used to aid locating the mussel platform, but without much success. The problem with the release was associated with a faulty design in the mechanical releaser as well as fouling of the release mechanism. These problems were subsequently solved and, since that time, the buoys have been used successfully.

In Long Island Sound waters, sampling was accomplished by laying down a ground line on the bottom with one end tied to the mussel platform. The Loran-C coordinates of the platform were recorded. During subsequent sampling trips, the platform could be retrieved by dragging for the ground line. To insure uninterrupted sampling of D1 and D3, a local fisherman was contracted to sample the platforms on a monthly basis, and ship the samples (packed in dry ice) to the Marine Sciences Institute, University of Connecticut at Noank, CT.

2.1.2 Laboratory Procedures

In the laboratory, 12 horse mussels were pooled into three samples of 4 animals per sample. In a similar fashion, triplicate samples of 8 blue mussels were collected. For baseline data, 8-10 replicates were used. The mussels were cleaned, measured, shucked, homogenized and lyophilized according to the established procedures for the project. The wet/dry weight ratio was calculated by dividing the homogenized tissue weight with the freeze dried tissue weight. Also during each sampling period, the number of dead mussels per bag was recorded. These data were used to construct a cumulative mortality graph for each site.

The concentration of trace metals in the mussel samples were determined by the established methods of atomic absorption spectrophotometry. Aliquots of freeze dried samples (0.8 g) placed in an acid cleaned glass volumetric flask, were digested in 5 ml Ultrax concentrated nitric acid for six hours at 50oC, and then diluted to a final volume of 50 ml with deionized glass distilled water. The diluted sample was filtered through an acid cleaned and pre-rinsed Millipore glass fiber filter to remove particulate materials which tend to block the aspirator during analysis.

Copper, iron and zinc were analyzed by conventional flame atomic absorption spectrophotometry using an Instrumentation Laboratory Model 151 Atomic Absorption Spectrophotometer. Mercury concentration was determined by using a cold vapor flameless atomic absorption spectrophotometer (Coleman MAS-50) after reduction of oxidized mercury to Hg^{o} with stannous chloride. Cadmium, chromium, cobalt, nickel and vanadium were analyzed by the graphite furnace flameless atomic absorption spectrophotometry (Perkin Elmer Model 5000 AA and HGA 500 graphite furnace). Results were corrected for reagent blanks and calibrated by comparison with aqueous standard solutions of trace metals (10% Vol/Vol nitric acid in DIDW). For quality control of the analytical results, a standardized reference material (NBS 1566 Oyster Tissues) prepared in the same manner as the mussel samples, was analyzed for comparison. Meticulous care was exercised to minimize contamination, particularly in sample preparations and cleaning of laboratory glass and plastic ware.

Statistical analyses of the data were carried out by applying a scheme specifically designed to eliminate or minimize the effect of intrinsic variables, e.g., wet/dry weight ratio and shell length on the trace metal concentration in the mussels. After this was achieved, stepwise multiple regression analyses were carried out to determine whether extrinsic variables, especially disposal of dredge materials or other variables were associated with the changing trace metal concentration in mussels. The last issue addressed was to ascertain whether trace metal concentrations and W/D ratios in mussels differed among the stations. This was accomplished by using the Friedman's Test. These procedures were outlined in detail in our previous report (Feng, 1982a).

3.0 RESULTS AND DISCUSSIONS

The trace metal concentrations (Cd, Cr, Co, Cu, Fe, Hg, Ni, Zn and V) in the tissues of two species of mussels: *Mytilus edulis* and *Modiolus modiolus* from two dumpsites: Eastern Long Island Sound Disposal Site and Portland Disposal Site, and their respective reference sites: Fishers Island South, Latimer's Light and Bulwark Shoals, are presented in Table 3-1. Graphic representations of temporal variations of the trace metal concentrations are depicted in Figures 3-3 to 3-11 for *M. edulis*

Table 3-1. A summary of statistics for trace metal concentrations in *Mytilus edulis* and *Modiolus modiolus* from Eastern Long Island Sound Disposal Site, Portland Disposal Site (Maine) and their reference sites. Figures within the parentheses are 1 s.d.

	Mytilus edulis				
Trace Metal	D1	D3	FIS	LLp	LLr
Cd	1.9(0.6)	1.8(0.4)	1.4(0.5)	1.4(0.5)	1.5(0.4)
Cr	10.5(11.9)	6.0(5.7)	4.1(3.7)	6.2(4.7)	4.1(3.4)
Co	0.6(0.3)	0.6(0.2)	0.5(0.3)	0.4(0.2)	0.6(0.4)
Cu	9.3(1.1)	9.4(1.2)	8.1(0.8)	8.1(1.2)	8.2(0.5)
Fe	395(235)	346(184)	222(139)	333(235)	289(180)
Hg	0.23(0.06)	0.22(0.06)	0.18(0.05)	0.20(0.06)	0.20(0.05)
Ni	6.4(5.4)	4.7(2.7)	3.0(2.3)	4.0(2.8)	3.2(1.8)
Zn	169(39)	166(40)	139(44)	147(58)	139(43)
V	2.0(1.7)	1.8(1.6)	2.1(2.0)	1.8(1.5)	1.7(0.6)
n	19	21	20	17	12

	Modiolus modiolus	
Trace Metal	Bulwark Shoals	Portland
Cd	12.5(4.5)	12.9(5.7)
Cr	1.4(0.8)	2.2(2.9)
Co	0.7(0.3)	0.7(0.2)
Cu	31.0(7.3)	29.4(5.8)
Fe	132(56)	168(72)
Hg	0.389(0.169)	0.398(0.283)
Ni	3.5(1.0)	4.0(3.0)
Zn	320(73)	338(264)
V	6.9(3.6)	6.1(3.9)
n	16	12

and Figures 3-14 to 3-17 for M. modiolus. Seasonal variations in the tissue wet and dry weight ratios are shown in Figures 3-2 and 3-17 for M. edulis and M. modiolus respectively. Also presented are cumulative percent mortalities in M. edulis maintained at the Eastern Long Island Sound Disposal Site (D1, D3) and at the reference site (Fishers Island South (FIS) and Latimer's Light (LLp)) (Fig. 3-12).

The physical parameters that were assessed (dredge volume, river runoff, and water temperature), and their changes during the study period are displayed in Figure 3-1.

Based on the data presented (Figs. 3-3 through 3-13), some general statements may be made regarding the behavior of trace metals in M. edulis maintained at the Eastern Long Island Sound Disposal Site and its associated reference sites: 1) There is a clear temporal trend in the concentrations of the nine trace metals examined, 2) The trace metal concentrations are lower in the summer and fall than in the late winter and early spring, and, 3) Such temporal trends in trace metals appear to vary with the tissue wet and dry weight ratio, water temperature, river runoff and dredge volumes (Figs. 3-1 and 3-2). In contrast with the horse mussels at the Portland Disposal Site and Bulwark Shoals reference site, no such cyclic fluctuations of trace metal concentrations were clearly discernible (Figs. 3-14 to 3-17). Chromium and zinc which show the greatest variations appear to exhibit elevated levels during the winter and early spring. In general, the variability of trace metal concentrations at the Portland Disposal Site is greater than that of the trace metal levels at the Bulwark Shoals Site; this is possibly associated

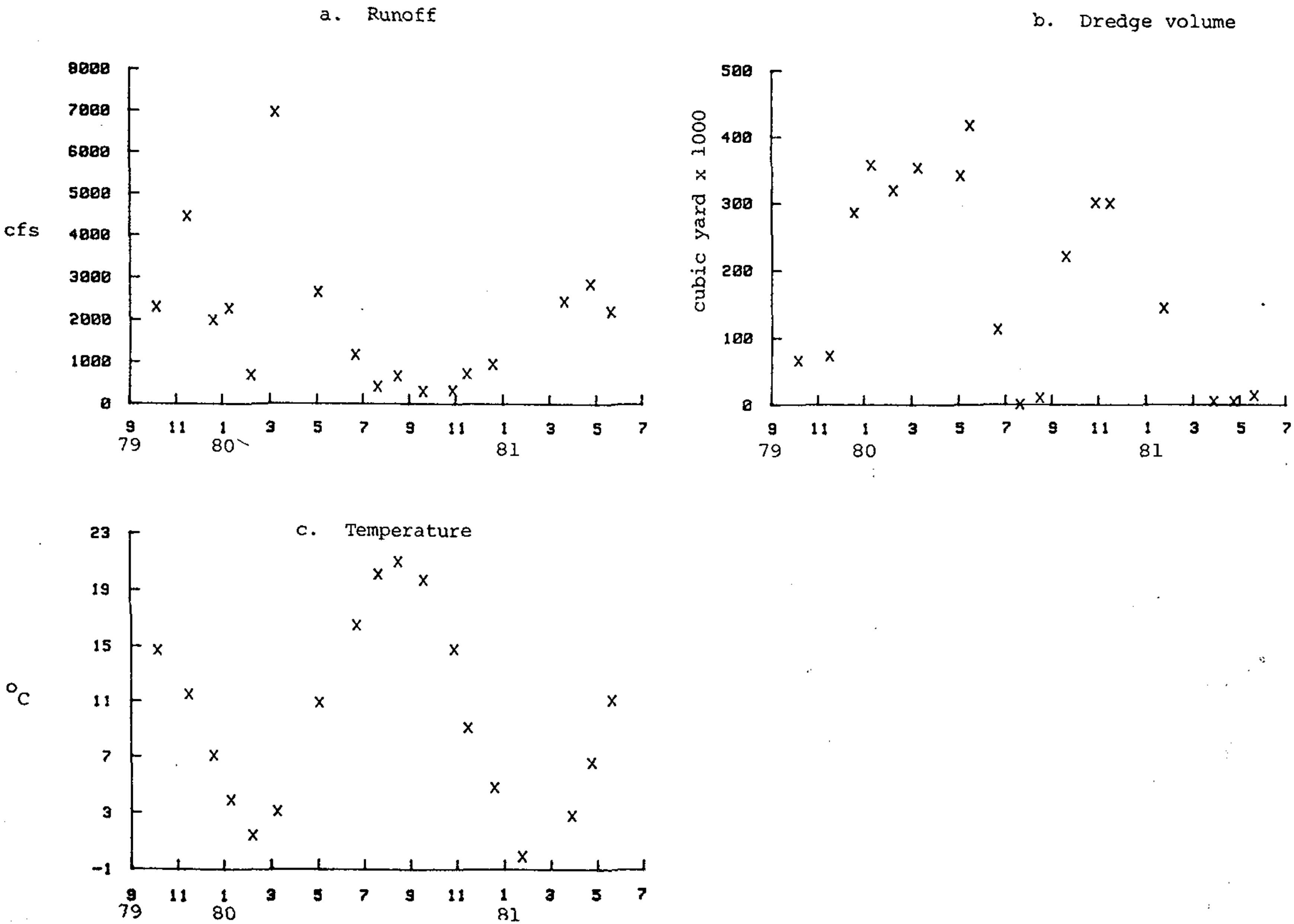

Figure 3-1. Temporal variations of three extrinsic variables: a. runoff from Thames River, B. dredge volume and c. water temperature °C from September 1979 to May 1981 at Eastern Long Island Disposal Site.

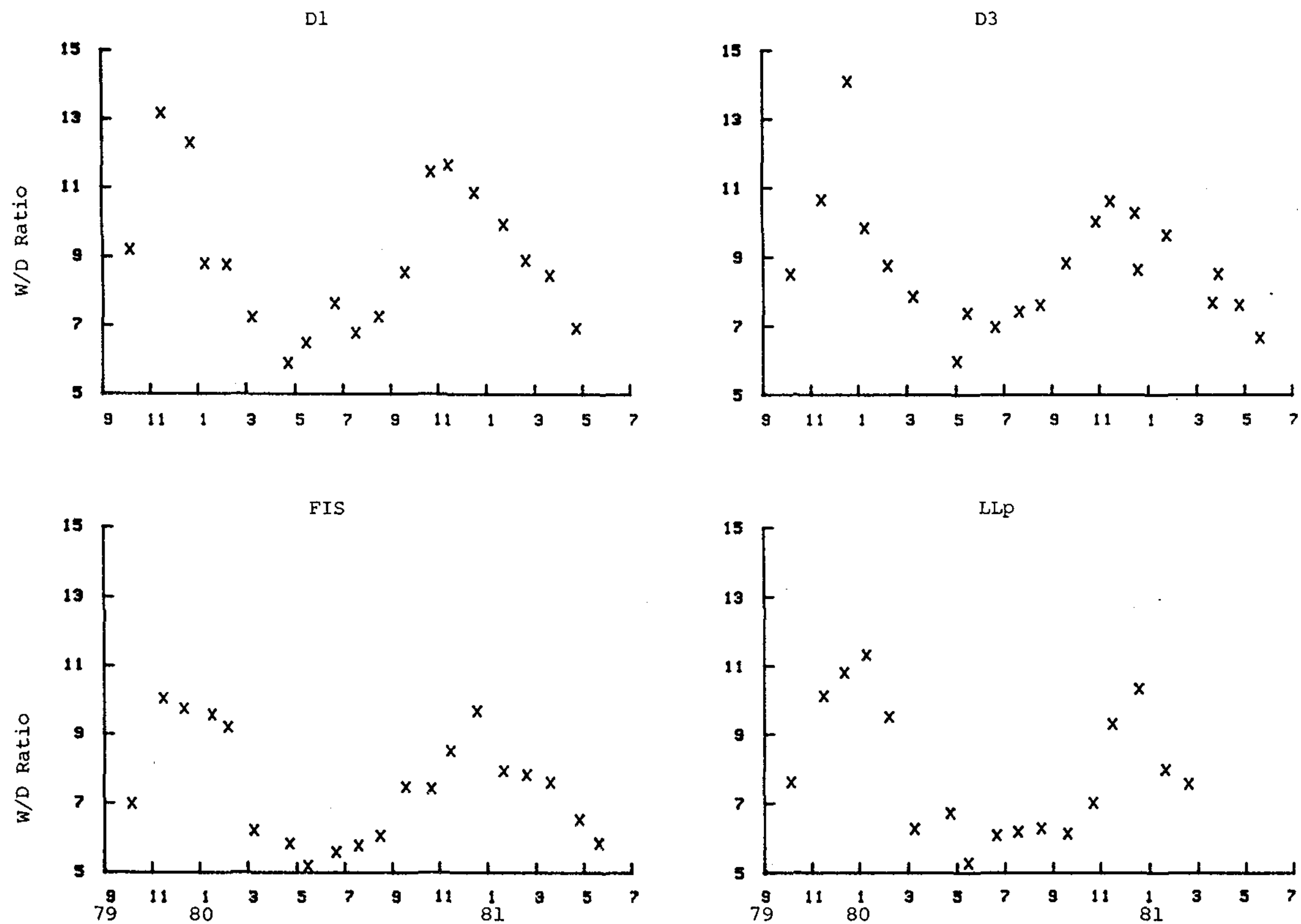

Figure 3-2. Temporal variations of M. edulis tissue wet/dry ratios at four monitoring stations: D1, D3, Fishers Island South (FIS) and Latimer's Light (LLp).

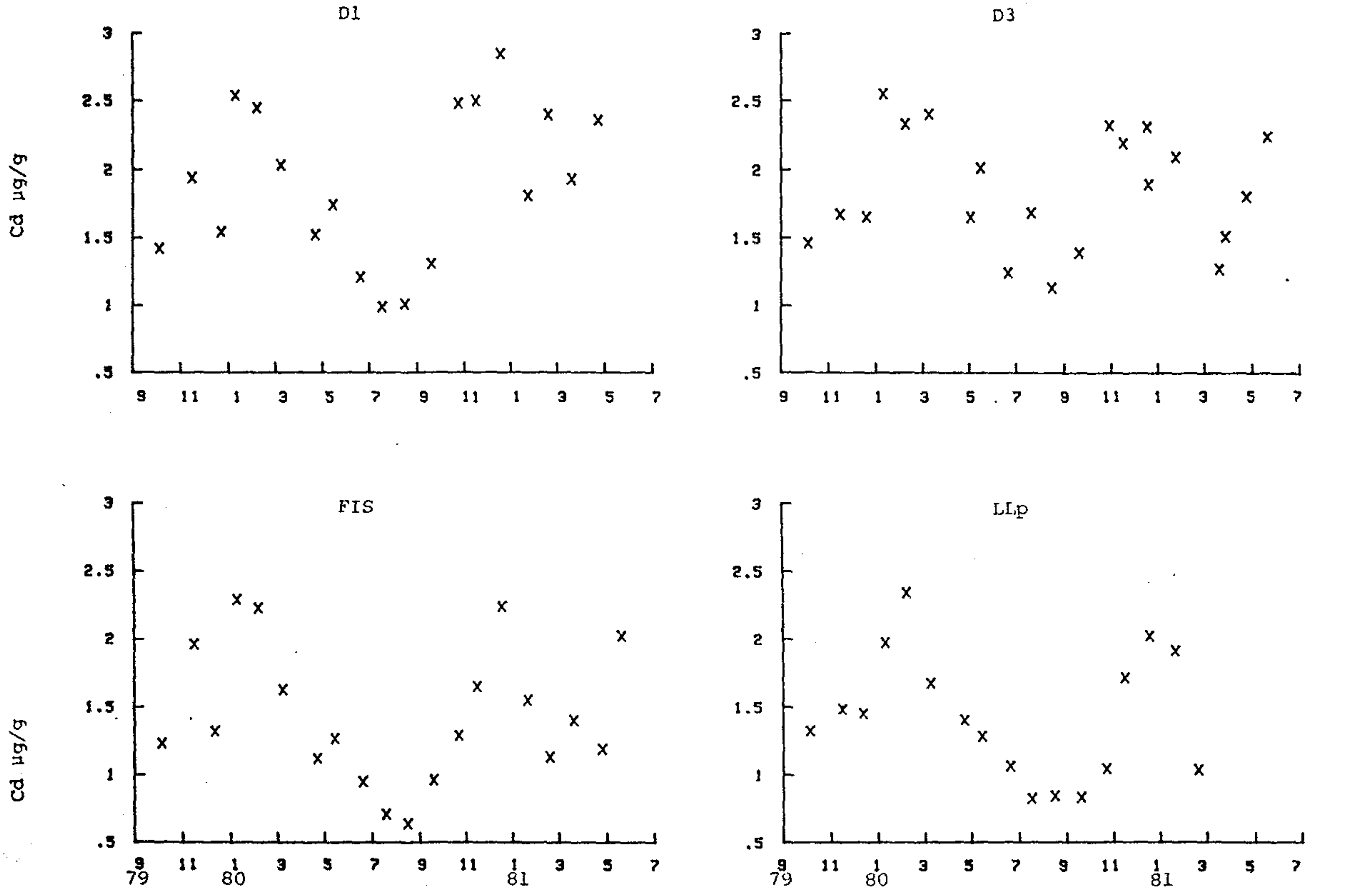

Figure 3-3. Temporal variations of cadmium concentrations in Mytilus edulis maintained at Stations: D1, D3, Fishers Island South (FIS) and Latimer's Light (LLp).

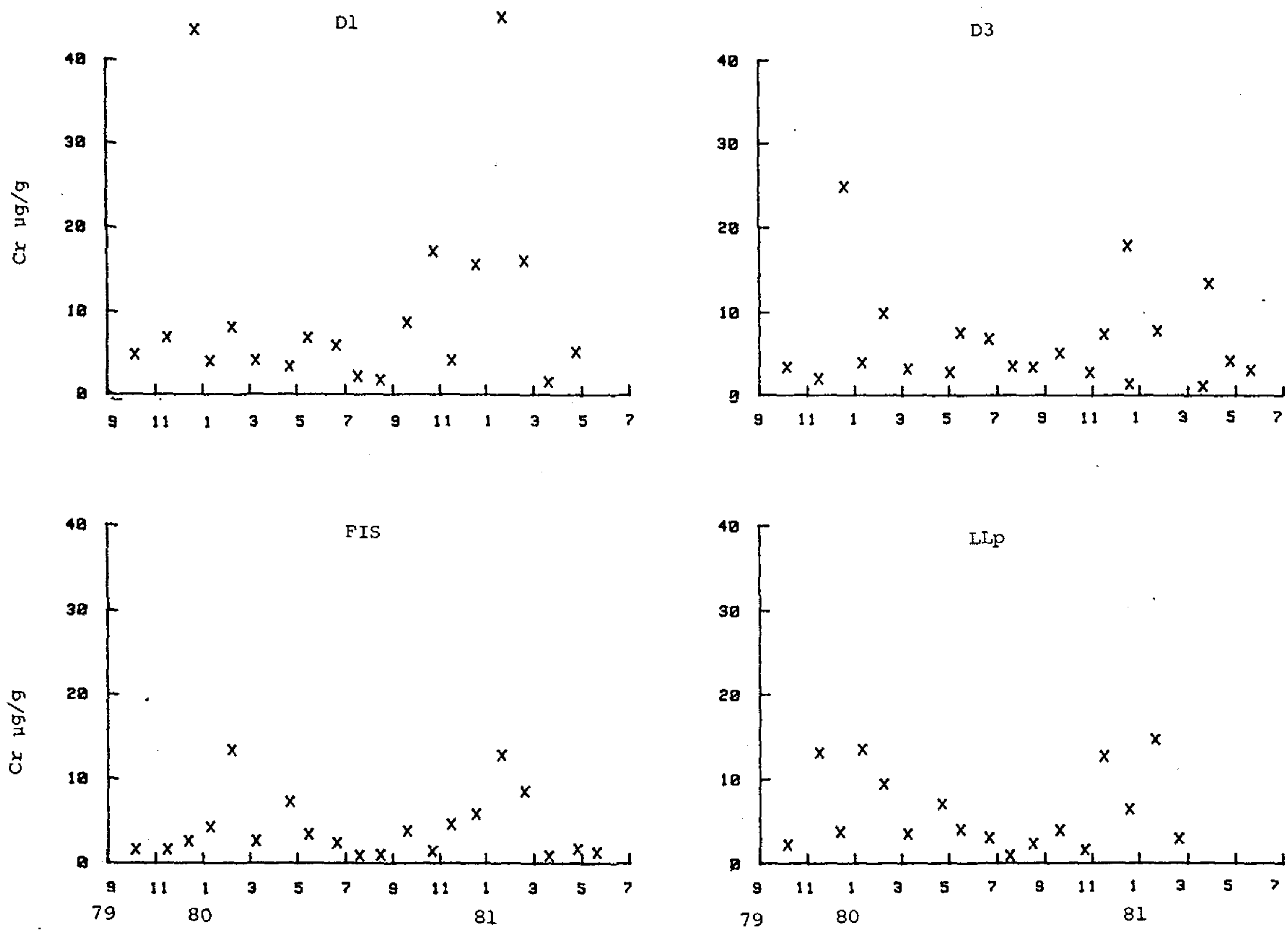

Figure 3-4. Temporal variations of chromium concentrations in *Mytilus edulis* maintained at Stations: D1, D3, Fishers Island South (FIS) and Latimer's Light (LLp).

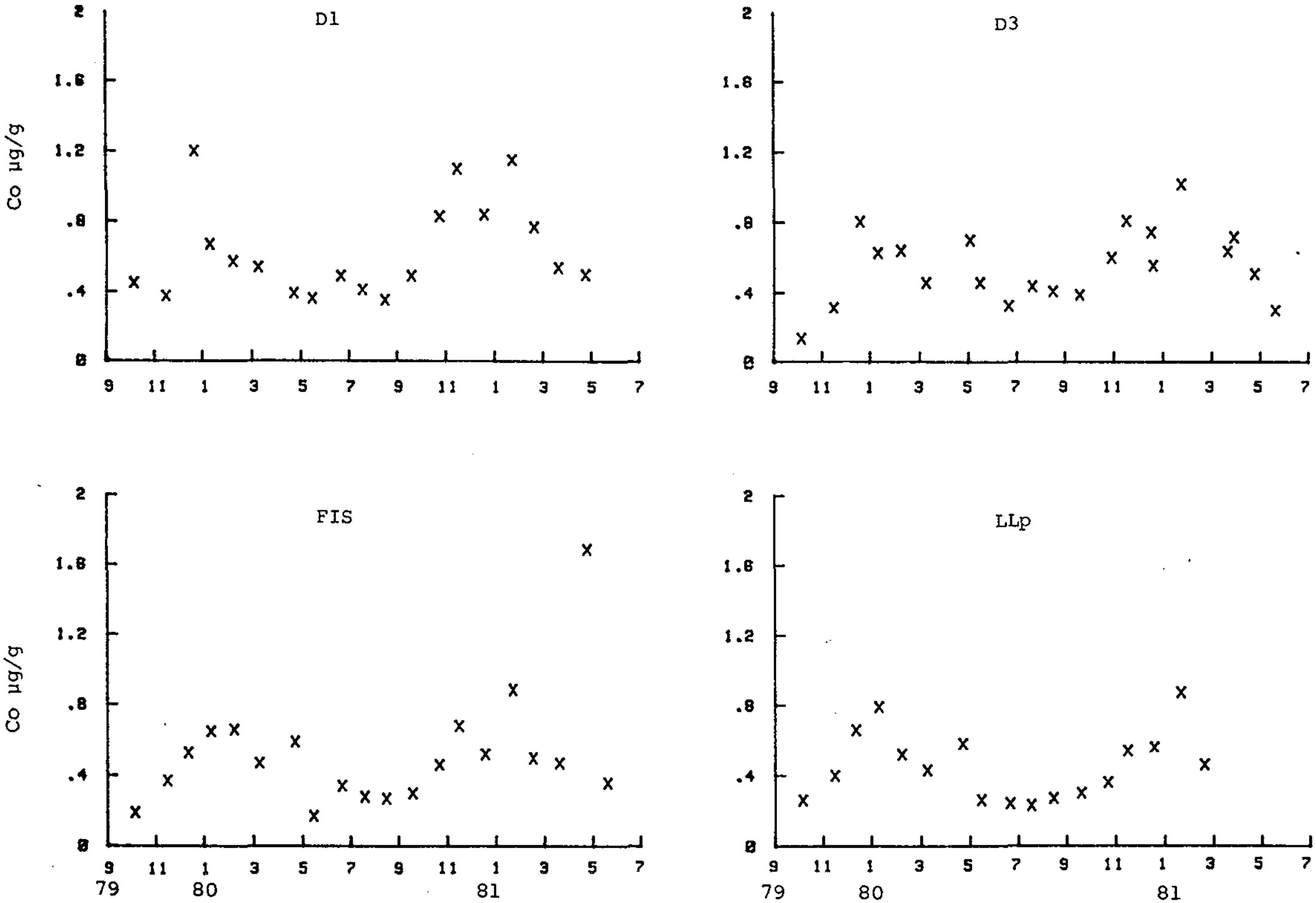

Figure 3-5. Temporal variations of cobalt concentrations in Mytilus edulis maintained at Stations: D1, D3, Fishers Island South (FIS) and Latimer's Light (LLp).

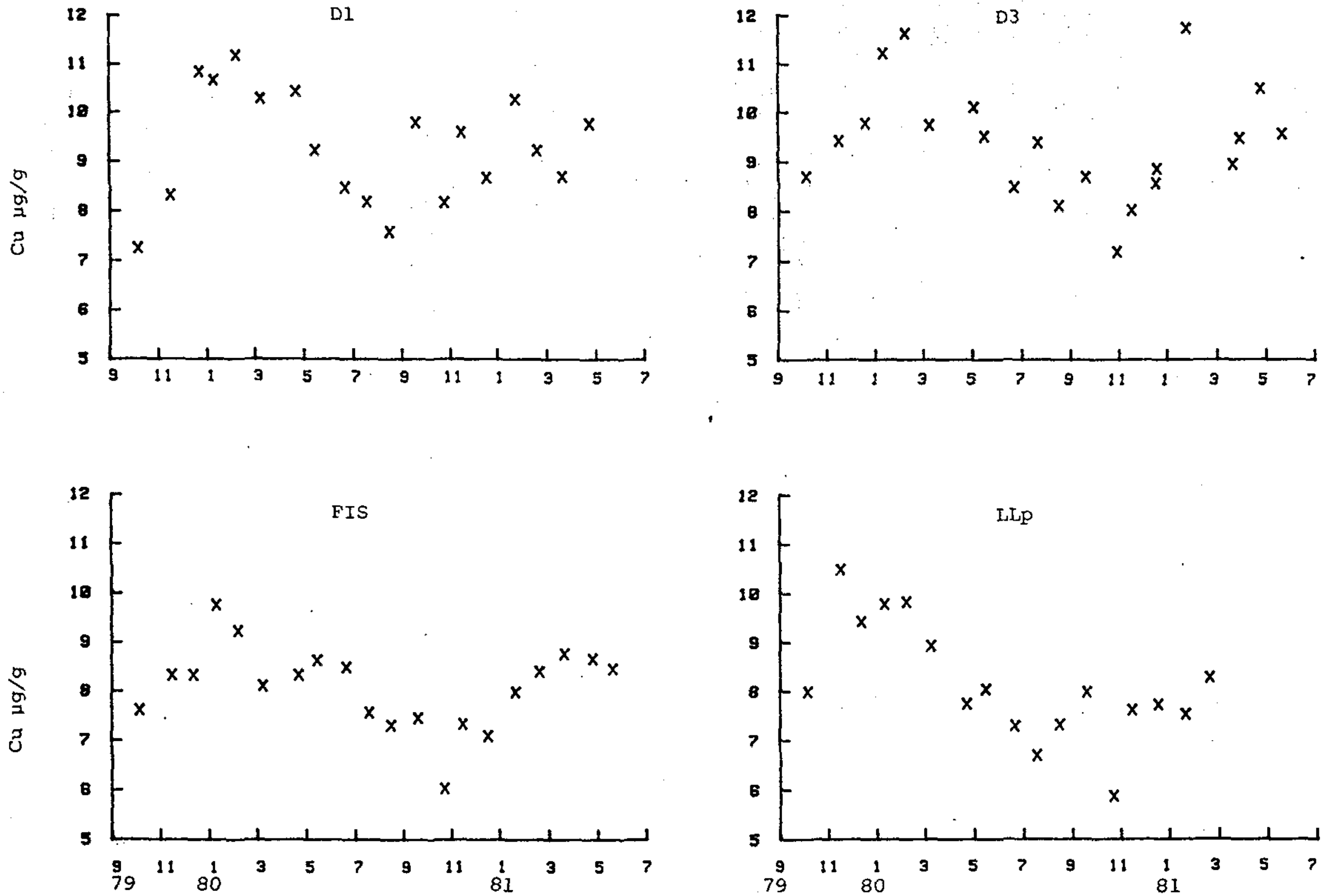

Figure 3-6. Temporal variations of copper concentrations in *Mytilus edulis* maintained at Stations: D1, D3, Fishers Island South (FIS) and Latimer's Light (LLp).

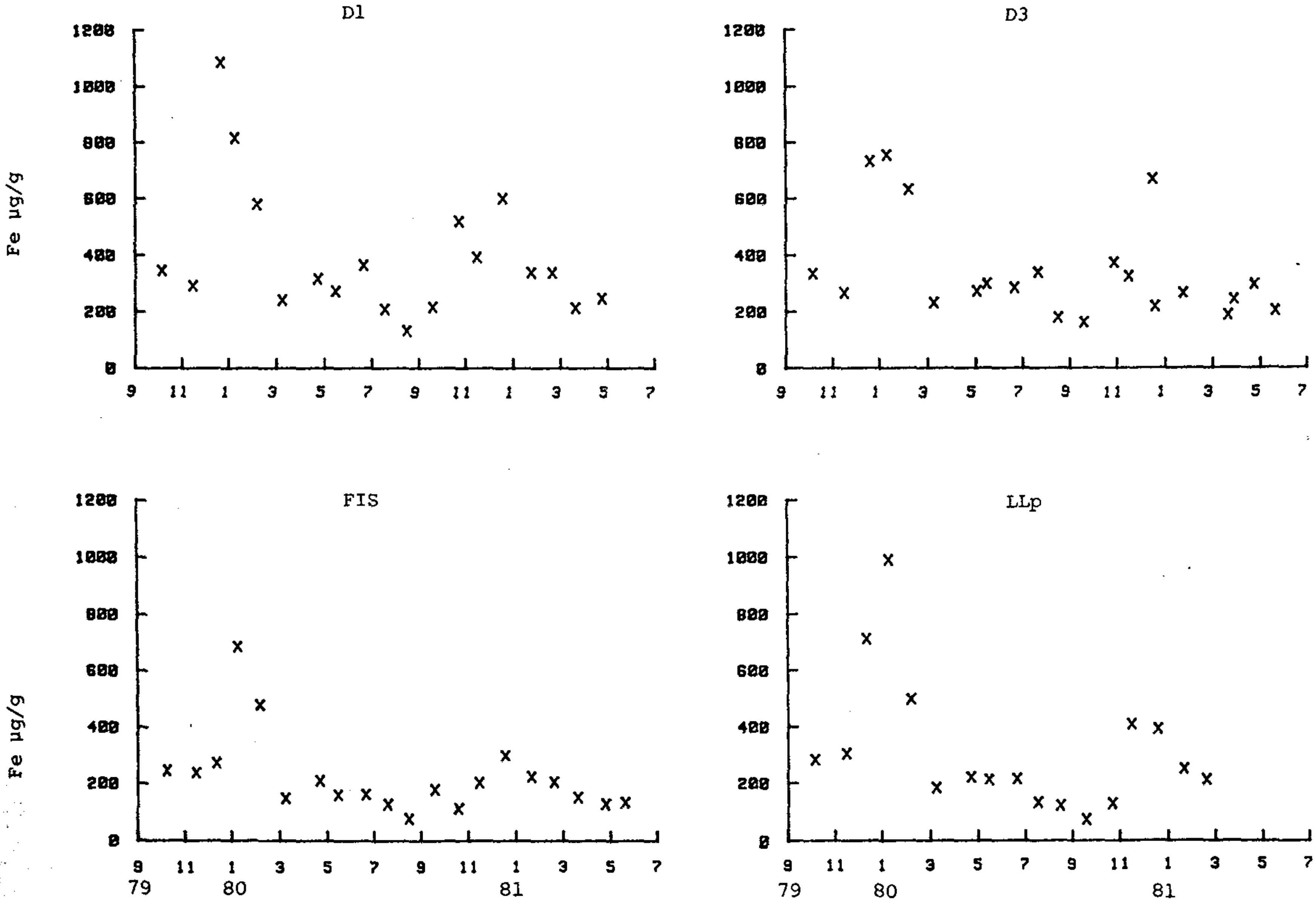

Figure 3-7. Temporal variations of iron concentrations in *Mytilus edulis* maintained at Stations: D1, D3, Fishers Island South (FIS) and Latimer's Light (LLp).

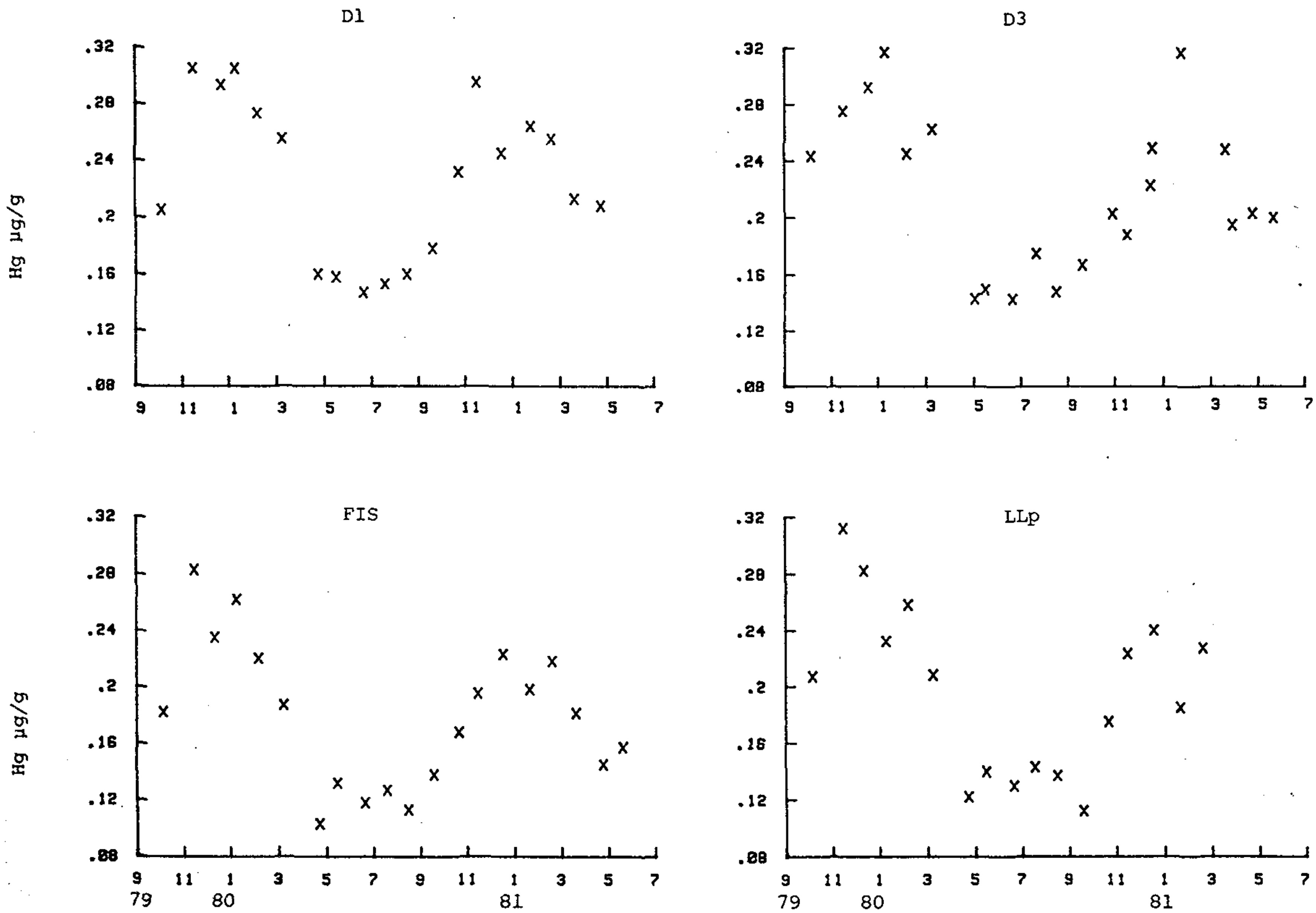

Figure 3-8. Temporal variations of mercury concentrations in _Mytilus edulis_ maintained at Stations: D1, D3, Fishers Island South (FIS) and Latimer's Light (LLp).

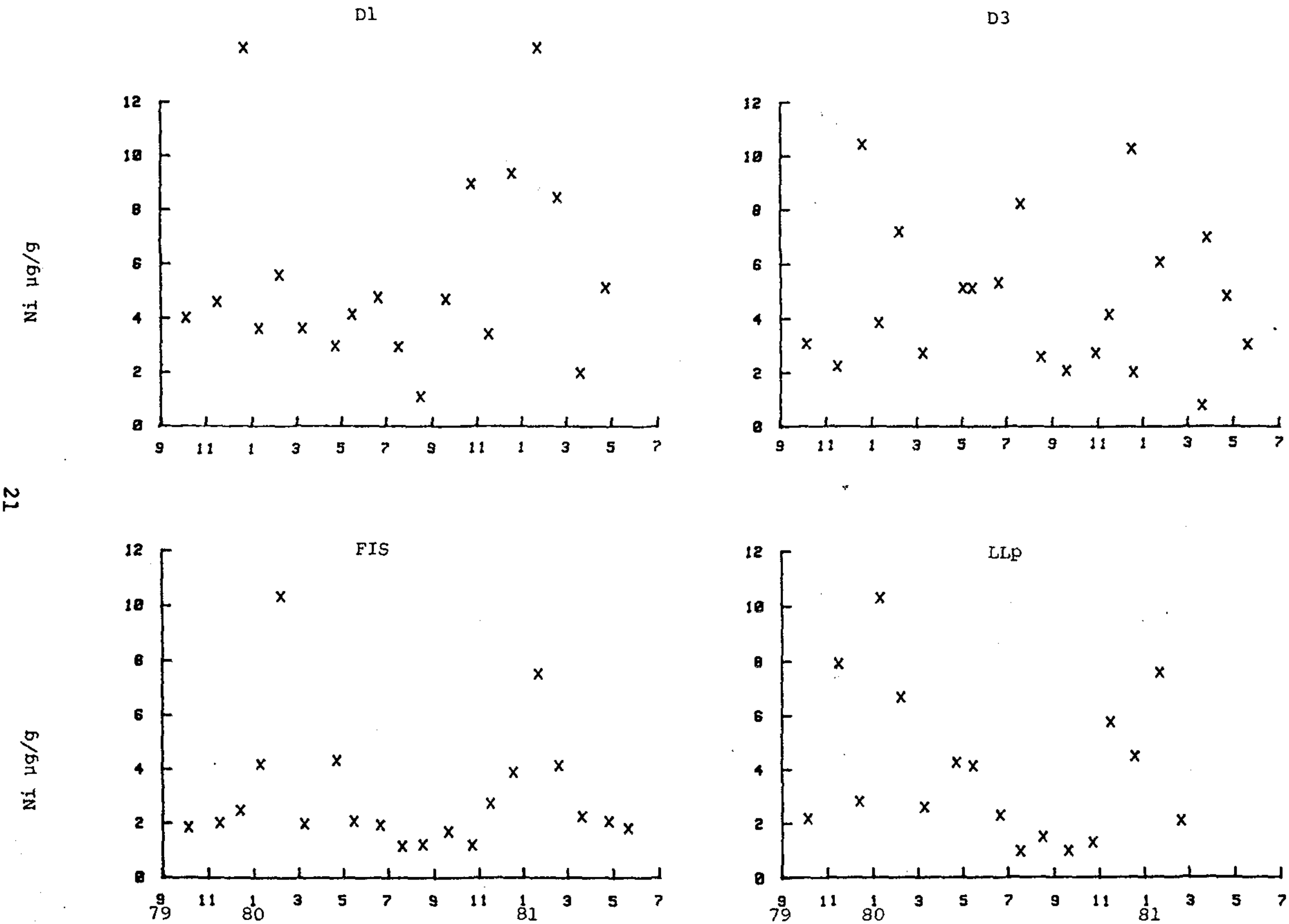

Figure 3-9. Temporal variations of nickel concentrations in <u>Mytilus edulis</u> maintained at Stations: D1, D3, Fishers Island South (FIS) and Latimer's Light (LLp).

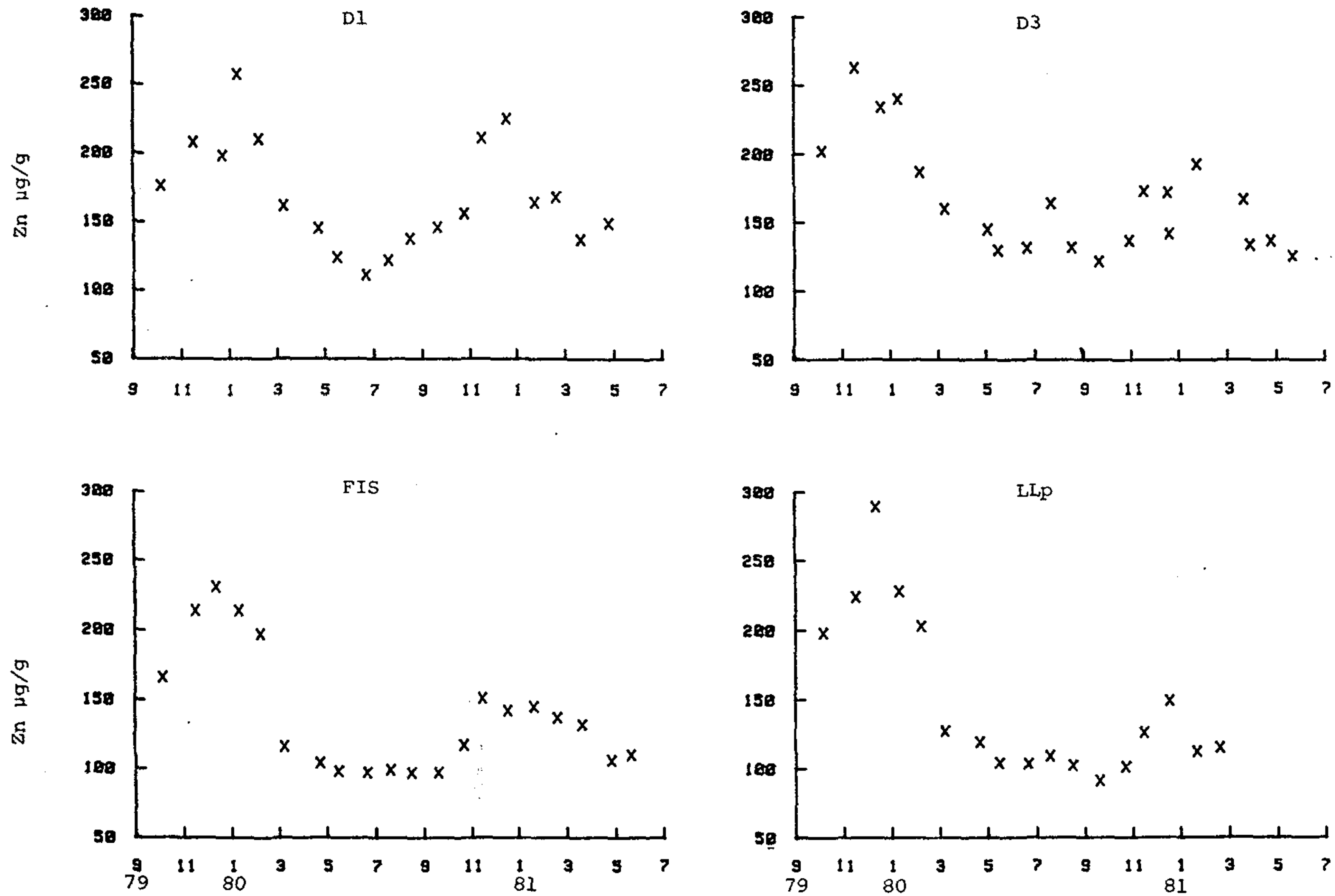

Figure 3-10. Temporal variations of zinc concentrations in *Mytilus edulis* maintained at Stations: D1, D3, Fishers Island South (FIS) and Latimer's Light (LLp).

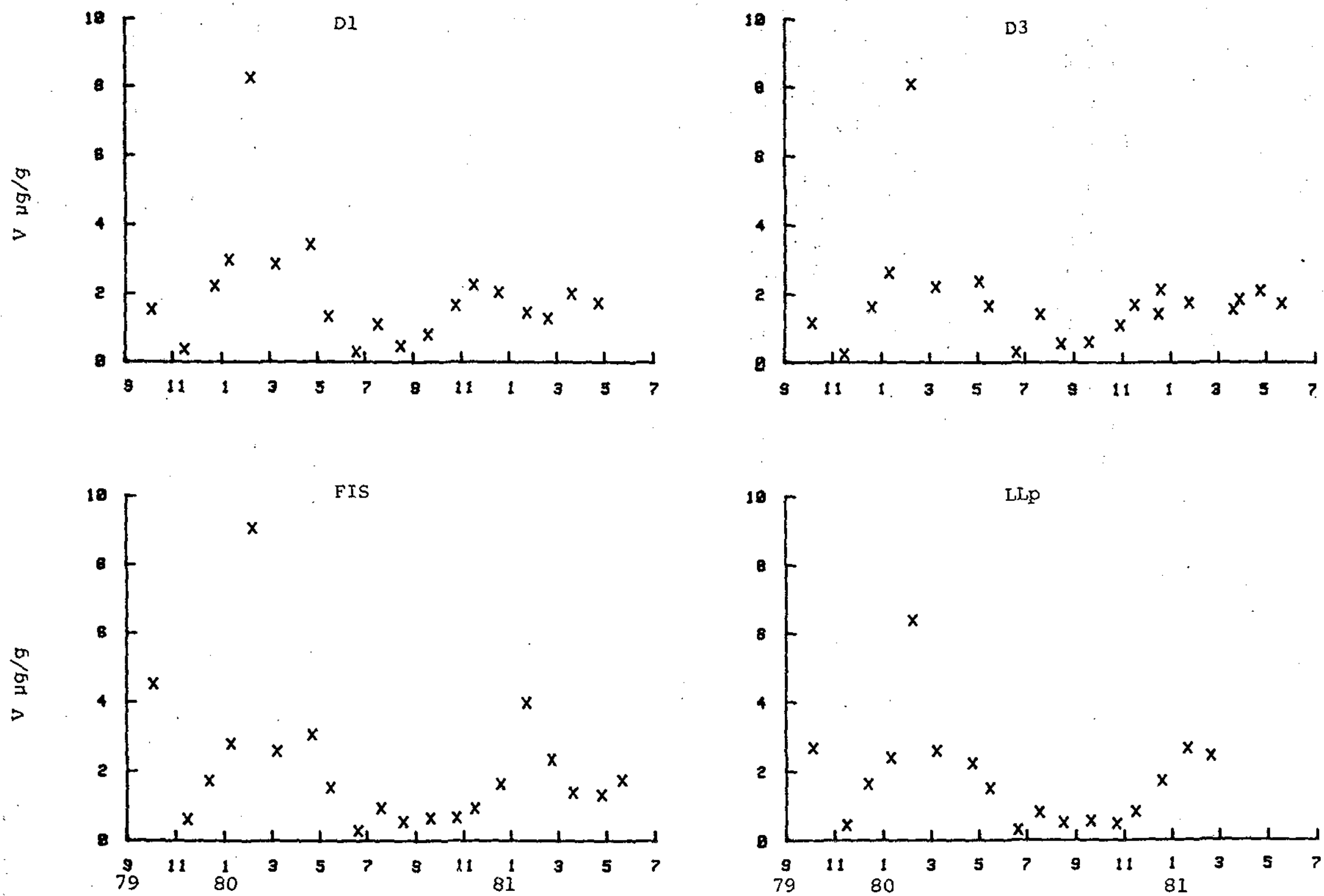

Figure 3-11. Temporal variations of vanadium concentrations in Mytilus edulis maintained at Stations: D1, D3, Fishers Island South (FIS) and Latimer's Light (LLp).

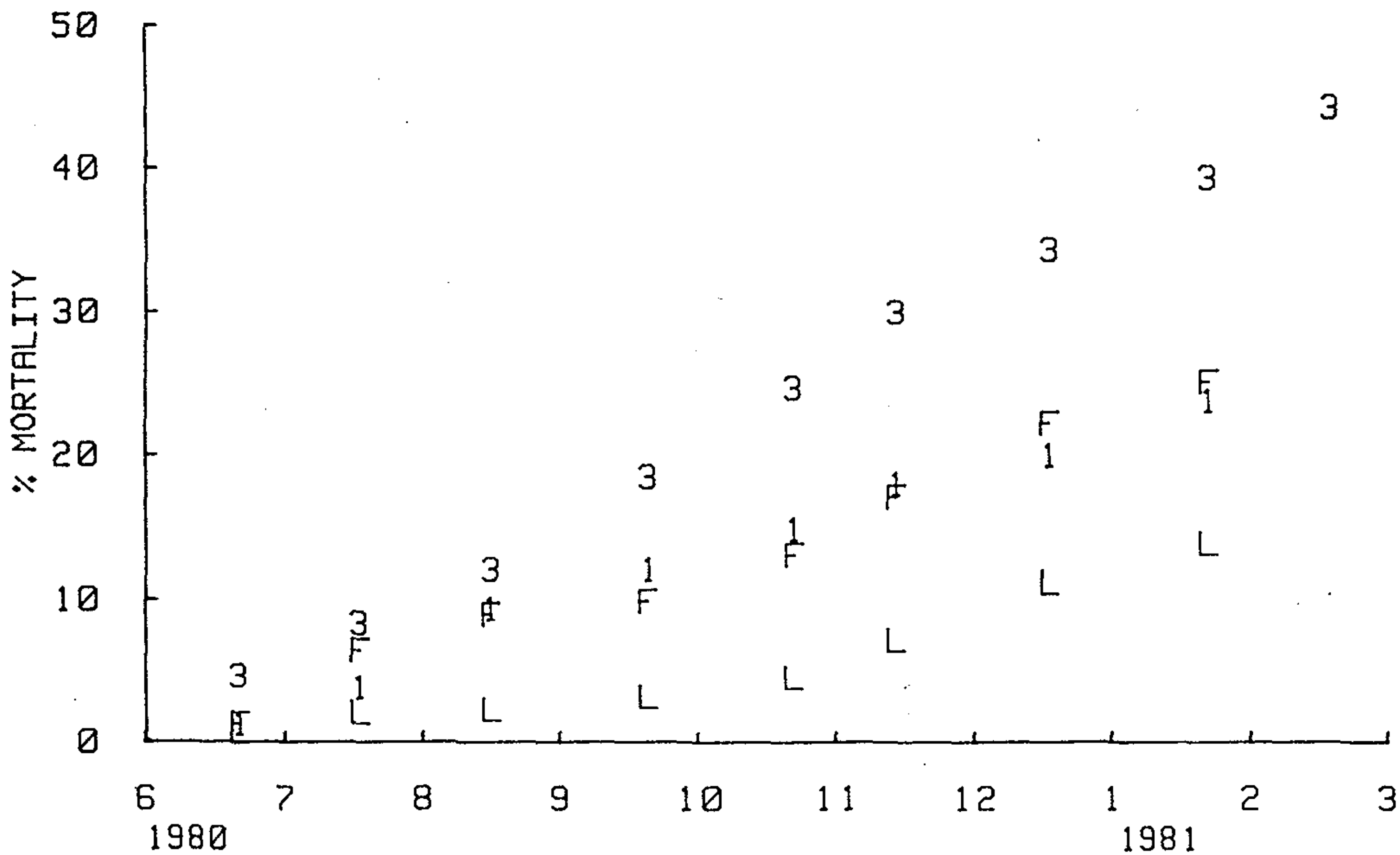

Figure 3-12. Cummulative percent mortalities in Mytilus edulis maintained at Stations: D1, D3, Fishers Island South (FIS) and Latimer's Light (LLp).

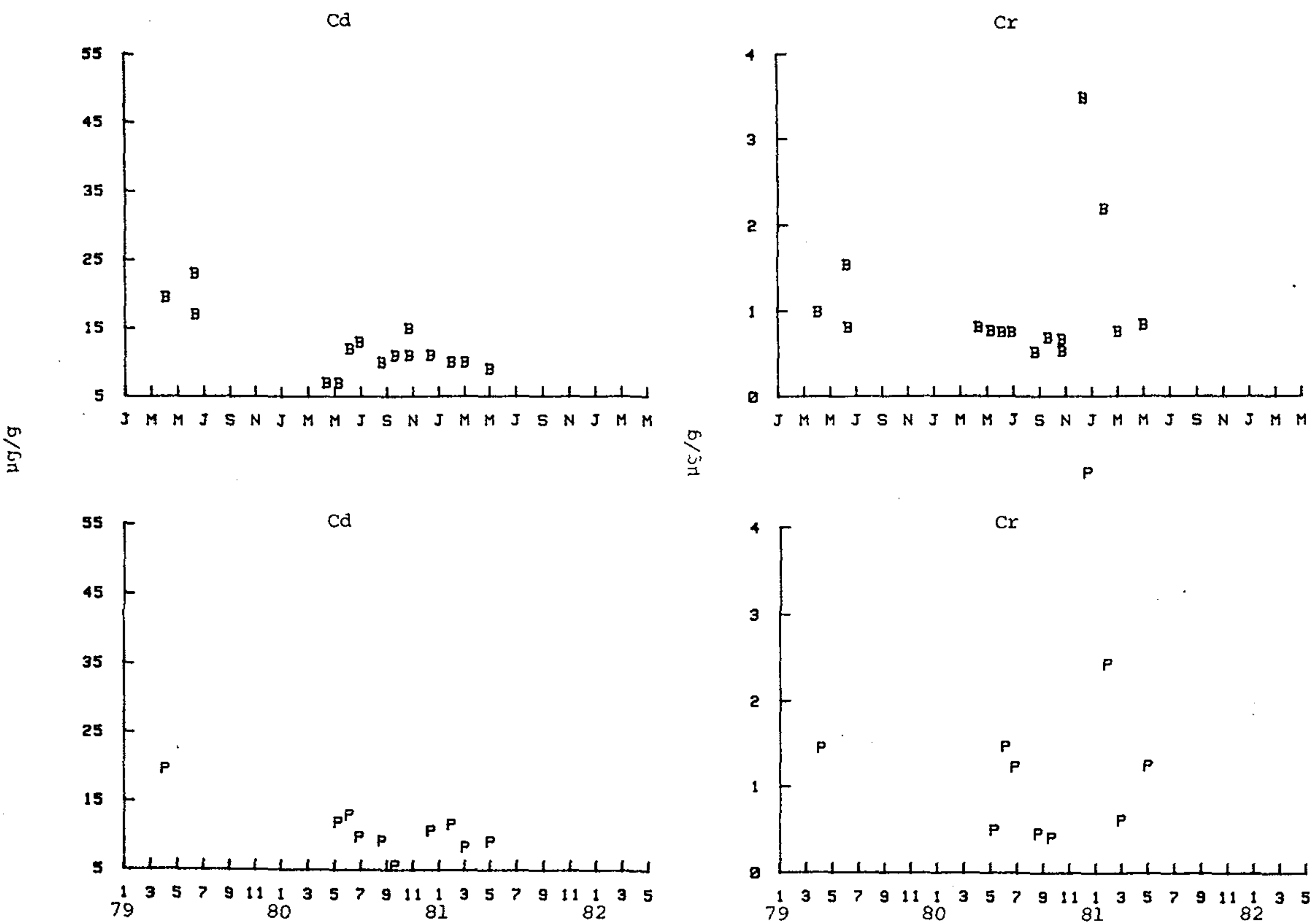

Figure 3-13. Temporal variations of cadmium and chromium concentrations in Modiolus modiolus deployed at Bulwark Shoals (B), the reference site and Portland (P) Disposal Site.

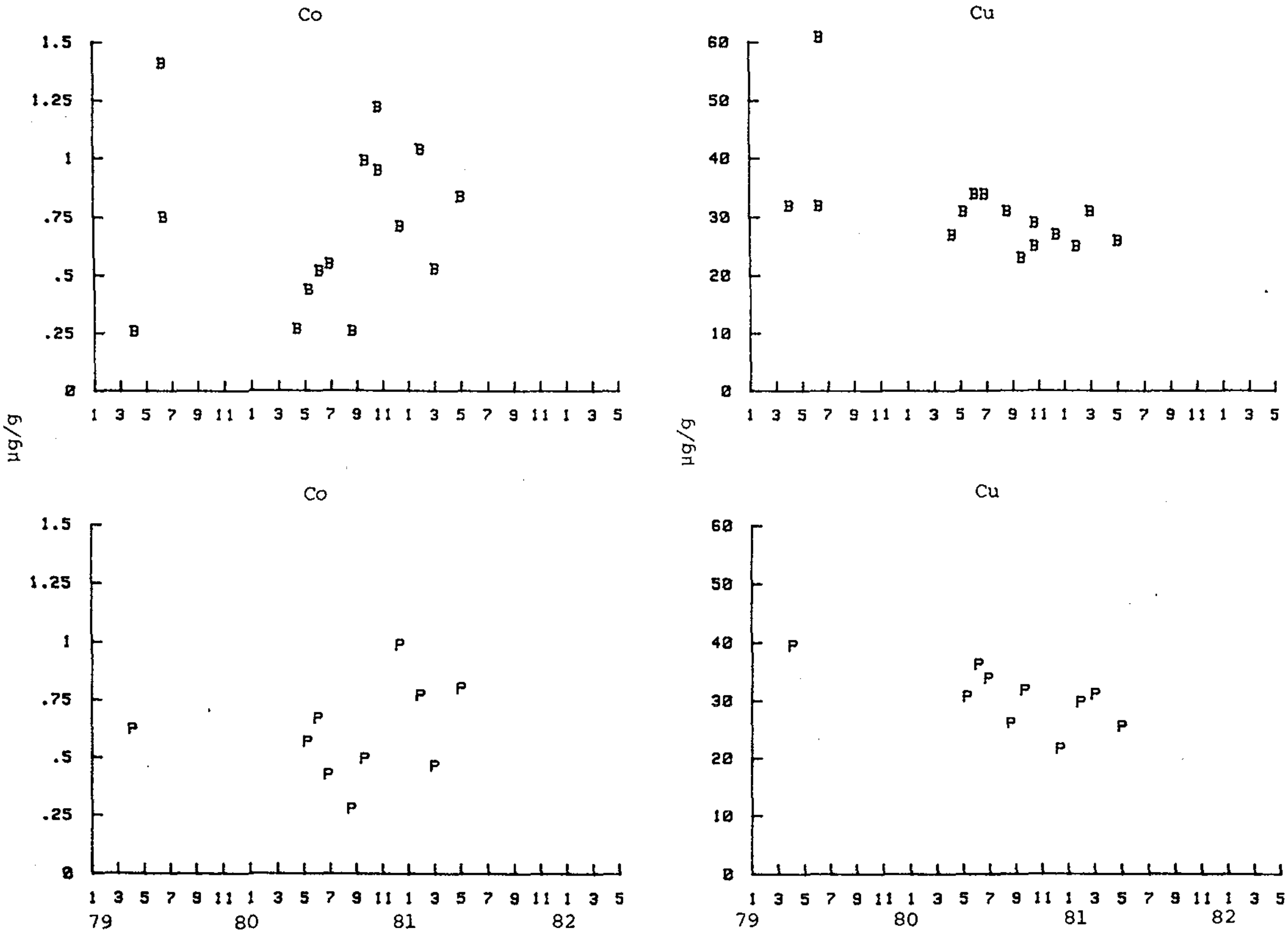

Figure 3-14. Temporal variations of cobalt and copper concentrations in Modiolus modiolus deployed at Bulwark Shoals (B), the reference site and Portland (P) Disposal Site.

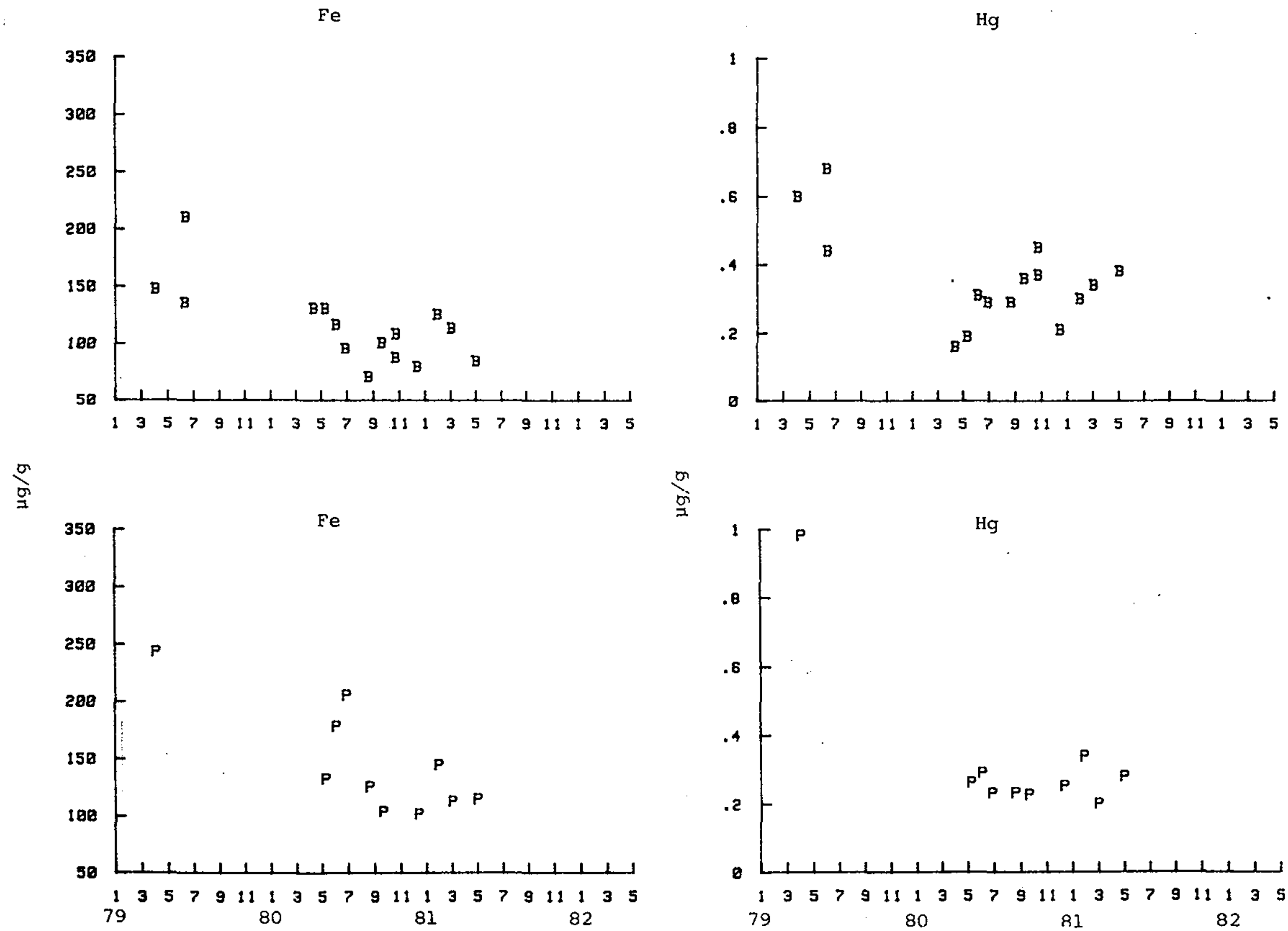

Figure 3-15. Temporal variations of iron and mercury concentrations in <u>Modiolus modiolus</u> deployed at Bulwark Shoals (B), the reference site and Portland (P) Disposal Site.

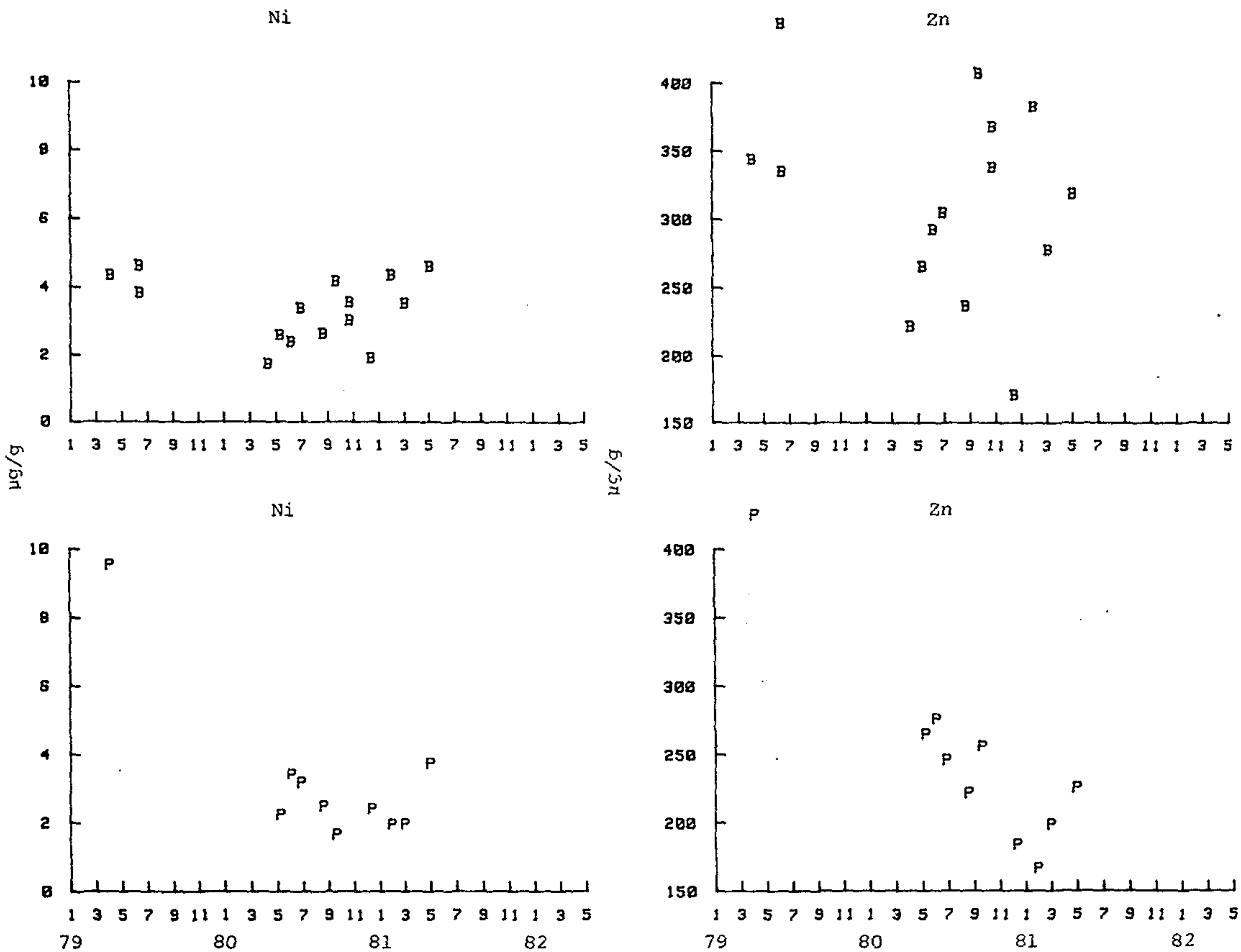

Figure 3-16. Temporal variations of nickel and zinc concentrations in Modiolus modiolus deployed at Bulwark Shoals (B), the reference site and Portland (P) Disposal Site.

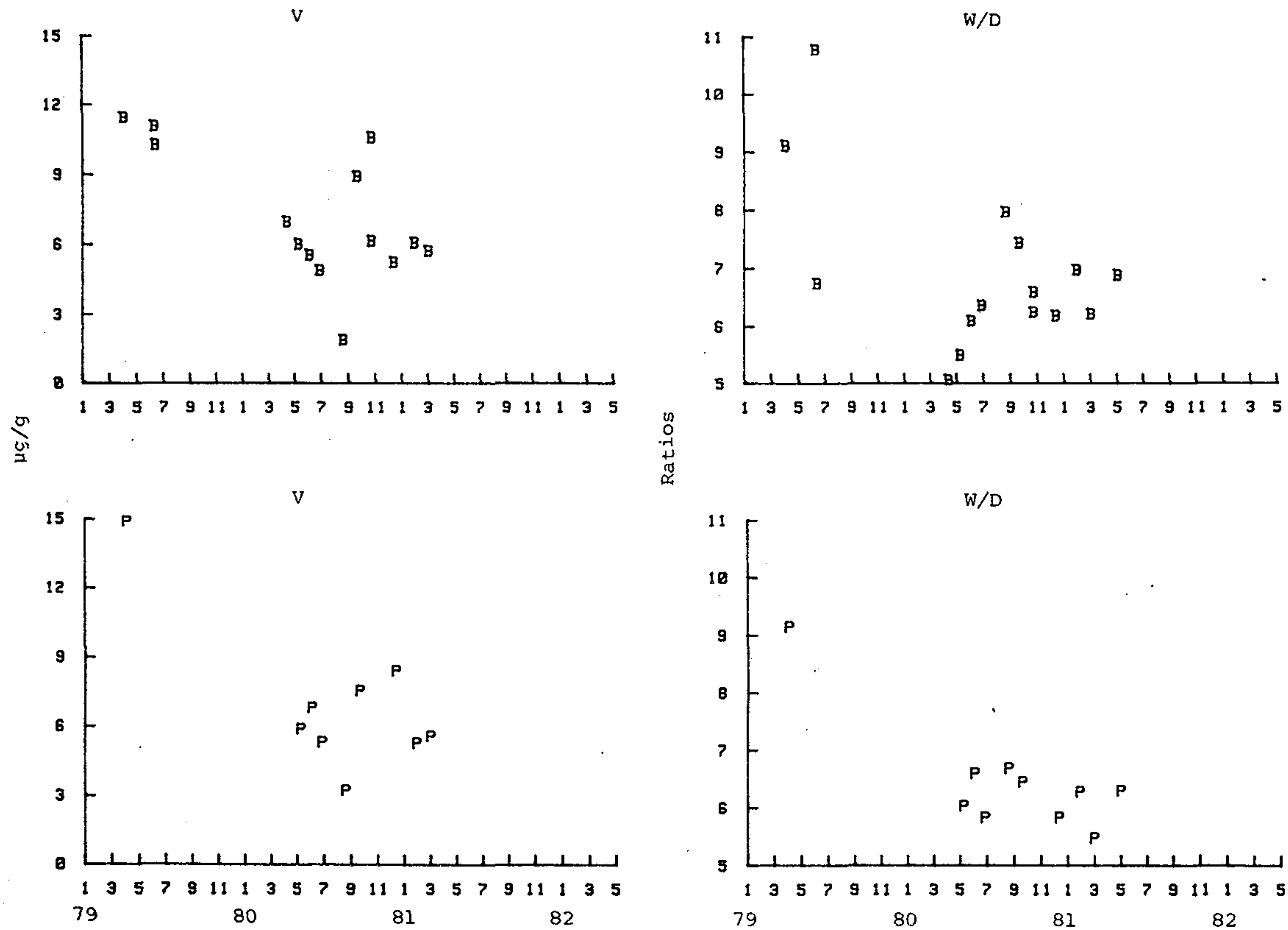

Figure 3-17. Temporal variations of vanadium concentrations and tissue wet/dry weight ratios in Modiolus modiolus deployed at Bulwark Shoals (B), the reference site and Portland (P) Disposal Site.

with the disposal operation at this site.

Mussels are generally useful as a bioindicator of trace metal input into coastal and estuarine environments, however, the interpretation of field results from the mussel monitoring project is complicatd by a variety of intrinsic and extrinsic variables (Feng, 1982a,b). A brief survey of literatures indicates that variance in mussel trace metal concentrations has been attributed to the location of the mussels in the intertidal zone (Graham, 1971), the season when they are collected (Dare and Edwards, 1975; Watling and Watling, 1976, Simpson, 1979), the volume of freshwater to which they are exposed (Davenport, 1977) and the concentration of phytoplankton associated with heightened levels of Cu and Pb in seawater (Seeliger and Edwards, 1977). Therefore, in interpreting field results, the observed levels of trace metals in the mussels represent a time-integration of all sources in the environment. Attempts must be made to partition or account for the variance in trace metal concentrations. This means that other than the dredge volume, an adequate number of intrinsic and extrinsic variables must be investigated concurrently in order to access the relative importance of these factors on the level of trace metals in the mussels. In most of the dredging studies, dredging has been assumed to be the major factor in assessing its environmental impacts. Our studies have shown that the field study of dredging and disposal operations is essentially a multifactor problem and requires special statistical analytical procedures to uncover the underlying major factors associated with the level of trace metals or any other parameters being investigated.

3.1 Eastern Long Island Sound Disposal Site

3.1.1 Variance in trace metal concentrations associated with intrinsic variables.

The seasonal cycle of W/D tissue weight ratio as reported by Feng (1982a,b) in mussels deployed at the Central Long Island Sound Disposal Site and Eastern Long Island Sound Disposal Site, was observed again during this study (Fig. 3-2).

In examining the temporal variations of Cd, Cr, Co, Cu, Fe, Hg, Ni, Zn and V (Figs. 3-3 to 3-11), the period of highest and lowest concentrations of trace metals was coincident with that of the W/D tissue weight ratios. The relationship between the trace metal concentrations and W/D ratios was confirmed by correlation analyses. Table 3-2 summarizes the correlation coefficients of W/D ratio and shell length with particular trace metals at the five stations: D1, D3, FIS, LLp, and LLr. Positive correlations between W/D ratio and trace metals: Hg, Zn, Cd, Fe, Cr, Co and Ni are particularly high; Cu and V show insignificant correlations with W/D ratios. In order to ascertain the contribution of the intrinsic variables: W/D ratios and shell length, to the variance of the trace metal concentration, they were regressed against metal concentrations. Table 3-3 shows the percent variance in trace metal concentration due to intrinsic variables. The median percent variance explained is 51.4% with a minimum value of 1.6% for Cu at D1 and a maximum value of 92.3% for Hg at LLr. The small percent variance for Cu at D1 confirms the correlation studies (Table 3-2).

Two hypotheses were tested for the data presented in Table 3-3: (1) there was no difference in the percent variance

Table 3-2. Correlation coefficients of the intrinsic variables, wet to dry weight ratio and shell length with particular trace metals at the four stations: D1, D3, FIS, and LL (including subgroups LLp and LLr).

Metal		Stations D1	D3	FIS	LLp	LLr
Cd	W/D	.395	.230	.681	.678	.719
	L	.116	-.001	-.434	-.589	.409
Cr	W/D	.508	.802	.377	.619	.559
	L	.201	-.337	-.167	-.545	-.565
Co	W/D	.625	.499	.262	.674	-.092
	L	.116	.130	-.025	-.589	-.721
Cu	W/D	-.041	.025	.543	.610	-.359
	L	-.118	-.269	.437	-.837	-.202
Fe	W/D	.512	.592	.606	.830	.688
	L	-.422	-.480	-.720	-.791	-.319
Hg	W/D	.742	.605	.865	.843	.956
	L	.012	-.264	-.562	-.086	-.241
Ni	W/D	.503	.472	.452	.676	.203
	L	.181	-.324	-.793	-.669	-.358
Zn	W/D	.616	.681	.752	.807	.020
	L	-.215	-.530	-.793	-.788	-.358
V	W/D	-.068	-.011	+.272	.279	.085
	L	-.272	-.235	-.484	.512	-.358

Table 3-3. Percent variance in trace metal concentrations explained by the intrinsic variables, wet to dry tissue weight ratio and shell length, in a stepwise regression model for each metal at the four stations: D1, D3, Fishers Island South (FIS) and Latimer's Light (LL). At LL two groups of mussels were sampled; one from the platform and the other from the natural rock substrate, hence, they were designated as LLp and LLr respectively.

	Stations				
Metal	D1	D3	FIS	LLp	LLr
Cd	16.9	5.5	48.6	47.8	63.0
Cr	54.8	65.4	14.2	40.1	53.7
Co	40.3	32.1	7.6	47.4	54.8
Cu	1.6	7.5	21.6	70.0	19.8
Fe	44.2	46.5	60.9	77.1	51.4
Hg	55.1	37.8	78.5	72.1	92.3
Ni	41.0	26.0	24.0	52.3	48.4
Zn	42.7	59.7	82.4	73.5	83.7
V	7.8	6.1	23.7	28.1	13.0

explained by the intrinsic variables among sites; and (2) the percent variance explained did not differ among metals. Friedman's tests were performed and rejected both hypotheses (p 0.05) indicating that there were differences among sites and trace metals. Further multiple comparison tests of rank sums revealed that the percent variance explained by the intrinsic variables differed significantly (p .10 between LLpr and D3 and that higher percentages of the variance were explained at the reference stations than at the dumpsite. Moreover, among the nine trace metals, Hg and Zn had significantly higher percentages of variance explained than vanadium; the percent variance explained did not differ among the other six trace metals.

3.1.2 Variance in trace metal concentrations due to single extrinsic variables as revealed by the partial correlation analysis.

Having determined the contribution of the intrinsic variables to the variance in trace metal concentration, the relationship between all potential extrinsic variables and tissue trace metal concentrations was scrutinized as if each extrinsic variable, e.g. dredge volume, temperature, river runoff, month,and year, were the only factors being studied. Similar dummy variables: spring, fall and amino acid were used, as in the previous studies to explore extrinsic variable which might account for unexplained variance.

The results of partial correlation analysis are presented in Tables 3-4 and 3-5. During this study, temperature replaces river runoff as one of the most frequently encountered significant partial correlation coefficients with trace metals; this could well be associated with the reduction of riverflow in

Table 3-4. A summary of the significant extrinsic variables, their partial correlation coefficients, (P.C.C.) and critical values for significance at the 0.05 level. n = sample size. The sign of the P.C.C. indicates the direction of the trend. Site 1 = D1, Site 2 = D3, Site 3 = Fishers Island South (FIS) and Site 4 = Latimers Light (LLp).

Metal	Site	Extrinsic Variables	n	P.C.C.	Critical Value
Cd	D1	Y	19	-.511	.482
	D1	T	19	-.683	.482
	D1	F	19	-.600	.482
	D3	T	18	-.572	.497
	FIS	T	20	-.509	.468
	FIS	F	20	+.562	.468
	FIS	A	20	+.581	.468
Cr	D1	T	19	-.598	.482
	FIS	M	20	-.587	.468
	FIS	T	20	-.551	.468
Co	D3	Y	18	-.662	.497
	D3	M	18	-.631	.497
	LLp	M	17	-.645	.514
	LLp	T	17	+.719	.514
Cu	D1	M	19	-.614	.483
	D1	T	19	-.697	.482
	D3	M	18	-.837	.497
	D3	T	18	-.748	.497
	FIS	M	20	+.716	.468
	FIS	T	20	+.526	.468
	FIS	R	20	+.684	.468
	LLr	T	12	-.646	.632
	LLp	F	12	-.661	.482
Fe	D1	T	19	-.491	.482
	FIS	Y	20	-.497	.468
	FIS	M	20	-.513	.468
	LLr	Y	12	-.806	.632

Table 3-4 Continued

Metal	Site	Extrinsic Variables	n	P.C.C.	Critical Value
Hg	D1	M	19	-.770	.482
	D1	T	19	-.789	.482
	D1	S	19	+.546	.482
	D3	M	18	+.714	.497
	D3	D	18	+.549	.497
	D3	R	18	+.522	.497
	FIS	D	20	+.540	.468
Ni	FIS	M	20	-.606	.468
	FIS	T	20	-.586	.468
	LLp	M	17	-.633	.514
	LLr	T	12	-.759	.632
Zn	D1	T	19	-.593	.482
	D3	D	19	+.544	.497
	FIS	Y	20	+.641	.468
	FIS	D	20	+.708	.468
	LLp	Y	17	+.825	.514
	LLp	D	17	+.839	.514
	LLr	D	12	+.682	.632
V	D1	M	19	-.539	.482
	D1	S	19	+.649	.482
	D3	M	18	+.545	.497
	D3	S	19	+.613	.497
	FIS	M	20	+.529	.468
	LLp	M	17	+.519	.514
	LLp	S	17	+.599	.514

Table 3-5. A summary of all significant extrinsic variables based on P.C.C. $p < 0.05$ listed in Table 3, for each metal at D1, D3, FIS and LL.

	Extrinsic Variables								Stations				
Metal	T	S	F	M	Y	D	R	A	D1	D3	FIS	LLp	LLr
Cd	X									X			
					X				X				
	X								X				
			X						X				
	X										X		
			X								X		
								X			X		
Cr	X								X				
				X							X		
	X										X		
Co					X					X			
				X						X			
				X								X	
	X											X	
Cu				X					X				
	X								X				
				X						X			
	X									X			
				X							X		
	X										X		
							X				X		
	X											X	
			X									X	
Fe	X								X				
					X						X		
				X							X		
					X								X

Table 3-5 Continued

Metal	Extrinsic Variables								Stations				
	T	S	F	M	Y	D	R	A	D1	D3	FIS	LLp	LLr
Hg				X					X				
	X								X				
		X							X				
				X						X			
						X				X			
							X			X			
						X					X		
Ni				X							X		
	X										X		
				X								X	
	X												X
Zn	X								X				
						X				X			
					X						X		
						X					X		
					X							X	
						X						X	
						X							X
V				X					X				
		X							X				
				X						X			
		X								X			
				X							X		
				X								X	
		X										X	

1980-1981 (Fig. 3-1a). A review of the riverflow data in the past five years showed that 1980 and 1981 were indeed relatively drier years than the preceeding three years. As the influence of river runoff on the dumpsite waned, the effect of dredge material disposal on the trace metal level seemed to have increased. It is important to note that during this study period, January 1979 to May 1981, the amount of dredge materials dumped at the site was approximately 3.6 million cubic yards which were more than double the dredge materials disposed (1.6 million cubic yards) in 1977 to 1979. "Dredge volume" was only partially correlated with two trace metals: Hg at D3 and FIS, and Zn at D3 , FIS, LLp and LLr. It was also noticed that "runoff" was also partially correlated with Hg at D3 which was nearest to the Thames River, and with Cu at FIS. Therefore, Hg at D3 was partially correlated with both extrinsic variables: "dredge volume" and "runoff".

The time related independent variables: "spring," "fall," "month" and "year" remained to be the dominant variables which were significantly correlated with trace metals. This reflects the temporal trend in the trace metal concentrations of the mussels. Among the six significant correlation coefficients of trace metals with the "year," two cases were positively correlated with Zn at the reference site FIS and LLp, and four negatively correlated with Cd at D1, Co at D3, Fe at FIS and LLr. This suggests a decline of these trace metal concentrations over the study period. "Spring" was positively correlated with V at D1, D3 and LLp, and also with Hg at D1. "Fall" was negatively correlated with Cd and Cu at D1 and LLp respectively, but was positively correlated with Cd at FIS.

Significant correlations between the "month" and trace metals were encountered 15 times. It was negatively correlated with Cr and Fe at FIS and Ni at FIS, and LLp. Vanadium was positively correlated with "month" at D3, FIS and LLp, but negatively at D1. "Month" was negatively correlated with Co at D3 and LLp, Cu at D1 and D3, and Hg at D1. At FIS and D3, "month" was positively correlated with Hg and Cu. In all, the time related variables accounted for 54% (or 28 out of 52 cases) of the significant partial correlation coefficients, "temperature" 29% (or 15 cases), "dredge volume" 11% (or 6 cases), "runoff" 4% (or 2 cases) and "amino" 2% (1 case). Forty six percent of the partial correlation coefficients were found in the dumpsite stations: D1 (25%) and D3 (21%) and the remaining 54% in the reference stations: FIS (31%) and LL (23%).

3.1.3 Variance in trace metal concentrations associated with groups of variables as demonstrated by the Stepwise Multiple Regression Analysis

This statistical procedure is designed to search for the "best" regression model that could account for the highest proportion of the variance in the trace metal concentrations (Feng, 1982a). The results expressed as total percent variance derived from 45 stepwise multiple regression analyses are presented in Table 3-6. We note that in five cases or 11% of the total number of cases, the variance contains only two intrinsic factors accounting for 44 to 77% of the variance in trace metals (median = 54.8%); this situation however, is limited to three trace metals: Cr, Co and Fe at Stations D1, D3, LLp and LLr. In the remaining 89% of the cases, the total percent variance accounted for by the combined intrinsic and extrinsic variables

Table 3-6. Total percent variance in trace metal concentration accounted by stepwise multiple regression models using intrinsic and extrinsic variables. One model constructed for each metal.

	Stations				
Metal	D1	D3	FIS	LLp	LLr
Cd	78.9	36.4	78.4	83.5	74.4
Cr	64.5	65.4	43.8	51.5	53.7
Co	62.7	77.1	27.7	74.6	54.8
Cu	61.3	72.3	86.5	75.9	91.4
Fe	44.2	46.5	79.3	77.1	93.0
Hg	86.3	91.4	89.8	84.0	95.6
Ni	53.2	41.6	57.4	67.5	78.1
Zn	70.7	74.4	94.1	92.2	91.3
V	47.3	86.0	45.1	55.0	37.6

varied from 27 to 96% with a median of 74%. The hypothesis that there was no difference among metals or among sites in the total percent variance accounted for by the model was tested by applying the Friedman's Test. It was sustained (p .3), suggesting that the total percent variance associated with stations and metals was explained by the data to about the same degree.

The stepwise multiple regression models are shown in Tables 3-7 and 3-8. Temperature entered the models 17 times and often was the first variable to enter after the intrinsic factors, confirming the results obtained from the partial correlation analysis (Tables 3-4 and 3-5). Temperature as an extrinsic factor, unlike runoff or dredge volume can not directly supply trace metals. It entered the models primarily because it is correlated with either physical, chemical and biological factors which in turn influence trace metal concentration in mussels. Time related variables: spring, fall, month and year which entered the models 24 times, remained as the major group of variables in explaining the variance in trace metals.

Dredge volumes and river runoff entered the models 9 and 8 times respectively as the 3rd or 4th variable; they were important extrinsic variables in accounting for the variance in trace metals at the Eastern Long Island Sound Disposal Site. In our 1977-79 study of the New London dumpsite, runoff was the dominant extrinsic variable in explaining the variance of trace metals. This apparent shift in the ranking of these extrinsic variables observed in this study probably reflects the reduction of Thames River flow as well as the augmentation of dredge

Table 3-7. Stepwise multiple regression models for Cd, Cr, Co, Cu, Fe, Hg, Ni, Zn and V at five stations: D1, D3, FIS, LLp and LLr. % = the amount of variance in the trace metal concentration explained by the model after the variable on the same row has entered the model. Variable code: L = shell length, W/D = wet/dry ratio, T = temperature, D = dredge volume, R = runoff, S = spring, F = fall, A = amino acid, M = months, Y = years. Transformation Code: * = $-1/x^2$, 2* = $-1/x^3$, 3* = x^2, 4* = x^3, 5* = $-1/\sqrt{x}$.

		Stations									
		D1		D3		FIS		LLp		LLr	
Metals	Variables		%		%		%		%		%
Cd	1st	W/D	15.6	W/D*	5.3	W/D	46.4	W/D	46.0	W/D**	57.8
	2nd	L	16.9	L	5.5	L	48.6	L	47.8	L	63.0
	3rd	T	55.7	T	36.4	A	65.9	T	83.5	R**	74.7
	4th	D	78.9			T	78.4				
Cr	1st	W/D	25.7	W/D****	64.3	W/D	14.2	W/D	38.3	L	31.9
	2nd	L	29.7	L	65.4	L	14.2	L	40.1	W/D	53.7
	3rd	T*	54.8			M	43.8	M	51.5		
	4th	D****	64.5								
Co	1st	W/D	39.0	W/D	24.9	W/D**	6.9	W/D	45.4	L	52.0
	2nd	L	40.3	L	32.1	L	7.6	L	47.4	W/D**	54.8
	3rd	T	52.5	Y	61.9	T	27.7	T	74.6		
	4th	R	62.7	T	77.1						
Cu	1st	L	1.4	L	7.2	L	19.1	L	70.0	W/D****	12.9
	2nd	W/D	1.6	W/D	7.5	W/D	21.6	W/D	70.0	L	19.8
	3rd	T	49.4	M	72.3	M	61.8	D	75.9	F	54.9
	4th	F	61.3			R*	80.3			R	80.3
	5th					A	86.5			M	91.4

Table 3-7 Continued

Metals	Variables	D1	%	D3	%	FIS	%	LLp	%	LLr	%
Fe	1st	W/D	26.2	W/D	35.1	W/D	51.9	W/D	70.3	W/D*	47.4
	2nd	L	44.2	L	46.5	L	60.9	L	77.1	L	51.4
	3rd					M	71.2			Y	83.0
	4th					S	79.3			M	93.0
Hg	1st	W/D	55.0	W/D	36.6	W/D	74.9	W/D	71.1	W/D*	91.4
	2nd	L	55.1	L	37.8	L	78.5	L	72.1	L	92.3
	3rd	T	83.0	T	71.1	D****	81.8	Y	78.9	D****	95.6
	4th	F	86.3	D	83.2	M	89.8	S	84.0		
	5th			A	87.6						
	6th			S	91.4						
Ni	1st	W/D	25.3	W/D*	22.3	W/D	20.5	W/D	45.7	L	34.6
	2nd	L	28.5	L	26.0	L	24.0	L	52.7	W/D	48.4
	3rd	D****	41.0	D	41.6	M	57.4	M	67.5	T*	78.1
	4th	Y	53.2								
Zn	1st	W/D	38.0	W/D	46.3	L	63.0	W/D	65.1	W/D	79.7
	2nd	L	42.7	L	59.7	W/D	82.4	L	73.5	L	83.7
	3rd	T	62.8	R*****	74.4	D****	91.2	D****	92.2	D****	91.3
	4th	F	70.0			A	92.8				
	5th					M	94.1				
V	1st	L	7.4	L	5.5	L	23.4	L	26.2	L	12.8
	2nd	W/D	7.8	W/D	6.1	W/D	23.7	W/D	28.1	W/D**	13.0
	3rd	T	47.3	T	41.6	M	45.1	T	55.0	R	37.6
	4th			R	58.0						
	5th			S	86.0						

Table 3-8. A summary of the extrinsic variables which entered the stepwise multiple regression models and were derived from Table 6. The Table is designed to determine at a glance which variable entered most often at particular stations. R = runoff, D = dredge volume, T = temperature, *S = spring, F = fall*, M = month, Y = year, and A = amino acid.

	Extrinsic Variables							
Metal	R	D	T	S	F	M	Y	A
Cd	LLr		D1, D3, FIS,LLp					FIS
Cr		D1	D1			FIS,LLp		
Co	D1		D1, D3 FIS,LLp				D3	
Cu	FIS,LLr	LLp	D1		D1,LLr	D3,FIS LLr		FIS
Fe				FIS		FIS,LLr	LLr	
Hg		D3,FIS LLr	D1, D3	D3,LLp	D1	FIS	LLp	D3
Ni		D1, D3	LLr			FIS,LLp	D1	
Zn	D3, FIS	LLp,LLr	D1		D1	FIS		FIS
V	D3,LLr		D1, D3 LLp	D3		FIS		

volumes as mentioned in the preceeding section. From October 1979 to May 1981, the Thames River runoff had a mean flow rate of 2200 cu/ft/sec. However, for the same period during 1977 to 1979, the meanflow rate was 3826 cu/ft/sec or 1.74 times the 1979 to 1981 rate. In a study of the dynamics of zinc in the Strait of Georgia, Thomas and Grill (1977) found that the highest concentration of soluble zinc occurred during the spring and early summer and suggested that such occurrence was attributable to the descriptive reactions of sediments being transported by the Fraser River to the Strait. Although the period of elevated concentrations observed in this study was only partially coincident, i.e. early spring, with that reported by Thomas and Grill (1977), it is likely that a similar mechanism may be operating in the Thames River estuary.

3.1.4 Comparison of trace metal concentrations, wet/dry weight ratios and percent cumulative mortalities among stations.

Friedman's test was applied to determine whether trace metal concentration and wet/dry weight ratios differ among stations. Comparison between the Latimer's Light platform (LLp) and Latimer's Light rock (LLr) was designed to answer the question whether the trace metal concentrations and the well being of the mussels expressed as W/D ratios were affected by suspending them one meter off the bottom. Based on the results presented in Table 3-9, there is no significant difference in trace metal concentrations and wet/dry tissue weight ratios between the mussels held on the platform and on the rock substrate.

In comparing the concentration of trace metals and W/D

Table 3-9. Friedman's Test compares the concentration of a trace metal and tissue W/D ratios between Latimer's Light platform (LLp) and Latimer's Light rock (LLr). Significance values close to or less than 0.10 suggest trace metal or W/D ratio differences between stations.

Variables	Stations	Rank Sum	Friedman's Statistics	D.F.	Significance
Cd	LLp	13			
	LLr	14	.11	1	.74
Cr	LLp	14			
	LLr	13	.11	1	.74
Co	LLp	13			
	LLr	14	.11	1	.74
Cu	LLp	12			
	LLr	15	.999	1	.31
Fe	LLp	15			
	LLr	15	.999	1	.31
Hg	LLp	12			
	LLr	15	.999	1	.31
Ni	LLp	15			
	LLr	12	.999	1	.31
Zn	LLp	14			
	LLr	13	.11	1	.74
V	LLp	14			
	LLr	13	.11	1	.74
W/D Ratio	LLp	14			
	LLr	13	.11	1	.74

ratios among mussels deployed at the disposal and reference sites, we found that with the exception of vanadium, the Friedman's statistics are highly significant (p 0.01) indicating that there were differences among sites (Table 3-10). Multiple comparison tests (Noether, 1976) were performed to identify which sites differed significantly ($p < 0.1$) (Table 3-11).

Table 3-11 shows that the stations are generally organized according to the descending order of rank sums: D1, D3, LLp, FIS. The pattern indicates that among sites, FIS had significantly lower concentrations of Cd, Cr, Cu, Fe, Hg, Ni and Zn; the lowest Co concentration found in LLp is the only exception. The pattern is less distinct for Fe and Zn. In Ni, Cr, and Hg, however, the order of D3 and LLp is reversed. Regardless of these minor inconsistencies, the pattern in most cases holds and reflects the proximity of the stations to the disposal site and riverine influences. Moreover, the significantly better condition of the mussels at FIS as shown by the lower W/D tissue weight ratio, provides additional support for this interpretation. However, this interpretation is confounded by the cumulative mortality study which shows that D1 and FIS have similar cumulative mortalities (Fig. 3-12). Mussels held at D3 exhibit the highest cumulative mortality while those maintained at Latimer's Light show the lowest cumulative mortality among the sites. It is difficult to explain the relatively high cumulative mortality in mussels at Fishers Island South (FIS), a location which is not expected to be influenced by the disposal operation farther to the west. The question whether the similarity in cumulative mortality between D1 and FIS is due

Table 3-10. Friedman's Test compares the concentration of a trace metal and tissue W/D weight ratios among D1(1), D3(2), FIS(3), and LLp(4). Significance values close to or less than 0.10 suggest trace metal or W/D ratio differences among stations.

Variables	Site	Rank Sum	Friedman's Statistics	D.F.	Significance
Cd	1	50			
	2	48			
	3	22			
	4	30	22.52	3	0.0001
Cr	1	53			
	2	29			
	3	26			
	4	52	18.60	3	0.0003
Co	1	55			
	2	44			
	3	27			
	4	24	25.64	3	0.0001
Cu	1	47			
	2	49			
	3	26			
	4	28	17.80	3	0.0005
Fe	1	48			
	2	40			
	3	22			
	4	40	14.52	3	0.0023
Hg	1	49			
	2	38			
	3	22			
	4	41	15.40	3	0.0015
Ni	1	49			
	2	38			
	3	24			
	4	39	12.68	3	0.0054
Zn	1	46			
	2	43			
	3	24			
	4	37	11.34	3	0.0097

Table 3-10 Continued

Variables	Site	Rank Sum	Friedman's Statistics	D.F.	Significance
V	1	41			
	2	31			
	3	41			
	4	37	2.68	3	0.44
W/D Ratio	1	48			
	2	39			
	3	21			
	4	32	16.94	3	0.001

Table 3-11. Multiple comparisons tests to determine which of the sites differed significantly in the concentration of a single trace metal and W/D ratio. Sites connected by lines are not significantly different ($p \geq .10$). This test was performed only after the Friedman's test (Table 10) was significant, indicating there was a difference among some sites. When the difference between any two rank sums is greater than the critical value then the rank sums are significantly different.

Cd

Site	D1	D3	LLp	FIS
Rank Sum	50	48	30	22

Critical value = 16.90

Cr

Site	D1	LLp	D3	FIS
Rank Sum	53	42	29	26

Critical value = 16.90

Co

Site	D1	D3	FIS	LLp
Rank Sum	55	44	27	24

Critical value = 16.90

Cu

Site	D3	D1	LLp	FIS
Rank Sum	49	47	28	26

Critical value = 16.90

Fe

Site	D1	D3	LLp	FIS
Rank Sum	48	40	40	22

Critical value = 16.90

Hg

Site	D1	LLp	D3	FIS
Rank Sum	49	41	38	22

Critical value = 16.90

Ni

Site	D1	LLp	D3	FIS
Rank Sum	49	39	38	24

Critical value = 16.90

Zn

Site	D1	D3	LLp	FIS
Rank Sum	46	43	37	24

Critical value = 16.90

W/D Ratio

Site	D1	D3	LLp	FIS
Rank Sum	48	39	32	21

Critical value = 16.40

to coincidence or other causes, e.g. predation, remains to be investigated.

3.2 Portland Disposal Site

The distance of this site from our home base in Connecticut, the depth and occasional logistic problems prevented us from sampling the site as often as we originally anticipated. Nevertheless, we did obtain one year of almost continuous data during a period when intensive disposal operations were being carried out at this site. Trace metal concentrations are shown in Figures 3-13 to 3-17.

3.2.1 Relationship between trace metal concentrations and intrinsic variables.

The tissue wet/dry weight ratios of the horse mussels were positively correlated with most trace metals (except Cu) at Bulwark Shoals and Portland Disposal Site (Table 3-12). Although the seasonality of the W/D ratio with a peak in August, was discernible at the nearshore Bulwark Shoals reference station, no such cycle was seen in mussels maintained at the Portland Disposal Site. This dissimilarity can be attributed to the physical difference between the two sites. Bulwark Shoals being inshore and in shallower waters, is subject to greater temperature fluctuations than the Portland Disposal Site which is in a deep open water area and characterized by a more stable temperature regime. Since temperature is one of the major factors controlling reproductive cycles of many marine invertebrates, it is not unexpected that the W/D ratios show little or no temporal variations at the Portland Disposal Site. However, within each station differences in W/D ratios between

Table 3-12. Correlation coefficients of the intrinsic variables, wet to dry weight ratio and shell length with particular trace metals at the two stations: Bulwark Shoals (B) and Portland (P), Maine.

Metal	Intrinsic Variables	Stations B	P
Cd	W/D	.843	.795
	L	.701	-.046
Cr	W/D	.008	.989
	L	.369	.092
Co	W/D	.287	.476
	L	.338	.146
Cu	W/D	.301	-.176
	L	-.080	-.126
Fe	W/D	.605	.915
	L	.327	.073
Hg	W/D	.877	.954
	L	.602	.030
Ni	W/D	.770	.961
	L	.594	.117

years are apparent. For example, the W/D ratios of 1979 were much higher than that of the subsequent years. At present, no plausible explanations for the obvious discrepancies exist, except to speculate that the relatively poor condition of the mussels in 1979 could be due to a lack of adequate food supplies (phytoplankton) in the water.

In the inshore waters at Bulwark Shoals, spawning probably takes place during July and August as indicated by the high W/D ratio at this time. This proposal, which differs from the report that spawning occurs in autumn and winter (Seed and Brown, 1977), is corroborated by our histological study of the horse mussel gonadal development. According to Arimoto and Feng (1982), the number of mature ova per unit area of tissue reaches a minimum (7.81 + 0.56) in August, a condition indicating that the mussel is spent. Hence, it is deduced that spawning must occur before August. However, at the Portland Disposal Site, spawning probably occurs in autumn, since the number of mature ova decreases to the lowest level (8.98 + 1.17) in November (Arimoto and Feng, 1982). Thus the differences in spawning times observed by Seed and Brown (1977) and Arimoto and Feng (1982) merely reflect the difference in environmental conditions of the respective site.

Positive correlations between most trace metals and shell length occur in 83% of the cases; Cu is the only exception where the correlations with shell length are negative at both stations. As reported for the blue mussels, the W/D weight ratio of *M. modiolus* is a better predictor than the shell length of trace metal concentrations.

One may ask at this point what is the contribution of the intrinsic variables: W/D ratio and shell length to the variance in trace metal concentrations? Based on the results obtained by the stepwise multiple regression analysis, 4 to 92% (median = 58%) of the variance observed in trace metal concentrations can be attributed to W/D ratio and shell length (Table 3-13). Again Cu is the worst case as revealed in the correlation study (Table 3-12). Only 4.2% and 21.9% of the Cu variance can be accounted for by the intrinsic factors at Portland Disposal Site and Bulwark Shoals respectively. Mercury is the best case where 77.2% and 92.4% of the variance are explained by the intrinsic factors at Portland and Bulwark Shoals respectively. This analysis shows that trace metals with high percent variance due to intrinsic factors are probably indicative of more internal organismic controls than external environmental influences.

3.2.2 *Variances in trace metal concentrations due to single extrinsic variables as revealed by the partial correlation analysis.*

It is important to examine all potentially significant extrinsic variables without bias; the variables should be treated as if each extrinsic variable were the sole variable studied. When stepwise multiple regression analysis is used, the entrance of extrinsic variables into the model is determined by their statistical significance. This could obscure extrinsic variables highly correlated with trace metal concentrations. Therefore, parial correlation analysis was used to discover which extrinsic variables: spring, fall, year, dredge volume and amino acid were correlated with trace metal concentrations. Amino acid is

Table 3-13. Percent variance in trace metal concentrations explained by the intrinsic variables, wet to dry tissue weight ratio and shell length, in a stepwise regression model for each trace metal at the two stations: Bulwark Shoals (B) and Portland (P) Maine. Portland is the disposal site and Bulwark Shoals, the reference site.

	Stations	
Metal	B	P
Cd	74.1	66.2
Cr	47.2	58.4
Co	12.3	23.2
Cu	21.9	4.2
Fe	37.1	84.3
Hg	77.2	92.4
Ni	59.6	92.5
Zn	39.8	57.9
V	24.5	40.6

fabricated as a dummy variable.

The results of partial correlation analysis are summarized in Table 3-14. Significant partial correlation coefficients ($p < 0.05$) of six trace metal concentrations with year, spring, and fall were detected three times, three times, and one time respectively (Table 3-15). No significant partial correlations were found in Cr, Ni and V with any extrinsic variables. Year was significantly correlated with Cd at Bulwark Shoals and Portland and with Hg at Portland. Spring was correlated with Co at Bulwark Shoals, with Cu and Zn at Portland. At Bulwark Shoals, fall was correlated with Fe. Dredge volume was conspicuously not correlated with any trace metals.

3.2.3 Variance in trace metal concentrations associated with groups of variables as demonstrated by the Stepwise Multiple Regression Analysis

The contribution of combined extrinsic and intrinsic variables to the variance of trace metal concentrations at each site was studied by applying the stepwise multiple regression analysis.

Table 3-16 summarizes the stepwise multiple regression analysis. In five of 18 cases (28%), extrinsic variables did not enter the models at all. They were Cr, Ni and Zn at Bulwark Shoals and Co and V at the Portland Disposal Site. The copper model, the largest model at the Portland Disposal Site, contained five variables and accounted for 95% of the variance. Three or more variables entered in 72% of the models strongly suggesting that trace metal concentrations are influenced by a number of intrinsic and extrinsic variables. As presented in Table 3-17, time related variables: year, spring and fall constituted 79% of

Table 3-14. A summary of the significant extrinsic variables, their partial correlation coefficients (P.C.C.) and critical values for significance at the 0.05. n = sample size. The sign of the P.C.C. indicates the direction of the trend. B = Bulwark Shoals reference site, P = Portland disposal site.

Metal	Site	Extrinsic Variable	n	P.C.C.	Critical Value
Cd	B	Y	13	.711	.602
Co	B	S	14	-.662	.576
Fe	B	F	14	.604	.576
Cd	P	Y	11	.769	.666
Cu	P	S	11	.669	.666
Hg	P	Y	11	.669	.666
Zn	P	S	11	.729	.666

Table 3-15. A summary of all significant extrinsic variables based on P.C.C. $p < 0.05$ listed in Table 14, for each trace metal at Bulwark Shoals (B) and Portland (P).

	Extrinsic Variables				
Metal	Y	S	F	B	P
Cd	X			X	
	X				X
Co		X		X	
Cu		X			X
Fe			X	X	
Hg	X				X
Zn		X			X

Table 3-16. Stepwise multiple regression models for Cd, Cr, Co, Cu, Fe, Hg, Ni, Zn and V at two stations: Bulwark Shoals (B) and Portland (P), Maine. % = the amount of variance in the trace metal concentration explained by the model after the variable on the same row has entered the model. Variable code: L = shell length, W/D = wet/dry tissue weight ratio, Y = year, S = spring, F = fall, D = dredge volume, A = Amino. Transformation Code: * = $1/x^3$, ** = x^3.

		Station			
Metal	Variables	B		P	
			%		%
Cd	1st	W/D	71.1	W/D	63.2
	2nd	L	74.1	L	66.2
	3rd	Y	87.2	Y	86.2
	4th			S	90.9
	5th			F	95.4
Cr	1st	L	13.6	W/D**	58.4
	2nd	W/D	22.3	L	58.4
	3rd			S	72.8
	4th			F	91.6
Co	1st	L	11.4	W/D	22.7
	2nd	W/D	12.3	L	23.2
	3rd	S	50.9		
Cu	1st	W/D	9.1	W/D**	3.1
	2nd	L	21.9	L	4.2
	3rd	Y	46.6	S	47.1
Fe	1st	W/D	36.6	W/D	83.8
	2nd	L	37.1	L	84.3
	3rd	F	60.1	A	90.4
	4th	A	72.7	S	93.9
Hg	1st	W/D	76.9	W/D	91.1
	2nd	L	77.2	L*	92.4
	3rd	Y	82.6	Y	95.8
Ni	1st	W/D*	59.2	W/D	92.4
	2nd	L	59.6	L	92.4
	3rd			A	95.5
	4th			D	97.9

Table 3-16 Continued

Metal	Variable	Station B		Station P	
			%		%
Zn	1st	W/D	39.1	W/D	55.7
	2nd	L	39.8	L	57.9
	3rd			S	80.3
V	1st	W/D	20.1	W/D	21.4
	2nd	L	24.5	L	40.6
	3rd	Y	42.3		

Table 3-17. A summary of the extrinsic variables which entered the stepwise multiple regression models. The Table is designed to determine at a glance which variable entered most often at particular stations. P = Portland, B = Bulwark Shoals, Y = year, S = spring, F = fall, D = dredge volume, A = amino acid.

	Extrinsic Variables				
Metal	Y	S	F	D	A
Cd	B,P	P	P		
Cr		P	P		
Co		B			
Cu	B	P			
Fe		P	B		B,P
Hg	B,P				
Ni				P	P
Zn	B	P			

the extrinsic variables that entered the models. Amino acid, the dummy variable, entered the models three times: twice at the Portland Disposal Site for Fe and Ni and once at the Bulwark Shoals Site for Fe. Dredge volume entered only once at the Portland Disposal Site, and it was the 4th or last variable to enter the model. Hence, it contributed only 2% to the variance of nickel concentration.

The stepwise multiple regression analysis showed that the combined intrinsic and extrinsic variables accounted for a large percentage of the variance found in the trace metal concentrations (Table 3-17). The total percent variance attributable to these variables varied from 42.3 - 98.6% with a median of 82.6%. In 28% of the cases, variance in trace metals (Cr, Co, Ni, Zn and V) was accounted for by the two intrinsic variables: W/D ratio and shell length; the percent variance ranges from 23.2 - 59.6% with a median of 40.6%.

In summary, the results of the stepwise multiple regression analysis confirm that of the partial correlation analysis. However, the latter analysis is more conservative than the former. Significant partial correlation coefficients were detected in the three extrnisic variables: year, spring and fall, while in the stepwise multiple regression analysis, five extrinsic variables: year, spring, fall, dredge volume and amino acid, entered the models.

3.2.4 Comparison of trace metal concentrations and wet/dry tissue weight ratios between stations

Friedman's test was employed to determine whether trace metal concentrations and wet/dry tissue weight ratios differ between mussels deployed at Bulwark Shoals and the Portland

Table 3-18. Total percent variance in trace metal concentration accounted by stepwise multiple regression models using intrinsic and extrinsic variables. One model was constructed for each metal. B = Bulwark Shoals, P = Portland.

	Station	
Metal	B	P
Cd	87.2	95.4
Cr	47.2	91.6
Co	50.9	23.2
Cu	46.6	47.1
Fe	72.7	93.9
Hg	82.6	98.6
Ni	59.6	97.9
Zn	39.8	80.3
V	42.3	40.6

disposal Site. The results are presented in Table 3-19. We found that there were signigicant differences in trace metal concentrations ($p \leq .10$) between stations. Chromium and iron concentrations were significantly higher at the Portland disposal Site than at the Bulwark Shoals reference site. Copper concentrations, on the other hand, were noticeably higher at the Bulwark Shoals reference site than the Portland Disposal Site. However, none of these significant differences could be attributed to the dredge material disposal. In fact, differences observed in Cr and Fe at the Portland Disposal Site and the reference site were due to spring, fall and amino acid, or other factors which we either did not measure or identify. Similar considerations also apply to the difference found in Cu concentrations. Had we determined the concentration of dissolved and particulate trace metals at the two sites simultaneously with mussel samples, we would probably be in a position to explain the result more plausibly. In conclusion, the observed differences in Cr, Fe and Cu at the two sites were not associated with the disposal operation, but were related to factors which were not investigated.

4.0 CONCLUSIONS

The behavior of trace metals in Mytilus edulis maintained at the Eastern Long Island Sound Disposal Site and its associated reference sites is summarized as follows: (1) There is a discernible seasonality in the concentration of the nine trace metals examined; (2) The trace metal concentrations are lower in the summer and fall than in the late winter and early spring; and

Table 3-19. Friedman's Test compares the concentration of a trace metal and tissue W/D ratio between Bulwark Shoals (B) and Portland (P) Sites. Significance values close to or less than 0.10 suggest trace metal or W/D ratio differences between stations.

Variable	Site	Rank Sum	Friedman's Statistics	D.F.	Significance
Cd	B	14			
	P	16	.399	1	.53
Cr	B	13			
	P	20	4.45	1	.03
Co	B	17			
	P	16	.09	1	.76
Cu	B	19			
	P	14	2.27	1	.13
Fe	B	12			
	P	21	7.36	1	.007
Hg	B	17			
	P	16	.09	1	.76
Ni	B	17			
	P	16	.09	1	.76
Zn	B	17			
	P	16	.09	1	.76
V	B	16			
	P	17	.09	1	.76
W/D Ratio	B	20			
	P	16	1.33	1	.25

(3) The variance in the trace metal concentrations is accountable by the intrinsic variables: W/D weight ratio and shell length, and extrinsic variables: water temperature, time related variables, river runoff and dredge volumes. In contrast with the 1977-1979 study, runoff is relegated to a lesser role. This is largely due to a considerable reduction of the Thames River mean flow rate from 3826 cu/ft/sec in 1977-1979 to 2200 cu/ft/sec in 1980-1981. Dredge volume, which was of minor importance in the 1977-1979 study, is a prominent variable in the present investigation, accounting for variance in Cr at D1, Cu at LLp, Hg at D3, FIS and LLr, Ni at D1 and D3, as well as Zn at LLp and LLr. This rising significance of dredge volume among the extrinsic factors is probably related to an increase in the volume of dredge materials (3.6 million vs. 1.6 million cubic yards) deposited at the disposal site.

In comparing trace metal concentrations among sites, we recognize that the trace metals, except vanadium, tend to have a significantly higher concentration ($p < .10$) at the disposal site than at the reference site. Similar situations exist when we compare W/D tissue weight ratios and cumulative mortalities; the reference station, FIS, always exhibits better W/D ratios and lower cumulative mortalities than at the disposal site stations.

One of the major features of the Mussel Watch project is the repeated and unmistakable rhythmic fluctuation of trace metal concentrations in Mytilus edulis regardless whether they are maintained on the platform or living on natural substrate. This observation justifies long-term monitoring in order to properly assess the effect of dredging and subsequent disposal operations on marine and estuarine organisms. Further investigation is needed to determine whether the peak tissue concentration of a given trace metal represents the limit of metal binding capacity of the organism in question. If so, the laboratory assessment of the bioaccumulation potential of the organism could be grossly distorted and misleading, because the bioaccumulation potential would depend on when the organism was collected for the assay.

At the Portland Disposal Site and the Bulwark Shoals reference site, no temporal variations in trace metal concentrations were seen in *Modiolus modiolus.* However, the W/D tissue weight ratio at Bulwark Shoals did show seasonal variations with a peak in August, but not at the Portland Disposal Site. We attribute this dissimilarity to the physical difference of the two sites, i.e., the depth and the temperature regime. As expected, spawning is closely related to W/D ratios and temperatures, but there is no indication that the disposal operation has affectd spawning. About 40% (median) of the variance in the trace metal concentrations at the two sites are explained by the intrinsic variables and 43% (median) by the extrinsic variables: year, spring, fall, dredge volume and amino. Dredge volume has entered only once into the Ni model at the Portland Disposal Site and contributed only 2% to the total variance of this trace metal. Significant differences in the concentration of Cr, Cu and Fe at the two sites are not associated with the disposal operation, but due to factors which we either did not measure or identify.

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