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FECAL BORNE MICROBIOLOGICAL CONTAMINANT STUDIES ASSOCIATED WITH NSY PORTSMOUTH ME

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Fecal-Borne Microbiological Contaminant Studies Associated With the Portsmouth Naval Shipyard

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FECAL-BORNE MICROBIOLOGICAL CONTAMINANT STUDIES ASSOCIATED WITH THE PORTSMOUTH NAVAL SHIPYARD

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Abstract

An assessment of fecal-borne microbial contaminants in sediments and water around the SHIPYARD was made from September 1991 to June 1993. Measurements were made of *Clostridium perfringens* in water and in surface and subsurface sediments at 28 sites in the vicinity of the SHIPYARD and in York Harbor from September 1991 through June 1993. Monthly measurements of enterococci and fecal coliforms were also made to compare trends for long-term and short-term fecal contamination in water. *C. perfringens* concentrations were relatively low in water samples near the SHIPYARD and site 23 in York Harbor had the consistently lowest levels of all sites. Enterococci and fecal coliform levels steadily decreased from relatively high levels in November to low levels in March 1992 through June 1993, except for March 1993 when much higher levels were observed at all sites. In contrast to *C. perfringens,* the highest geometric means for fecal coliforms and enterococci were at site 23 in York Harbor. The highest levels of contamination in surface sediments and sediment cores were generally near Seavey Island, site 2 and the Rt. 95 bridge, while lower levels of *C. perfringens* were apparent at sites in channels away from the Piscataqua River and in York Harbor. Sediment core profiles showed highly contmainated layers at some sites. Comparison of *C. perfringens* to lead and mercury concentrations showed similar trends in spatial distributions. This study is useful for determining the distribution of fecal contamination near the SHIPYARD and will be helpful for evaluating the contribution of non-microbial contaminants in the harbor from the SHIPYARD in relation to other sources associated with fecal contamination.

Introduction

A critical aspect of assessing the impact that a certain source of pollution has had on its surrounding environment is to be able to separate the impact of the target source from the influences of other sources. The Portsmouth Naval Shipyard (PNSY) has different types of waste materials located at a variety of sites around Seavey Island that could potentially have an impact on the surrounding environment. However, other sources of some of the same potentially toxic materials exist or have existed in close proximity to Seavey Island. For example, the outfall for effluent from the Portsmouth municipal wastewater treatment facility is in the channel of the Piscataqua River near Seavey Island, and other sewage effluent and storm drain outfall pipes are also located in and around Portsmouth Harbor. In addition, more historic sources of heavy metals and PAHs located upstream in Portsmouth and near Dover, New Hampshire, and the Berwicks in Maine could also be sources of the pollutants that have accumulated in the sediments near Seavey Island (Jones et al., 1992). Thus, any potential impact of toxic organic and inorganic compounds on the biota in Portsmouth Harbor may not necessarily be solely attributed to PNSY.

Many of the sources of potentially toxic pollutants to Portsmouth Harbor are also sources of fecal contamination, whereas this is only a minor component of the wastes coming from PNSY. Thus, the use of an indicator of fecal contamination could help to assess the relative toxicological influence of the more fecally-contaminated pollution sources from the potential influence of PNSY on the biotic communities in Portsmouth Harbor (Jones, 1995). There are numerous bacteria, bacteriophages, and viruses that are common to the microbial communities of the intestines of warm-blooded animals, and some of these organisms are quite specific indicators of fecal contamination. Detection of one of these microbial indicators of fecal contamination could help fingerprint the distribution of fecally-contaminated sediments in Portsmouth Harbor.

This study is an attempt to determine the environmental impact of the PNSY wastes and toxic materials that have been or are presently being released into the environment. Most fecal indicator microorganisms cannot survive for decades, which is the time scale over which PNSY waste materials of concern could have had an influence on the environment, and would therefore be of little use as indicators of the presence of fecal contamination in sediments. Conversely, one fecal-borne bacterium, *Clostridium perfringens*, will respond to certain environmental stresses by forming spores that can survive for long periods of time. *C. perfringens* has been used to provide a record of fecal contamination in sediments cores (Valente et al., 1992), as a sewage sludge tracer in sediments around ocean dumpsites (White et al., 1993; Emerson and Cabelli, 1982; 1985), and to assess groundwater contamination from land-applied sewage (St. John and Matches, 1982). Thus, the longevity of the endospore makes this organism especially useful for the study of long-term fecal contamination.

In the present study, *C. perfringens* was used as an indicator of fecal pollution to determine the distribution of fecal pollution in sediments around Portsmouth Harbor. The concentrations of *C. perfringens,* enterococci and fecal coliforms in water column samples from sites throughout the Harbor were also measured as a means of locating existing sources of fecal pollution. Two sites in York Harbor were included in this investigation as comparative sites to Portsmouth Harbor.

Objectives

The purpose of this study was to gain information on past and present fecal contamination in sediments and water in Portsmouth Harbor. Such information is needed for differentiating fecal-borne toxic compound contaminants in sediments and water from contaminants from non-fecally contaminated sources, like the SHIPYARD. Integration of bacterial contamination data with that of toxic compounds known to be prevalent in sewage can provide a fingerprint of fecal-borne contamination. *C. perfringens* and enterococci/fecal coliforms were used as bacterial indicators of long-term and more recent fecal pollution, respectively. These goals were accomplished through the following specific objectives:

1.) determine potential existing sources and the distribution of fecal contamination in Portsmouth Harbor water;

2.) determine the distribution of fecal-borne contaminants from relatively recent sources deposited in top layers of surface sediments in Portsmouth Harbor;

3.) determine long-term trends for fecal contamination apparent in deeper sediments around Portsmouth Harbor.

Methods

Sediment and water samples were collected from 28 sites according to SOP procedures without difficulty. The key aspect from a microbiological standpoint was that no cross contamination occurred and that samples were adequately preserved to minimize stress to the microbes. Water and sediment samples were all analyzed for *C. perfringens* according to SOP procedures, also without difficulty. Details of the procedures are described in JEL SOP 1.09 and ERL-N SOP 1.03.017 for enumeration of *C. perfringens* in sediments and marine waters, respectively. Water samples collected from Sept. 1991 to June 1993 at six of the original 23 sample stations were analyzed for *C. perfringens.*

Monthly (11/91-10/92) and quarterly (12/92-6/93) water samples were also analyzed for enterococci and fecal coliforms, using accepted methods (U.S.E.P.A., 1986). This additional information was included for comparison of the indicator of long-term fecal contamination (*C. perfringens*) to indicators of more short-lived duration (enterococci; fecal coliforms) that would be more indicative of recent fecal contamination. Enterococci is the indicator presently used by both the State of Maine and the State of New Hampshire as the standard for assessing the sanitary quality of marine recreational waters, and fecal coliforms are used by both states to classify shellfish-growing waters.

Results and Discussion

Water samples

Concentrations of *C. perfringens* in water samples collected from 23 Portsmouth and York Harbor stations during September 1991 were relatively low (Figure 1; Table 1). Station 21 in Spruce Creek and Station 22 in outer York Harbor had the lowest (1 cfu/100 ml) level of contamination. Other sites were more contaminated, although levels for each sample ranged from 1 to only 14 cfu/100 ml. Station 16 on the Maine side of the Piscataqua River near the Rt. 95 bridge being the highest level, with a mean of 12 cfu/100 ml.

Monthly/quarterly monitoring of water samples from 6 sites representative of the different areas in the two harbors showed monthly and seasonal variations (Table 1). Figure 2 shows the levels of *C. perfringens* remained relatively low through April, 1992 (except for Station 16 in February, 1992) followed by even lower levels from May to October, 1992 at all stations. Levels of *C. perfringens* were slightly greater in December, 1992, then increased dramatically at all stations in March, 1993, during snowmelt. The variability between sites was such that no site was always either the most or the least contaminated.

Monthly samples of water collected at the six sites revealed different trends for enterococci and fecal coliform levels (Figures 3&4; Table 2). Enterococci concentrations declined in November to very low levels in March through September, 1992. No striking differences in contaminant levels was apparent at the different stations. Fecal coliform levels were relatively low from May, 1992 to June, 1993, except for during snowmelt in March, 1993 and station 23 in June, 1992.

Average indicator levels were relatively low for all stations (Table 3). Stations 15 and 16 had the highest level of *C. perfringens* and the geometric means for these stations were higher than the means for other stations (Table 3). Station 23, followed by Stations 8, 10 and 1 had lower levels of contamination. There were virtually no differences in geometric means for enterococci levels between stations (Table 3), with Station 23 having the highest (4.3/100 ml) and Station 8 the lowest (1.8/100 ml) levels. Fecal coliform levels at different stations were also similar, with the highest levels at Station 23 (12.7/100 ml) and the lowest at Station 1 (5.7/100 ml). Station 15 was the most or one of the most contaminated by all three indicators. However, the distribution of contamination using fecal coliforms and enterococci differed from that indicated by *C. perfringens* levels in that Station 23 had either the highest or the lowest levels for a given indicator. These results for York Harbor suggest that this site is not as pristine as would be expected of a reference site. The Gulfwatch program of the Gulf of Maine Council has also had difficulties in finding 'clean' reference stations for toxic contaminants in blue mussels in Maine, new Hampshire and Massachusetts (GOMCME, 1994). In comparison to the other areas in the estuary, levels of fecal indicators near the SHIPYARD were relatively low most of the time. For example, the mean enterococci concentration at the mouth of the Squamscot River (low tide) for the same time period was 26/100 ml and *C. perfringens* was 32/100 ml (Jones and Langan, 1994). The geometric means for enterococci in the study area waters were generally consistent with safe recreational use criteria set by Maine and New Hampshire (geometric mean <35/100 ml). The geometric means for fecal coliforms were all lower than the limit of 14 fecal coliforms/100 ml for approved shellfish-growing waters, but the frequency of samples greater than 43/100 ml was greater than 10% at the 6 stations. Thus, the waters were not quite consistent with all criteria required for approved classification (NSSP, 1992).

Box core surface sediment samples

The concentrations of *C. perfringens* in surface sediments were measured in September 1991 to determine the distribution of *C. perfringens*/fecal contamination deposited relatively recently in sediments at 23 sites in the two harbors (Table 4; Figure 5). MPN values for four analytical replicates at each site were averaged arithmatically to compare sites. Some stations

showed wide variation in levels among the four replicate samples. For example, Station 10 values ranged from 800 to 74,400 MPN/g, and Station 6 ranged from 900 to 48,500 MPN/g. Other sites had more consistent replicate analyses. For example, the four replicates at Station 13 ranged from 8,000 to 10,400 MPN/g. Average *C. perfringens* levels at the different sites fell into three general ranges. The sites with lowest contamination had <2000 MPN/g, the sites with highest contamination had >10,000 MPN/g, and the rest of the stations had *C. perfringens* levels between these ranges. Two sites had *C. perfringens* levels less than 1000 MPN/g: Station 22 in York Harbor (650 MPN/g) and Station 20 in Spruce Creek (890 MPN/g). The next lowest levels were at Station 23 (1650 MPN/g), Station 1 (1890 MPN/g) and Station 14 (2020 MPN/g). Sites where levels were also less than 10,000 MPN/g included Station 2 at the mouth of the Piscataqua River, the other Spruce Creek station (21), 2 of the 6 Clark Cove stations (3&8), the station in the Back Cove area behind Pierce Is. (Station 11), the two Back Channel sites (18 & 19), Station 16 on the Maine side of the Rt. 95 bridge crossing the Piscataqua River, and Stations 12 and 13 around Seavey Island. The stations where *C. perfringens* levels exceeded 10,000 MPN/g were Station 9 near Clark Island, Station 12 near the dry docks, Station 15 on the NH side of the Rt. 95 bridge, Station 17 off Badger Island, Stations 4-7 in Clark Cove, and Station 10 near the dry docks had the highest average level (22,500 MPN/g). In comparison to other areas in the estuary, *C. perfringens* levels in surface sediments at the mouths of the Lamprey and Squamscott rivers consistently exceeded 15,000 MPN/g, while levels in the Oyster River did not exceed 3000 MPN/g (Jones, unpublished).

In general, the highest levels of contamination was apparent at sites away from the channel of the Piscataqua River, i.e., in York Harbor and the mouth of Spruce Creek, off Gerrish and Pierce Islands, and in the Back channel behind Pierce Island. All of the stations around Seavey Island (3-10; 12, 13, 18, 19) had *C. perfringens* levels >6000 MPN/g, and included the highest levels observed, the 22,500 MPN/g at Station 10. Thus, it appears that levels of fecal contamination in recently deposited surface sediments are relatively higher at sites around the SHIPYARD compared to other sites away from Seavey Island.

Vibracore sediment samples with depth

Sediment cores from 22 of the 26 sites were collected during September, 1991 and 1992 and analyzed for *C. perfringens* concentrations. MPN values for *C. perfringens* levels in different horizons of the cores were averaged arithmatically and compared between depths and stations (Table 5&6). *C. perfringens* levels with depth for the 1991 cores are illlustrated in Figure 6. The upper layer (~0-10 cm) of the cores at all sites contained *C. perfringens* ranging from 1640 MPN/g for the top 0-2 cm at Station 2 to 93,000 MPN/g for the top 0-5 cm at Station 17 (Tables 5&6). *C. perfringens* could not be detected in some lower sediment layers at stations 11,15,16,20, 21, 100 and 101. The highest levels for a given sediment layer were found in deeper sediment layers at Stations 5 (47,500 MPN/g layer B), 10 (36,000 MPN/g layer D), and 15 (34,000 MPN/g layers C&D) for the September 1991 samples and Stations 3 (>125,000/g layers D&E) and 15 (>100,000 MPN/g layers E,G&H) for the 1992 samples. Concentrations of *C. perfringens* decreased with depth at 12 stations (1,2,3,6,7,11,14,16,17,19,20,51,100, and 101), suggesting that the highest levels of fecal contamination within the sediments sampled are of more recent origin. The three stations (4,8, and 12) where levels increased with depth are indicative of fecal contamination being greater in the past with more recent, less-contaminated sediment overlying older, more-contaminated sediment. At two stations (5 and 13), levels increased then decreased, indicative of a distinct middle layer being more contaminated than more recent and older sediment layers, while the opposite was true for Stations 10 and 15. In general, *C. perfringens* levels tended to be low in sediments at sites located away from the river channel. *C. perfringens* levels in cores from Stations 1, 11, 14, 16, 20, 21, 51, 100 and 101 were low in the top horizon and either extremely low or not detected in lower horizons. This pattern of contamination amongst sites suggests that fecal pollution sources have had greatest impact historically on sediments at sites in close proximity to the Piscataqua River channel, including sites surrounding Seavey Island.

Comparative distributions of fecal contamination and heavy metals

Heavy metal analyses were conducted on many of the same sediment samples that were analyzed for *C. perfringens*. Thus, data were analyzed to determine if there is any indication that heavy metals of concern could be of fecal origin as opposed to being from the SHIPYARD. The metal of most concern is lead (Munns et al., 1994). For both core and surface sediment samples, there appears to be a prevalence of lower lead levels in samples with relatively low *C. perfringens* levels and higher lead levels in samples with relatively high *C. perfringens* levels (Figures 7 and 8). Because of the high degree of variability in the *C. perfringens* analysis, average lead and *C. perfringens* levels were calculated for samples grouped according to ranges of increasing *C. perfringens* levels. In sediment core and surface samples, a clear pattern of increasing lead concentrations is apparent for samples containing increasing levels of *C. perfringens* (Figures 9 and 10). This relationship was not as clear for mercury in both types of sediment samples (Figures 11 and 12). In core samples mercury levels were not very different for samples with *C. perfringens* concentrations from 0-20,000 MPN/g, then increased dramatically in more contamnated sediments. For surface sediments, levels of mercury increased with increasing *C. perfringens* concentration.

There appears to be indications from the *C. perfringens* data that some metals in sediments at stations around the SHIPYARD may be of fecal origin. Unfortunately, not all metal data has been available for review. More detailed analysis of sediment data for all sites with grain size, metals and *C. perfringens* analyses, when they become available for review, would be needed to statistically test this assertion.

Summary

Fecal-borne bacterial contaminants in water samples from sites around Seavey Island from September, 1991 through June, 1993 were relatively low in comparison to other areas in the Great Bay Estuary, reflecting the absense of any significant sources of fresh sewage in the vicinity. Fecal coliform and enterococci levels were highest among the study sites at Station 23 in York Harbor, which shows that the site chosen as a reference site is subject to short-term fecal contamination at somewhat greater levels than in Portsmouth Harbor. Surface sediments contained relatively high levels of *C. perfringens*, especially at sites near the SHIPYARD. *C. perfringens* levels in sediment cores varied with depth, and were extremely high in some deep layers. These data suggest that the sediments at sites near the SHIPYARD have historically and continue to be areas where sewage-borne contaminants are deposited. The trend of lead and mercury concentrations in sediments relative to fecal-borne *C. perfringens* suggest that the heavy metals of most concern may be associated with sewage sources.

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Table 1. C. perfringens concentrations in water samples collected from sites in Portsmouth (#1-21) and York (#22-23) Harbors: September, 1991.

Sta. #	EPA ID (#)	Rep. (#)	cfu/100ml mean of 2	cfu/100 ml station
1	110122	0.1	9.5	8.5
1	110122	0.2	7.5	
2	110102	0.1	13.0	11.8
2	110102	0.2	10.5	
3	110103	0.1	11.5	10.0
3	110103	0.2	8.5	
4	110108	0.1	3.5	6.8
4	110108	0.2	10.0	
5	110104	0.1	11.0	10.5
5	110104	0.2	10.0	
6	110107	0.1	4.5	3.3
6	110107	0.2	2.0	
7	110105	0.1	4.5	6.8
7	110105	0.2	9.0	
8	110106	0.1	5.5	5.5
8	110106	0.2	5.5	
9	110118	0.1	11.5	10.0
9	110118	0.2	8.5	
10	110115	0.1	7.5	9.3
10	110115	0.2	11.0	
11	110121	0.1	11.0	8.5
11	110121	0.2	6.0	
12	110116	0.1	6.0	6.8
12	110116	0.2	7.5	
13	110117	0.1	7.0	5.5
13	110117	0.2	4.0	
14	110114	0.1	8.0	5.8
14	110114	0.2	3.5	
15	110119	0.1	3.5	5.5
15	110119	0.2	7.5	
16	110120	0.1	13.5	12.3
16	110120	0.2	11.0	
17	110113	0.1	6.5	6.0
17	110113	0.2	5.5	
18	110112	0.1	11.0	10.5
18	110112	0.2	10.0	
19	110111	0.1	6.0	6.3
19	110111	0.2	6.5	
20	110110	0.1	7.5	5.0
20	110110	0.2	2.5	
21	110109	0.1	1.0	1.3
21	110109	0.2	1.5	
22	110100	0.1	0.5	0.8
22	110100	0.2	1.0	
23	110101	0.1	3.5	3.0
23	110101	0.2	2.5	

Table 2. Enterococci and fecal coliform concentrations (per 100 ml) in water samples collected from sites near the SHIPYARD in Portsmouth (#1-16; PH) and York (#23) harbors.

ENTEROCOCCI

Date	Station 1	Station 8	Station 10	Station 15	Station 16	Station 23	Average PH
Nov, 91	31.0	32.0	61.0	61.0		23.0	46.3
Dec	32.0	9.0	8.5	26.0		6.0	18.9
Jan, 92	7.0	3.0	3.0	21.0	7.0	16.0	8.2
Feb	12.0	4.0	0.0	0.3	2.0	15.0	3.7
Mar	0.5	1.0	0.3	3.0	0.0	1.0	1.0
Apr	2.5	1.3	2.8	1.3	3.3	1.5	2.2
May	0.3	0.5	0.3	0.0	0.3	0.5	0.3
June	0.5	3.3	3.3	1.5	0.3	9.5	1.8
July						9.3	
Aug	2.8	1.0	4.3	5.0	4.5		3.5
Sept	0.0	0.0	1.8	1.0	1.0	2.5	0.8
Oct	2.5	3.8	58.0	8.3	4.5		15.4
Dec	1.8	1.0	1.8	0.8	2.0		1.5
Mar, 93	34.0	39.5	39.5	265.0	256.8	155.0	127.0
June	2.0	0.0	1.0	2.0	1.8	0.3	1.4

FECAL COLIFORMS

Date	Station 1	Station 8	Station 10	Station 15	Station 16	Station 23	Average PH
May, 92	0.8	1.8	7.8	3.0	1.5	8.0	3.0
June	5.0	10.3	7.3	3.3	2.8	187.0	5.7
July						12.5	
Aug	11.8	15.5	7.8	12.3	11.8	22.8	11.8
Sept	0.8	10.0	3.5	5.8	15.8	10.5	7.2
Oct	11.0	8.3	24.0	47.8	34.5	5.0	25.1
Dec	6.8	1.3	0.3	4.0	2.5		3.0
Mar, 93	58.3	140.5	144.0	243.3	210.5	39.5	159.3
June	8.3	7.8	8.4	10.4	8.8	0.8	8.7

Table 3. Geometric mean C. perfringens, enterococci and fecal coliform concentrations (per 100 ml) in water samples collected from sites near the SHIPYARD in Portsmouth (#1-16; PH) and York (#23) harbors: 1991-1993.

Indicator	Station 1	Station 8	Station 10	Station 15	Station 16	Station 23	Average PH
Clostridium perfringens	7.2	5.9	6.5	10.2	12.5	3.8	9.1
Enterococci	2.4	1.8	2.5	3.2	2.2	4.3	3.4
Fecal coliforms	5.7	8.6	7.6	11.6	10.2	12.7	10.5

Table 4. C. perfringens concentrations in surface sediments from sites near the Shipyard: September, 1991.

core #	Sample type	EPA ID #	Sed sample WW	DW fraction	Cp/g DW sed.	St.dev.
19	boxcore	110210	1.00	0.43	6960	10200
18	boxcore	110211	1.00	0.59	6240	6150
16	boxcore	110212	1.00	0.74	4770	4860
21	boxcore	110213	1.00	0.61	5140	2110
14	boxcore	110214	1.00	0.73	2020	1090
15	boxcore	110215	1.00	0.46	11300	15700
11	boxcore	110216	1.00	0.57	2670	2090
17	boxcore	110217	1.00	0.6	11100	5220
12	boxcore	110218	1.00	0.69	9400	10600
13	boxcore	110219	1.00	0.35	9400	1030
10	boxcore	110220	1.00	0.4	22500	34800
1	boxcore	110221	1.00	0.68	1890	500
4	boxcore	110222	1.00	0.34	12600	4030
20	boxcore	110223	1.00	0.72	890	1080
6	boxcore	110224	1.00	0.33	14900	22500
8	boxcore	110225	1.00	0.38	6590	1520
7	boxcore	110226	1.00	0.34	12200	11400
23	boxcore	110227	1.00	0.78	1650	330
22	boxcore	110228	1.00	0.62	650	180
9	boxcore	110229	1.00	0.53	11100	5610
2	boxcore	110230	1.00	0.39	9870	3920
3	boxcore	110231	1.00	0.49	8330	7020
5	boxcore	110232	1.00	0.29	15200	11600

Table 5. C. perfringens concentrations at different depths in sediment cores from sites near the Shipyard: 1991.

core #	EPA ID#	REP	Horizon depth (cm)	Ave. MPN/g WW	Sed. samp. WW	DW fraction	Cp/g DW sed.
1	110001	A	0-10	3000	1.00	0.73	4100
	110001	B	10-20.	800	1.00	0.71	1100
2	110002	A	0-8	9000	1.00	0.44	20000
	110002	B	30-38	7000	1.00	0.59	12000
	110002	C	70-78	550	1.00	0.55	1000
3	110003	A	0-8	10500	1.00	0.59	17800
	110003	B	8-16.	7000	1.00	0.54	13000
4	110004	A	0-10	5000	1.00	0.37	13500
	110004	B	10-20.	10500	1.00	0.39	26900
5	110005	A	0-10	9500	1.00	0.37	25700
	110005	B	10-20.	17000	1.00	0.4	42500
	110005	C	20-30	7000	1.00	0.37	18900
6	110006	A	0-7	6000	1.00	0.41	14600
	110006	B	20-27	162	1.00	0.77	210
7	110007	A	0-8	9000	1.00	0.36	25000
	110007	B	25-33	7000	1.00	0.5	14000
	110007	C	42-50	650	1.00	0.77	840
8	110008	A	0-8	4000	1.00	0.41	9800
	110008	B	16-24	6000	1.00	0.42	14300
10	110010	A	0-8	7000	1.00	0.5	14000
	110010	B	30-38	9000	1.00	0.48	18700
	110010	C	60-68	3000	1.00	0.47	6400
	110010	D	90-98	17000	1.00	0.47	36000
	110010	E	132-138	10500	1.00	0.58	18000
11	110011	A	0-8	12500	1.00	0.66	18900
	110011	B	20-28	1.9	1.00	0.75	3
	110011	C	50-58	1.8	1.00	0.74	2
12	110012	A	0-8	3000	1.00	0.64	4700
	110012	B	10-18.	4900	1.00	0.63	7780
	110012	C	20-28	11500	1.00	0.54	21600
13	110013	A	0-8	2580	1.00	0.6	4300
	110013	B	20-28	12500	1.00	0.55	22700
	110013	C	40-48	23.5	1.00	0.79	30
14	110014	A	0-8	1400	1.00	0.71	1980
	110014	B	20-28	270	1.00	0.6	450
	110014	C	40-48	36.5	1.00	0.68	50
15	110015	A	0-8	7000	1.00	0.6	11700
	110015	B	30-38	1.8	1.00	0.52	3
	110015	C	60-68	16000	1.00	0.47	34000
	110015	D	100-108	17000	1.00	0.48	35400
16	110016	A	0-8	2350	1.00	0.75	3100
	110016	B	20-28	4000	1.00	0.73	5500
	110016	C	50-58	3	1.00	0.61	5
	110016	D	100-108	1.8	1.00	0.56	3
17	110017	A	0-8	17000	1.00	0.58	29300
	110017	B	30-38	5000	1.00	0.49	10200
	110017	C	70-78	1400	1.00	0.51	2750
19	110019	A	0-8	7000	1.00	0.51	13700
	110019	B	20-28	9200	1.00	0.49	18800
	110019	C	50-58	1500	1.00	0.51	2900
20	110020	A	0-8	1200	1.00	0.65	1850
	110020	B	20-28	19	1.00	0.67	30
	110020	C	50-58	1.8	1.00	0.75	2
21	110021	A	0-8	2600	1.00	0.59	4400
	110021	B	20-28	1000	1.00	0.64	1560
	110021	C	50-58	40	1.00	0.61	70
	110021	D	85-92	1.8	1.00	0.65	3

Table 6. C. perfringens concentrations at different depths in sediment cores from sites near the Shipyard: 1992.

Core #	EPA ID #	REP	Depth (cm)	Ave. MPN/g	Sed. sample WW	DW fraction	Cp/g DW sediment
PH 2	111952	C	0-2	700	1.07	0.42	1640
	111952	D	32-34	1700	1.06	0.72	2100
	111952	B	68-70	170	0.50	0.68	250
PH 3	111953	C	0.2	20500	1.12	0.41	45000
	111953	D	10	70000	1.03	0.42	162000
	111953	E	35	43500	0.90	0.39	125000
PH 7	111957	C	0.2	32500	1.07	0.39	77000
	111957	D	10	5000	1.01	0.36	14000
	111957	E	40	250	1.02	0.80	310
PNS 15	111965	C	0-5	59000	1.05	0.59	93800
	111965	D	10	15500	1.07	0.51	28700
	111965	E	30	160000	1.02	0.49	323000
	111965	F	40	11500	1.03	0.45	25000
	111965	G	60	160000	1.07	0.51	292000
	111965	H	90	59000	1.04	0.53	107000
PNS 17	111967	C	7	25550	1.01	0.53	47800
	111967	D	20-23	2700	1.05	0.51	5000
	111967	E	38-40	3000	1.08	0.54	5100
	111967	F	50-52	6000	1.03	0.58	10100
PH 19	111969	C	0.2	3150	1.00	0.52	6000
	111969	D	10	6000	1.02	0.53	11000
	111969	E	40	1285	1.02	0.42	3000
PNS 51	111951	C	0-2	6350	1.01	0.57	11100
	111951	D	10	260	1.02	0.60	420
	111951	E	30	10	1.01	0.66	15
PH 100	111980	B	0.2	3600	1.03	0.58	6100
	111980	C	30	190	1.02	0.40	460
	111980	D	60	0	1.06	0.49	0
PH 101	111981	C	0.2	900	1.02	0.51	1750
	111981	D	10	500	1.03	0.56	880
	111981	E	35	0	1.06	0.72	0

Figure 1. C. perfringens concentrations in water samples from Portsmouth Harbor (#1-21) and York Harbor (#22-23): September, 1991.

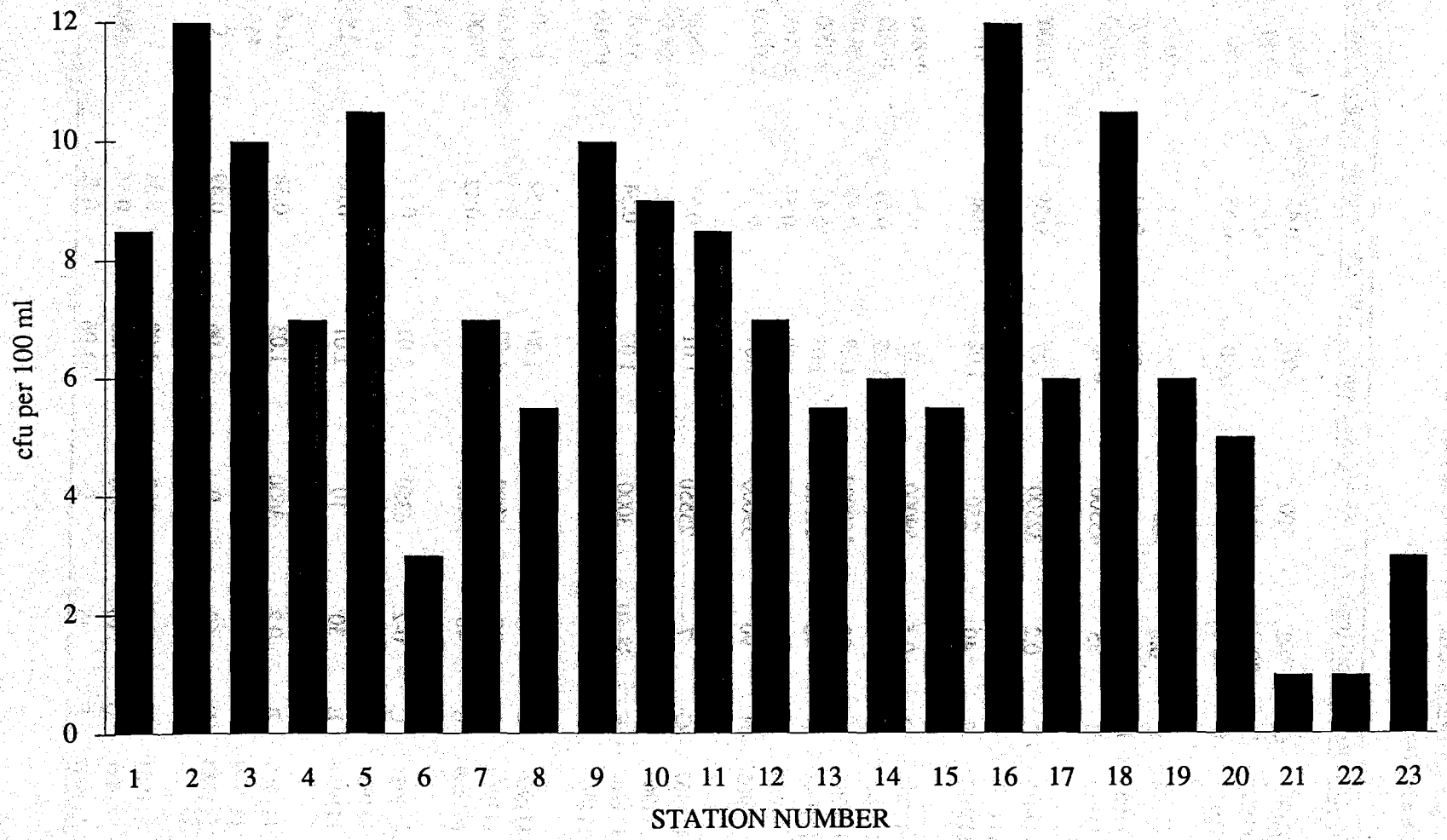

Figure 2. Monthly concentrations of C. perfringens in water at different sites in Portsmouth (#1-16) and York (#23) Harbors: 9/91-6/93

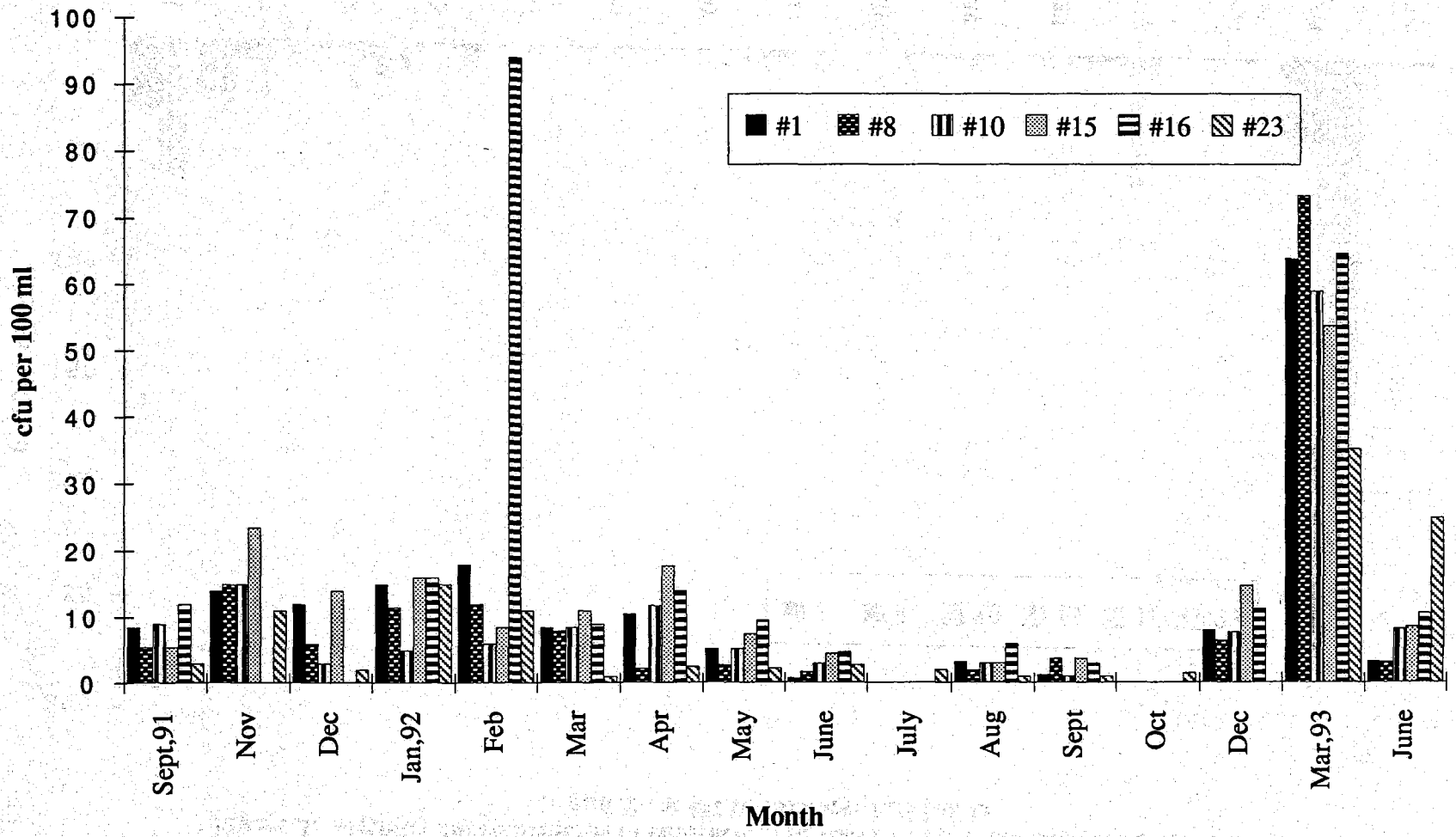

Figure 3. Monthly concentrations of enterococci in water at different sites in Portsmouth (#1-16) and York (#23) Harbors: 11/91-6/93

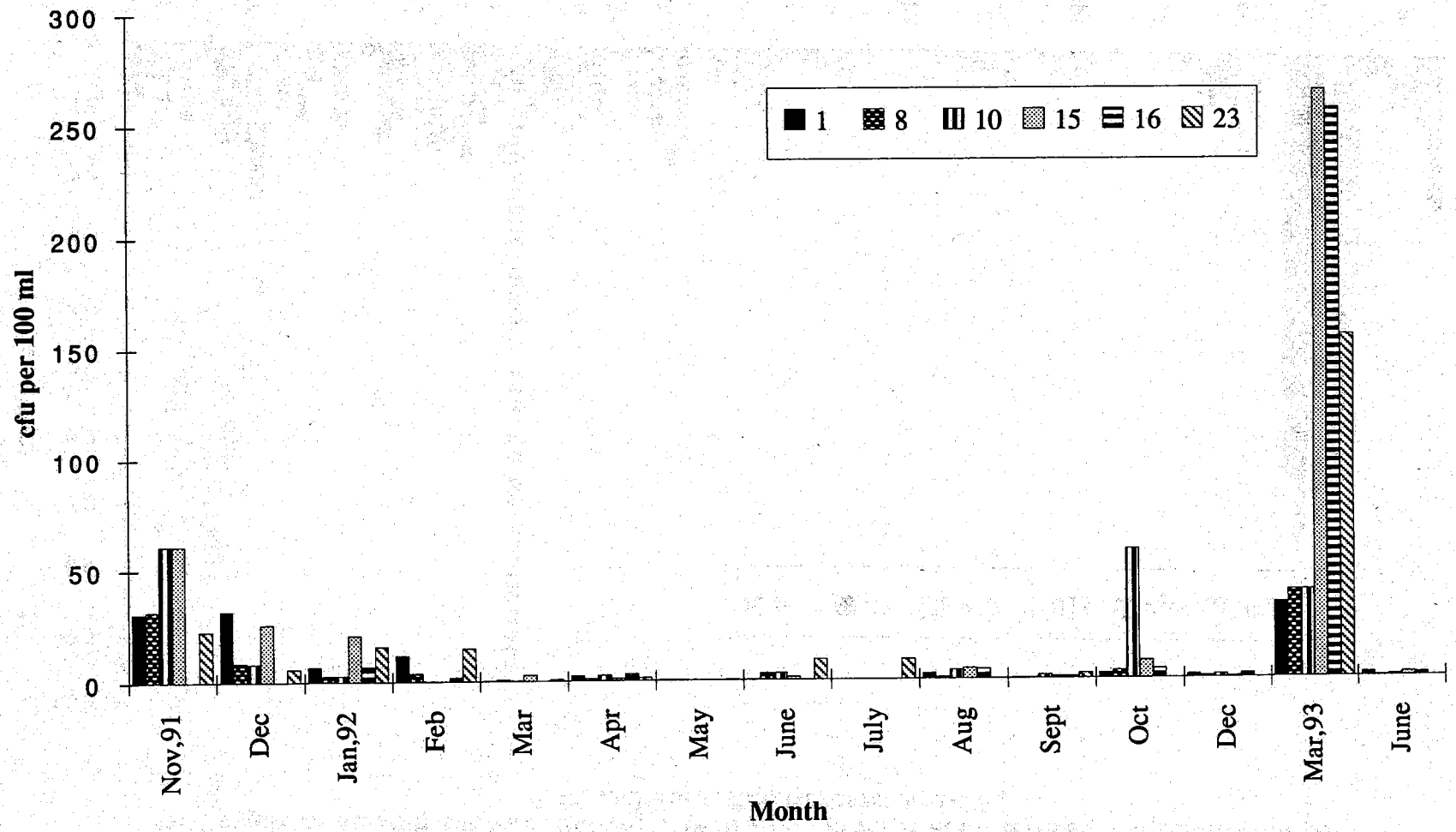

Figure 4. Monthly concentrations of fecal coliforms in water at different sites in Portsmouth (#1-16) and York (#23) Harbors: 5/92-6/93

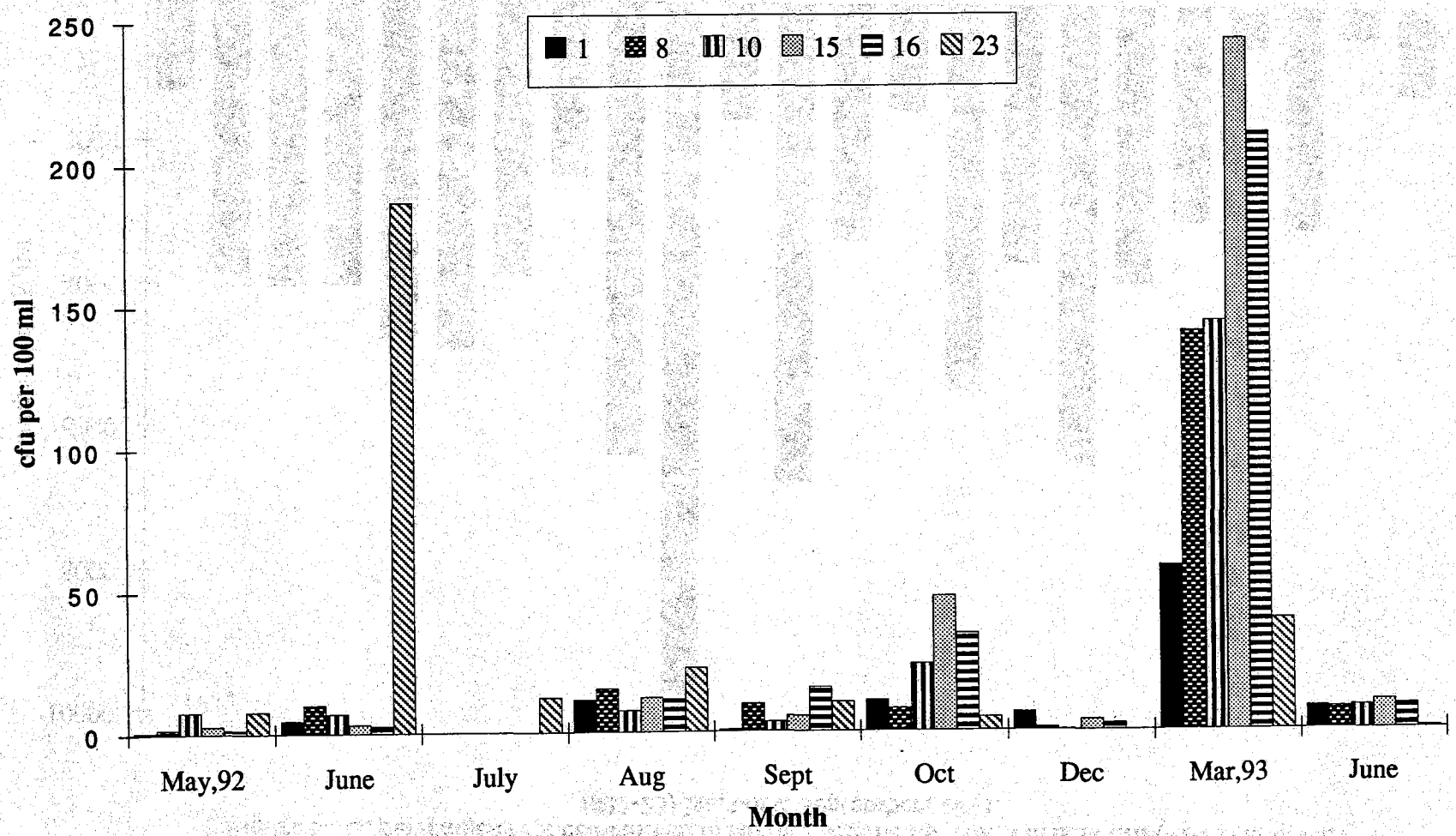

Figure 5. C. perfringens concentrations in surface sediments from Portsmouth (#1-21) and York (#22-23) Harbors: September, 1991.

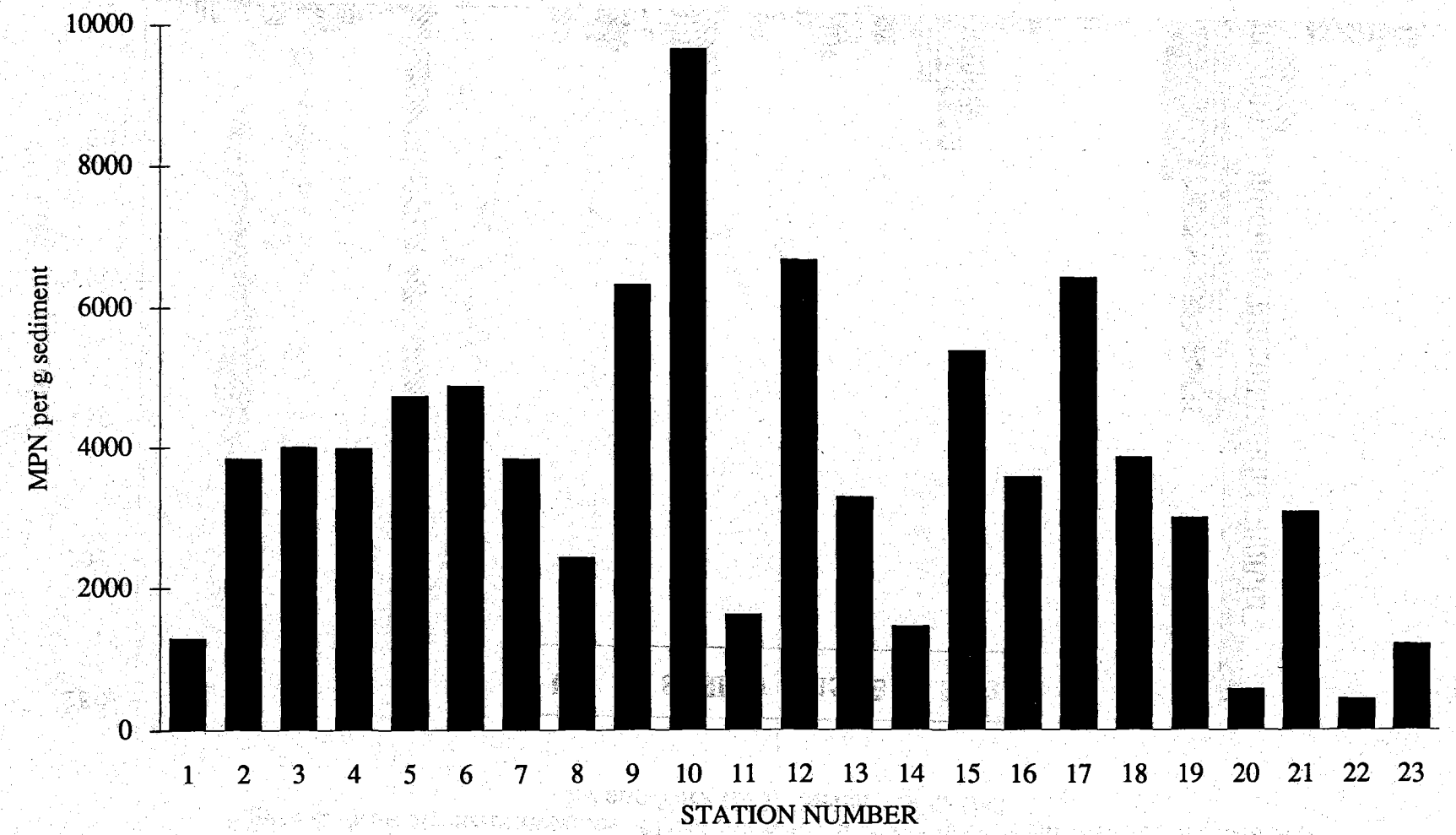

Figure 6. ***C. perfringens*** **concentrations at different depths (A-E) in sediment cores from Portsmouth Harbor: September, 1991.**

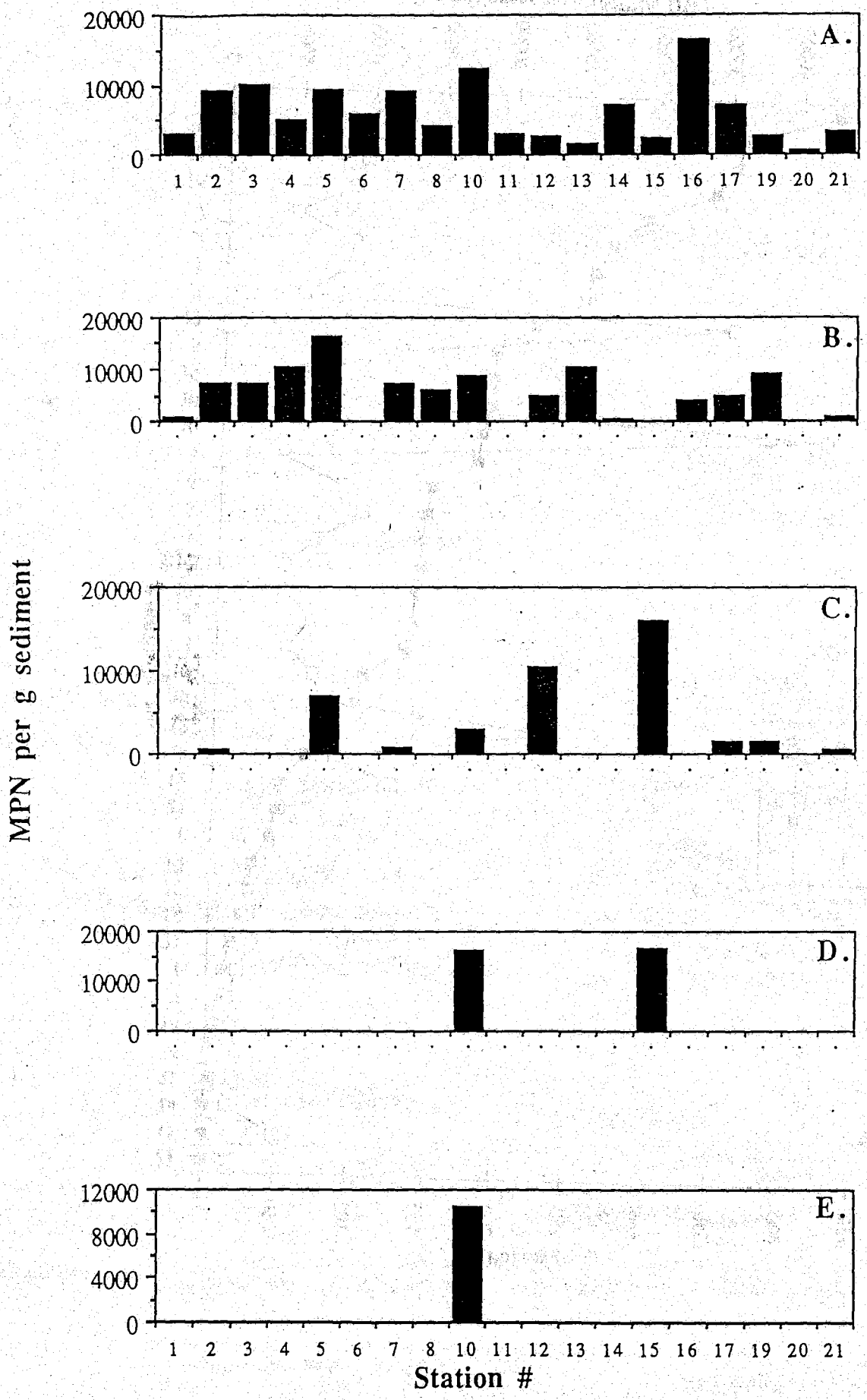

Figure 7. Concentrations of C. perfringens and lead in sediment core samples from sites in Portsmouth and York harbors: 1991.

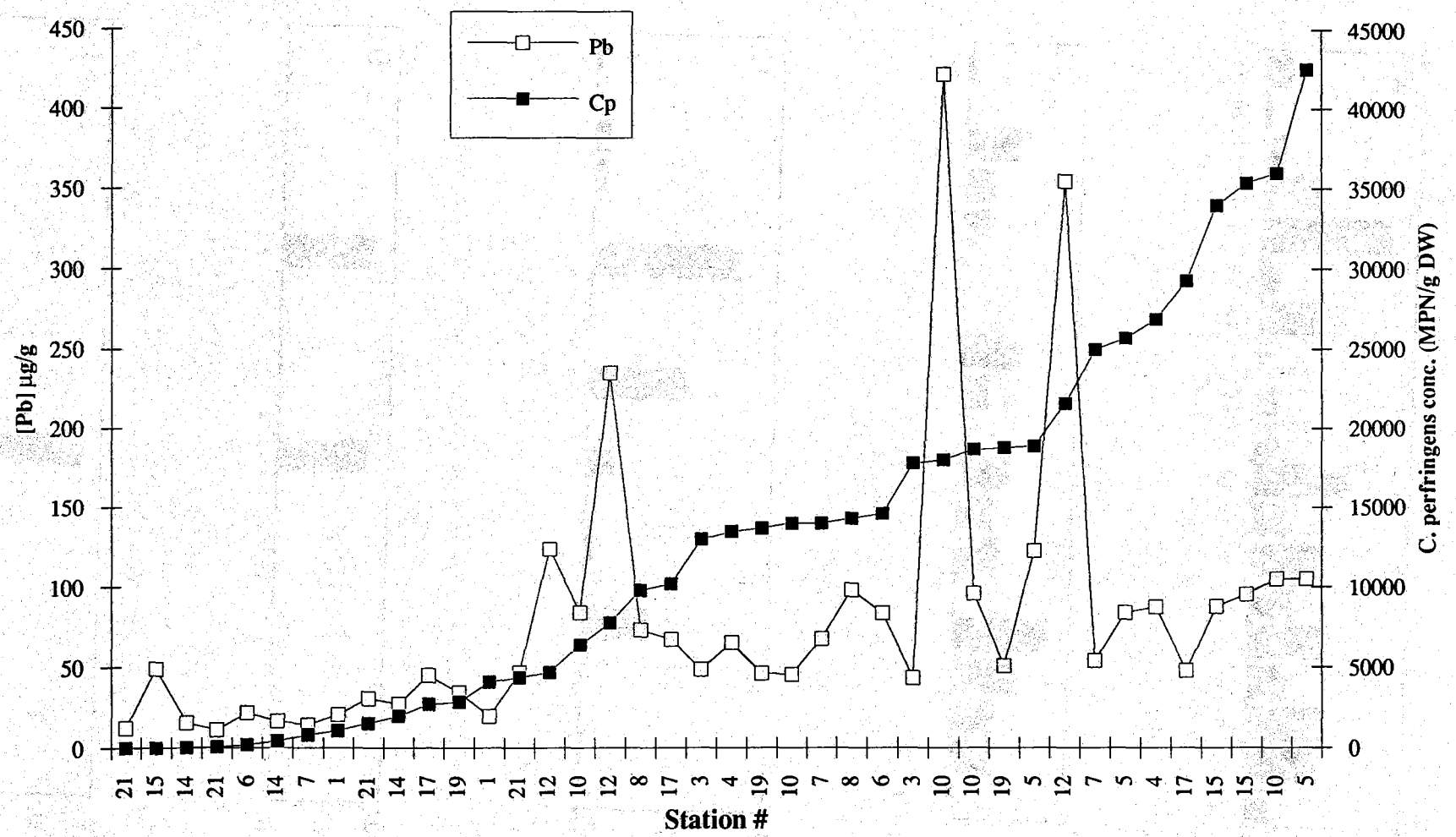

Figure 8. Relationship between lead and C. perfringens concentrations in surface sediment grab samples: 1991.

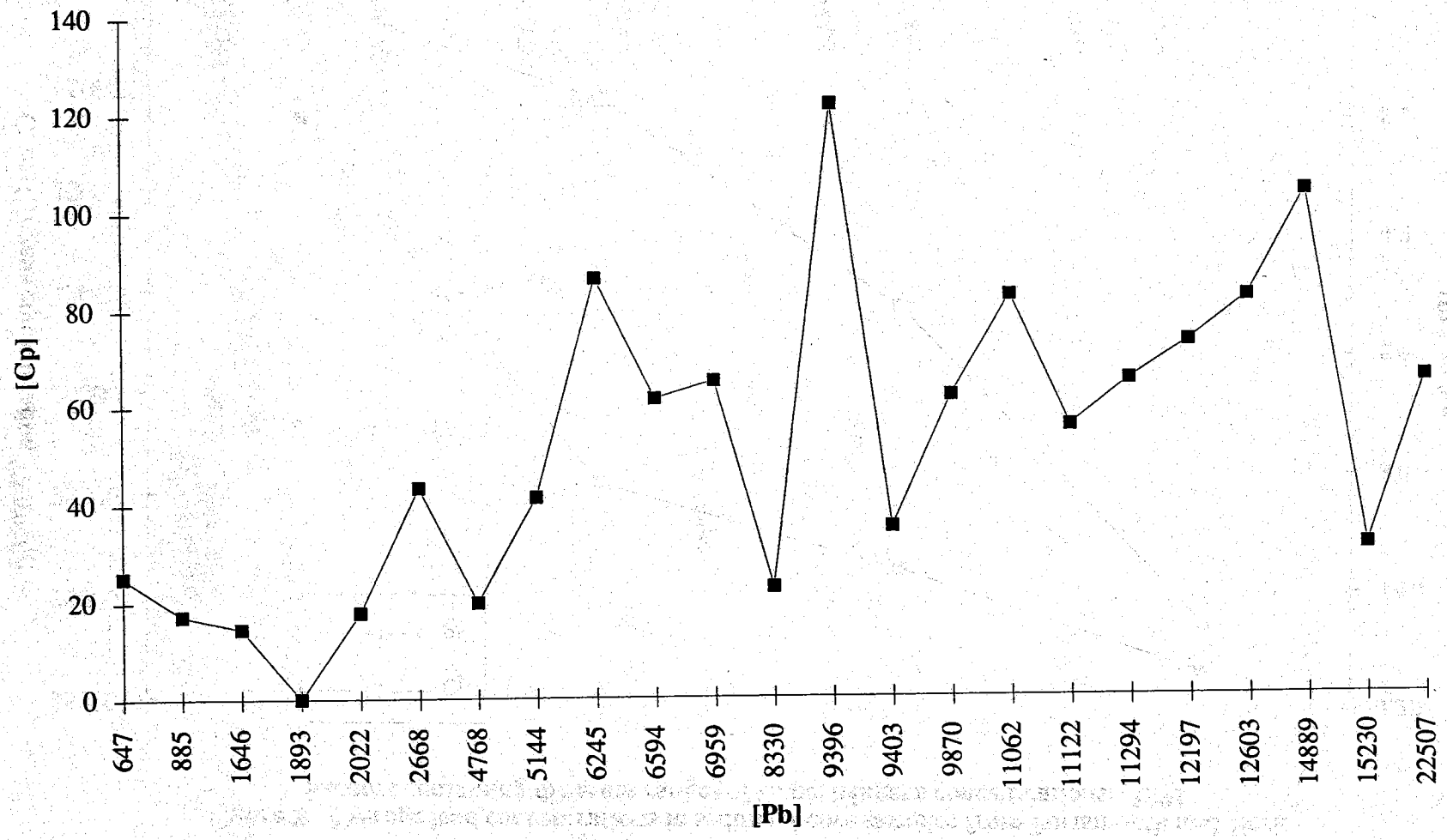

Figure 9. Average lead concentrations in sediment core samples from Portsmouth and York harbors containing different ranges of C. perfringens concentrations: 1991.

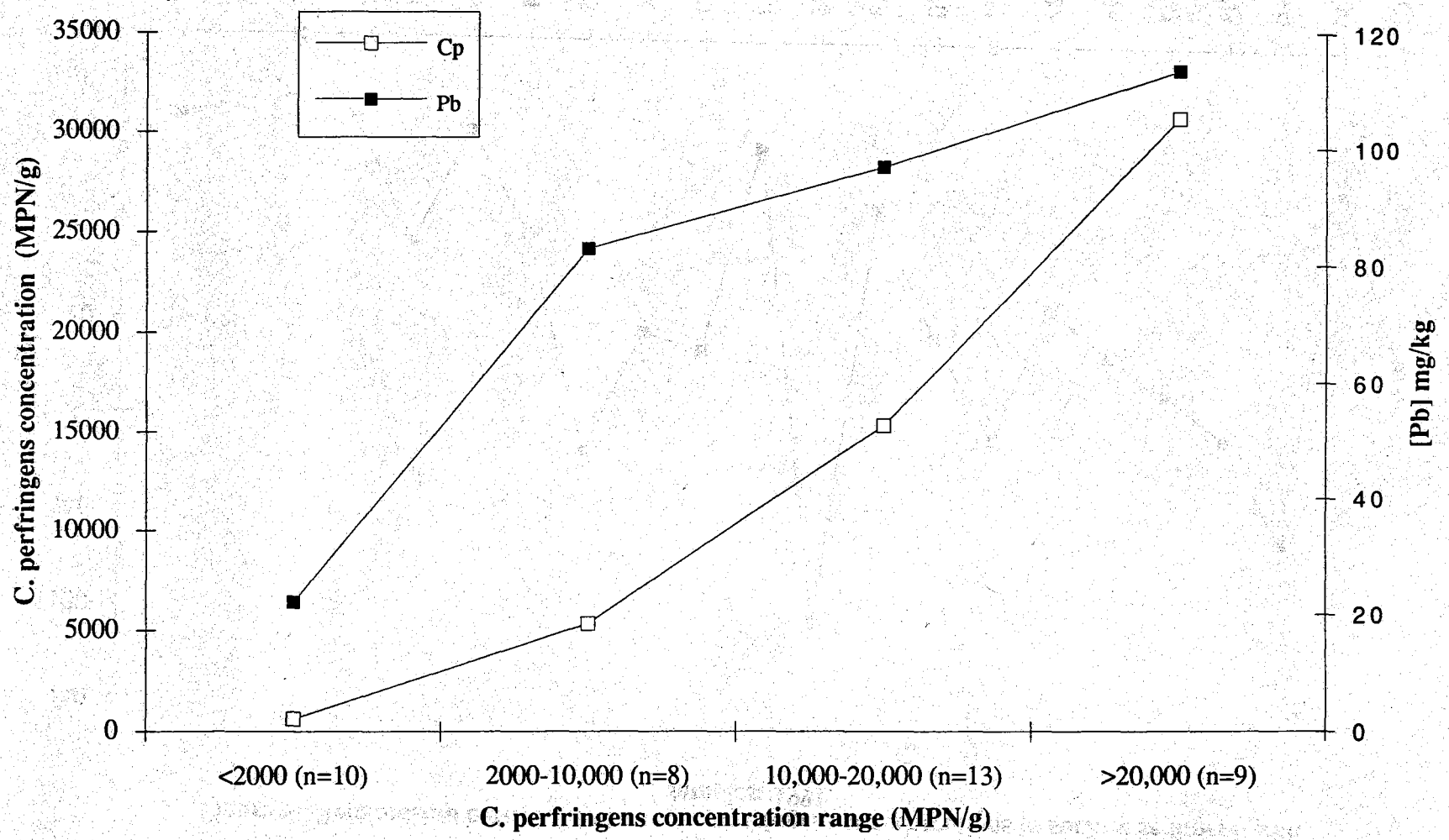

Figure 10. Average mercury concentrations in sediment core samples from Portsmouth and York harbors containing different ranges of C. perfringens concentrations: 1991.

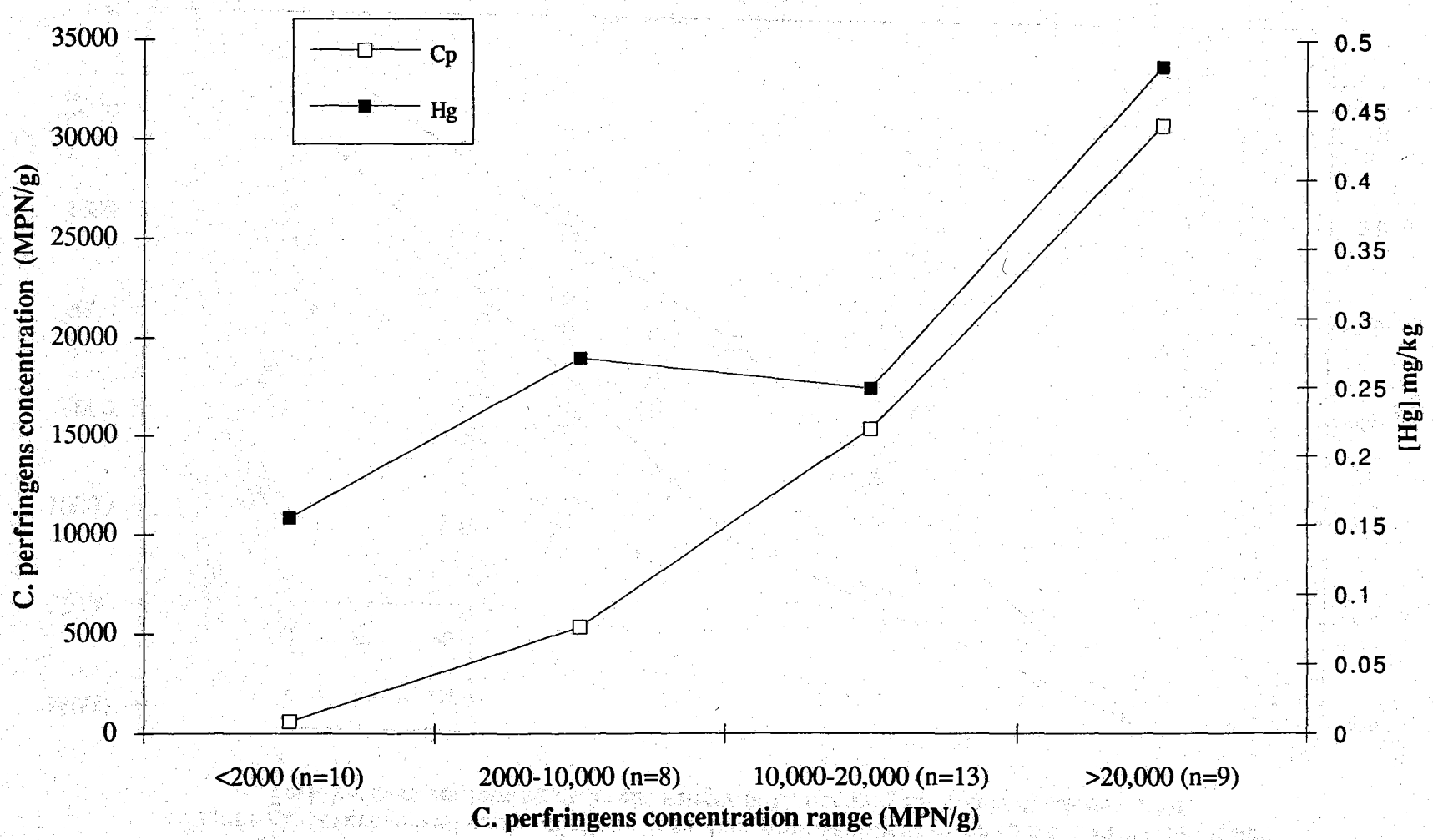

Figure 11. Average lead concentrations in surface grab sediment samples from Portsmouth and York harbors containing different ranges of C. perfringens concentrations: 1991.

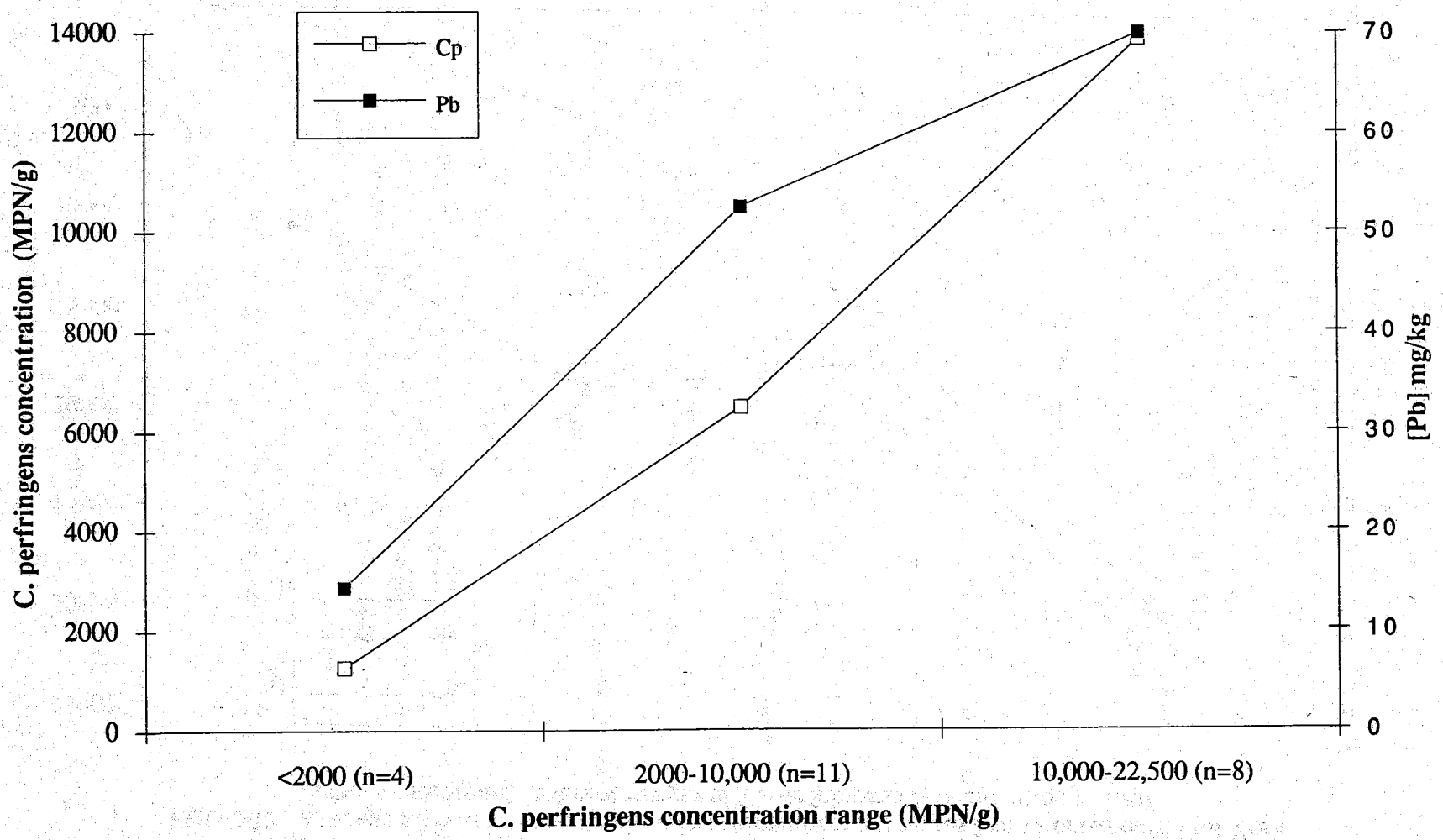
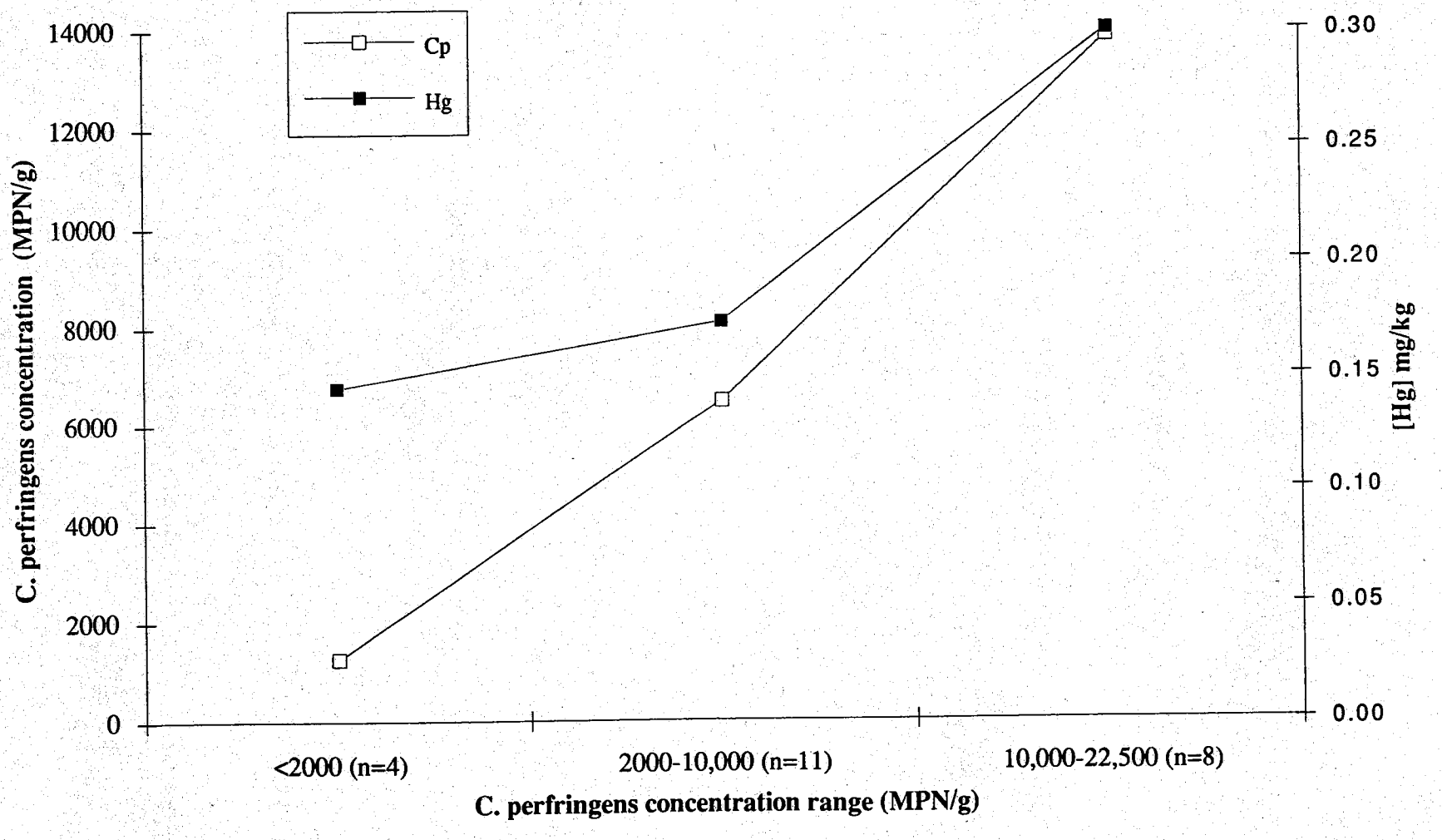
Figure 12. Average mercury concentrations in surface grab sediment samples from Portsmouth and York harbors containing different ranges of C. perfringens concentrations: 1991.