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CONSERVATION AND PROTECTION
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PACIFIC AND YUKON REGION

DISTRIBUTION AND ENVIRONMENTAL IMPACT OF SELECTED BENTHIC CONTAMINANTS IN VANCOUVER HARBOUR, BRITISH COLUMBIA

1985 TO 1987

Regional Program Report: 89-02

by

D. Goyette
J. Boyd

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REVIEW NOTICE

This report has been reviewed and approved for publication by the Marine Programs Division, Environmental Protection. Readers may direct comments or questions to:

Mr. Darcy Goyette
Marine Programs
Environmental Protection
Conservation and Protection
Environment Canada
Kapilano 100 - Park Royal South
West Vancouver, British Columbia
V7T 1A2
(604) 666-2880

ABSTRACT

Environment Canada initiated a study of selected contaminants in Vancouver Harbour sediments and biota in May of 1985 following a review of existing environmental information on the harbour. The study objectives were to determine the distribution of specific organic and inorganic contaminants, potential industrial and urban sources, the health of the benthic environment, and the need for remedial measures. A total of 88 stations for sediment and 11 trawl stations for biota were sampled in Vancouver Harbour (Point Atkinson to Port Moody Arm) from May 1985 to October 1987. Sediment studies focused on the concentration and distribution of trace metals (e.g. arsenic, cadmium, chromium, copper, iron, mercury, nickel, lead and zinc), hydrocarbons, polychlorinated biphenyls (PCB), chlorophenols, and polycyclic aromatic hydrocarbons (PAH). The emphasis of the biological studies was trace metal and PAH levels in tissue of benthic (bottom dwelling) species including sole, crab and shrimp. Further study of the prevalence of liver lesions in English sole, associated with chemical exposure, was also undertaken. Potential urban and industrial sources of contamination in Vancouver Harbour have been identified.

key words: Vancouver Harbour, contaminants, sediment, biota, trace metals, polycyclic aromatic hydrocarbon, PAH, polychlorinated biphenyl, PCB, liver lesions, benthic.

RESUME

Environnement Canada a initié une étude de contaminants sélectionnés dans les sédiments et les organismes marins du Port de Vancouver en mai 1985 à la suite d'une revue de l'information environnementale existante dans les eaux du port. Les objectifs de l'étude étaient de déterminer la distribution de contaminants organiques et inorganiques spécifiques, les sources potentielles industrielles et urbaines, la santé de l'environnement benthique, et le besoin de mesures de redressement. Un total de 88 stations pour les sédiments et 11 stations de chalutage pour les organismes marins furent échantillonnées dans le Port de Vancouver (Point Atkinson à Port Moody Arm) de mai 1985 à octobre 1987. Les études de sédiment portaient plus particulièrement sur la concentration et distribution des métaux à l'état de trace (e.g. arsenic, cadmium, chrome, cuivre, fer, mercure, nickel, plomb et zinc), hydrocarbures, biphényles polychlorés (BPC), chlorophénols, et hydrocarbures aromatiques polycycliques (HAP). Les études biologiques ont mis l'accent sur les niveaux de métaux à l'état de trace et de HAP dans les tissus des espèces benthiques (habitant le fond) incluant les soles, crabes et crevettes. Une étude additionnelle de la prédominance de lésions dans le foie des soles anglaises, associée avec l'exposition de produits chimiques, fut aussi entreprise. Les sources potentielles de contamination d'origine urbaine et industrielle dans le Port de Vancouver furent aussi identifiées.

Mots-clés: Port de Vancouver, contaminants, sédiment, organismes marins, métaux à l'état de trace, hydrocarbure aromatique polycyclique, HAP, biphényle polychloré, BPC, lésions de foie, benthique.

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EXECUTIVE SUMMARY

Following a review of existing information on environmental conditions in Vancouver Harbour, Environment Canada initiated a study of selected contaminants in harbour sediments and biota (1985-87). Objectives were to:

1) determine the environmental health of the benthic environment and the need for remedial measures; and

2) describe the distribution of specific contaminants to aid in identifying potential industrial and urban sources.

Sediment studies focused on the concentration and distribution of trace metals, hydrocarbons, polycyclic aromatic hydrocarbons (PAH), polychlorinated biphenyls (PCB) and chlorophenols. Biological studies emphasized abundance and diversity of benthic (bottom dwelling) organisms, trace metal and PAH levels in tissues of selected species, and prevalences of liver lesions in English sole associated with chemical exposure.

Vancouver Harbour was divided into four areas for study: the outer harbour from Point Atkinson to First Narrows; the inner harbour between First and Second Narrows; the central harbour from Second Narrows to the entrance of Port Moody Arm; and the eastern harbour, Port Moody Arm. In the surveys conducted between 1985 and 1986, 73 stations for sampling sediment and 11 trawl stations for biota were established throughout the harbour. In 1987, 15 sediment stations were added to Port Moody Arm. Loughborough Inlet, a relatively undisturbed coastal fjord, provided an estimate of natural conditions in addition to references selected within the harbour.

Trace metals studied were primarily arsenic, cadmium, chromium, copper, iron, mercury, nickel, lead and zinc. Concentrations of these metals at each station were compared to estimated natural or background reference levels and one of the sediment quality values established from studies in Puget Sound, Benthic Apparent Effects Threshholds (BAET). The latter is the

estimated concentration of a particular contaminant above which adverse biological effects are always expected (i.e. a reduction in the taxa of benthic infauna).

- Arsenic concentrations throughout most of the harbour were below detection (<8 µg/g) with the exception of slightly elevated levels off the concentrate loading docks at Vancouver Wharves.

- Cadmium was above reference level (0.3 µg/g) at most stations and more than half were above the BAET (5.8 µg/g). Possible sources of cadmium, included oil refineries, bulk loading terminals, stormwater discharges and combined sewer overflows.

- Chromium was occasionally above reference level (50 µg/g) but rarely above BAET (59 µg/g) except in Port Moody Arm where the latter was exceeded at most of the stations. The major source appeared to be the oil refinery at Ioco.

- Copper was above reference level (65 µg/g) throughout the study area, although it was primarily above the BAET (310 µg/g) in the inner harbour. Major sources were the metal concentrate bulk loading facilities at Vancouver Wharves, unidentified sources at other deepsea docks, stormwater discharges and combined sewer overflows.

- Mercury was often above reference level (0.2 µg/g), but only two stations were above the BAET (0.88 µg/g). These two stations were near combined sewer overflows. Other possible sources were ship repair and shipbuilding facilities.

- Lead levels were elevated in most areas of the harbour, but were above the BAET (300 µg/g) in only two areas, off Vancouver Wharves and the Clark Drive/Vernon Relief combined sewer overflows. Other sources of lead contamination were the Ioco oil refinery and unidentified sources along the south shore of the inner harbour.

Trace metal concentrations in the surface sediments at most locations in Vancouver Harbour were substantially above those reported for Roberts Bank, Sturgeon Bank and Iona Island areas in the Fraser River estuary. Values reported for these areas have been included for comparison.

A summary of the organic compounds measured in Vancouver Harbour sediment is as follows.

- Oils and grease and hydrocarbon concentrations in sediment were high mainly in Port Moody Arm and along the south shore of the inner harbour. Major sources were the oil refineries and combined sewer overflows.

- PAH were included in the analysis because of their acute toxicity, mutagenic and carcinogenic properties, and links to certain types of liver lesions in English sole. Highest levels of PAH were found in Port Moody Arm, followed by the inner harbour. Levels were lower in the outer harbour and not detectable at the reference site. Chief sources were the combined sewer overflows at Clark Drive, the Ioco oil refinery, and near the Petro-Canada loading docks and Reed Point Marina.

- PCB occurred in the sediment at relatively low levels throughout the harbour and elevated in specific areas of the inner harbour. Past studies have shown higher levels at specific nearshore locations of the inner harbour. PCB's are of global concern because of their long term persistence in some environments, very strong tendency to bioaccumulate in tissues and severe biological effects at high tissue concentrations.

Sediment characteristics including particle size and organic carbon content were among the variables measured. These can control the bioavailability of trace metals and to a lesser extent partitioning of organic contaminants. Sediment types in Vancouver Harbour included:

- well oxygenated, largely mineral substrates capable of supporting marine life, occurring in most of the harbour;
- highly organic, reducing sediments with strong odours of highly toxic hydrogen sulfide gas, occurring mainly in Port Moody Arm; and
- sewage sludge deposits near the combined sewer overflows.

Vancouver Harbour continues to support a diverse benthic fish and invertebrate community, despite the extent of contamination noted above. In addition, there was no significant uptake of trace metals in tissues of selected benthic species sampled from offshore areas. Commercial and recreational species in the harbour have included Dungeness crab, pandalid shrimp, and sixteen species of flounder and sole. Presence of the smaller size classes of fish suggest the use of the harbour for rearing. Highest catches of shrimp occurred along the West Vancouver shore and entrance to Coal Harbour. Dungeness crab catches were generally higher in the inner harbour and Port Moody Arm. The latter area has supported a small commercial fishery. The inner harbour, between first and second narrows, is closed to fishing.

Generally, benthic infauna were diverse and abundant, indicating ecologically "healthier" biological communities than would be expected based on the level of contamination. Analysis showed distinctly different communities within the harbour. These differences may reflect variation in sediment types, levels of contamination, and natural variables such as water depth and circulation.

PAH was not detected in fish, although traces of PAH were found in some crab hepatopancreas (digestive gland) and muscle tissues. Because fish are known to metabolize PAH, the absence of detectable levels in tissues is expected even with considerable exposure. Measureable levels in crab tissues were found in Ioco and Coal Harbour.

In 1986, prevalence of idiopathic (non-infectious, non-parasitic) lesions in livers of English sole were dependent on area of capture.

Highest prevalences were found in Port Moody Arm (58% of the fish examined), followed by the north shore of the inner harbour near Burrard Yarrows (30%). In the outer harbour, 13% of sole livers had lesions while the south shore of the inner harbour was 10%. The lowest prevalence (8%) occurred in the centre of the inner harbour. The study was repeated in 1987 with similar results except that the maximum proportion of fish with lesions was 75%, again in Port Moody Arm. Both preneoplastic (precursors to tumor development) and neoplastic lesions (tumors) were included. The neoplastic lesions included both adenomas (non-invasive, or benign tumors) and carcinomas (cancer). Based on critera established in Puget Sound, all stations sampled in Vancouver Harbour in 1986 and 1987 would be classed as either primary or secondary areas of concern. Based on results from Vancouver Harbour, it is suggested that exposure to high molecular weight PAH concentrations as low as 3 - 4 µg/g in sediment could cause liver lesions in English sole.

Port Moody Arm is the area of the harbour most affected by accumulation of organic and inorganic contaminants followed by the inner harbour, along the south shore near the deepsea docks and north shore adjacent to bulk loading facilities.

A number of remedial actions have been initiated at industrial operations including the Ioco oil refinery, Pacific Coast Terminals and Vancouver Wharves, in cooperation with municipal and provincial authorities. A remedial action plan is currently in preparation by the Greater Vancouver Regional District, with the cooperation and support of various levels of government.

1.0 INTRODUCTION

Vancouver Harbour is the major seaport on the west coast of British Columbia serving a large industrial and urban community. Historically, the harbour has been subject to waste discharges from point and non-point sources. While considerable effort has been directed towards control and treatment of waste discharges, a number of stormwater outlets, municipal combined sewer overflows (CSO), industrial process effluents and urban runoff remain as potential sources of environmental impact on the harbour.

In addition to various recreational activities, the Harbour supports commercial, sport and native food fisheries on resident and migratory marine species including shrimp, crab, flatfish and salmon. Continual population growth and urban development in the Greater Vancouver area will increase the commercial and recreational value of Vancouver Harbour. Resulting pressure on the marine environment therefore demands a higher level of protection to maintain or improve environmental quality.

Studies of major urban centers in North America have investigated the environmental impacts associated with a variety of anthropogenic chemicals (Malins et al., 1980, 1982; O'Connor and Hugget, 1987; McCain et al., 1988; Wright and Phillips, 1988). Malins et al. (1984) reported more that 900 organic compounds in bottom sediments from Commencement Bay, an urbanized area in Puget Sound. Mean concentrations of aromatic hydrocarbons in some urban embayments exceeded those of undisturbed bays as much as 46 times. Recent studies in Puget Sound have shown elevated levels of aromatic hydrocarbons in the bile of fish resulting from exposure to contaminated sediments (Kraun, 1986). Aromatic hydrocarbons in sediments have also been linked to the development of idiopathic liver lesions in English sole (Malins et al., 1984, 1985, 1988; Myers et al., 1987; McCain et al., 1988). Over 300 aromatic hydrocarbons have been identified in sediment from Chesapeake Bay on the east coast of the United States (O'Connor and Huggett, 1988). Toxic effects from the contaminants and health risks associated with the consumption of contaminated seafood have prompted authorities in some areas, such as Puget Sound (PSWQA, 1988), to develop active remedial programs to cleanup and control sources of pollutants.

A review of existing environmental data on Vancouver Harbour identified toxicological effects of various inorganic and organic chemicals (Waters, 1985a, 1985b). Concentrating on the benthic environment, the report concluded that contamination ranged from chronic to severe. The Greater Vancouver Regional District (GVRD) has developed a Liquid Waste Management Plan (LWMP) to sewage and drainage disposal within the Greater Vancouver area. The Plan's purpose is to find the most environmentally acceptable and cost effective method of disposing of liquid wastes such as sewage treatment plant effluents, urban runoff and combined sewer overflows (GVRD, 1989). Part of this study included an inventory of existing data on receiving waters and a preliminary assessment of environmental conditions in the 21 major waterbodies including Vancouver Harbour (Coastline Environmental Services and Envirochem Limited 1987). The report concluded that data was limited. However, it did suggest that receiving water conditions were fair to poor for many waterbodies.

Following the reports by Waters (1985a, 1985b), Environment Canada, initiated a series of field studies in May of 1985 to investigate the distribution of organic and inorganic chemicals in the harbour. Since sediments generally provide a "sink" for contaminants, the study concentrated on levels in the sediments and associated biota. The primary objectives of the study were to:

1) establish a database of contaminant levels in sediment and biota to determine the status of the benthic environment in the harbour and the need for remedial measures.
2) provide data on the temporal and spatial distributions of specific contaminants to identify sources of input within the harbour.

Sediment chemical studies focused on the concentration and distribution of trace metals, hydrocarbons, oil and grease, polycyclic aromatic hydrocarbons (PAH), polychlorinated biphenyls (PCB) and chlorophenols. Biological studies emphasized tissue trace metal levels in selected benthic organisms (e.g. flatfish, crab and shrimp), tissue PAH concentrations in crab and sole, and prevalences of liver lesions in English sole (Parophrys vetulus) which are known to be associated with chemical exposure. Abundance and distribution of various epibenthic species in the harbour were also determined.

This report summarizes the results from 8 field surveys conducted between May 1985 and October 1987. Individual data reports provided in the Appendices, include:

Appendix A	Trace Metals in Sediment (1985/86)
Appendix B	Organic Compounds in Sediment (1985/86)
Appendix C	Trace Metals and Organic Compounds in Sediment (1987)
Appendix D	Sediment Particle Size Distribution, Residue and Bacteria Content (1985/86)
Appendix E	Trace Metals in Tissue (1985/86)
Appendix F	Polycyclic Aromatic Hydrocarbons in Sole and Crab Tissues (1985/86)
Appendix G	Further Studies on the Prevalence of Idiopathic Liver Lesions in English Sole.

2.0 DESCRIPTION OF STUDY AREAS

Geographical locations of the two study areas, Vancouver Harbour and the reference site, Loughborough Inlet, are shown in Figure 1.

2.1 Vancouver Harbour

Vancouver Harbour was divided into four hydrographic regions (Figure 2): the outer harbour, which lies between Point Atkinson and First Narrows; the inner harbour, First to Second Narrows; the central harbour, which extends from Second Narrows to the entrance of Port Moody Arm; and eastern harbour, Port Moody Arm.

2.1.1 Outer Harbour

The outer harbour is approximately 70 km^2 and predominantly bounded by residential areas and parkland. The Lions Gate primary sewage treatment plant, near the entrance to First Narrows, is the major point source discharge into the outer harbour. Effluent is discharged through a submerged outfall and digested sludge is periodically released with the effluent during ebb tides. The outer harbour is influenced by the Fraser River and tidal outflows from the inner harbour, False Creek and Howe Sound. While it is a popular area for recreational boating, fishing and swimming, it also provides anchorage for deep sea vessels awaiting berthage in the inner harbour. A small commercial shrimp and crab fishery operates along the Spanish Banks and West Vancouver shoreline.

2.1.2 Inner Harbour

The inner harbour is the most active region of the harbour with a variety of urban, industrial and other harbour activities along the south and north shores. The distance between First and Second Narrows is about 8.5 km; maximum width of the inner harbour is about 3.7 km. Average depths range from 21 to 65 metres. Tides in the inner harbour are from -0.2 to 5.6 metres with an average of 3.3 metres (Canadian Hydrographic Service Annual

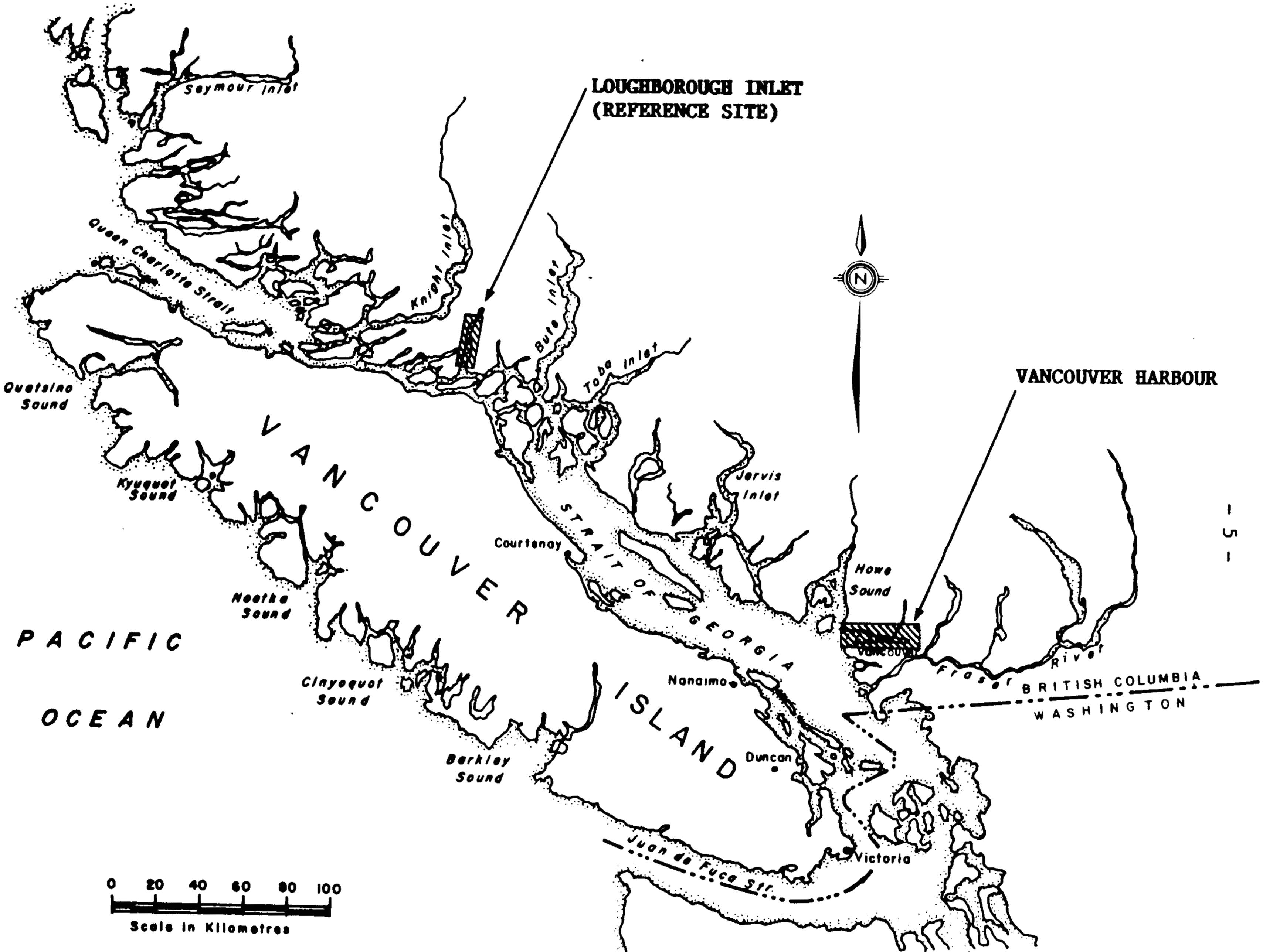


FIGURE 1 VANCOUVER HARBOUR STUDY AREA AND REFERENCE SITE, LOUGHBOROUGH INLET

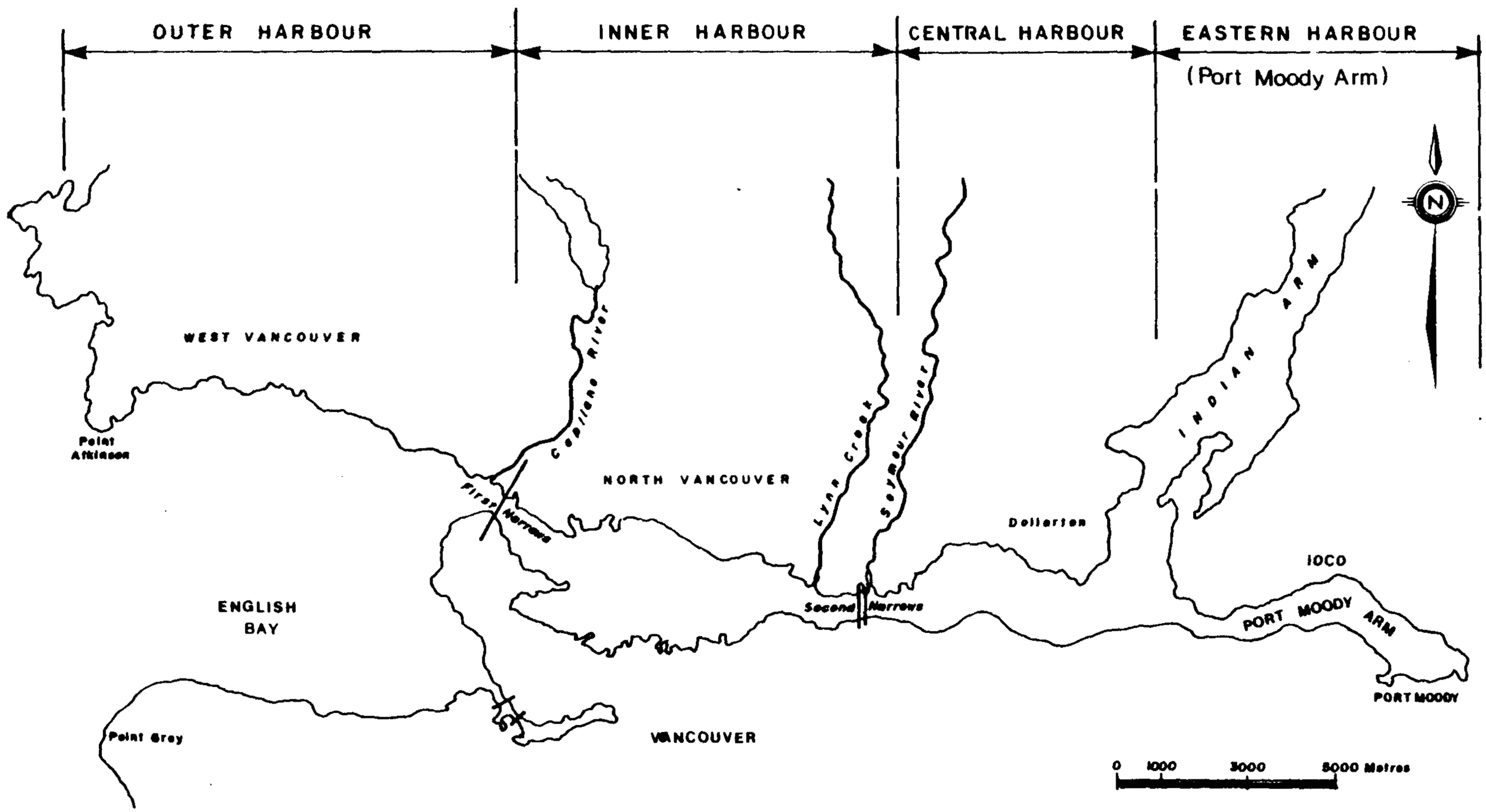


FIGURE 2 FOUR HYDROGRAPHIC REGIONS OF VANCOUVER HARBOUR - OUTER, INNER, CENTRAL, AND EASTERN HARBOURS

Tide and Current Tables, 1989) and currents through the First and Second narrows can exceed 6 knots. The inner harbour and portions of the outer and central harbours receive a considerable degree of flushing and mixing (Canadian Hydrographic Service Tidal Current Atlas, 1981), which can influence the distribution and deposition of contaminants within the harbour.

Industrial activity in the inner harbour includes among others bulk loading facilities (coal, sulphur, potash, phosphate, metal concentrates, wood chips, and grain), marinas, shipyards, sawmills, fish processing plants and fuel docks. Generally, municipal sewage is treated by either the Lions Gate sewage treatment plant or treatment plants located along the Fraser River. However, during periods of heavy rainfall municipal sewage and stormwater can discharge directly to the harbour through combined sewer overflows located along the north and south shores of the harbour.

2.1.3 Central Harbour

The central harbour covers an area of approximately 10 km^2; the width averages 1.4 km. Tidal currents through Second Narrows can extend throughout this section. The central harbour is comprised of a mixture of industrial and residential areas. Industrial activities include a sodium chlorate plant and a chlor-alkali plant, two petrochemical refineries, a crude oil terminal, shipyards, a sawmill and additional anchorage for deepsea vessels. Treated process effluent from both refineries is discharged directly into the GVRD sewer system. Treated stormwater from tank farms and refinery areas is discharged directly to the harbour.

2.1.4 Eastern Harbour - Port Moody Arm

Port Moody Arm, about 7.0 km in length, is relatively shallow, (mean depth of 9 metres) and requires periodic dredging to maintain shipping channels. The head of the arm is mainly tidal flats. No major river systems flow into Port Moody Arm and water circulation is relatively poor, Waldichuk (1965) estimated a 30% exchange of water during each tidal cycle.

Industrial activity in Port Moody Arm includes two petroleum refineries, which discharge treated stormwater directly into the arm, a thermal power generating plant (using natural gas since 1978), a bulk loading terminal, two chemical plants (phenolic resin, alum), a sawmill and a marina. The release of treated process effluent by one of the refineries ceased in March of 1989. Municipal sources in Port Moody Arm include two combined sewer overflows, a number of stormwater discharges and an abandoned landfill site. Portions of the shoreline are also used for residential areas and marine parklands.

2.2 Loughborough Inlet (Reference Site)

Loughborough Inlet is a relatively undisturbed coastal inlet located between Knight and Bute inlets approximately 40 miles north of Campbell River (Figure 1). Minor activities in the area are logging and recreational boating.

3.0 MATERIALS AND METHODS

3.1 Field Surveys

The sampling locations in Vancouver Harbour are shown in Figures 3 and 4, and outlined below. Sites were named for ease of reference and do not necessarily imply a source of contamination.

		Sediment	Biota
Outer Harbour	- Spanish Banks	SB	-
	- Point Atkinson	ATK	-
	- Pacific Environment Institute	PEI	Pacific Environment Institute
	- Dundarave	DD	-
Inner Harbour	- North Shore	1 - 13B	Burrard Yarrows
	- Centre	14 - 16	Centre
	- South Shore	17 - 31	Sterling, Coal Harbour Vanterm
Central Harbour	- Chevron	-	Chevron
	- Cates Park	CP	-
	- Boulder Rock	BR	-
Eastern Harbour	- Port Moody Arm	32 - 47	Ioco, Port Moody

Six surveys were conducted between 1985 and 1986 to sample 73 stations for sediment and 11 trawl stations for biota. Due to the extent of the study area, most sediment sampling sites with the exception of certain trawl stations were sampled only once to maximize coverage. In October 1987, sediment sampling was concentrated in Port Moody Arm including 17 existing stations and 15 new stations. In 1987, two stations in Loughborough Inlet, were added to provide a baseline reference for sediment and English sole liver lesions.

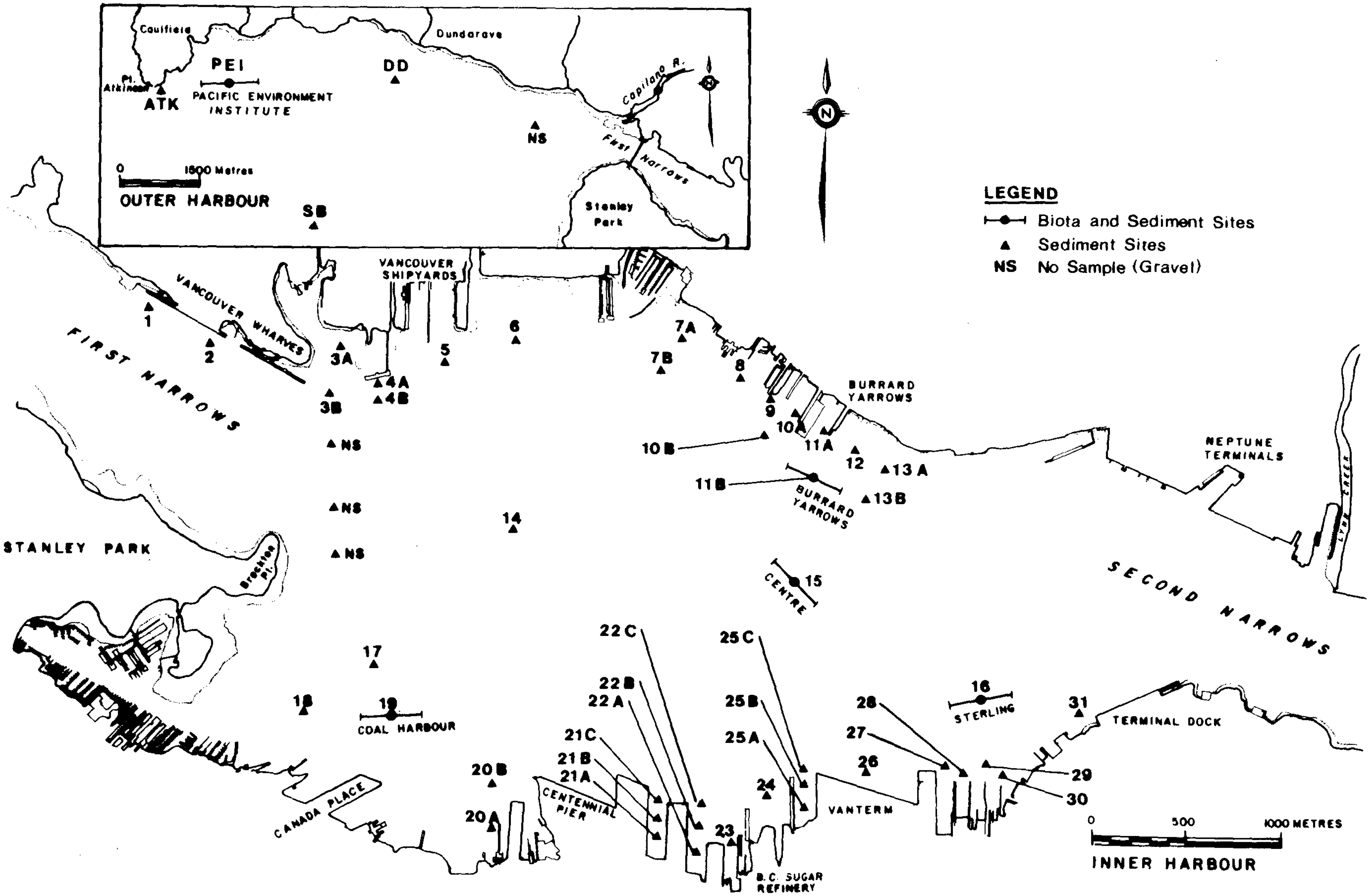


FIGURE 3 SEDIMENT AND BIOTA SAMPLING STATIONS IN VANCOUVER HARBOUR - OUTER AND INNER HARBOUR

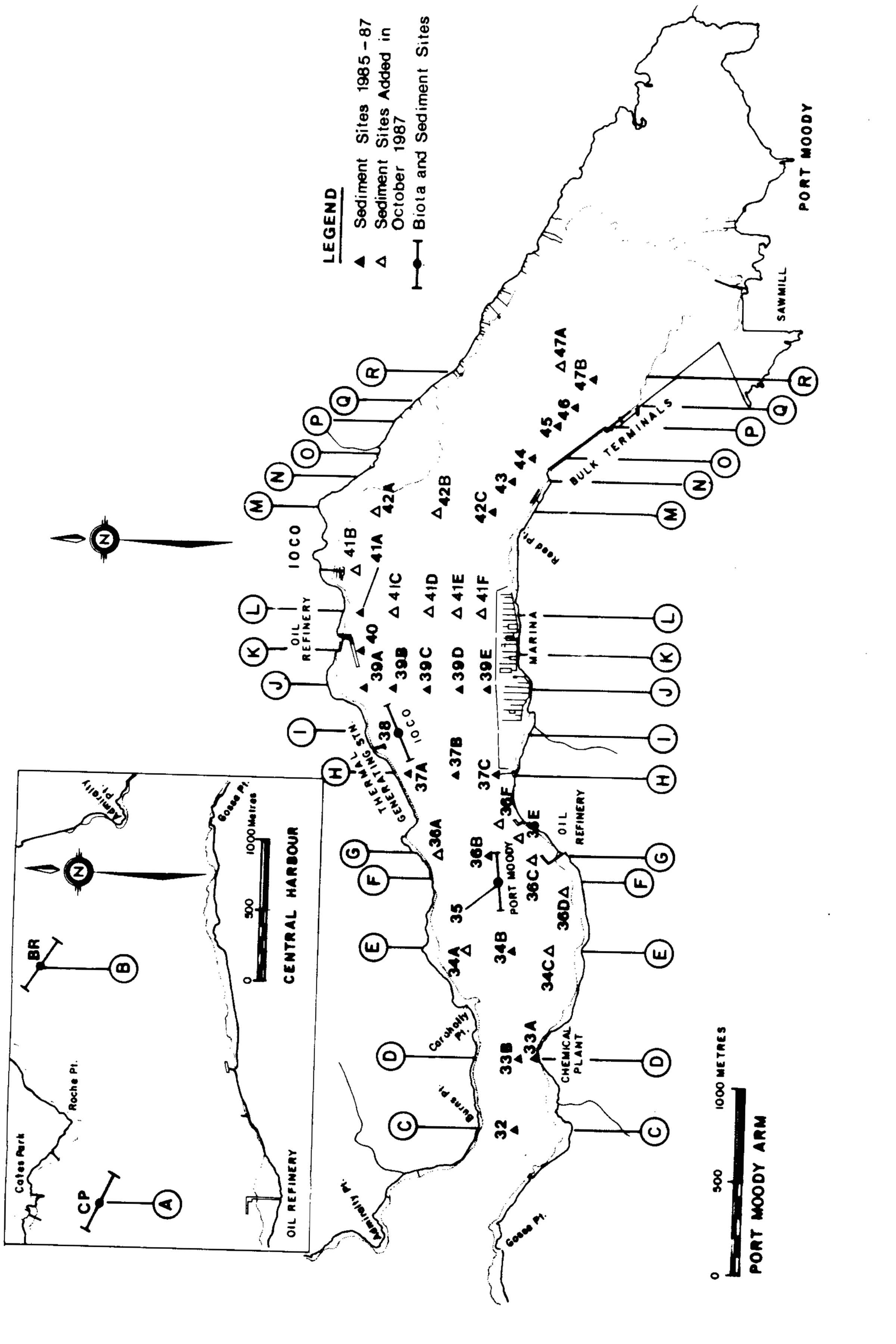


FIGURE 4 SEDIMENT AND BIOTA SAMPLING STATIONS IN VANCOUVER HARBOUR - CENTRAL HARBOUR AND PORT MOODY ARM

Details on sampling schedule, collection methods, and laboratory analyses are given in Appendices A-G.

Earlier reports on the prevalence of external abnormalities in flatfish and liver lesions in English sole (Goyette et al., 1987) and species abundance and distribution (Goyette and Thomas, 1987) in Vancouver Harbour may also be referred to for specific methods.

3.2 Computer Graphics

Bar graphs were generated by customized software to illustrate surface sediment concentrations in Vancouver Harbour relative to baseline levels, CEPA ocean dumping criteria (formally the Ocean Dumping Control Act - O.D.C.A.), and the benthic Apparent Effects Thresholds (BAET). The latter criteria, developed in Puget Sound, define the sediment concentration level at which a detrimental effect is expected 100% of the time. Spatial distribution maps for the inner harbour and Port Moody Arm in 1985/86 were prepared using a microcomputer based geographic information system (GIS), and spatial analysis system (SPANS). Contaminant concentrations were interpolated between sampling points using 0.75 km radius of influence. An exponential function was used to model the influence of each data point with distance (i.e. the influence would drop by half from the sample point). Concentration ranges were pre-selected to reflect the overall concentration range throughout the harbour, natural reference levels, and federal CEPA ocean dumping criteria. A maximum of 5 concentration ranges were choosen for ease of reference.

4.0 RESULTS AND DISCUSSION

The following discussion is based on results provided in the individual data reports (Appendicies A to G). Refer to the relevant report for specific information, such as raw data and descriptive statistics (mean, standard deviation, and ranges). All chemical results are given in µg/g, dry weight.

4.1 Sediment Chemistry

Most chemical pollutants have a strong affinity for particulate matter, ultimately accumulating in the bottom sediments. Murphy et al. (1988), for example, reported that over 90% of the hydrocarbons entering Puget Sound are deposited in the estuarine sediments; 63% percent of the PAH and 100% of the petroleum hydrocarbons settled directly from surface waters. Based on accumulation and geographical distribution, sediment chemistry can indicate potential point and non-point sources of pollutants as well as the temporal and spatial extent of the impact. In addition, it can provide a relative measure of the overall benthic environmental quality and potential toxicological conditions. Concentration alone, however, does not necessarily dictate the degree of environmental impact. The availability of chemical contaminants to the environment in general, will also depend on other factors, such as pH, redox potential, oxygen content, and organic content of the sediment or overlying water (Dickson et al., 1987).

Concentration can also depend on sediment particle size. Generally, the finer the fraction, the higher the concentration due to increased surface area and therefore chemical affinity. Sediments in this study were clay/silt to fine sand (<149 microns or minus 100 mesh). Table 1 summarizes the range in mean surficial sediment concentration of the chemical contaminants measured in Vancouver Harbour (1985/86 and 1987) and Loughborough Inlet (1987).

Puget Sound has been the subject of numerous studies on organic and inorganic contaminant levels and associated biological effects (Tetra Tech,

TABLE 1 RANGE IN MEAN SURFACE SEDIMENT CONCENTRATION OF SELECTED CONTAMINANTS IN VANCOUVER HARBOUR (1985/86 & 1987) AND LOUGHBOROUGH INLET (1987)

Parameter	Concentration in µg/g, dry weight Vancouver Harbour	Loughborough Inlet (reference site)
Trace Metals		
Arsenic	<8 - 96	<8
Cadmium	<.3 - 10.2	0.31 - 0.65
Chromium	29 - 267	32.2 - 38.8
Copper	48 - 9760	56 - 72
Iron	2.2 - 8.2	2.9 - 3.6
Mercury	0.11 - 4.6	0.12 - 0.13
Nickel	7 - 119	18 - 25
Lead	17 - 15,420	21 - 23
Zinc	88 - 2267	102 - 135
Organic Compounds		
Hydrocarbons	19 - 6587	57 - 70
PAH - Total	1.34 - 36.89	-
- LPAH	0.31 - 7.51	-
- HPAH	1.02 - 32.14	-
PCB	<0.02 - 0.90	0.02 - 0.05
Chlorophenols		
Penta-	<0.0001 - 0.135	<0.0001
Tetra-	<0.0002 - 0.079	-
Tri-	<0.0005 - 0.0245	-

1986; Evans-Hamilton and D.R. Systems, 1987; Malins et al., 1985, 1988; Puget Sound Water Quality Authority, 1988). In addition, sediment quality values (SQV) for a variety of inorganic and organic chemicals have been developed for Puget Sound (Tetra Tech, 1986). The Apparent Effects Threshold (AET) is an SQV which represents the sediment concentration of a particular contaminant above which biological effects would always be expected within 95% confidence. These criteria have been empirically derived from paired sediment chemistry data for a range of biological effects indicators (e.g. amphipod mortality, oyster larvae abnormalities, Microtox bioassays, and reduction in total benthic infauna abundance). The SQV's were intended for preliminary screening for ocean disposal of sediment and while certain geochemical differences may exist between the two areas, they can provide a relative measure of the toxicological state of the Vancouver Harbour sediments. Comparisons have therefore been made between the 1985/86 results from Vancouver Harbour and the Puget Sound AET values for benthic infauna (BAET). These latter values have been based on a 50% reduction in total abundance of major taxa.

4.1.1 Surface Sediment Trace Metal Distribution

Ranges in mean surface sediment trace metal concentration for arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), mercury (Hg), nickel (Ni), lead (Pb) and zinc (Zn) specific of Vancouver Harbour in 1985/86 are given in Table 2. Estimated natural concentrations using Spanish Banks and Cates Park sampling stations in Vancouver Harbour, Loughborough Inlet sampled in 1987, and Puget Sound reference levels (Tetra Tech, 1986; Evans-Hamilton and D.R. Systems, 1987) are also included for comparison. The results from Spanish Banks (SB) and Cates Park (CP) sampling stations indicated that sediments were relatively free from anthropogenic trace metals. Concentrations at both sites were also within the limits found at other non-urban, non-industrialized areas along the B.C. coast (Goyette and Christie, 1982; Harding and Thomas, 1987), including Loughborough Inlet.

TABLE 2 RANGE IN MEAN SURFACE SEDIMENT TRACE METAL CONCENTRATIONS BY AREA - VANCOUVER HARBOUR - 1985/1986 & 1987

AREA	CONCENTRATION (µg/g, dry weight) As	Cd	Cr	Cu	Fe(%)	Hg	Ni	Pb	Zn	No. of Stations
OUTER HARBOUR - 1985/86	<8-28	<0.3-0.8	55-67	65-504	3.8-4.1	0.14-0.29	7-51	17-67	108-206	4
- 1987	<8	.24 -.38	49-52	180-298	3.7-3.8	0.15-0.17	37-40	40-53	142-157	2
INNER HARBOUR - 1985/86	<8-96	<0.3-7.4	29-77	90-4353	2.2-8.2	0.09-4.6	9-296	20-15400	93-2267	44
-North Shore	<8-96	<0.3-7.4	29-77	115-4353	2.5-8.2	0.09-3.1	9-296	20-15400	93-2267	19
-Centre	<8-19	0.56-0.76	33-43	333-465	2.7-3.4	0.21-0.33	22-32	64-85	155-235	2
-South Shore	<8-27	<0.3-1.6	32-52	90-991	2.2-3.6	0.13-4.6	15-65	59-343	113-374	23
Central Harbour - 1985/86	<8	<0.3 0.5	28-30	64-152	2.8-3.6	0.11-0.27	7-18	19-48	88-131	2
Eastern Harbour - 1985/86	<8-40	<0.3-2.4	48-267	48-184	3.3-4.7	0.13-0.49	22-44	12-182	98-461	23
- 1987	-	.8-10.2	48-128	62-238	3.2-4.4	0.11-0.47	25-32	19-298	192-317	32
Spanish Banks* Cates Park* - 1985/86	<8	<0.3	29-50	64-65	3.6-3.9	0.11-0.14	7-39	17-19	19-108	2
Loughborough Inlet** - 1987	<8	0.31-0.56	33.8-38.4	62-65	3.0-3.4	0.12	21-23	22	103-137	2
Puget Sound***	17	1.9	59	74	-	0.28	-	24	100	-

* Vancouver Harbour Reference Sites
** Coastal Reference Sites
*** Puget Sound Reference Levels (Source: Evans-Hamilton and D.R. System, 1987; Tetra Tech, 1986 for mercury)

Concentration percentiles (50, 75, 90) by area for Vancouver harbour are given in Table 3, including the level and station location of maximum concentrations. Table 4 compares the concentration percentiles for Vancouver Harbour with those reported for Puget Sound (Tetra Tech, 1986). Maximum concentrations for chromium, iron, nickel, and lead in Vancouver Harbour exceeded those reported for Puget Sound. Ninety percentile values for chromium, copper, iron and zinc were also higher. These also exceeded the BAET. Concentrations of other trace metals have been summarized in Appendix A and C.

Sediment samples were routinely collected at each trawl station (PEI, 11B, 15, 16, 19, 35, and 38) to provide comparable data for tissue trace metals and to assess seasonal variability. PEI, for example, was sampled on 5 occasions between 1985 and 1987 (Appendix A & C). Based on an analysis of variance (ANOVA), there were no obvious seasonal differences.

Compared to the estimated natural reference levels for Vancouver Harbour, all stations except Spanish Banks and Cates Park showed elevated sediment concentrations of at least one trace metal. Some concentrations were substantially above the reference values. Copper and lead concentrations at Station 1, near the metal concentrate loading dock at Vancouver Wharves, were up to 150 and 642 times the reference level. Figure 5 illustrates the percentage of sampling stations above the natural reference concentration and the Puget Sound BAET value for cadmium, chromium, copper, mercury, lead, and zinc.

The following discusses the distribution pattern of more important trace metals in the harbour and compares them to the Puget Sound BAET, Fraser River estuary and Ocean Dumping Criteria established under CEPA.

4.1.1.1 Arsenic. Arsenic compounds can be released into the environment through pesticide use, refining and smelting of nonferrous metals, fossil fuel combustion, incineration of municipal waste, use of arsenic based wood preservatives, and burning of wood treated with arsenic based preservatives (Garrett, 1988). In a review of information on arsenic in the environment,

TABLE 3 CONCENTRATION PERCENTILE AND MAXIMUM CONCENTRATION VALUES (µg/g DRY WEIGHT) FOR SEDIMENT TRACE METALS IN VANCOUVER HARBOUR FOR THE TOTAL STUDY AREA AND SUBAREAS - 1985/86

	TOTAL AREA			OUTER HARBOUR			INNER HARBOUR (North Shore)			INNER HARBOUR (South Shore)			PORT MOODY ARM			Maximum Concen- tration	Station
	50	75	90	50	75	90	50	75	90	50	75	90	50	75	90		
Cd	.63	.99	1.80	.28	.60	.72	.60	2.40	6.30	.85	1.20	1.60	.60	1	1.60	7.70	3A
Cr	42.5	59.4	81.9	55.2	58.3	64.7	42	49	61	13	34	39	67	91	141	310	41
Cu	236	361	685	208	220	449	285	685	2140	341	426	762	161	181	193	8890	1
Fe	33500	38000	42800	39800	41700	45200	32500	36700	53700	30600	32100	34100	37500	39500	46500	102000	1
Hg	.21	.29	.46	.24	.26	.29	.16	.22	.31	.29	.43	.62	.40	.41	.47	9.63	25A
Ni	27	32	43	42	43	49	20	33	45	27	31	35	27	31	33	404	1
Pb	59	85	179	47	64	69	81	159	315	80	110	143	110	131	138	30000	1
Zn	149	214	489	148	160	195	380	708	1480	213	256	303	214	243	359	3050	1

TABLE 4 COMPARISON OF VANCOUVER HARBOUR SURFACE SEDIMENT TRACE METALS TO PUGET SOUND* USING CONCENTRATION PERCENTILES, AND BENTHIC AET (μg/g, dry weight)

	VANCOUVER HARBOUR					BENTHIC AET	PUGET SOUND*			
	50	75	90	MAX.	MIN.		50	75	90	Max.
Cd	0.63	0.99	1.80	7.7	<.3	5.8	.48	1.78	3.07	180
Cr	42.5	59.4	81.9	310	21	59	35	53	66	129
Cu	236	361	685	8890	48	310	49	83	167	11400
Fe	3.35	3.80	4.28	10.2	2.2	3.7	1.9	2.7	3.2	5.3
Hg	.21	.29	.46	9.63	.09	.88	.20	.46	.98	52
Ni	27	32	43	296	7	49	27	41	50	118
Pb	59	85	179	30000	12	300	39	92	190	6250
Zn	149	214	489	3050	88	260	91	140	292	3320

* Source: Tetra Tech (1986).

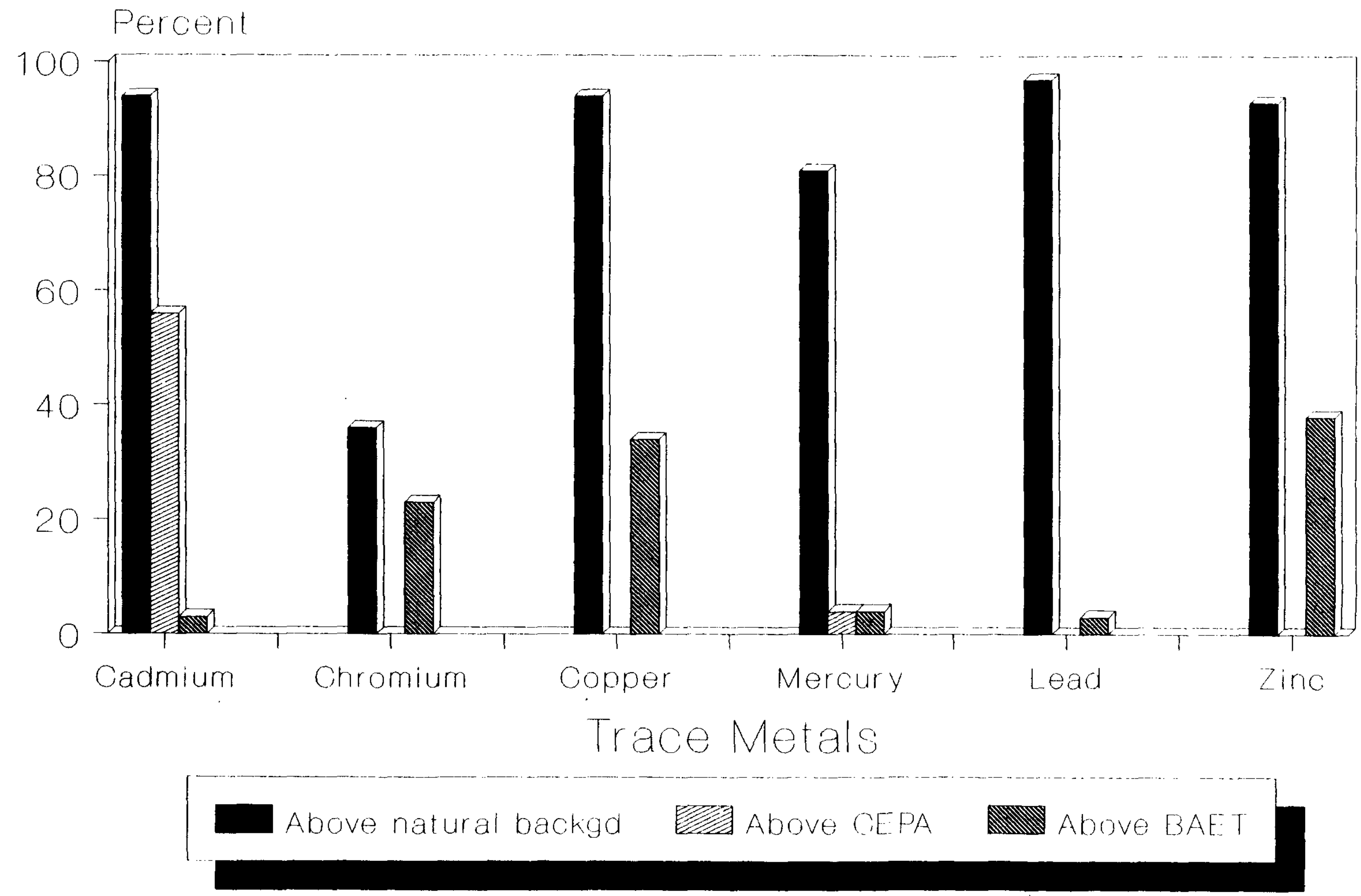


FIGURE 5 PERCENTAGE OF STATIONS ABOVE NATURAL AND BENTHIC AET VALUES

Garrett (1988) indicated that natural concentrations may range from <0.4 to >450 µg/g in ocean sediments with an average of 30 µg/g. Natural levels in Hastings Arm in Northwestern B.C. were between 10 and 19 µg/g (Goyette and Christie, 1982) and in Alice Arm, up to 38 µg/g (Reimer et al., 1985). In Puget Sound, the maximum reference concentration has been given as 17 µg/g, with an estimated average concentration throughout Puget Sound at 9 µg/g (Evans-Hamilton and D.R. Systems, 1987). Arsenic concentrations in Loughborough Inlet in 1987 were <8 µg/g (Appendix C). The majority of sampling sites in Vancouver Harbour were also <8 µg/g. Previous studies in Vancouver Harbour showed high concentrations of arsenic in shore sediments collected near an ore loading facility (≤330 µg/g) and certain shipbuilding/repair facilities in the harbour (≤483 µg/g) (Garrett, 1988).

Unfortunately, in the present study, some analytical problems were experienced with arsenic determinations in the 1985/86 samples. A change from wet to microwave digestion appeared to increase arsenic recovery in standard reference materials (MESS and BCSS) during the initial stages of the changeover (see Appendix A). A corresponding increase also occurred in the field samples making interpretation difficult. Arsenic levels in the samples were not however, considered high enough to warrant re-analysis; concentrations at most sites were below the detection limit of <8.0 µg/g.

In 1987, arsenic concentrations were determined using only microwave digestion procedures. Stations in the outer and inner harbour were below the 8 µg/g detection limit (Appendix C) except for Stations 1 and 2 which ranged from <8 - 20 µg/g. Spillage of metal concentrates during vessel loading and unloading (also refer to sections on copper, lead, and zinc) was the probable source of the arsenic. Concentrations at most stations in Port Moody Arm were <8 µg/g.

Fanning et al. (1989) reported arsenic levels on Sturgeon Banks in the Fraser River estuary at 5.33 - 7.51 µg/g. Roberts Bank values were reported at <8 µg/g (Harding et al., 1988). Arsenic concentrations near the ASARCO smelter in Puget Sound were up to 12,200 µg/g (Evans-Hamilton and D.R. Systems, 1987). In Elliot Bay, near Seattle, the maximum concentration was 280 μg/g (Evans - Hamilton and D.R. Systems, 1987).

Factors other than total concentration of arsenic in the solid phase, may determine its availability. Reimer et al. (1985) found that despite the lower total arsenic concentrations (13.4 μg/g) in marine tailings deposits from Alice Arm compared to the natural sediments (30 μg/g), the soluble arsenic levels in the interstitial water were nearly four times greater. The predominant species of arsenic were As III and IV, two of the more toxic forms of arsenic.

There are no federal limits for arsenic in marine sediments, however, arsenic is classified as a restricted substance under Part IV of the ocean dumping provisions in CEPA. Applications for ocean disposal are reviewed individually. The BAET for arsenic in the Puget Sound area is 85 μg/g (Tetra Tech, 1986), well above the maximum concentrations found in Vancouver Harbour. In most regions of the harbour, arsenic levels in the sediment do not appear to represent a problem.

4.1.1.2 **Cadmium**. Cadmium can originate from a number of urban and industrial sources. It is used in electroplating and metal coating, paint pigments, plastic stabilizers, pesticide catalysts and manufacture of nickel-cadmium batteries (Garrett, 1985b).

The mean concentration of cadmium in Vancouver Harbour sediments ranged from <0.3 to 7.4 μg/g in 1985/86. Computer estimates (SPANS) of cadmium distribution are shown in Figure 6. Mean concentration for each sampling location are mapped in Appendix A (Figure 2) for 1985/86 and Appendix C (Figure 4) for 1987. By comparison, sediment cadmium concentrations reported for the Fraser River estuary on Sturgeon Banks ranged from <0.025 - 0.13 μg/g (Fanning et al., 1989) and 1.0 - 7.0 μg/g off Roberts Bank (Harding et al., 1988). Cadmium concentrations in Puget Sound reached a maximum of 184 μg/g (Evans-Hamilton and D.R. Systems, 1987).

Figure 7 relates average concentration per station (1985/86) to an estimated natural reference level for the harbour (<0.3 μg/g), the 0.6 μg/g

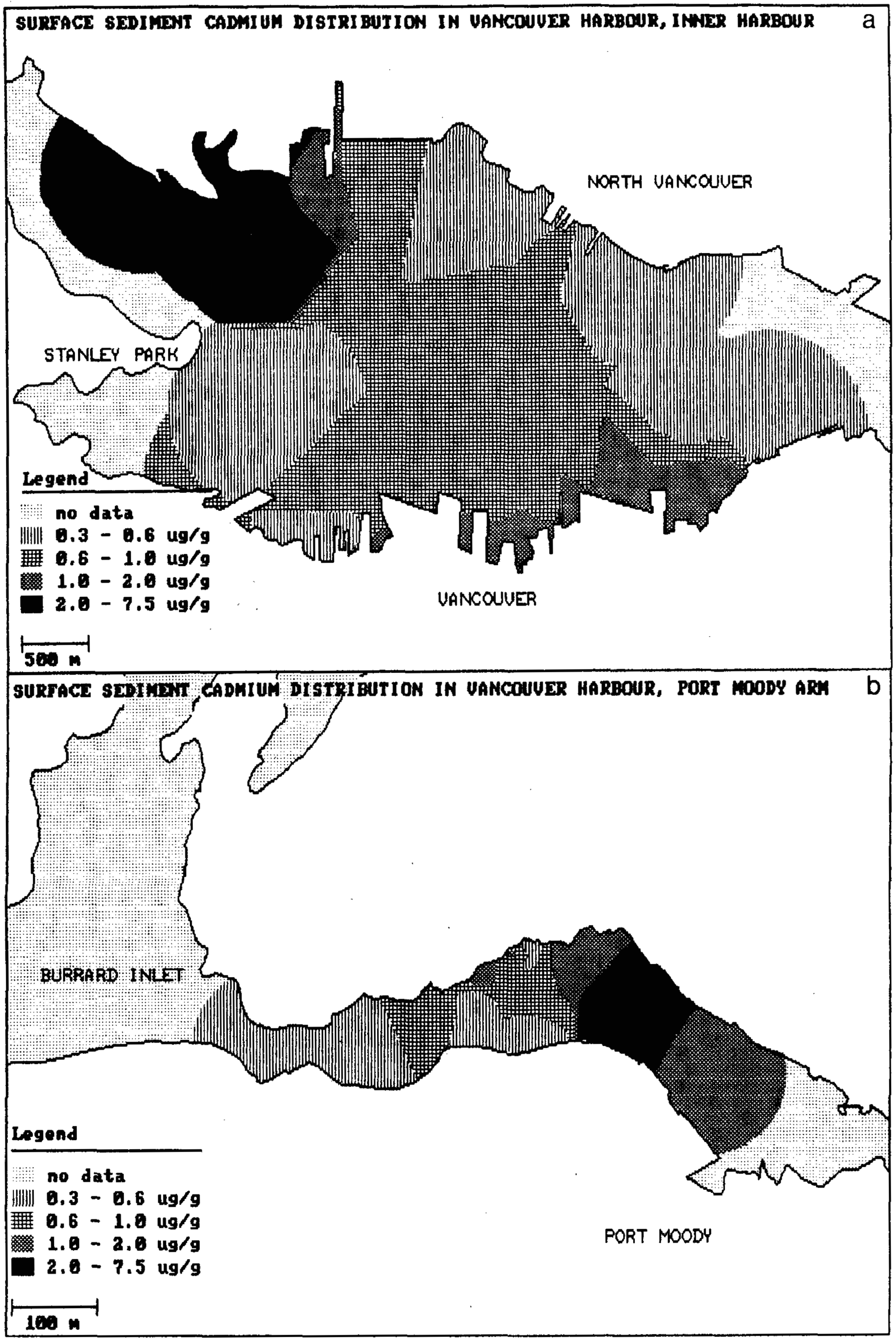


FIGURE 6 SURFACE SEDIMENT CADMIUM DISTRIBUTION IN VANCOUVER HARBOUR (1985/86) A) INNER HARBOUR B) PORT MOODY ARM

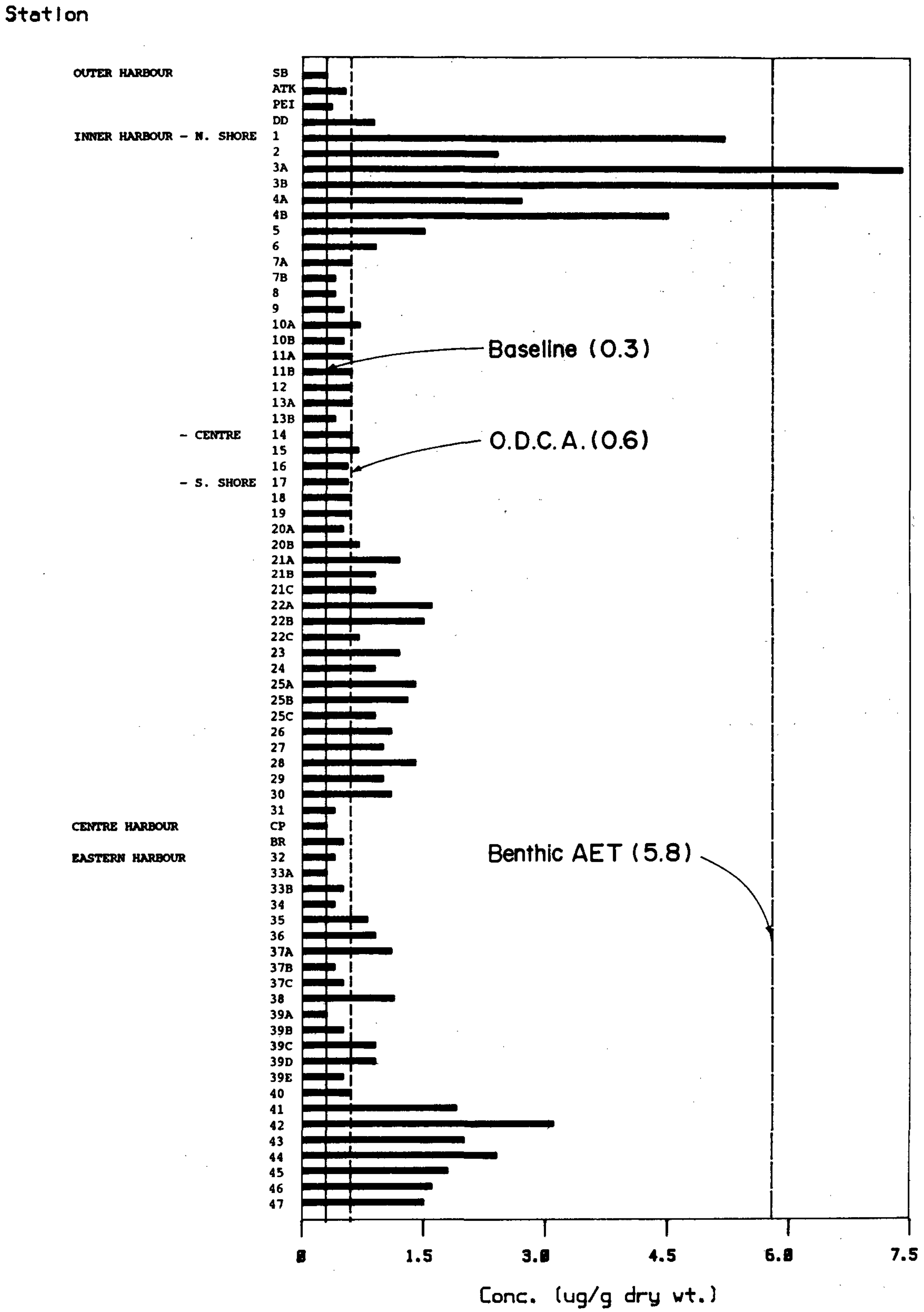


FIGURE 7 Mean Surface Sediment Cadmium Concentrations in Vancouver Harbour (1985-86)

CEPA screening limit for ocean dumping applications, and the Puget Sound BAET, 5.8 µg/g, (Tetra Tech, 1986).

Natural cadmium concentrations for Vancouver Harbour are estimated at <0.3 µg/g based on levels at the Spanish Banks and Cates Park stations (1985/86). In 1988, surface sediment in two samples from Spanish Banks averaged 0.09 µg/g (Goyette, unpublished data). At two sites in Loughborough Inlet, in 1987 concentrations averaged 0.31 and 0.56 µg/g, respectively (Appendix C). Maximum and average reference levels for Puget Sound have been given as 1.9 µg/g and 0.3 µg/g, resepctively, (Evans-Hamilton and D.R. Systems, 1987). Harding and Thomas (1987) found cadmium levels at unpolluted coastal inlets to range from 0.9 µg/g to 1.4 µg/g.

Including 1987 data, concentrations in the outer harbour ranged from <0.3 - 0.9 µg/g, average 0.4 µg/g at Station PEI (6 surveys). In 1988, levels in a 157 cm. core sample taken at Station PEI were 0.09 - 0.31 µg/g (unpublished data). The lowest concentration was recorded at 40 - 42 cm.

Mean cadmium concentration obtained from 44 sites in the inner harbour in 1985/86 was 1.35 ± 1.59 µg/g. Higher levels (1.5 and 7.4 µg/g) were confined to the north shore of the inner harbour at Stations 1 - 5 and along the South shore (Stations 21 - 30) where mean concentrations were from 1.0 - 1.6 µg/g (Figure 7). Similar results were obtained in 1987 at Stations 1, 2, 22A and 25A (Appendix C - Figure 2). Offshore levels in the inner harbour were generally below 1.0 µg/g. In 1980 and 1981, Garrett found cadmium levels ranging from 0.4 to 24.5 µg/g along the foreshore near Stations 1 and 2, and ≤11.9 µg/g inshore from Station 5 (unpublished data).

Mean concentration from 23 sites in Port Moody Arm in 1985/86 was 1.06 ± 0.76 µg/g (range, <.3 - 3.1 µg/g) and slightly higher in 1987 at 2.14 ± 1.91 µg/g (range, 0.66 - 10.22 µg/g) (32 sites). Two noticeably high values (4.89 and 10.22 µg/g) were observed in samples from Stations 34C and 36C in 1987. Samples were re-analyzed and results confirmed. Lower concentrations generally occurred near the entrance to the arm and increased towards the head (Stations 42 to 47) near the Pacific Coast Terminals

(Appendix A - Figure 2). Bourne (1974) reported a range of 0.1 to 3.3 µg/g from 70 sampling stations throughout Port Moody Arm. He also observed lower values (0.1 to 0.9 µg/g) near the entrance and in the upper portions of the arm, and higher levels along the nearshore areas of the middle portion.

In 1988, a core sample taken from the middle of Port Moody Arm (Station 39C) was within 1.2 - 1.7 µg/g throughout an 118 cm core measured at 10 cm intervals (Goyette, unpublished data). A similar pattern was evident in a core sample taken near the entrance to the arm (Station 33B) except a sharp increase to 3.5 µg/g which occurred at 70 cm. in the core. A corresponding increase also occurred with copper, lead and zinc concentrations. Possible anthropogenic sources of cadmium in Port Moody Arm include the oil refinery at Ioco, bulk loading operations at Pacific Coast Terminals, stormwater discharges, and combined sewer overflows. A detailed inventory on the various industrial and urban discharges would determine potential sources, more precisely.

Although the sources of cadmium in Port Moody Arm appears to be largely anthropogenic, natural sources also need to be considered. Pedersen et al., (1988), found that cadmium (and molybdenum) enrichment in a west coast inlet resulted from the natural addition from the overlying seawater into organic-rich, anoxic sediments. The strong hydrogen sulfide odour and black appearance of the sediment samples at most locations in Port Moody Arm suggest that similar conditions exist in Port Moody Arm.

In 1985/86, 90% of the sample sites in the harbour were above the natural level estimated for Vancouver Harbour (<0.3 µg/g), 56% were above the screening limit for ocean disposal (0.6 µg/g), and 5% were above the Puget Sound BAET (5.8 µg/g). In 1987, all concentrations in Port Moody Arm exceeded the 0.6 µg/g CEPA Ocean Dumping Screening level, although most offshore areas were below 1.0 µg/g. Control of cadmium sources is needed to avoid exceeding CEPA ocean dumping limits on dredge material intended for ocean disposal and to minimize the potential for uptake and toxicological effects to marine species. Spillage from metal concentrate loading facilities, oil refinery operations, and combined sewer overflows appear to be the primary sources of cadmium to the harbour.

4.1.1.3 **Chromium**. Chromium is used in electroplating, pigment and dying processes, tanning, and the production of ferroalloys; it may be also discharged to municipal sewer systems from other sources. Chromium can be highly toxic to marine organisms; the degree of toxicity depends on its valence state. Hexavalent chromium (Cr VI) for example is more toxic than trivalent chromium (Cr III). In the marine environment Cr IV can be reduced to Cr III by a sulphate reducing bacteria (Smillie et al., 1984; Jenkins, 1982) which has less biological activity (Langard, 1980). Chromate solutions have induced gill hyperplasia in rainbow trout (Temmink et al., 1983), and caused carcinogenic effects in mammals Langard (1980).

Mean chromium concentrations in the harbour in 1985/86, ranged between 25 and 267 µg/g. Computer estimated (SPANS) chromium distribution in the surface sediments are shown in Figure 8. Mean concentration for each sampling location are mapped in Appendix 3 (Figure 3) for 1985/86 and Appendix C (Figure 5) for 1987. This can be compared to chromium levels reported for Sturgeon Banks in the Fraser River estuary, 30 - 63 µg/g (Fanning et al., 1989). Harding et al. (1988) found concentrations off Roberts Bank ranging from 30.4 to 68.7 µg/g. Maximum concentration in Puget Sound has been reported at 129 µg/g (Tetra Tech, 1986).

Figure 9 relates average concentration per station (1985/86) to the maximum natural reference level (50 µg/g) for Vancouver Harbour, and Puget Sound BAET (59 µg/g - Tetra Tech, 1986). Reference chromium level for Vancouver Harbour has been estimated from the mean concentration at Spanish Banks in 1985/86 (Appendix A) and results from a series of samples taken in the outer harbour in 1988 (unpublished data). Concentrations from two sites in Loughborough Inlet in 1987 averaged 33.8 and 38.4 µg/g, respectively (Appendix C). The reference level for Puget Sound, based on 7 nonurban sites, has been given as 54 µg/g (Tetra Tech, 1986). Chapman et al. (1986) reported a reference level for the Fraser River estuary at 48 µg/g.

Chromium concentrations throughout most of Vancouver Harbour sediments were <50 µg/g. The inner harbour averaged 42.2 ± 10 µg/g (range,

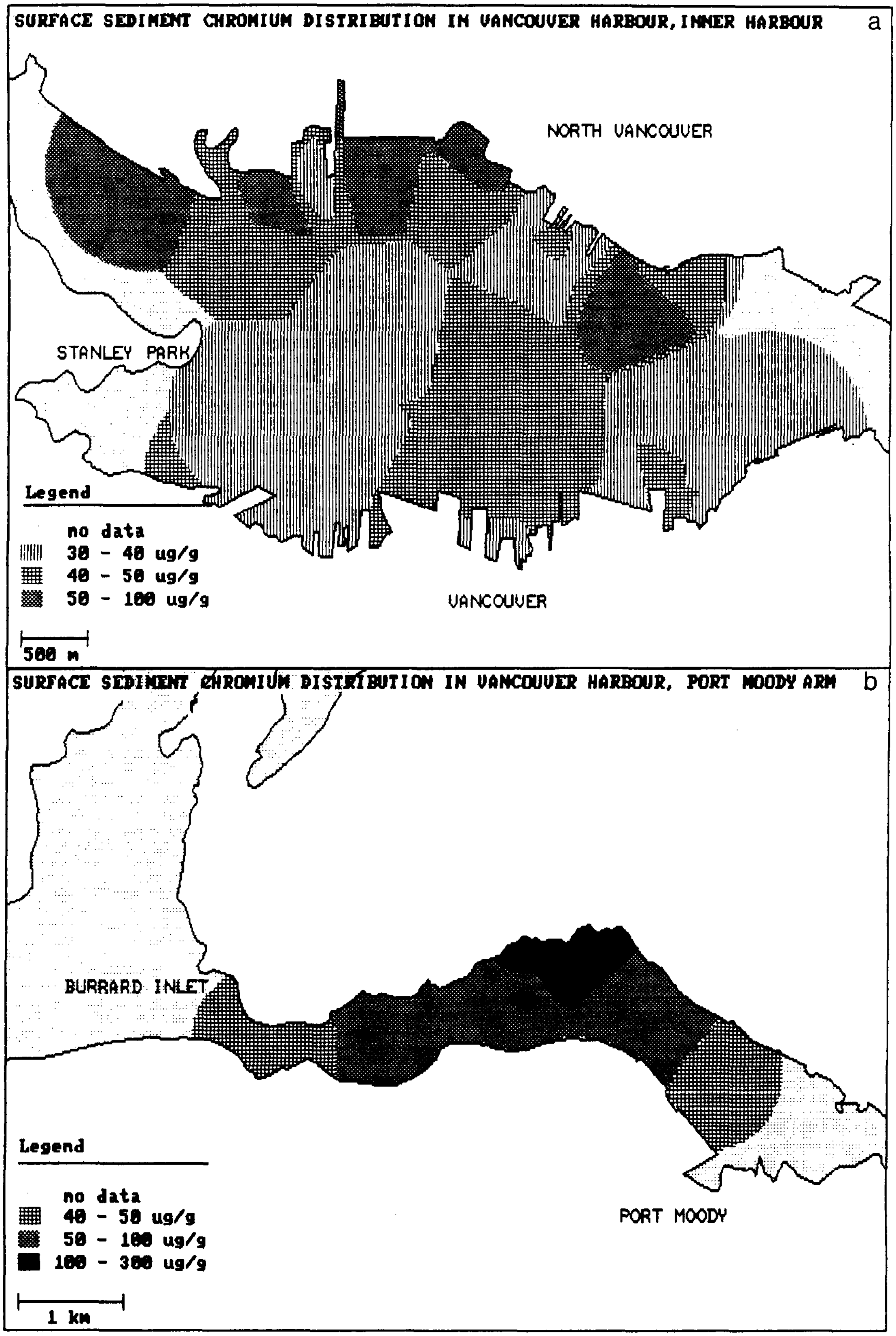


FIGURE 8 SURFACE SEDIMENT CHROMIUM DISTRIBUTION IN VANCOUVER HARBOUR (1985/86) A) INNER HARBOUR B) PORT MOODY ARM

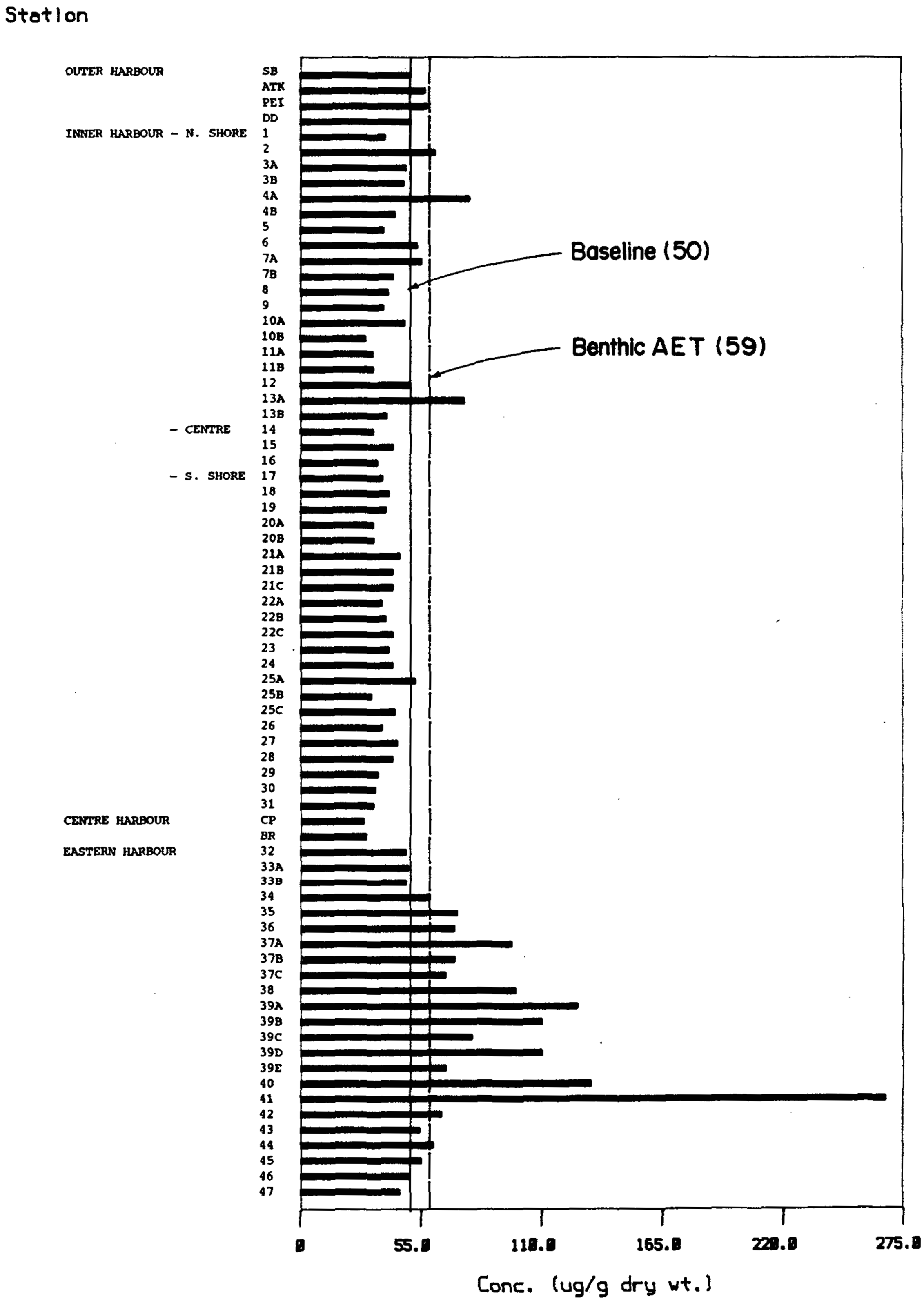


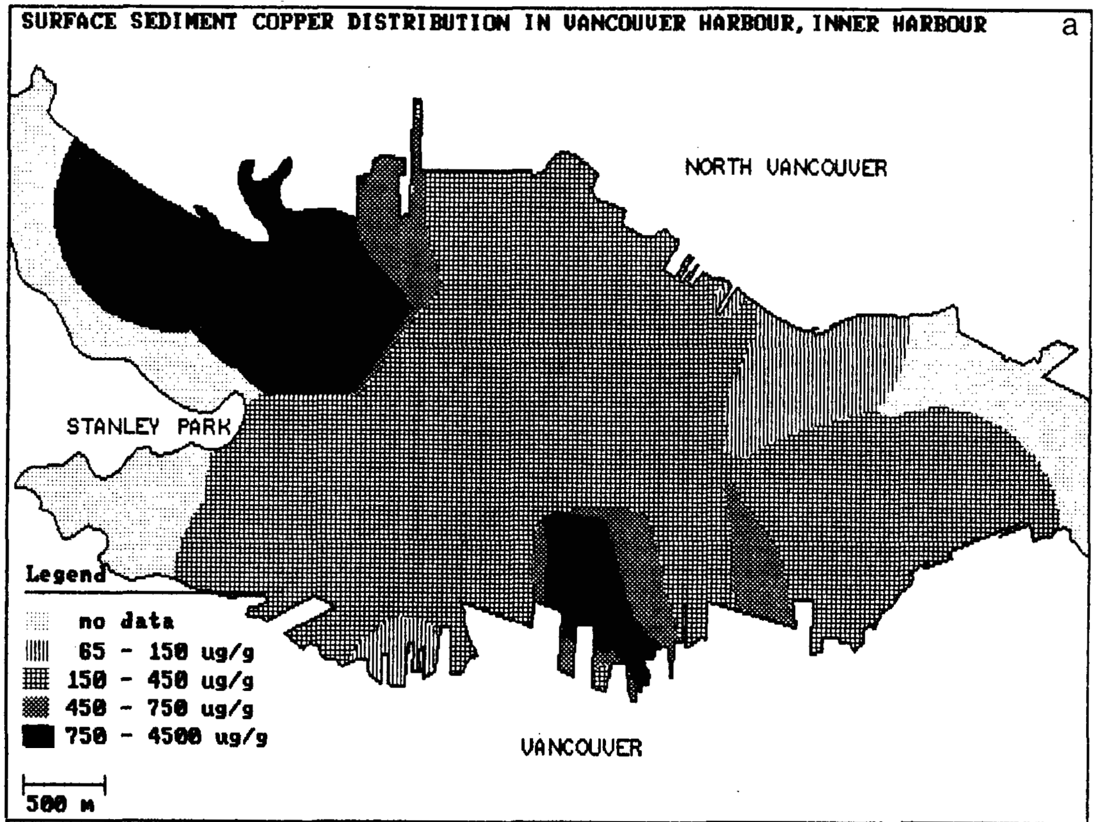
FIGURE 9 Mean Surface Sediment Chromium Concentrations in Vancouver Harbour (1985-86)

29 - 77 µg/g). Levels in Port Moody Arm, ranged from 45 µg/g, near the head of the arm (Station 47) up to 267 µg/g, off the Ioco refinery (Station 41), the maximum level in Vancouver Harbour. The overall mean concentration in Port Moody Arm in 1985/96 was 82.2 ± 47.8 µg/g and 69.2 ± 17.1 µg/g (range, 50.6 - 128.0 µg/g) in 1987. The maximum concentration in 1987 again was found at Station 41 (128 µg/g).

The major source of chromium in the harbour appears to be the Ioco oil refinery in Port Moody Arm. The GVRD combined sewer overflows in the inner harbour (Stations 25 and 30) were not a significant source. Except for Port Moody Arm, chromium levels in the harbour do not indicate any major areas of concern. Levels found in Port Moody Arm and their relationship to fish liver lesions needs further investigations.

4.1.1.4 Copper. Loading facilities for bulk metal concentrates, shipyards (anti-fouling paints), blasting abrasives (smelter slags), and herbicides are major urban sources of copper to the marine environment. Although copper is an essential element in biological processes, it can be highly toxic to marine organisms. Copper can also act synergistically with other metals, such as zinc. Lewis and Cave (1982) provide a detailed review of the beneficial and detrimental effects of copper to marine and estuarine organisms.

Of all the metals examined, copper showed the most widespread contamination. Mean sediment concentrations for the entire study area in 1985/86, ranged from 48 µg/g to 4353 µg/g. Computer estimated (SPANS) copper distribution in the surface sediments in the inner harbour and Port Moody Arm (1985/86) are shown in Figure 10. Mean concentration per station are also shown by maps contained in Appendix A (Figure 4) for 1985/86 and Appendix C (Figure 6) for 1987. By comparison, sediment copper levels in the Fraser River estuary (Sturgeon Bank) have been reported as 9.8 - 39.3 µg/g (Fanning et al., 1989) and 14.9 - 30.7 µg/g off Roberts Bank (Harding et al., 1988). Concentrations in Puget Sound ranged from 3 to 14,300 µg/g (Evans-Hamilton and D.R. Systems, 1987), the latter recorded near the ASARCO copper smelter. Nearshore areas in Elliot Bay and Commencement Bay ranged



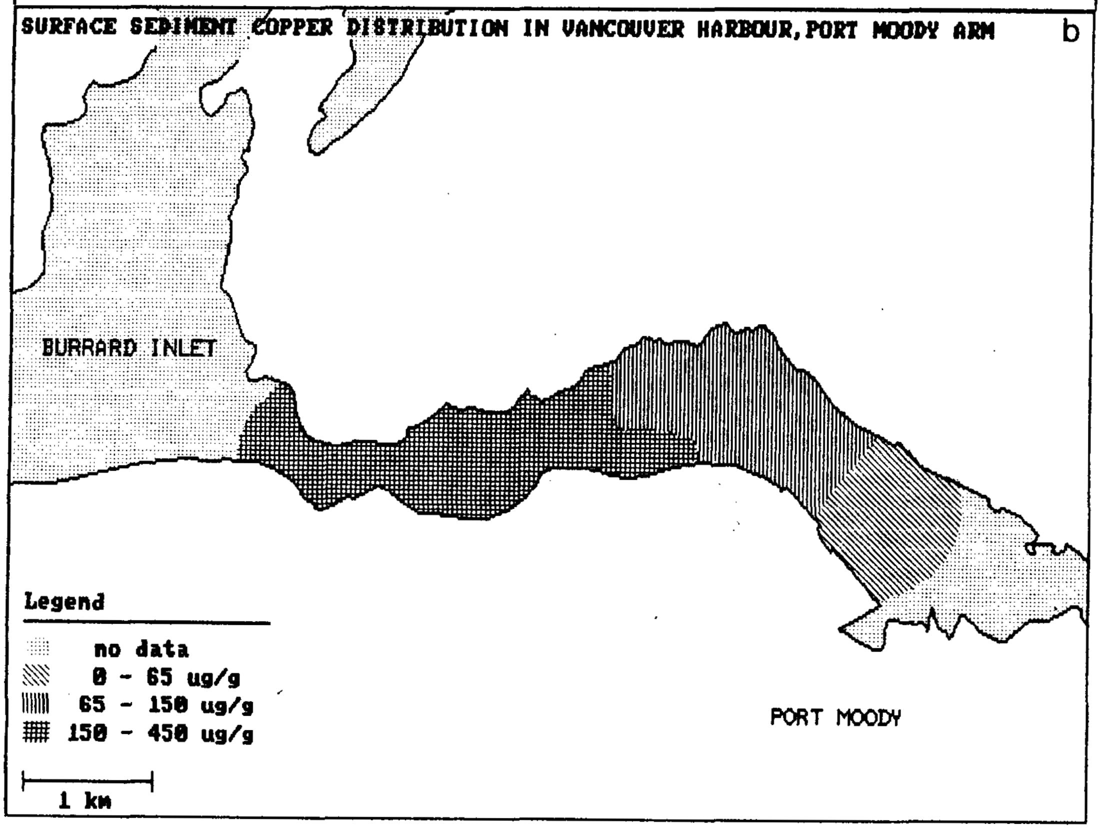


FIGURE 10 SURFACE SEDIMENT COPPER DISTRIBUTION IN VANCOUVER HARBOUR (1985/86) A) INNER HARBOUR B) PORT MOODY ARM

from 23 - 1679 µg/g and 20 - 14,300 µg/g, respectively.

Figure 11 illustrates the relationship of the average concentration at each sampling location in 1985/86 to the natural reference level (65 µg/g) and Puget Sound BAET (310 µg/g - Tetra Tech, 1986). Natural sediment copper levels for Vancouver Harbour are estimated to be <65 µg/g from 1985/86 results from Spanish Banks and Cates Park and a core sample from PEI in 1988, in which copper concentrations ranged from 62 µg/g at 14 - 16 cm. to 40 µg/g at core depth (157 cm) (Goyette, unpublished data), essentially reflecting the natural levels below the contaminated surface layer. Copper levels in Loughborough Inlet (2 sites) in 1987 averaged 64 µg/g (Appendix C). Harding and Thomas (1987) reported baseline levels for Barkley Sound, Quatsino Sound, and Surf Inlet between 23.9 and 68.8 µg/g. Reference levels for Puget Sound are given as 74 µg/g (Evans-Hamilton and D.R. Systems, 1987).

Average copper concentrations in the outer harbour, ranged from 65 - 504 µg/g; elevated levels (>241 µg/g) were observed out as far west as Point Atkinson, the outermost sampling site. In 1988, concentrations at this site were 221 - 227 µg/g (Goyette, unpublished data). The Dundarave site (DD) averaged 504 µg/g in 1985/86 (Appendix A, Figure 4) and ranged from 420 - 486 µg/g in 1988 (Goyette, unpublished data).

Within the inner harbour (1985/86) concentrations ranged from 90 - 4353 µg/g. Maximum levels of 4083 µg/g and 4353 µg/g, were observed at Station 1 and 2, respectively, off the concentrate loading dock at Vancouver Wharves. In 1987, concentrations at these two sites were to 9760 µg/g and 6547 µg/g, respectively. The impact from this single source extended for a considerable distance into the outer harbour (ATK and DD Stations). Eastward along the north shore of the inner harbour, concentrations ranged from 439 to 1967 µg/g. Strong tidal currents through First Narrows would account for the copper distribution in these areas (Canadian Hydrographic Service, 1981).

Elevated copper levels were also found along most of the south shore of the inner harbour, particularly at Station 22A. Copper concentrate

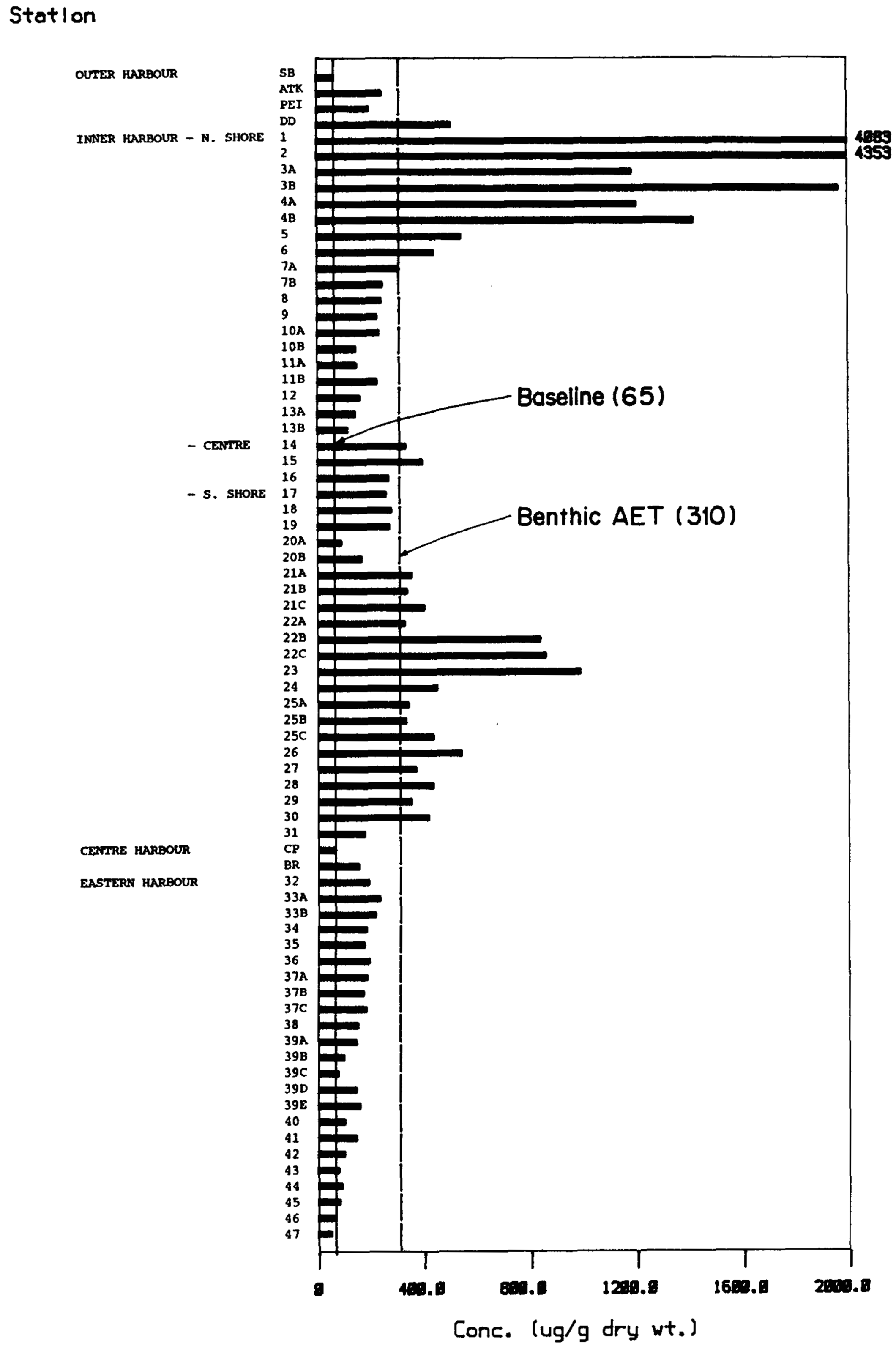


FIGURE 11 Mean Surface Sediment Copper Concentrations in Vancouver Harbour (1985-86)

had been temporarily stored on a nearby dock facility after the June 1986 survey. Concentrations increased from 328 µg/g before storage (Appendix A) to 1240 µg/g in 1987 (Appendix C). Spillage during the vessel loading probably accounts for most of the increase in copper concentration in the marine sediments. In general, urban and industrial sources of copper have been sufficient to cause all increase throughout most of the inner harbour. Copper levels in 1985/86 at Stations 14 and 15, located along the centre of the harbour, averaged 333 µg/g and 465 µg/g, respectively, well above the natural baseline.

Copper concentrations in Port Moody Arm were generally lower compared to an inner harbour mean of 683 µg/g. The 1985/86 average was 138 ± 53 µg/g (range, 48 - 234 µg/g), 1987 was 154 ± 43 µg/g (range, 62 - 238 µg/g). Bourne (1974) reported a mean concentration of 66 µg/g from 70 stations in Port Moody Arm (range 9.5 - 162 µg/g). The distribution pattern did not reveal any specific anthropogenic sources of copper within Port Moody Arm in either 1985/86 or 1987, although concentrations tended to increase towards the entrance to the arm, suggesting possible sources from outside the arm.

Overall, 94% of the stations sampled in Vancouver Harbour in 1985/86 exceeded the reference concentration and 37% were above the Puget Sound BAET. Although there are no federal regulatory limits for copper, it is considered a restricted substance under the ocean dumping provision of CEPA and applications are considered individually. Attention to the various anthropogenic sources in the harbour is required if sediment copper levels are expected to improve significantly in the future, particularly with bulk metal concentrate handling, stormwater discharges and combined sewer overflows. Dockside vessel repairs, particularly along the south shore of the inner harbour may also be a source of copper contamination.

4.1.1.5 Mercury. According to Garrett (1985a), the application of mercury is extensive and diverse in industry. Uses which would likely affect the harbour are in electrical equipment, scientific instruments, paints, pesticides, dental amalgams, pharmaceuticals and chemical manufacturing.

Waste from these sources would be present largely in municipal sewage and urban runoff.

Computer estimated (SPANS) mercury distribution in the surface sediments of the inner harbour and Port Moody Arm (1985/86) is shown in Figure 12. Mean concentration per station are shown on maps in Appendix A (Figure 6) for 1985/86 and Appendix C (Figure 8) for 1987. Mercury concentrations in subtidal sediments from the Fraser River estuary (Roberts Bank), by comparison, have been reported between 0.087 and 0.253 µg/g (Harding et al., 1988), 0.023 and 0.11 µg/g at Sturgeon Bank (Fanning et al., 1989). Levels in Puget Sound have been reported between 1 - 100 µg/g (Evans-Hamilton and D.R. Systems, 1987).

Figure 13 compares average concentration at each sampling location in 1985/86 to a natural reference level (0.2 µg/g), CEPA Ocean Dumping screening limit (0.75 µg/g), and Puget Sound BAET (0.88 µg/g - Tetra Tech, 1986). Reference levels for sediment mercury in Vancouver Harbour are estimated to be <0.20 µg/g. Concentrations at the Spanish Banks and Cates Park stations, averaged 0.14 µg/g and 0.10 µg/g, respectively. In 1988, mercury levels at the former station were 0.11 - 0.13 µg/g (Goyette, unpublished data). In Loughborough Inlet, mercury concentrations averaged 0.12 µg/g (Appendix C). Reference concentrations for Puget Sound have been given as 0.28 µg/g (Evans-Hamilton and D.R. Systems, 1987), and 0.08 µg/g (Chapman et al., 1986).

Sediment mercury concentrations >1.0 µg/g generally warrant further investigation since they are often associated with elevated levels in aquatic biota tissue (Garrett 1985a). All mercury values in the harbour were below this limit except for stations 25A and 30, along the south shore of the inner harbour (Figure 3). Both sites were adjacent to combined sewer overflows at Clark Drive/Vernon Relief and Victoria Drive, respectively. Concentrations at these two locations were 4.6 and 2.2 µg/g, respectively, well above the baseline level estimated for the harbour. Mercury concentration in 1987 at Station 25A averaged 2.5 µg/g. The sediment samples from Station 25A were mainly raw sewage, indicating that municipal

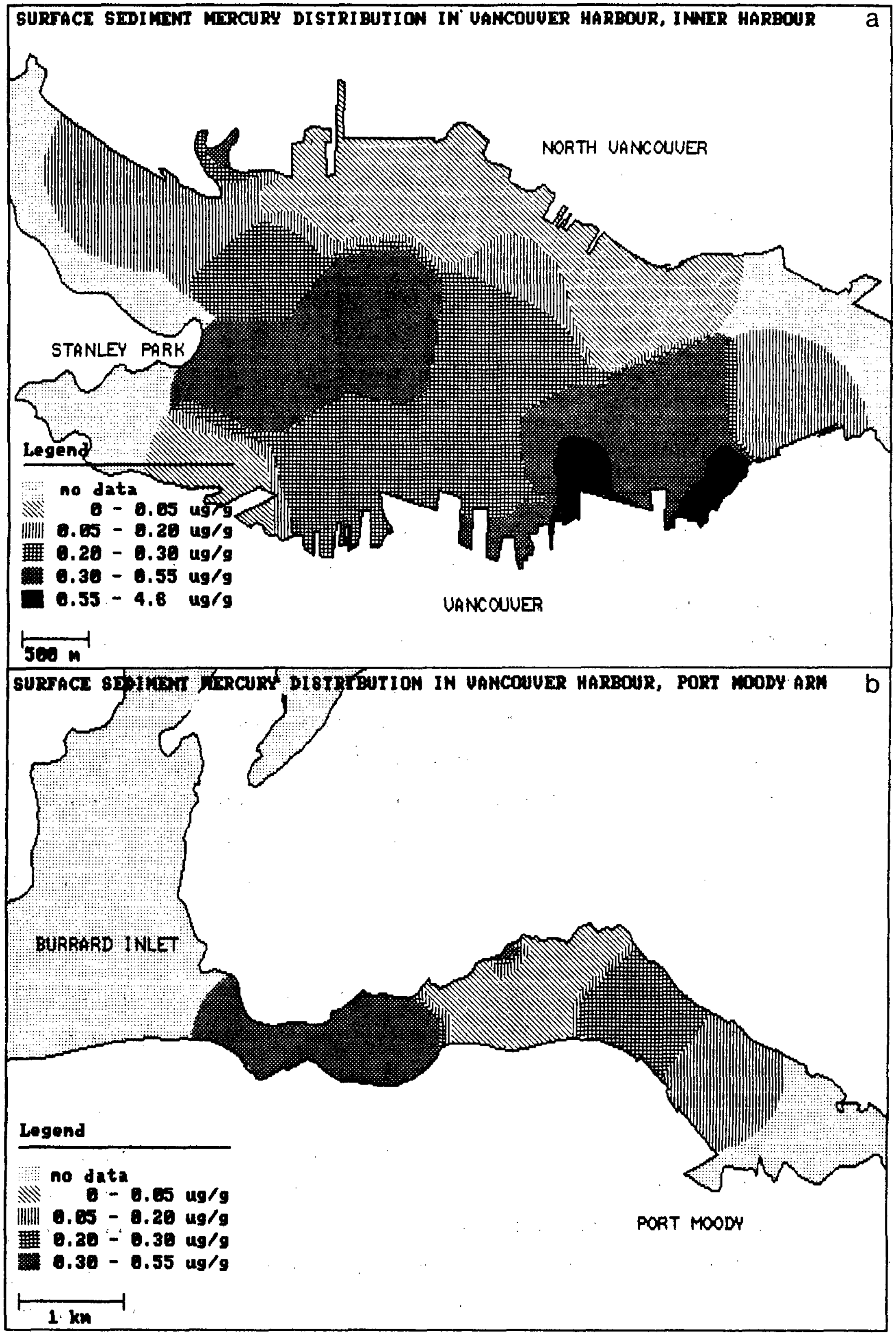


FIGURE 12 SURFACE SEDIMENT MERCURY DISTRIBUTION IN VANCOUVER HARBOUR (1985/86) A) INNER HARBOUR B) PORT MOODY ARM

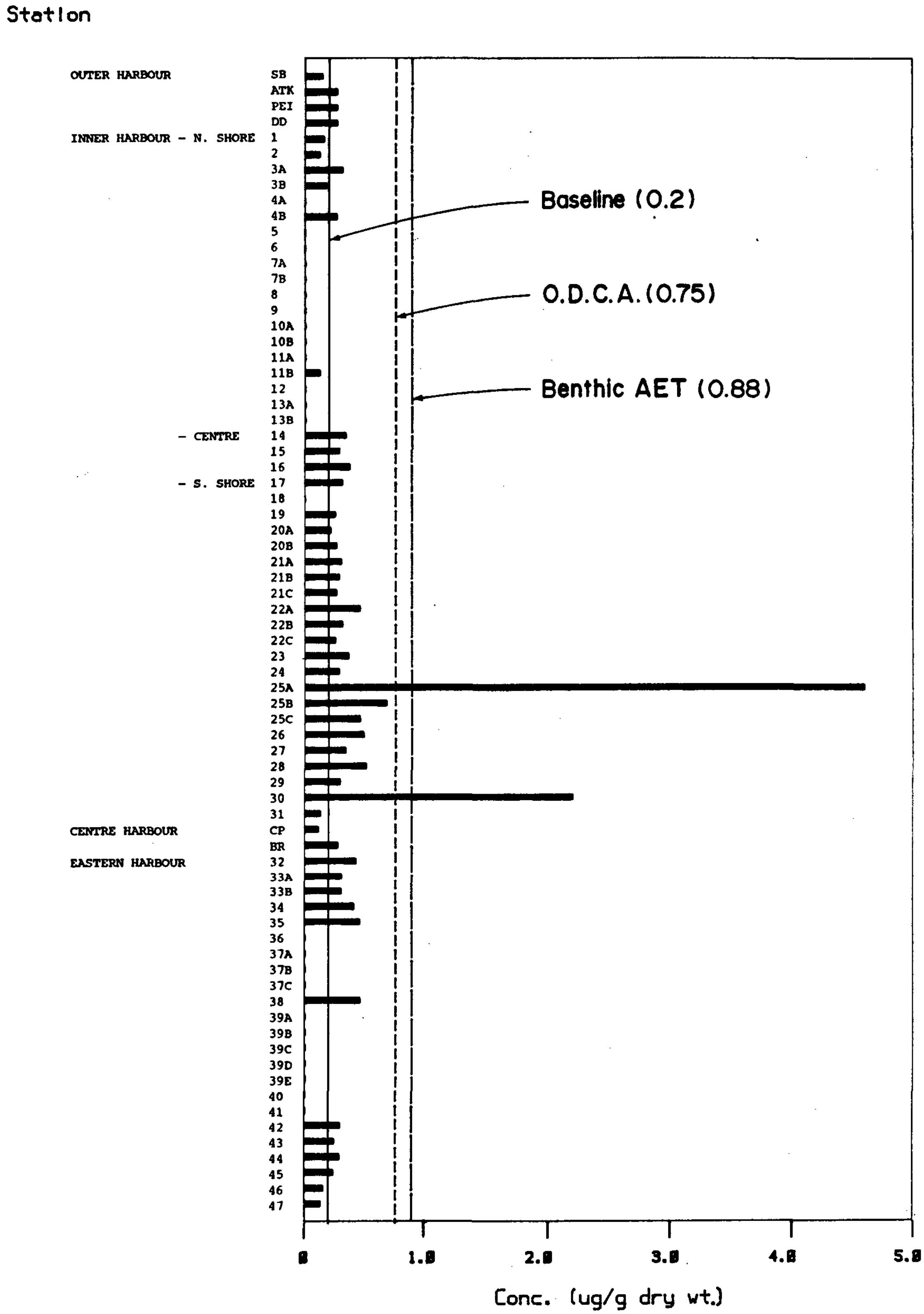


FIGURE 13 Mean Surface Sediment Mercury Concentrations in Vancouver Harbour (1985-86)

effluents were the major source of mercury. Another potential source may include shipyard and repair facilities located near Station 30.

Mercury concentration in the inner harbour in 1985/86 (34 sites) averaged 0.48 μg/g. In Port Moody Arm, concentrations averaged 0.30 ± .11 μg/g in 1985/86 (12 sites) and 0.32 ± .08 μg/g in 1987 (32 sites). Foreshore sampling along the north shore in 1984 showed mercury levels up to 0.45 μg/g adjacent to Vancouver Wharves, 1.7 μg/g near Vancouver Shipyards, and up to 6.4 μg/g near the Burrard Yarrows shipyards (Garrett, unpublished data). The present study did not find any evidence of mercury contamination extending to nearshore or offshore sites (Stations 1-4B & 11B) adjacent to areas sampled by Garrett.

Of the 48 stations sampled for sediment mercury in 1985/86, 81% were above the estimated reference level for the harbour (0.20 μg/g). Mercury is considered a restricted substance under the CEPA ocean dumping provisions and the maximum allowable limit is 0.75 μg/g in the solid phase and the Puget Sound BAET for mercury is given as 0.88 μg/g; most stations are below these levels. The combined sewer overflows along the south shore of the inner harbour are considered the major mercury contributors.

4.1.1.6 Lead. According to Garrett (1985b), the source of lead to the aquatic environment is primarily anthropogenic, either directly or by atmospheric deposition. In an urban environment, primary sources might be metal plating operations, gasoline combustion, battery disposal, paint wastes, various consumer products, and spillage from metal concentrate loading.

Elevated lead levels were found in most sediment samples in Vancouver Harbour; mean concentrations ranged from 12 - 15,420 μg/g. Computer estimated (SPANS) lead distribution in 1985/86 are shown in Figure 14. Mean concentrations per station are mapped in Appendix A (Figure 8) for 1985/86 and Appendix C (Figure 10) for 1987. By comparison, sediment lead concentrations in Puget Sound were reported up to 10,635 μg/g (Evans-Hamilton and D.R. Systems, 1987); those along the Seattle waterfront

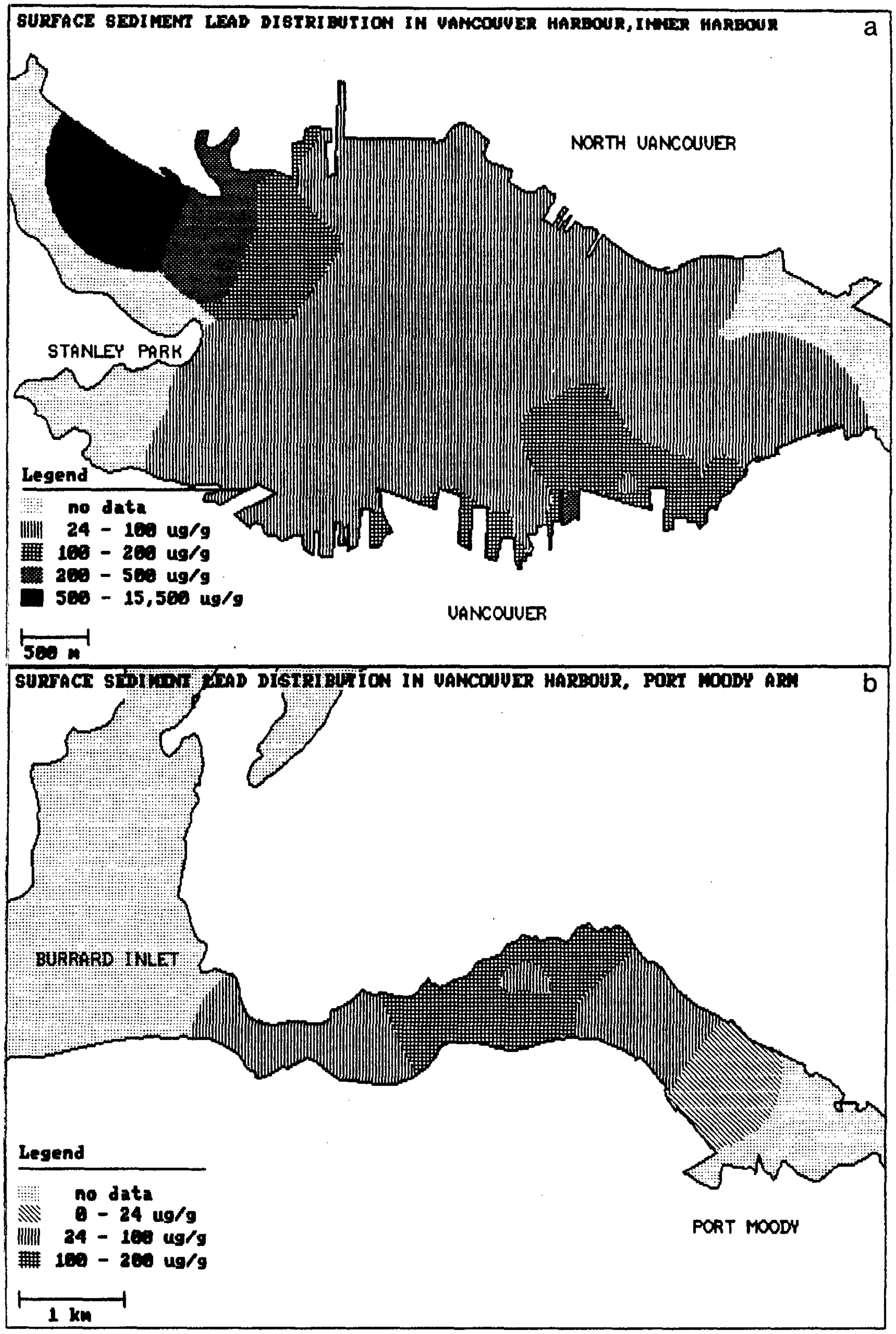


FIGURE 14 SURFACE SEDIMENT LEAD DISTRIBUTION IN VANCOUVER HARBOUR (1985/86) A) INNER HARBOUR B) PORT MOODY ARM

averaged 1700 µg/g. In the Fraser River estuary, concentrations on Sturgeon Bank were reported at 2.99 - 12.3 µg/g (Fanning et al., 1989) and <3 µg/g in sediment samples taken from Roberts Bank (Harding et al., 1988). Chapman (1986) reported lead concentrations at 6.6 - 18.5 µg/g in sediment samples taken near the outfall from the Iona sewage treatment plant.

Figure 15 illustrates the relationship of the average concentration at each sampling location in 1985/86 to an estimated natural reference level in Vancouver Harbour (<24 µg/g), and Puget Sound BAET (300 µg/g - Tetra Tech, 1986). In 1985/86, the mean concentration at the Spanish Banks was 17 µg/g. In 1988, it was 18.3 - 18.5 µg/g (Goyette, unpublished data). Mean lead concentrations in Loughborough Inlet sediment in 1987 was 22 µg/g (Appendix C). In Puget Sound, the reference level for lead has been given as 24 µg/g (Evans- Hamilton and D.R. Systems, 1987); similar natural levels are reported for Alice Arm (Goyette and Christie, 1982). Chapman et al. (1986) gave a reference level for the Fraser estuary at 7.8 µg/g.

In the outer harbour, values ranged from 17 - 67 µg/g. Mean concentration in the inner harbour in 1985/86 ranged from 39 - 15,420 µg/g (Mean 468 ± 2308 µg/g). As for copper, highest lead concentrations were found at Stations 1 and 2, off the Vancouver Wharves concentrate loading docks. In 1985/86, mean lead levels at these sites were 15,420 and 585 µg/g, respectively and in 1987, 2060 and 1023 µg/g, respectively. Between 1981 and 1983, Garrett found concentrations of 9.3 to 1670 µg/g in foreshore samples taken near Vancouver Wharves (unpublished data). During the same period, shoreline lead levels adjacent to Vancouver Shipyards were 5 - 624 µg/g and at Burrard Yarrows shipyard, 3 - 1710 µg/g. Although substantually lower than those found at Stations 1 and 2, elevated levels were also found along the south shore of the inner harbour during the present study. Concentrations adjacent to the GVRD Clark Drive/Vernon Relief combined sewer overflows were 241 and 342 µg/g, respectively at Stations 25A and 25B. Mean concentrations in the central portion of the inner harbour (Stations 14 and 15) were between 64 and 81 µg/g.

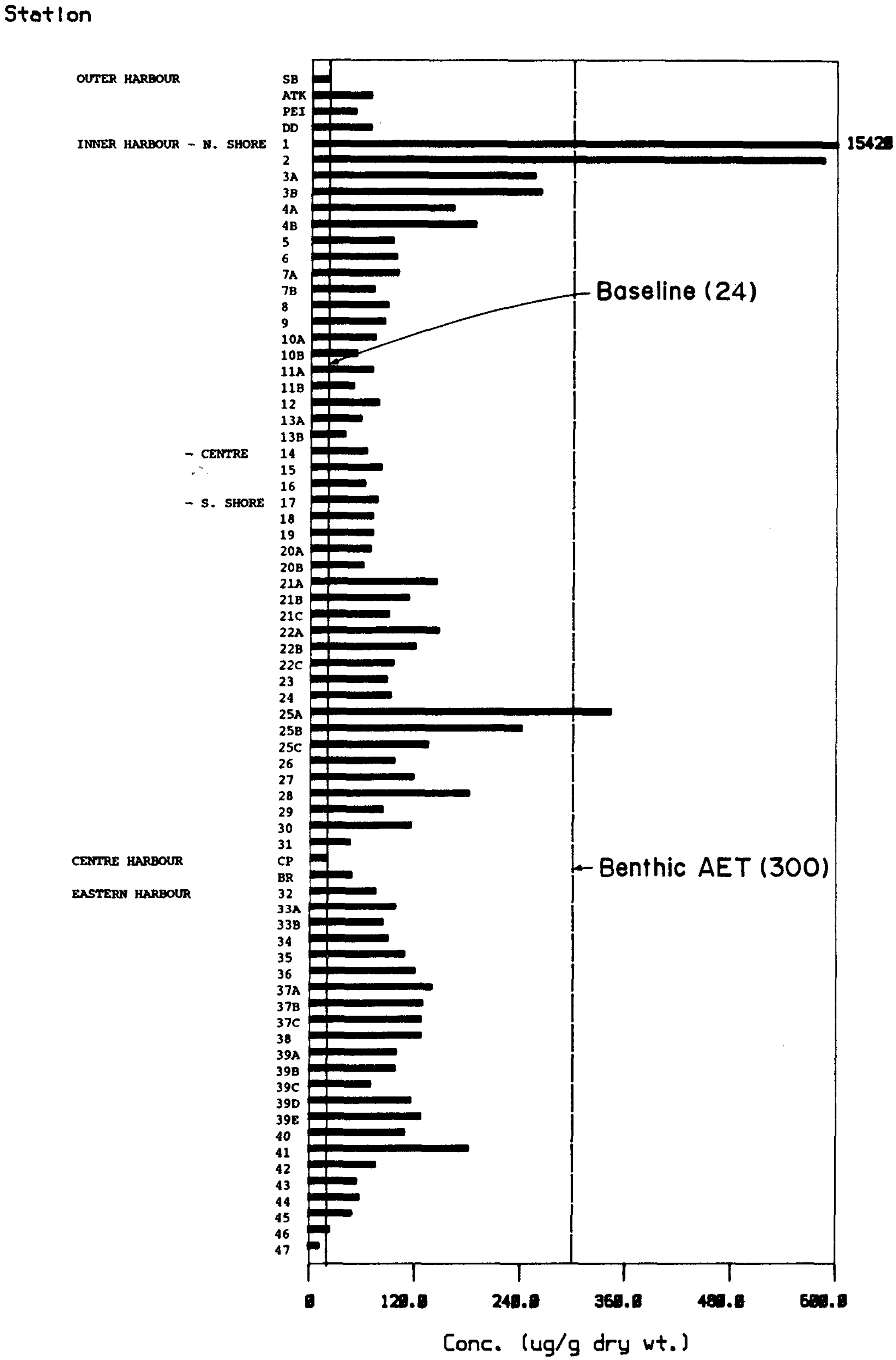


FIGURE 15 Mean Surface Sediment Lead Concentrations in Vancouver Harbour (1985-86)

Although generally lower than those found in the inner harbour, lead levels were elevated in Port Moody Arm. In 1985/86, concentrations averaged 94.4 ± 39.4 µg/g (range, 12 - 182 µg/g). In 1987, the average was 92.5 ± 43.4 µg/g (range, 19 - 298 µg/g). The distribution of surficial sediments indicated an increase towards the Ioco refinery. Maximum concentrations occurred at Station 41 (182 µg/g) in 1985/86 and Station 40 (298 µg/g) in 1987, both located near the refinery. Bourne (1974) reported lead levels in surface sediment samples from 70 stations in Port Moody Arm ranging 1.0 - 260 µg/g (mean, 70 µg/g).

In addition, elevated levels were found in core samples taken in the middle of Port Moody Arm (Station 39C) in 1988, to a core depth of 16 cm. (Goyette, unpublished data). Concentrations in the upper 42 cm of a core taken near the entrance to the arm (Station 33B) ranged between 25 - 173 µg/g, increasing sharply to 674 µg/g at the core bottom (70 cm). Historically, there had been a source of lead near the entrance to Port Moody Arm at the Allied Chemical plant, however, periodic channel dredging in the area limits investigation. At Station 40, the pattern was reversed; lead concentrations in core samples decreased from 197 µg/g to 10 µg/g between the 16 and 20 cm, down to <8 µg/g at 80 cm.

Most areas of Vancouver Harbour (96%) exceeded the natural sediment lead levels (24 µg/g) while only 8% were above the Puget Sound BAET (300 µg/g). The three critical areas of contamination were adjacent to Vancouver Wharves, the south shore of the inner harbour near the CSO, and the north shore of Port Moody Arm near the Ioco refinery.

Lead is a restricted substance under the ocean dumping provisions of CEPA, although there are no set criteria for ocean disposal of dredge spoils containing lead. By comparison, Quebec and Ontario provincial criteria for ocean disposal specify maximum lead concentrations of 20 µg/g and 50 µg/g, respectively. (Garrett, 1985d).

4.1.1.7 Zinc. Zinc has wide industrial application due to its chemical and metallurgical properties. It is used primarily in galvinizing metals, zinc-based alloys and brass (Moore and Ramamoorthy, 1984a), but also used in paints, textile dying, printing, and making rubber.

Mean sediment zinc concentrations in Vancouver Harbour in 1985/86 ranged between 88 and 2267 µg/g. Computer estimated (SPANS) zinc distribution is shown in Figure 16. Mean concentration per station are mapped in Appendix A (Figure 9) for 1985/86 and Appendix C (Figure 11) for 1987. Zinc concentrations for Puget Sound have been reported between 19 and 4700 µg/g (Evans-Hamilton and D.R. Systems, 1987). Nearshore areas in Elliot Bay, near Seattle, were reported as 32 - 4700 µg/g; outer Elliot Bay, 21 - 830 µg/g. In the Fraser River estuary, Fanning et al. (1989) reported concentrations between 51.8 - 107 µg/g on Sturgeon Bank and Harding et al. (1988), between 57.7 - 86.0 µg/g on Roberts Bank.

Figure 17 relates average concentration at each sampling location in 1985/86 to the natural reference level (<115 µg/g) and Puget Sound BAET (260 µg/g - Tetra Tech, 1986). Natural reference levels for Vancouver Harbour are estimated to be <115 µg/g. Mean concentration at Spanish Banks in 1985/86 was 108 µg/g. In 1988, zinc concentrations in the surface sediments at this site ranged from 104 - 114 µg/g (Goyette, unpublished data). Zinc concentrations in Loughborough Inlet in 1987 averaged 120 µg/g (Appendix C). Natural sediment zinc concentrations in the Puget Sound region are reported at 100 µg/g (Evans-Hamilton and D.R. Systems, 1987). Alice Arm natural background levels range from 90 to 150 µg/g (Goyette and Christie, 1982).

In the outer harbour, zinc concentrations were from 108 - 206 µg/g. In 1985/86, the inner harbour averaged 416.8 µg/g (range, 113 - 2267 µg/g). Similar to copper and lead, zinc concentrations maximized in the vicinity of Vancouver Wharves (Stations 1 and 2). Sediment concentrations at these locations were 2267 and 654 µg/g, respectively, decreasing to 520 and 518 µg/g, respectively, in 1987. In 1980/81, Garrett found levels as high as 4650 µg/g on the shoreline adjacent to the loading docks (unpublished data). Elevated levels (519 to 1372 µg/g) extended eastward along the north shore (Stations 3 - 5) diminishing to 256 - 646 µg/g at Stations 7 to 13 near

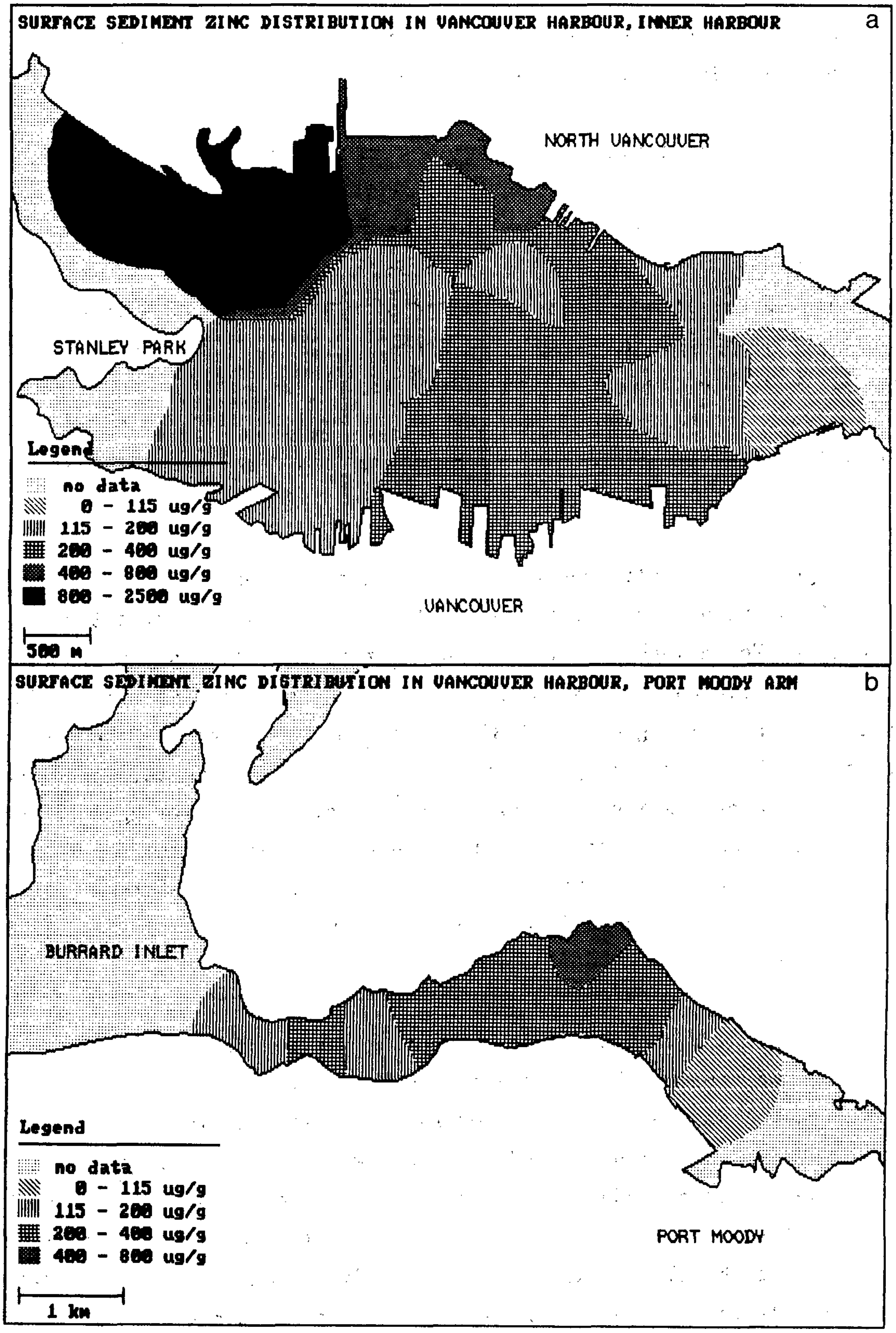


FIGURE 16 SURFACE SEDIMENT ZINC DISTRIBUTION IN VANCOUVER HARBOUR (1985/86) A) INNER HARBOUR B) PORT MOODY ARM

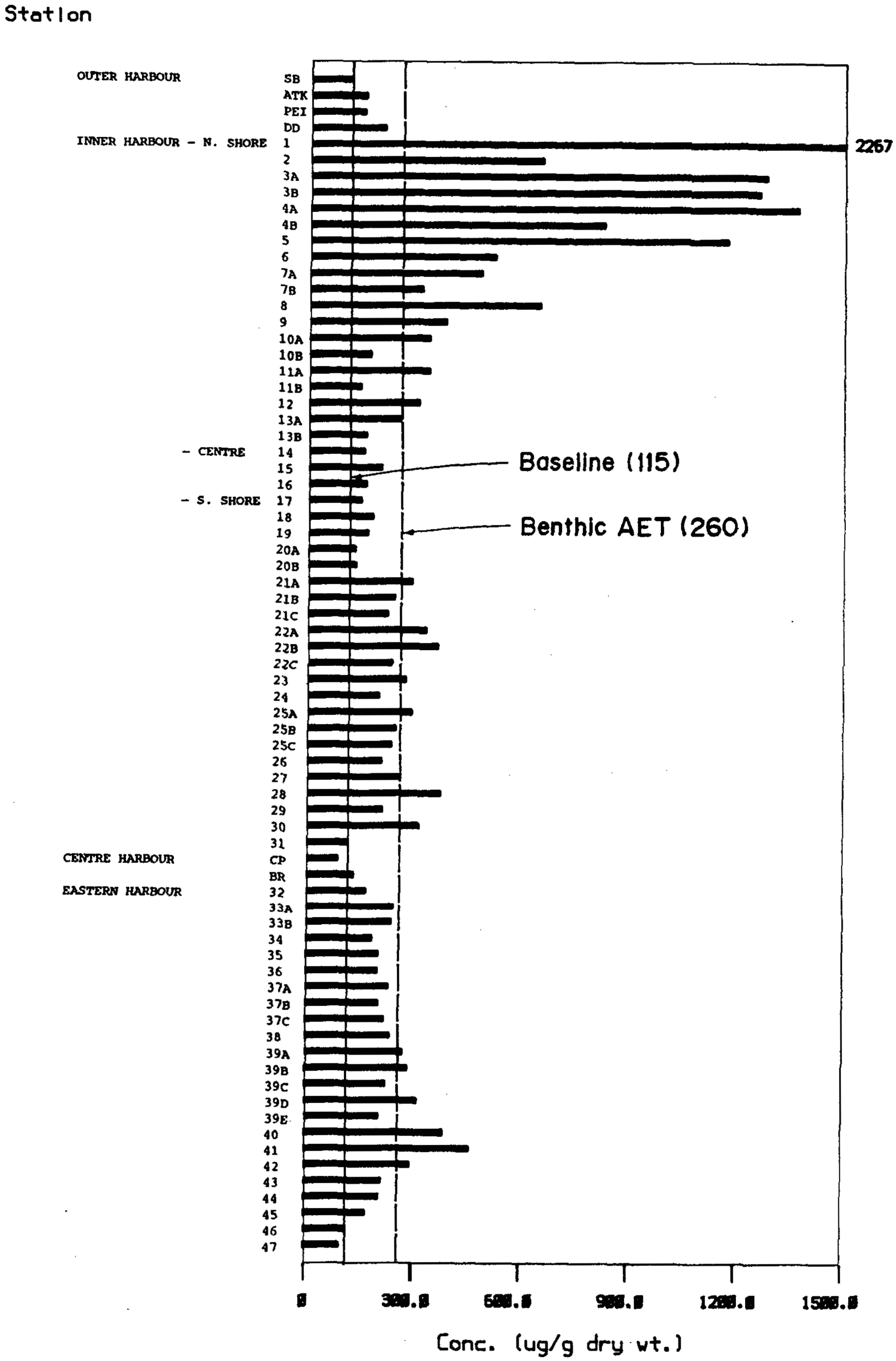


FIGURE 17 Mean Surface Sediment Zinc Concentrations in Vancouver Harbour (1985-86)

Versitile Pacific Shipyards (formerly Burrard Yarrows). In 1979, Garrett found levels between 53 and 9910 µg/g at several foreshore locations adjacent to the Burrard Yarrows site (unpublished data). In 1985/86 sources of zinc contamination were also apparent along the south shore of the inner harbour; mean concentrations ranged between 209 and 363 µg/g (16 sites) around the loading docks of the south shore between Stations 21 and 30 (Appendix A). In 1987, Stations 22A and 25A were repeated with similar results (Appendix C).

For 1985/86 and 1987, zinc levels throughout most of Port Moody Arm were slightly above the baseline level for the harbour. Mean sediment concentration in 1985/86 at 23 sites was 227.0 ± 92.2 µg/g (range, 98 - 461 µg/g); in 1987 at 32 sites, the mean was 210.1 ± 31.1 µg/g (range, 126 - 317 µg/g). Concentrations in core depths below 16 cm were <115 µg/g in 1988 (Goyette, unpublished data). Bourne (1974) reported zinc concentrations at 70 stations in Port Moody Arm ranging from 40 to 663 µg/g (mean, 152 ± 93 µg/g,).

In 1985/86, 93% of the sampling stations in Vancouver Harbour exceeded the baseline level for the harbour (115 µg/g) and 38% were above the Puget Sound BAET (260 µg/g). The stations that exceeded both were predominantly along the north shore of the inner harbour. A few bounded the south shore of the inner harbour and the Ioco refinery in Port Moody Arm. Similar to copper and lead, the major source of zinc input into the Vancouver Harbour appears to be the concentrate loading area at Vancouver Wharves due to the zinc concentrate spillage during vessel loading and unloading. The impact extends for a considerable distance along the north shore of inner harbour.

4.1.2 Surface Sediment Trace Organic Compounds

4.1.2.1 Oils and Grease and Hydrocarbons. The term "oils and grease" refers to organic compounds, such as hydrocarbons, fatty acids, soaps, fats, waxes, and oils, which are extracted by a particular solvent, Freon 113 in this case. This parameter is included since it is often used in monitoring liquid effluents. The hydrocarbon measure is a subsequent step to oils and grease qualification, differing only by the addition of silica gel to the sample. This eliminates some interferences present in the oils and grease test, such as organic dyes and sulphur compounds. However, it is a crude test, and dependent on the method of extraction, therefore, its use in identifying specific hydrocarbon sources is limited. Sulphur is present in the marine sediments off the bulk loading facilities in Port Moody Arm and on the north shore of the inner harbour.

Based on extrapolations from point data (SPANS) hydrocarbon distribution in the surface sediments of the inner harbour and Port Moody Arm (1985/86) are shown in Figure 18. Maps of mean hydrocarbon concentration for each sampling location are contained in Appendix B (Figure 3) for 1985/86 and Appendix C (Figure 12) for 1987. Refer to these appendices for oils and grease values as well.

A bar graph showing the variation in mean hydrocarbon levels per station is given in Figure 19. Existing data on the harbour is insufficient to distinguish natural from anthropogenic sediment hydrocarbons levels in the harbour. The lowest level in the harbour was 19 µg/g (Station 13A). Sediment along the north shore was slightly coarser than other regions of the harbour and may account for the lower concentration. In 1987, hydrocarbon concentrations in sediment samples from Loughborough Inlet averaged 66 µg/g) (Appendix C). Baseline levels below 70 µg/g in unpolluted sediments have been reported by Berge et al. (1987) and Law and Androlewicz (1983).

Mean concentrations in the outer harbour in 1985/86 and 1987 were between 150 and 294 µg/g. In 1985/86, levels in the inner harbour averaged 680.7 µg/g (range, 19 - 6587 µg/g). A major source of hydrocarbons to the inner harbour appears to be the combined sewer overflows located on the south shore. Maximum concentrations occurred at Station 25A, near the Clark Drive/Vernon Relief outfalls (mean, 6587 µg/g). Near the one at Victoria Drive, mean concentrations were 2310 and 1160 µg/g for Stations 29 and 30, respectively. Elevated levels (1241 - 1883 µg/g) were also observed at

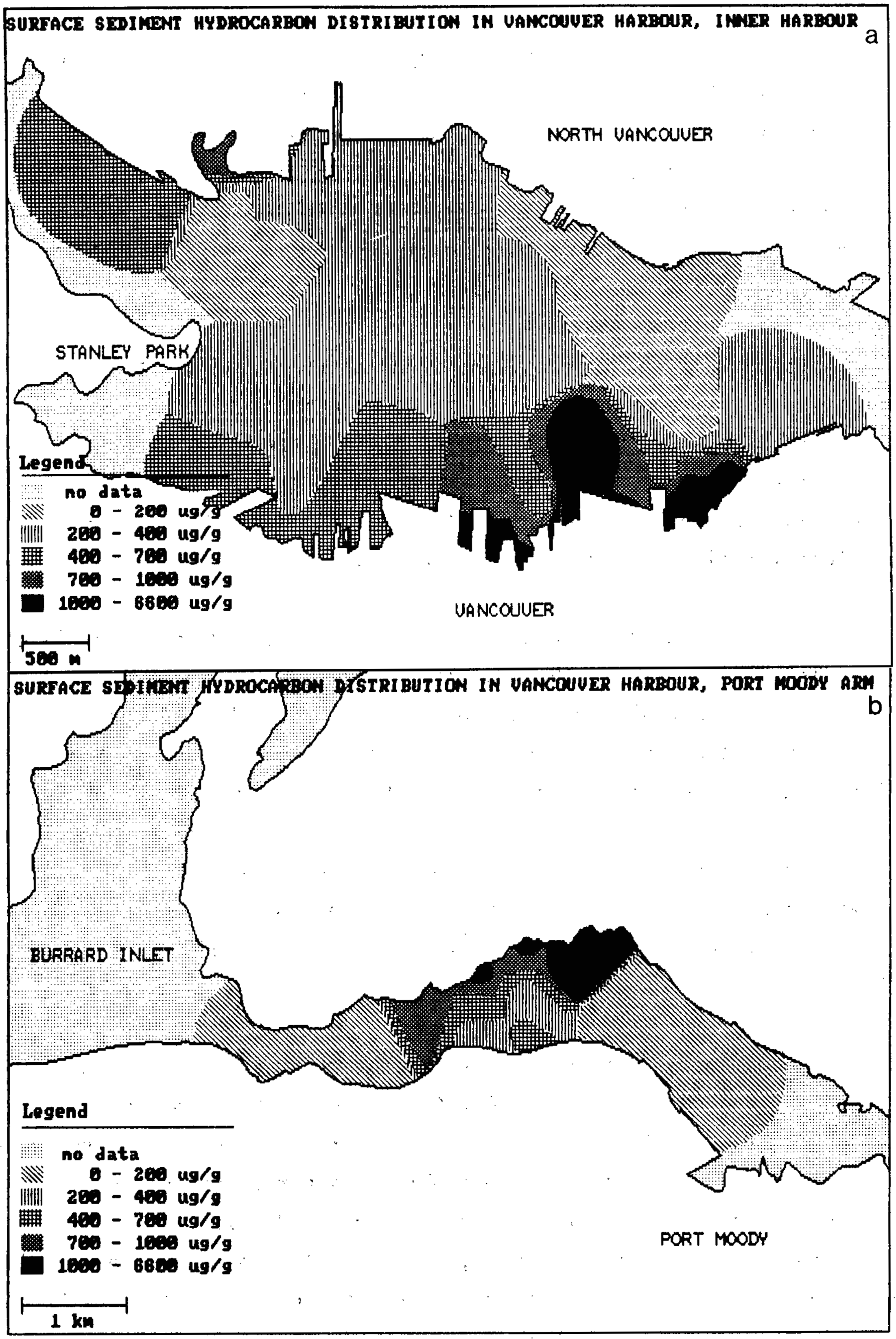


FIGURE 18 SURFACE SEDIMENT HYDROCARBON DISTRIBUTION IN VANCOUVER HARBOUR (1985/86) A) INNER HARBOUR B) PORT MOODY ARM

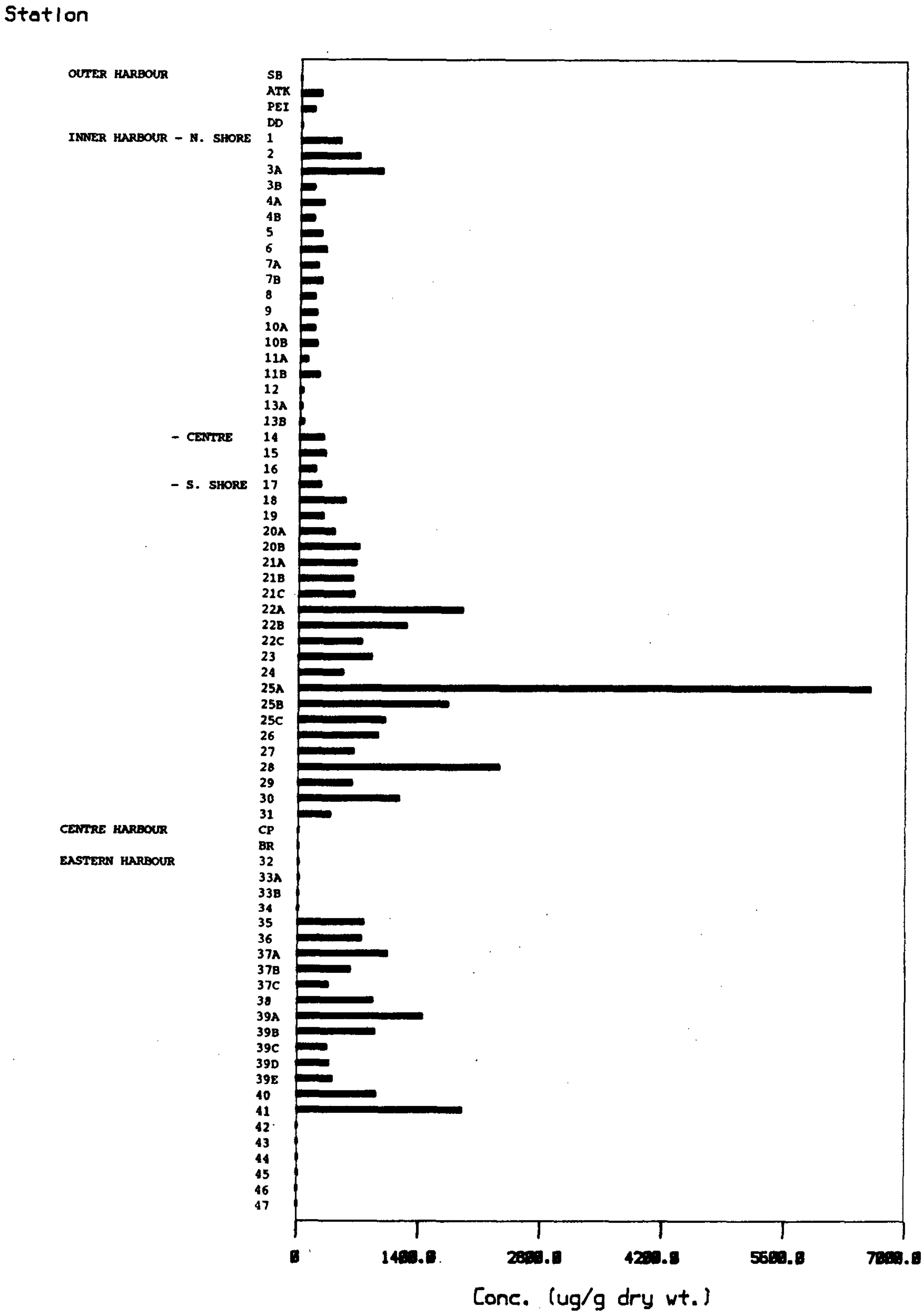


FIGURE 19 Mean Surface Sediment Hydrocarbon Concentrations in Vancouver Harbour (1985-86)

Stations 22A and 22B. In 1987, concentrations at Stations 25A and 22A decreased marginally to 4467 and 1334 μg/g, respectively. Other studies have also shown that urban stormwater runoff contributes significant hydrocarbon inputs to the receiving environment (Brown et al., 1985; Eganhouse and Kaplan, 1981; Hoffman et al., 1982).

Port Moody Arm has had a long history of petroleum refining operations dating back to 1917. Until March 1989, the Ioco refinery discharged both treated stormwater and treated process water directly into the arm. The treated process water now goes to the GVRD sewer system. Other refineries in the area discharge treated stormwater directly into Port Moody Arm. The history of petroleum refining in Port Moody Arm is reflected by the hydrocarbon concentrations throughout the arm. In 1985/86, the sediment hydrocarbon concentration averaged 813 ± 456 μg/g; the range was 729 - 1897 μg/g at 13 stations. Detailed sampling conducted in 1987 showed a broader range of 496 - 2483 μg/g (mean, 1178 ± 379 μg/g) with concentrations in the middle of Port Moody Arm consistantly above 1000 μg/g, increasing toward the Ioco refinery. Higher concentrations were also found off the Petro-Canada loading dock and Reed Point Marina. Drainage from the Petro-Canada tank farm and an abandoned landfill site represent potential sources of hydrocarbon contamination.

High hydrocarbon levels in Port Moody Arm may be partly due to the low water circulation and reduced oxygen levels in the bottom sediments. Waldichuk (1965), reported about 30% exchange on each tidal cycle. Mille et al. (1988) found rapid hydrocarbon degradation in sediment when the dissolved oxygen concentration in the overlying seawater was high and the redox potential was around +150 mV. Degradation was slower when the dissolved oxygen concentration and redox potential decreased. Under suboxic conditions (dissolved oxygen 0.2-0.3 mg/l) no degradation occurred. The black appearance of sediment from most areas of Port Moody Arm and strong odour of hydrogen sulphide indicating anoxic conditions, suggest that the hydrocarbon degradation rate would be relatively low. Degradation rates in most other parts of the harbour, would be greater because of the increased tidal flushing and resulting higher oxygen levels.

4.1.2.2 **Polycylic Aromatic Hydrocarbons**. Polycyclic aromatic hydrocarbons (PAH), are important organic contaminants in sediments from industrial and urban environments due to their toxicity and carcinogenic properties.

PAH can originate from both natural and anthropogenic sources, two prime ones being fossil fuels and incomplete combustion of organic compounds. The most significant anthropogenic source to the aquatic environment is connected with oil and industrial processes involving fossil fuels. Other urban sources include partially combusted fuels, exhaust soot, and asphalt and automobile tire wear; crude oil and petrochemical refining effluents; creosote pilings; and used motor oils. Pruell et al. (1988) found that PAH were not detected in new automotive crankcase oils but increased rapidly with usage. Carcinogenic PAH (e.g. benzo(a)pyrene) were only detected in oil used for the longest distance (about 5800 miles).

Few PAH are produced or used commercially. Napthalene is used to manufacture solvents, lubricants, and dyes (Moore and Ramamoorthy, 1984b). It is also used in moth repellant, insecticides, vermicides, and intestinal anticeptics. Acenaphthalene is used as an intermediate in dyes, plastics and pesticide synthesis. Phenanthrene is also used as an intermediate in dye manufacturing.

Earlier screening of sediment for EPA priority pollutants, at key industrial areas in Vancouver Harbour indicated that phthalate esters (catalysts used in producing plastics) and PAH were the predominant organic chemicals present. Total PAH concentrations were up to 43.2 μg/g (Garrett, unpublished data). Due to low water solubility, PAH in aquatic environments are generally associated with suspended or deposited particulate matter. According to Neff (1979), once deposited in sediments, PAH are less subject to photochemical or biological oxidation, especially if the sediment is anoxic. Hence, sedimentary PAH tend to be quite persistant and may accumulate to high concentrations. Sediments will nearly always contain concentrations of 1,000 or more than the overlying water (Neff, 1979).

The environmental significance of PAH to marine organisms is becoming increasingly apparent. Recent studies, particularly in Puget Sound (Malins et al., 1988), have shown a strong relationship between sediment associated PAH and the prevalence of preneoplastic and neoplastic liver lesions in English sole (Parophrys vetulus) and other flatfish (Malins et al., 1988; Myers et al., 1987; Mix, 1986). Impairment in ovarian development through exposure to PAH contaminated sediments has been shown in English sole from Puget Sound (Johnson et al., 1988). Payne et al. (1988) demonstrated changes in basic metabolic functions in winter flounder (Pseudopleuronectes americanus) maintained for up to four months on crude oil-contaminated sediments containing less than 1 µg/g, total PAH. The presence of PAH in sediment has therefore lead to both environmental and human health concerns.

Low molecular weight PAH (LPAH), 2-3 ring aromatics such as naphthalene, fluorene, phenanthrene, and anthracene, are generally more acutely toxic to aquatic organisms. (Neff, 1979; Moore and Ramamoorthy, 1984b). They are often associated with petroleum-derived materials (Readman et al., 1982). High molecular weight PAH (HPAH), 4-6 ring aromatics, are generally not acutely toxic but a number have proved carcinogenic (Moore and Ramamoorthy, 1984b). While sediment PAH concentration is frequently given as total PAH (TPAH), the sum of the individual compounds, the toxicological and carcinogenic effects largely depend upon the molecular weight. Toxicity using Puget Sound BAET values (Tetra Tech, 1986) is compared to relative carcinogenicity (National Academy of Science, 1972) for 20 PAH compounds in Table 5.

Mean sediment PAH concentrations in 1985/86 (24 sites) and 1987 (23 sites) are summarized by low molecular weight, high molecular weight, and total (Table 6). Sampling was concentrated in the inner harbour in 1985/86 and in Port Moody Arm in 1987. Figure 20a and 20b shows the results graphically for 1985/86 and 1987, respectively, comparing low molecular weight PAH, high molecular weight PAH and total PAH concentrations. Results are detailed in Appendix B for 1985/86 and Appendix C for 1987.

TABLE 5 COMPARISON OF PAH TOXICITY BASED ON THE BENTHIC APPARENT EFFECTS THRESHOLD (BAET) (TETRA TECH, 1986) AND RELATIVE CARCINOGENICITY (NATIONAL ACADEMY OF SCIENCE, 1972).

PAH Compounds	Puget Sound BAET (µg/g)	Relative Carcinogenicity*
Low Molecular Weight PAH (LPAH)		
naphthalene	2.1	-
acenaphthylene	.640	-
acenaphthene	.500	
fluorene	.640	-
dibenzo(a,h)fluorene	-	+/-
phenanthrene	3.20	-
anthracene	1.30	-
Total LPAH	**6.1**	
High Molecular Weight PAH (HPAH)		
fluoranthene	6.30	-
pyrene	>7.3	-
benzo(a)anthracene	4.5	+
chrysene	6.7	+/-
benzofluoranthenes	8.0	
benzo(b)fluoranthene	-	++
benzo(j)fluoranthene	-	++
benzo(k)fluoranthene	-	-
benzo(a)pyrene	6.8	+++
dibenz(a,h)pyrene	-	+++
benzo(e)pyrene	-	-
indeno(1,2,3-c,d)pyrene	>5.2	+
dibenzo(a,h)anthracene	1.2	+++
benzo(g,h,i)perylene	5.4	-
Total HPAH	**>51**	

* - not carcinogenic
+/- weakly carcinogenic or uncertain
+ carcinogenic
++, +++, strongly carcinogenic

TABLE 6 MEAN POLYCYCLIC AROMATIC HYDROCARBON (PAH) CONCENTRATIONS (µg/g DRY WEIGHT) IN VANCOUVER HARBOUR - LOW MOLECULAR WEIGHT (LPAH), HIGH MOLECULAR WEIGHT (HPAH) AND TOTAL PAH - 1985/86 AND 1987.

STATION	1985/86			1987		
	LPAH	HPAH	TOTAL PAH	LPAH	HPAH	TOTAL PAH
OUTER HARBOUR						
PEI	0.32	1.13	1.45	0.31	1.45	1.76
EB	-	-	-	0.79	3.04	3.83
INNER HARBOUR						
1	2.78	4.68	7.46	-	-	-
2	0.32	0.71	1.03	-	-	-
3A	3.42	8.82	12.24	-	-	-
3B	0.78	1.84	2.62	-	-	-
4A	1.80	5.33	7.13	-	-	-
14	0.43	1.16	1.59	-	-	-
15	0.75	1.79	2.54	0.59	1.82	2.41
16	1.34	3.58	4.92	0.83	2.70	3.53
17	1.43	4.25	5.68	-	-	-
19	1.55	5.49	7.04	1.10	3.59	4.69
21	2.21	2.01	4.22	-	-	-
22A	7.51	6.60	14.11	2.29	9.93	12.22
23	2.58	2.65	5.23	-	-	-
24	1.39	1.50	2.89	-	-	-
25A	2.57	2.40	4.97	3.39	14.03	17.42
28	1.37	3.50	4.87	-	-	-
30	3.73	5.80	9.53	-	-	-
PORT MOODY ARM						
33B	-	-	-	1.13	3.28	4.41
35	0.71	2.23	2.94	-	-	-
36A	-	-	-	1.07	2.97	4.04
36B	-	-	-	1.14	4.22	5.36
36C	-	-	-	5.64	11.55	17.19
37A	-	-	-	1.53	5.78	7.31
39A	-	-	-	1.80	6.77	8.57
39C	1.02	2.46	3.48	1.60	4.48	6.08
39D	1.31	2.55	3.86	-	-	-
39E	0.88	2.34	3.22	4.76	31.97	36.73
40	1.84	3.09	4.93	2.96	18.82	21.78
41A	1.15	3.68	4.83	1.45	6.58	8.03
41B	-	-	-	1.19	5.34	6.53
41D	-	-	-	1.50	4.05	5.55
42A	-	-	-	1.63	3.23	4.86
42B	-	-	-	1.14	3.88	5.02
42C	-	-	-	1.09	3.57	4.66
47A	-	-	-	1.06	3.40	4.46

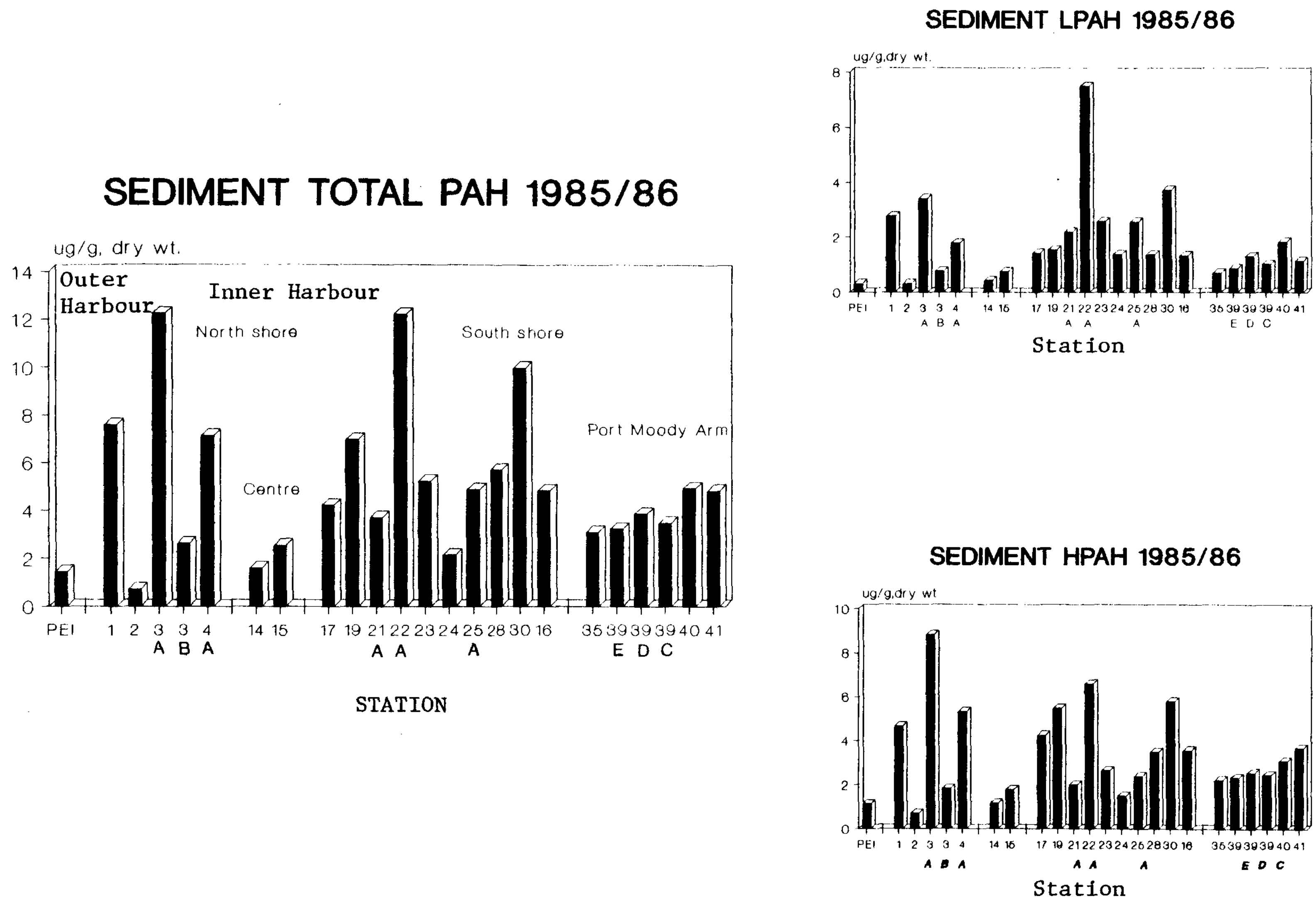


FIGURE 20A COMPARISON OF 1985/86 SEDIMENT PAH CONCENTRATIONS (UG/G DRY WEIGHT) IN VANCOUVER HARBOUR - LOW MOLECULAR WEIGHT, HIGH MOLECULAR WEIGHT AND TOTAL

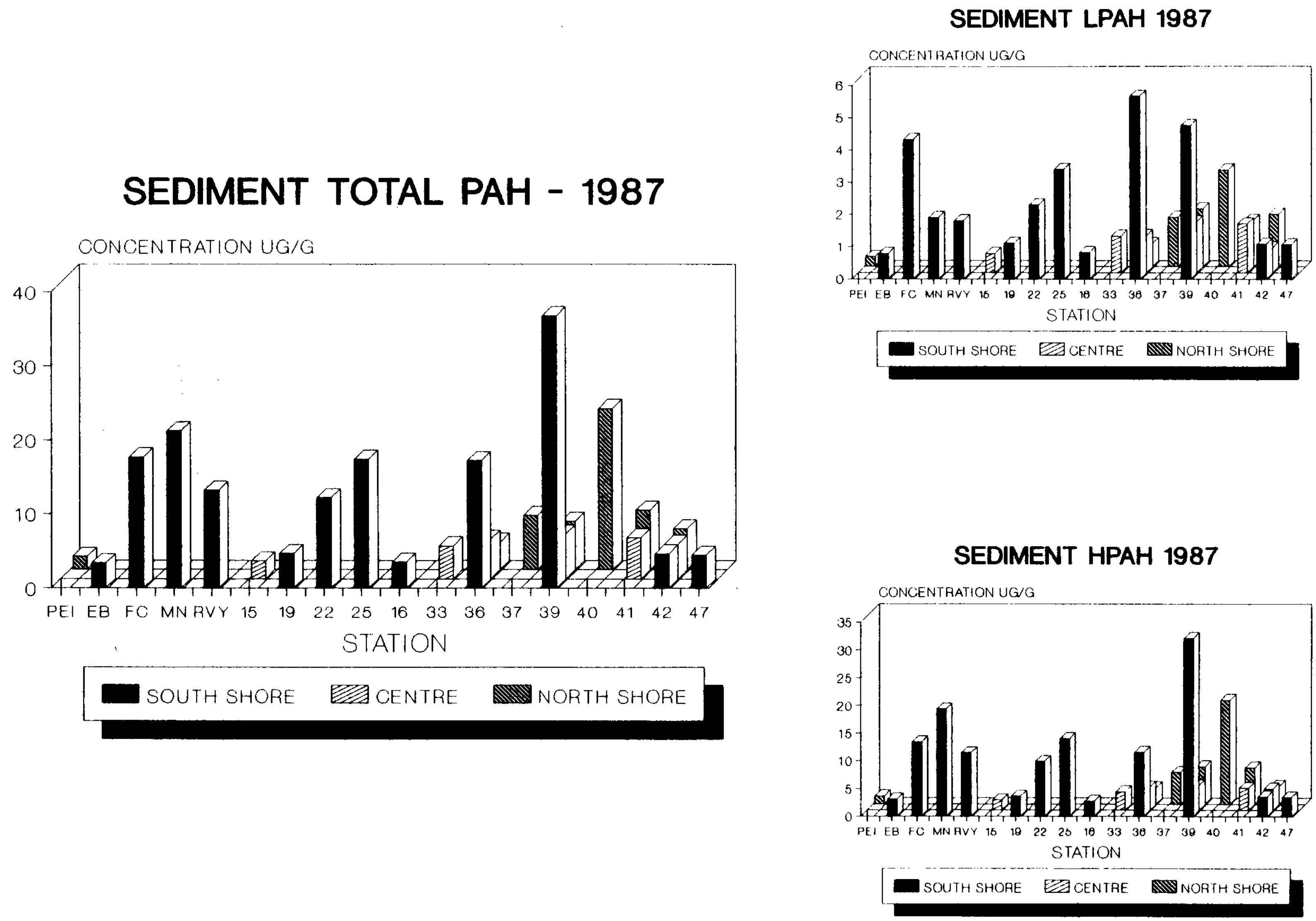


FIGURE 20B COMPARISON OF 1987 SEDIMENT PAH CONCENTRATIONS (UG/G DRY WEIGHT) IN VANCOUVER HARBOUR - LOW MOLECULAR WEIGHT, HIGH MOLECULAR WEIGHT AND TOTAL

Existing data on sediment PAH concentrations in Vancouver Harbour are insufficient to estimate a baseline level. Fanning et al. (1989), however, found that total PAH concentrations in the Fraser River estuary were all below the detection limits of 0.04 - 0.12 µg/g. Reference levels given for LPAH and HPAH in Puget Sound were 0.056 µg/g and 0.058 µg/g, respectively (Evans-Hamilton and D.R. Systems, 1987). In the outer harbour (Station PEI), total PAH concentrations, in 1985/86 and 1987 were 1.45 µg/g (LPAH = 0.32 µg/g; HPAH = 1.13 µg/g) and 1.76 µg/g (LPAH = 0.31 µg/g; HPAH = 1.45 µg/g), respectively. However, this station would still likely be under the influence of some anthropogenic sources, either locally or from within the inner harbour, or possibly both.

Total PAH concentrations for the inner harbour in 1985/86 ranged from 1.03 µg/g (Station 2) to 14.11 µg/g (Station 22A). The latter concentration was partly due to particularly high naphthalene levels not observed at other sampling locations. In 1987, maximum concentrations in the inner harbour (17.42 µg/g) occurred off the combined sewer overflows at Station 25A. Concentrations of benzo(a)pyrene, a known carcinogen (Table 5), ranged from 0.73 - 1.6 µg/g. Sediment samples from the east basin of False Creek (FC), English Bay (EB), near the entrance to False Creek and Coal Harbour (MN & RYC) were recently analyzed for PAH (Goyette, unpublished data). These results have been included in Figure 21 for comparison. In 1988, total PAH concentration in False Creek east basin was 17.2 µg/g (LPAH = 4.3 µg/g; HPAH = 12.9 µg/g). Concentrations up to 331.6 µg/g have been reported previously in the same area (Greater Vancouver Regional District, 1987). In English Bay, near the entrance to False Creek, total PAH concentration was 3.38 µg/g (LPAH = 0.70 µg/g; HPAH = 3.04 µg/g). Levels at two locations in Coal Harbour, Menchions shipyard (MN) and the Royal Vancouver Yacht Club (RVY), were 21.2 µg/g (LPAH = 1.9 µg/g: HPAH = 19.3 µg/g) and 13.2 µg/g (LPAH = 1.8 µg/g; HPAH = 11.4 µg/g), respectively.

The major PAH compounds found in surface sediments from the harbour were phenanthrene in the low molecular weight range and fluoranthene, pyrene, chrysene, benzo(k)fluoranthene, and benzo(b)fluoranthene in the high molecular weight range. Carcinogenic compounds including benzo(a)pyrene and indeno(1,2,3-cd)pyrene were also present. The HPAH, the more carcinogenic fraction, represented the largest PAH fraction in most samples (0.71 - 8.82 µg/g). Total PAH concentrations in the offshore areas of the inner harbour (Stations 14 and 15) were 1.59 and 2.54 µg/g, respectively. In Port Moody Arm (1985/86), concentrations ranged from 2.94 µg/g, near the entrance to Port Moody Arm (Station 35) to 4.93 µg/g, off the Ioco refinery (Station 40). In 1987, total PAH concentrations in Port Moody Arm ranged fom 4.04 µg/g (Station 36A) to 36.73 µg/g (Station 39E). Benzo(a)pyrene concentrations in two samples from Station 39E were 1.9 and 3.0 µg/g. In 1988, PAH were found in core samples down to the bottom core depths of 12 cm at Stations 33B (TPAH = 3.1 µg/g) and 16 cm at Station 40 (TPAH = 5.7 µg/g) (Goyette, 1988, unpublished data).

Sediment PAH concentrations reported for the Fraser River estuary are considerably lower than those found in Vancouver Harbour. Near the Iona sewage treatment plant outfall, total PAH concentrations were all below detection (<.10 µg/g), (Fanning et al. 1989). Harding et al. (1988) reported low levels (0.166 - 0.177 µg/g) in the same area. PAH concentrations in samples from Roberts Bank and Sturgeon Bank were below 0.10 µg/g (Harding et al. 1988). PAH concentrations in Sidney Harbour, Nova Scotia were reported between 0.0029 and 310 µg/g, total PAH (Kieley et al., 1988), the latter near the Sidney Steel Company Tar Ponds. In the Puget Sound area, HPAH varied over four orders of magnitude (Evans-Hamilton and D.R. Systems, 1987); maximum concentrations occurring in urban embayments. Levels near a sewer trunk outfall were reported at 8.1 - 258 µg/g; off a coal-tar processing plant in Eagle Harbour, 10.4 - 63.9 µg/g; and at nearshore areas in Elliot Bay (Seattle), 0.210 - 134 µg/g. Evans-Hamilton and D.R. Systems (1987) indicate that there were more areas of concern in Puget Sound for HPAH than any other parameter.

The chief sources of PAH input to the Vancouver Harbour appear to be the combined sewer overflows at Station 25A, the Ioco refinery and sources near the Petro-Canada loading docks and Reed Point Marina. Unidentified sources occur near Stations 22A and 3A. No sampling stations exceeded the Puget Sound BAET value (6.6 µg/g) for LPAH, nor the BAET for

HPAH (>51 µg/g) (Table 5). However, the Puget Sound BAET values are based primarily on acute toxicity and do not necessarily address chronic effects such as the pathological changes which have been linked with exposure to PAH (see Section 4.2.4.3). An interim screening limit of 2.5 µg/g, total PAH has been proposed under the Canadian Environmental Protection Act for dredge spoils intended for ocean disposal. Additional provisions state that above this level toxicological tests are required, and material containing carcinogenic compounds (i.e. HPAH) should not be be placed on critical habitats.

4.1.2.3 **Polychlorinated Biphenyls**. Polychlorinated Biphenyls (PCB) have been used extensively to produce plastics, inks, paints, pesticides, in addition to dielectric, hydraulic high temperature lubricating and heat transfer fluids. The latter represented the greatest use in British Columbia (Garrett, 1985c). Due to widespread concern over the persistance, bioaccumulation, and biomagnification, PCB production ceased and severe restrictions were imposed on their use in the mid-1970's. In 1976, surveys of sewage treatment plants in British Columbia revealed low PCB levels in all discharges (Garrett, 1985c). Like many contaminants, PCB can accumulate in the sediment and persist for many years. Harbour areas in particular can contain high PCB levels. In Baltimore Harbour, levels were between 1.0 - 2.0 µg/g at most locations: one sample was 84 µg/g (Garrett, 1985c). In Puget Sound, the maximum PCB concentration (21.6 µg/g) was found in the Duwamish Waterway (Evans-Hamilton and D.R. Systems, 1987). Nearshore areas in Elliott Bay, near Seattle, averaged 0.75 µg/g (range, 0.002 - 13.5 µg/g). Concentrations in Commencement Bay were reported as 5.2 µg/g. Reference level for PCB in Puget Sound is given as 0.020 µg/g (Evans-Hamilton and D.R. Systems, 1987).

Concentrations for Vancouver Harbour in 1985/86, ranged from <0.02 µg/g to 0.90 µg/g. Computer estimated (SPANS) PCB sediment distribution is shown in Figure 21. Mean PCB concentrations for each station are illustrated in Figure 22. Detailed results from sediment samples collected in 1985/86 and 1987 are given in Appendix B and C, respectively. By comparison, PCB concentrations in Loughborough Inlet (1987) averaged 0.04

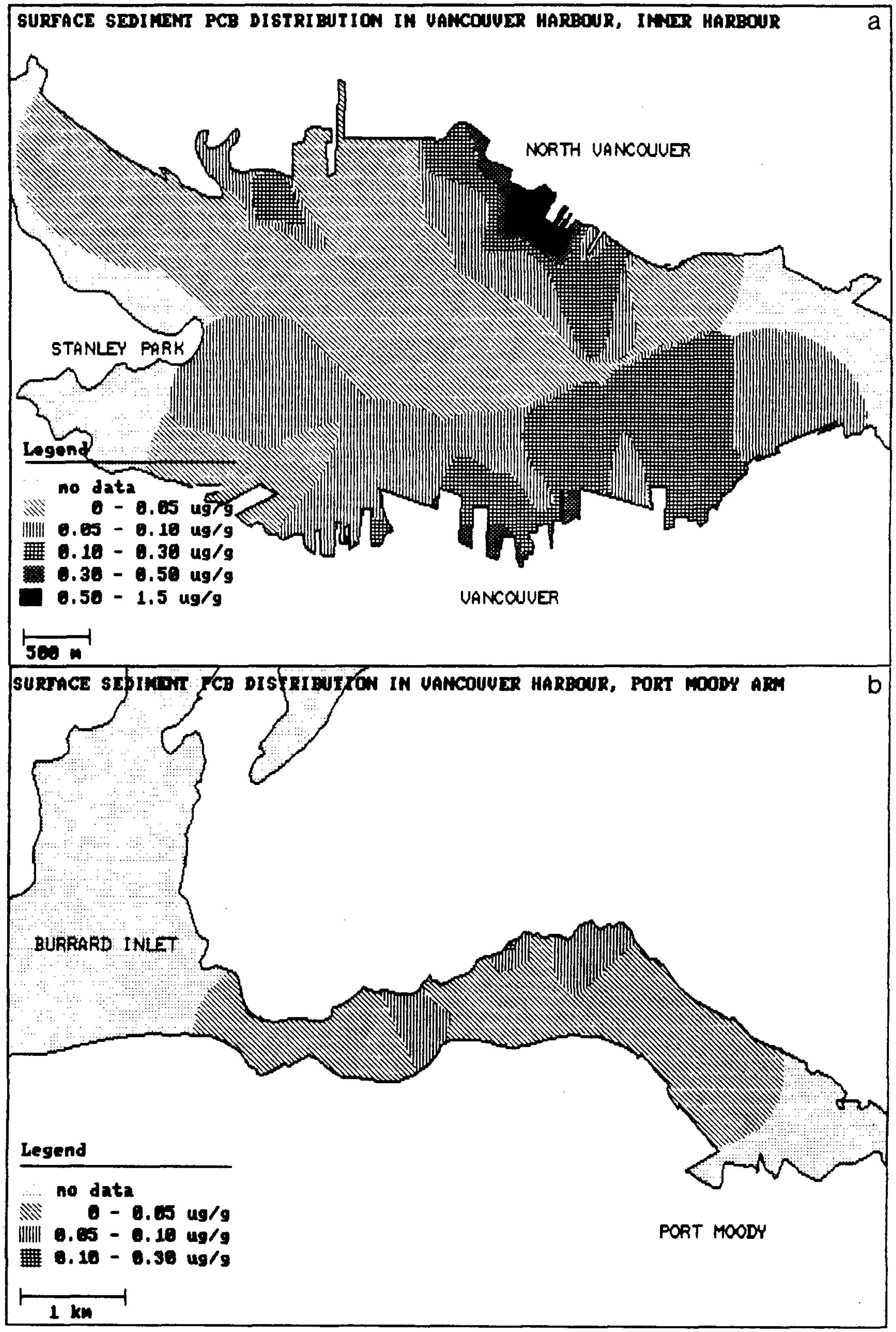


FIGURE 21 SURFACE SEDIMENT PCB DISTRIBUTION IN VANCOUVER HARBOUR (1985/86) A) INNER HARBOUR B) PORT MOODY ARM

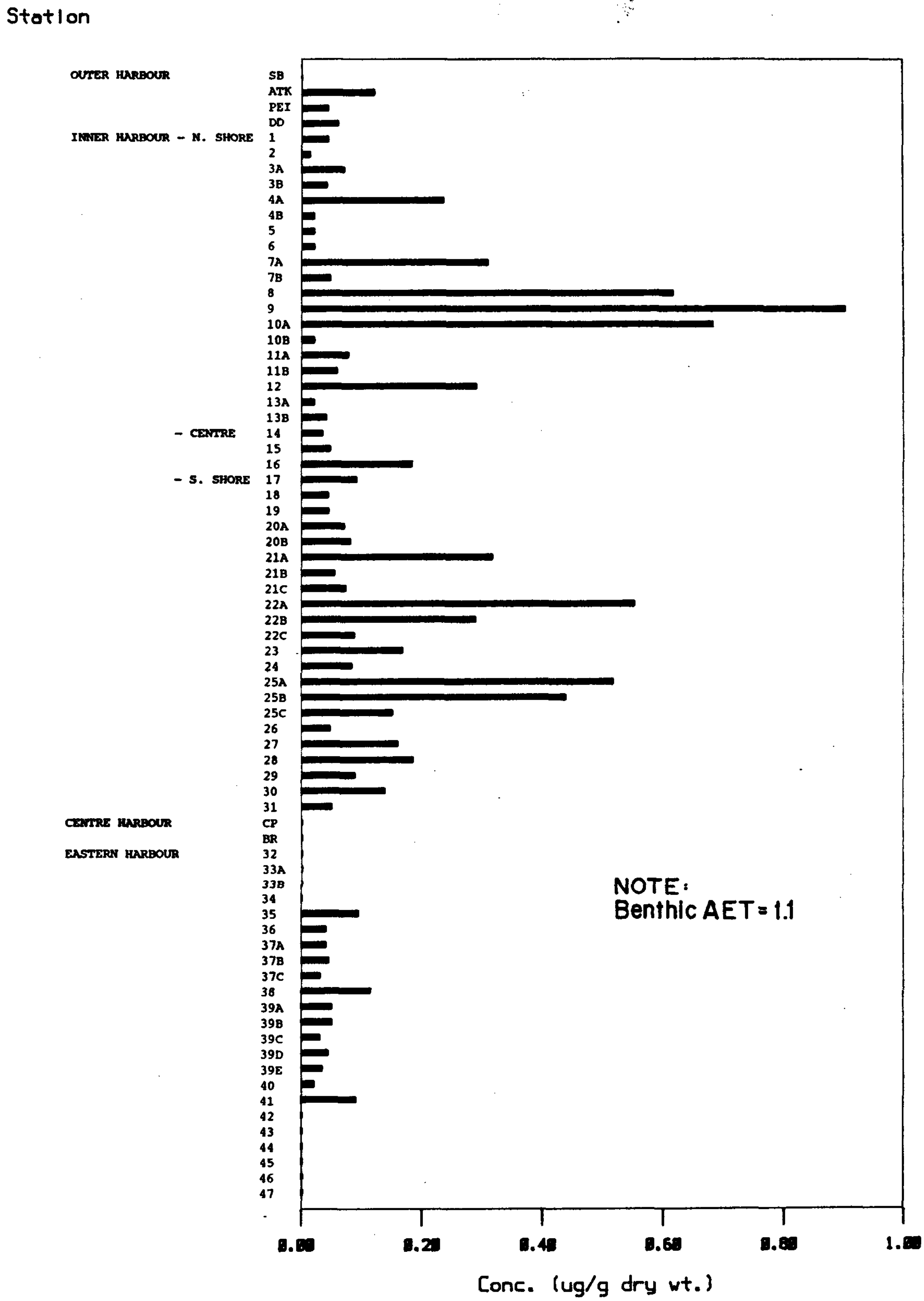


FIGURE 22 Mean Surface Sediment Polychlorinated Biphenyl (PCB) Concentrations in Vancouver Harbour (1985-86)

μg/g (range, 0.02 - 0.05 μg/g) (Appendix C). In the Fraser River estuary near Iona, PCB concentrations were <0.10 μg/g (Fanning et al. 1989). Harding et al. (1988) reported PCB concentrations at Iona, Sturgeon Bank, Fraser River Main Arm, and Roberts Bank at <0.02 μg/g.

From earlier sediment samples taken in 1981-83 Vancouver Harbour by Environmental Protection, PCB were found along the shore near shipbuilding and ship repair facilities. Garrett (1985c) reported up to 16.8 μg/g in sediment from the Coal Harbour area. In general, PCB levels found in the present study were considerably lower than foreshore samples reported by Garrett (1985). Nearshore stations along the north shore of the inner harbour (Stations 4A, 7A, 8, 9, and 10A) and the south shore (Stations 21A, 22A, 22B, 25A, 25B, 27 and 30) showed slightly higher concentrations (>0.1 μg/g) but most other areas were <0.05 μg/g. Overall mean level for the inner harbour (44 sites) was 0.17 ± 0.20 μg/g. Sediment PCB concentrations in Port Moody Arm in 1985/86 (13 sites) averaged 0.06 μg/g (range, 0.02 - 0.18 μg/g), in 1987 (32 sites) the average was 0.13 μg/g (range, 0.03 to 0.32 μg/g).

All 1985/85 and 1987 stations sampled in Vancouver Harbour were below the Puget Sound BAET (1.1 μg/g) given by Tetra Tech (1986) for PCB. The AET method, however, does not consider the bioaccumulative properties of this class of compounds, which are major environmental concerns. Under the CEPA ocean dumping provisions, PCB is a Schedule I substance and concentrations in ocean disposed materials must not exceed "0.01 parts of the concentration shown to be toxic to marine animal and plant sensitive organisms in a bioassay sample" (Garrett, 1985c). Generally, sediment containing more than 0.1 μg/g PCB are not eligible for ocean disposal. Twenty out of sixty harbour sites (primarily nearshore) in 1985/86 exceeded this limit.

4.1.2.4 <u>**Chlorophenols**</u>. Chlorinated phenols (chlorophenols) commonly originate from industries using chlorination process (Moore and Ramamoorthy, 1984b). Industries such as pulp mills and wood protection plants, and other chemical plants have relatively high residues in the effluents.

Chlorination of domestic sewage is another possible source. Chlorophenols are also used for their fungicidal and bactericidal properties. Pentachlorophenol and tetrachlorophenol are used mainly in wood protection (Garrett and Shrimpton, 1988).

Sediment chlorophenol concentrations were generally low throughout the harbour. Pentachlorophenol (PCP) levels in 1985/86 ranged from 0.001 - 0.135 μg/g; tetrachlorophenol (T_4CP) from 0.001 - 0.079 μg/g; and trichlorophenol between <.0003 and 0.0245 μg/g. In 1987, PCP concentrations, in samples taken primarily in Port Moody Arm, ranged from <0.0001 μg/g to 0.0019 μg/g. PCP levels found in samples from Loughborough Inlet in 1987 were all <0.0001 μg/g (Appendix C). The sediment PCP distribution pattern for the inner harbour and Port Moody Arm is shown in Figure 23. Detailed results are given in Appendix B for 1985/86 and in Appendix C, for 1987.

The sampling program did not specifically address areas of the harbour that would be directly affected by chlorophenol contamination. The most probable source would be stormwater releases from treated lumber storage yards. Studies in 1986 and 1987 by Environment Canada (Krahn et al. 1987) found up to 66 mg/l total chlorophenols was found in the runoff from lumber dip-treating facilities. Bioassay tests on stormwater discharges from lumber storage yards produced rainbow trout mortalities within 40 to 120 minutes. Sediments off the two main lumber storage terminals in Vancouver Harbour, located on the north shore near Second Narrows, were not sampled in the present study.

Garrett and Shrimpton (1988) have reported sediment concentrations from areas in southern British Columbia, including Vancouver Harbour. Between 1983 and 1985, PCP and T_4CP levels were low (<0.015 μg/g) at most sites. Maximum levels detected were 0.078 μg/g T_4CP and 0.216 μg/g respectively. In 1985, sediment samples taken near the Iona sewage discharge contained maximum levels of 0.01 μg/g PCP and 0.013 μg/g T_4CP. Reference samples were $\leq$0.001 μg/g for both compounds. Once heavily industrialized, False Creek contained relatively low levels of chlorophenols (0.089 ug/g PCP, 0.07 μg/g T_4CP), near a former wood treatment facility.

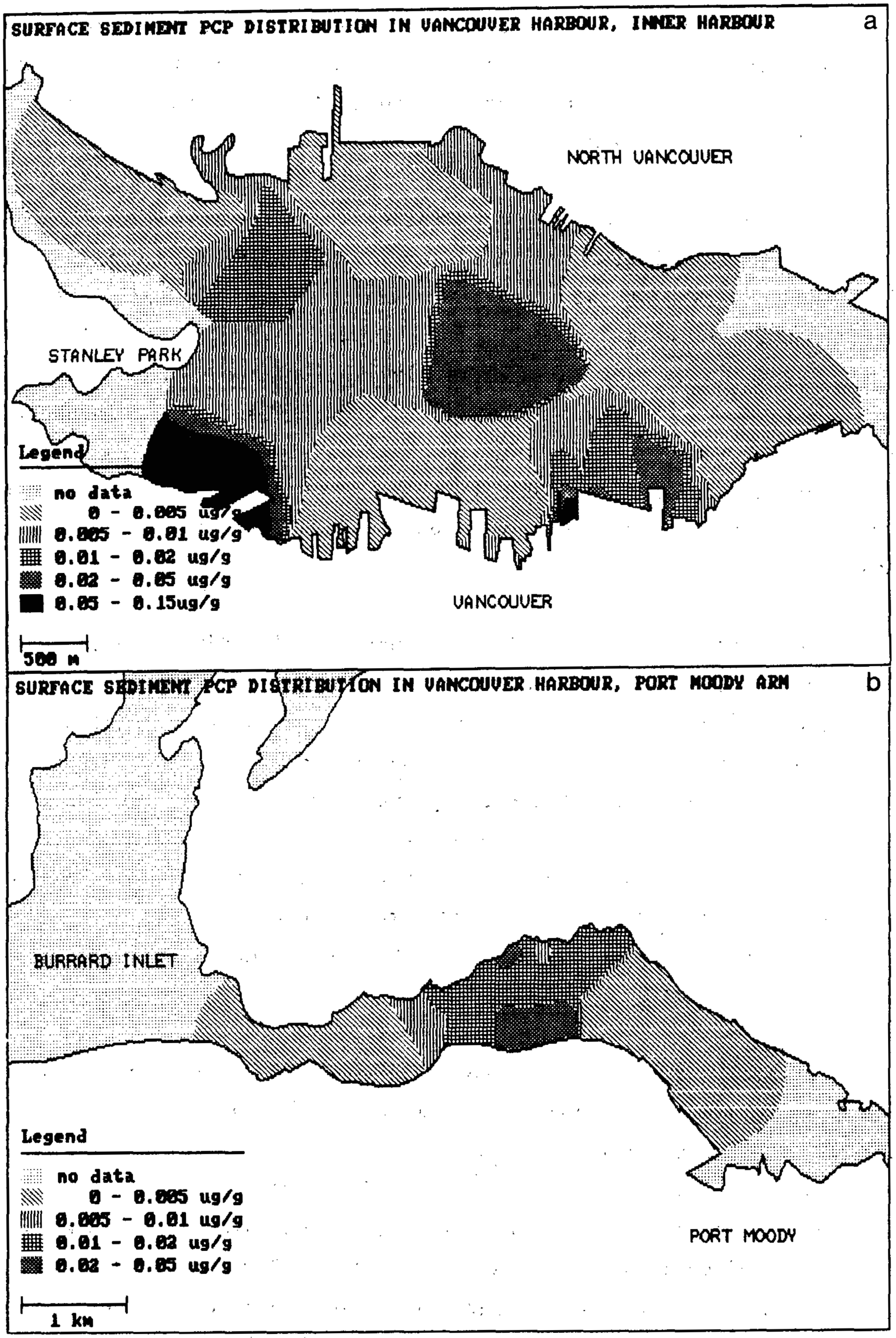


FIGURE 23 SURFACE SEDIMENT PCP DISTRIBUTION IN VANCOUVER HARBOUR (1985/86) A) INNER HARBOUR B) PORT MOODY ARM

Puget Sound BAET level for PCP is >11 µg/g (Tetra Tech, 1986), well above concentrations found in Vancouver Harbour. Chlorophenols are controlled under the ocean dumping provisions of CEPA. In the Pacific and Yukon Region, a guideline of 1.0 µg/g is used as an acceptable criteria for ocean disposal (Garrett and Shrimpton, 1988). Because of their relatively high water solubility, concern over chlorophenols is primarily with the levels in water, rather than sediment.

4.1.2.5 **Organotins**. Tributyltin is highly toxic and moderately persistant in water and sediment (Maguire et al., 1985). It is usually found in areas of heavy boating and shipping traffic, consistant with its use as an antifouling agent. From 1982 and 1985, water and sediment samples were collected for organotin analysis from 265 locations across Canada which included 36 sites in Vancouver Harbour (Maguire et al., 1985). Twelve had high tributyltin concentrations which exceeded other sampling sites across Canada (1.50 µg/g - 10.78 µg/g). These sites were primarily near shipyard facilities in the inner harbour. The other sites ranged from 0.02 - 0.57 µg/g.

4.1.3 Surface Sediment Characteristics

Surface sediment characteristics were determined by visual observations, particle size distribution, and residue content (volatile and fixed residue). Particle size distribution measured the sediment texture (Table 7); residue analysis estimated organic carbon content (Figure 24). Fine grained sediments, rich in organic matter, generally have higher contaminant levels because of increased surface area and adsorptive characteristics. Detailed results are provided in Appendix D.

Sediment in the outer harbour was predominantly fine light brown silt, indicative of that from the Fraser River. Surface sediment at the Dundarave Station consisted of fine mud. The texture became coarser (sand and gravel) toward the First Narrows, making sediment grabs difficult to obtain. Along on the north shore of the inner harbour (Stations 1 to 3B) bottom sediments consisted largely of fine, black mud. Samples at Stations

TABLE 7 SEDIMENT PARTICLE SIZE DISTRIBUTION IN VANCOUVER HARBOUR (1985 - 1986)

Station	Median Particle Size	silt and clay (%)	very fine sand (%)	fine sand (%)	medium sand (%)	coarse sand (%)	very coarse sand (%)	granules (%)
SB	silt and clay	61	11	11	11	4	2	0
PEI-M85	silt and clay	51	9	12	13	8	6	1
-085	silt and clay	71	11	15	3	0	0	0
-J86	silt and clay	57	8	10	16	9	0	0
-M86	silt and clay	76	5	6	9	4	trace	0
-S86	silt and clay	84	3	3	2	2	2	4
DD	coarse sand	16	4	12	15	13	9	31
1	fine sand	15	11	37	25	5	2	5
2	medium sand	8	6	30	31	13	6	6
3A	medium sand	24	8	10	11	7	8	32
4A	fine sand	13	15	51	13	5	2	1
5	silt and clay	50	14	7	7	8	6	8
6	very fine sand	38	23	15	9	8	4	3
7A	very fine sand	36	21	13	14	11	5	trace
7B	very fine sand	34	20	11	10	9	9	7
8	very fine sand	31	31	18	10	7	3	trace
9	very fine sand	37	23	15	9	7	4	5
10A	fine sand	20	22	22	16	13	6	1
10B	fine sand	29	20	25	12	9	4	1
11A	fine sand	18	26	29	9	5	3	10
11B-M85	fine sand	5	13	70	7	2	2	1
-085	fine sand	3	8	69	17	1	1	1
-J86	fine sand	18	24	39	11	4	1	3
-M86	very fine sand	28	24	35	6	3	2	2
-S86	fine sand	18	20	49	7	2	2	2
12	fine sand	22	15	30	20	7	3	3
13A	medium sand	8	7	31	29	12	7	6
13B	fine sand	7	8	61	20	2	2	2
14	fine sand	26	23	22	10	5	3	11
15-J86	fine sand	28	21	14	14	14	2	7
-M86	very fine sand	38	32	19	6	3	1	1

TABLE 7 SEDIMENT PARTICLE SIZE DISTRIBUTION IN VANCOUVER HARBOUR (1985 - 1986)

Station	Median Particle Size	silt and clay (%)	very fine sand (%)	fine sand (%)	medium sand (%)	coarse sand (%)	very coarse sand (%)	granules (%)
16-M85	fine sand	5	13	70	7	2	2	1
-085	very fine sand	31	32	25	9	1	trace	2
-M86	very fine sand	36	31	21	6	4	1	1
-S86	very fine sand	26	32	29	7	4	1	1
17	very fine sand	43	30	15	6	2	1	3
18	fine sand	25	18	25	20	10	1	1
19-M85	silt and clay	61	13	9	8	6	2	1
-085	very fine sand	33	27	21	14	3	1	1
-J86	very fine sand	28	24	21	16	7	1	3
-M86	very fine sand	47	28	11	8	4	1	1
20A	silt and clay	84	5	3	4	3	1	trace
20B	very fine sand	42	22	18	8	6	2	2
21A	medium sand	15	7	19	22	8	6	23
21B	medium sand	16	11	31	31	7	2	2
21C	fine sand	25	12	20	26	10	4	3
22A	silt and clay	55	21	13	6	4	1	trace
22B	very fine sand	39	21	19	11	5	2	3
22C	very fine sand	40	16	13	11	9	8	3
23	fine sand	29	20	27	13	6	2	3
24	coarse sand	13	7	10	13	10	10	37
25A	fine sand	20	16	30	16	9	6	3
25B	fine sand	16	28	29	13	8	3	3
25C	medium sand	21	13	15	9	8	8	26
26	very fine sand	29	30	21	10	6	3	1
27	medium sand	26	11	12	17	15	9	10
28	medium sand	18	16	15	16	11	4	20
29	fine sand	25	24	19	14	7	4	7
30	very fine sand	29	32	21	7	4	2	5
31	fine sand	9	13	32	11	5	7	23
CP	fine sand	2	7	45	13	15	14	4
BR	very fine sand	38	34	15	7	5	1	trace

TABLE 7 SEDIMENT PARTICLE SIZE DISTRIBUTION IN VANCOUVER HARBOUR (1985 - 1986)

Station	Median Particle Size	silt and clay (%)	very fine sand (%)	fine sand (%)	medium sand (%)	coarse sand (%)	very coarse sand (%)	granules (%)
32	fine sand	40	8	8	14	15	14	1
33A	fine sand	31	11	12	13	16	12	5
33B	very fine sand	41	11	10	13	13	9	3
34	medium sand	34	6	8	15	18	18	1
35 -M85	medium sand	31	6	10	13	15	20	5
-085	very fine sand	49	8	10	12	9	6	6
-J86	medium sand	30	9	11	21	21	6	2
-M86	fine sand	40	6	8	13	14	13	6
36	medium sand	37	4	6	10	10	14	19
37A	fine sand	42	5	5	7	10	15	16
37B	medium sand	33	6	7	12	15	20	7
37C	medium sand	31	8	10	14	15	15	7
38 -J86	medium sand	27	7	11	19	22	13	1
-M86	fine sand	43	5	8	12	14	12	6
39A	coarse sand	20	5	6	9	12	19	29
39B	coarse sand	30	5	6	9	12	20	18
39C	coarse sand	25	5	7	12	16	22	13
39D	fine sand	42	5	7	7	14	14	7
39E	coarse sand	25	6	7	12	15	20	15
40	coarse sand	26	4	7	11	15	19	18
41	very coarse sand	19	4	6	11	9	14	37
43	very coarse sand	26	5	6	12	18	24	9
44	coarse sand	25	4	8	12	17	25	9
45	medium sand	37	5	7	11	13	18	9
46	medium sand	30	6	10	12	14	23	5
47	fine sand	37	7	10	10	9	15	12

silt and clay = <0.063 mm
very fine sand = 0.063-0.125 mm
fine sand = 0.125-0.25 mm
medium sand = 0.25-0.50 mm
coarse sand = 0.50-1.00 mm
very coarse sand = 1.00-2.00 mm
granules = >2.00 mm

SB = Spanish Banks
DD = Dundarave
CP = Cates Park
BR = Boulder Rock

M85 = MAY 1985
085 = OCTOBER 1985
J86 = JANUARY 1986
M86 = MAY 1986
S86 = SEPTEMBER 1986

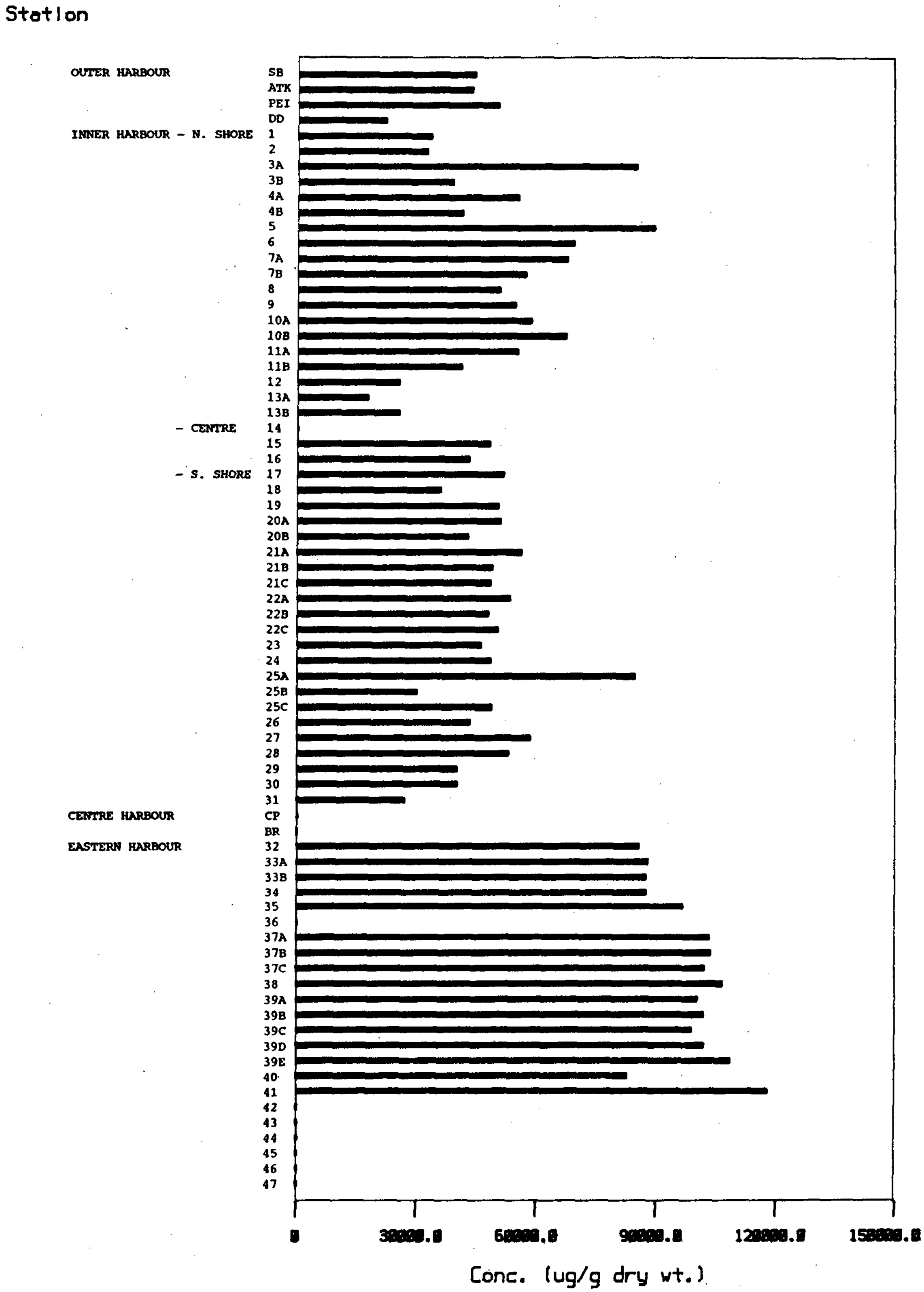


FIGURE 24 Mean Surface Sediment Volatile Residue (SVR) in Vancouver Harbour (1985-86)

3A and 3B were also fine in texture, with a strong odour of H_2S and lumps of blackened sulphur. Near stations 1 and 2, the bottom sediments were largely of sand, gravel and small rocks. This is likely due to scouring by strong tidal currents through First Narrows. Wood chips dominated samples from Station 4A and 4B, located off the Fibreco chip loading facilities. Stations 10 to 13 along the north shore consisted of fine to coarse sand, wood and shell debris, again likely due to the tidal action.

Along the south shore, sediment consisted of silt and clay at the entrance to Coal Harbour (Station 17 - 20) and fine sand along deepsea docks further east (Stations 21 - 30). Slightly coarser material was usually present near the outer ends of the docks (i.e. Stations 21C, 22C, and 25C), probably caused by scour from the propeller wash. Station 25A, near the Clark Drive/Vernon Relief combined sewer overflows, consisted of raw sewage. A thick white layer of bacteria covered the surface of the sample. Bacteria counts (MPN/100g >2.5 million) by Environmental Protection in June 1986 confirmed the composition (Appendix D). Tidal flow in this region is severely restricted by the docks allowing the accumulation of sludge deposits. Sunken logs and concrete debris were often caught in the otter trawl when fishing along the south shore. In the centre on the harbour, the trawl was frequently full of wood debris indicative of past dumping. East of Second Narrows, the bottom was largely sand, gravel and rocks. Absence of fine sediment would likely preclude significant accumulations of chemical contaminants in this area.

Sediments in Port Moody Arm were generally very fine. Sites along the north shore and areas near the Ioco townsite had black sediment smelling of H_2S. Along Pacific Coast Terminals the surface sediment appeared lighter in colour and lacked the H_2S odour. This region serves as a turning basin for deepsea vessels and is dredged periodically.

Mean surface sediment volatile residues throughout Vancouver Harbour are compared in Figure 24. Concentrations in 1985/86 ranged from 17,533 (Station 13B) to 118,000 μg/g (Station 41). Most stations in Port Moody Arm exceeded 100,000 μg/g. Refer to Appendix D for details.

4.1.4 Bacteria Content

Sediment total coliform, fecal coliform, and fecal streptococci counts are given in Table 8 for 13 sites (N=28) along the south shore of the inner harbour. Station 21A is located near a GVRD combined sewer overflow; Station 25A, near the GVRD Clarke Drive/Vernon Relief combined sewer overflows; Station 28, off the GVRD Victoria Drive combined sewer overflow; and Station 30 near a City of Vancouver stormwater discharge. The highest bacteria count (>2.4 million MPN/100g) occurred at Station 25A. Total coliform content from the other locations ranged between 17,000 and 285,000, MPN/100g (Table 8). Natural bacteria counts in sediment would be expected to be around 20 MPN/100g or less (Kay, pers. com.).

TABLE 8 SEDIMENT BACTERIA CONTENT AT SELECTED STATIONS IN VANCOUVER HARBOUR - JUNE 1986 (MPN/100 g).

Station	Total coliform	Fecal coliform	Fecal streptococci
20A	17 000	2 800	53 000
20B	17 000	2 000	15 000
21A	56 000	22 000	62 500
21C	88 000	13 000	104 500
22A	110 000	22 000	109 500
22C	67 000	15 950	74 500
24	28 000	3 300	144 500
25A	>2 400 000	>2 400 000	>2 400 000
25C	51 000	12 000	35 000
26	190 000	15 450	51 500
27	285 000	2 800	105 000
28	195 000	13 150	185 000
30	100 000	28 000	89 500

Water movement along the south shore is severely restricted by the numerous loading docks. High bacteria counts, high levels of elevated hydrocarbons and trace metals, and the accumulation of sewage sludge off the Clark Drive/Vernon Relief overflows, suggest that much of the material from these combined overflows remains in the immediate area. The highest concentrations of mercury, hydrocarbons and PAH were also found at Station 25A.

4.2 Biota

4.2.1 Species Abundance

During tissue collections each trawl catch was enumerated by species to determine their relative abundance and distribution. These data help to compare the significance of the biota tissue chemical results. Results obtained from 6 surveys between 1985 and 1986, indicate that the harbour continues to support a diverse vertebrate and macroinvertebrate epibenthic community despite the level of contaminants found in the bottom sediments. Flounder, sole, Dungeness crab (Cancer magister), and pandalid shrimp were the commercial and recreational species which dominated the catches. Vancouver Harbour catches were much higher relative to other coastal inlets sampled with the same otter trawl. English sole (Parophrys vetulus), the most common flatfish, represented up to 88% of the total flatfish catch in some locations. Many were in the small (mean, 22 cm) to medium (mean, 27 cm) size class, suggesting that Vancouver Harbour is used as a rearing area. The most common pandalid shrimp were pink shrimp (Pandalis borealis) and sidestripe shrimp (Pandalopsis dispar), to a lesser extent, the humpback (Pandalis hypsinotus) and coonstripe (Pandalis danae) shrimps. The highest catches of shrimp occurred along the West Vancouver shore (Station PEI) and entrance to Coal Harbour. Crab catches were generally higher in the inner harbour and Port Moody Arm. Detailed results on the numbers and species caught at each trawl location are given by Goyette and Thomas (1987).

4.2.2 Trace Metals in Tissue

Numerous benthic invertebrate and demersal fish species were collected for trace metal analysis of muscle, liver/hepatopancreas, and gill tissue. Detailed results are given in Appendix E. Although initially (May 1985) a variety of species were sampled, efforts concentrated on Dungeness crab, 4 species of pandalid shrimp (P. borealis, P. danae, P. hypsinotus and Pandalopsis dispar), and English sole, in subsequent surveys. Table 9 summarizes the range of tissue trace metal concentrations for these species (1985/86). Figures 2 - 4 in Appendix E show the mean concentrations at each site.

Table 9. Summary Table Showing The Ranges in Mean Tissue Trace Metal Concentration (µg/g dry weight), Dungeness crab, Pandalid shrimp and English sole - Vancouver Harbour, 1985 - 1986

Species	Trace Metal Concentration (µg/g, dry wt.)													
	As		Cd		Cr		Cu		Hg		Pb		Zn	
	Max.	Min.	Max.	Min	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
Dungeness Crab														
Muscle	5	64	0.04	0.46	0.4	2.1	29	75.9	0.11	1.28	0.1	2.7	122	233
Hepatopancreas	11	51	0.08	4.0	0.5	4	8.7	888	0.02	1.06	0.26	2.96	60	175
Gill	0.4	2.2	0.4	2.18	0.8	17.7	106	371	0.06	0.38	0.23	75.0	73.3	427.7
Pandalid Shrimp														
Muscle	14	50	0.04	0.73	0.4	1.6	11.5	30.4	0.06	0.54	0.09	1.43	43.9	61.4
Hepatopancreas	13	67	2.2	31.2	0.4	3.0	274	1350	0.06	0.27	0.20	2.15	60.7	132.5
English sole														
Muscle	19	123	0.04	0.51	0.5	2.1	0.4	4.6	0.19	0.50	0.08	1.59	5.1	39.8
Liver	8	64	0.10	5.1	0.5	1.3	6.1	64.1	0.09	0.41	0.7	6.5	82.3	169.5
Gill	4	9	0.04	2.1	1.1	3.3	2.8	24.6	0.05	0.42	0.09	6.0	46.5	108

Generally, there was no evidence of metal uptake in the species examined during the study, despite the elevated metal levels in the surrounding sediments. Metal concentrations in English sole and shrimp muscle were similar to those reported from unpolluted and coastal areas in B.C. (Harding and Goyette, 1989). Detailed statistical analysis, which is beyond the present scope of the study, is required to determine if subtle trends masked by the natural variability in the data are present. Tissue trace metal levels in a few selected offshore species represents only one aspect associated with trace metal contamination in Vancouver Harbour. Sediment toxicity arising from the accumulation of one or more of the trace metals, synergistic effects between metals, and uptake in other species, particularly intertidal species, requires further examination. Sediment from areas in Vancouver Harbour contaminated with trace metals has been shown by earlier studies to be toxic to amphipods (Section 4.3) and concentrations in a number of areas in the harbour exceeded the Puget Sound Benthic AET values.

4.2.3 PAH Concentrations in Tissue

Results of the PAH in Dungeness crab (muscle and hepatopancreas) and English sole (muscle and liver) collected from Vancouver Harbour in January and September 1986 are detailed in Appendix F. The January data are considered questionable because agreement between blind split replicates was poor. The September samples were analyzed by another lab and agreement between blind duplicates was good. PAH concentrations in English sole muscle and liver from September were all below detection (0.01 µg/g). This is expected since most fish are capable of metabolizing PAH into compounds that are undetectable when analyzing for the parent PAH compounds. For crab samples, PAH concentrations were generally below detection, however, trace amounts of anthracene/phenanthrene (up to 0.17 µg/g) were found in hepatopancreas samples from Coal Harbour. Trace levels were also observed in crab hepatopancreas from PEI and Port Moody Arm (Ioco), as well as crab muscle tissue from Ioco.

In 1988, frozen 1986 Dungeness crab tissue from the harbour and samples collected by Department of Fisheries and Oceans in 1988 from False Creek and upper Indian Arm, were analyzed for PAH content. Results are summarized in Table 10. The general detection limit was 0.02 µg/g except for indeno(1,2,3-c,d)pyrene, dibenzo(a,h)anthracene and benzo(g,h,i)perylene which was 0.06 µg/g. Some reported values were below the general detection limits. However, when at least two ions were present for confirmation, but concentrations registered less than the set method detection limit (0.02 µg/g), semi-quantitative PAH levels were estimated (Enviro-Test Laboratories, 1989). Tissue PAH concentrations appeared to correspond to the level of background PAH contamination in the receiving environment. Measurable values were found in both muscle and hepatopancreas from False Creek, Ioco and Coal Harbour. Historically, False Creek has had total PAH levels up to 332 µg/g in the marine sediments taken from the east basin (Greater Vancouver Regional District, 1987). Crab samples in this area showed the highest concentrations in both muscle and hepatopancreas, as well as having the most LPAH and HPAH compounds present (including benzo(a)pyrene) (Table 10). Total PAH in muscle tissue ranged from 0.025 - 0.169 µg/g; hepatopancreas, from 0.148 - 1.24 µg/g. In the Ioco samples, PAH were present, predominantly as LPAH. Levels in the hepatopancreas were higher than muscle tissue with total PAH concentrations ranging up to 0.996 µg/g. Muscle samples were between 0.01 - 0.02 µg/g. The Ioco samples were collected from an area where sediment total PAH concentrations were 4.87 - 21.8 µg/g in 1987. PAH averaged 7.5 µg/g throughout Port Moody Arm (Section 4.1.2.2.).

Exposure to crabs to PAH in the Coal Harbour area should be less than that of False Creek and Port Moody Arm. Sediment total PAH concentrations in the area of capture (Stations 17 and 19) were 5.7 - 7.0 µg/g. There was no evidence of PAH in crab from either Station PEI in the outer harbour or Indian Arm. At PEI, sediment total PAH levels in 1985/86 and 1987 were 1.45 and 1.76 ug/g, respectively. In Indian Arm PAH levels would be expected to be very low.

TABLE 10. RANGE OF PAH CONCENTRATIONS ($\mu g/g$, dry weight) IN DUNGENESS CRAB TISSUE SAMPLED FROM VANCOUVER HARBOUR (1986 and 1988)

SAMPLE LOCATION:	PEI	COAL HARBOUR		IOCO		FALSE CREEK		UPPER INDIAN ARM	
	Hepato (N=2)	Hepato (N=3)	Muscle (N=3)	Hepato (N=4)	Muscle (N=6)	Hepato (N=3)	Muscle (N=3)	Hepato (N=3)	Muscle (N=3)
LOW MOLECULAR WEIGHT POLYCYCLIC AROMATIC HYDROCARBONS (LPAH)									
Napthalene	ND	ND - 0.021	ND	ND - 0.080	ND	0.021 - 0.076	0.01 - 0.069	ND	ND
Acenapthylene	ND	ND	ND	ND - 0.01	0.006 - 0.01	0.01 - 0.024	ND - 0.01	ND	ND
Acenaphthene	ND	0.020 - 0.46	ND - 0.028	ND - 0.18	0.005 - 0.01	0.039 - 0.27	0.005 - 0.01	ND	ND
Fluorene	ND	ND - 0.067	ND - 0.01	ND - 0.17	ND	0.01 - 0.06	0.005 - 0.01	ND	ND
Phenanthrene	ND	ND - 0.015	ND	ND - 0.27	ND	0.01 - 0.15	0.005 - 0.015	ND	ND
Anthracene	ND	ND	ND	ND - 0.076	ND	0.005 - 0.061	ND - 0.005	ND	ND
TOTAL LPAH:	ND	ND - 0.563	ND - 0.038	ND - 0.786	0.011 - 0.02	0.095 - 0.641	0.025 - 0.119	ND	ND
HIGH MOLECULAR WEIGHT POLYCYCLIC AROMATIC HYDROCARBONS (HPAH)									
Fluoranthene	ND	ND	ND	ND - 0.11	ND	0.01 - 0.19	ND - 0.01	ND	ND
Pyrene	ND	ND	ND	ND - 0.10	ND	0.01 - 0.14	ND - 0.01	ND	ND
Benzo(a)anthracene	ND	ND	ND	ND	ND	0.01 - 0.059	ND - 0.01	ND	ND
Chrysene	ND	ND	ND	ND	ND	0.023 - 0.14	ND - 0.01	ND	ND
Benzo(b)fluoranthene + Benzo(k)fluoranthene	ND	ND	ND	ND	ND	ND - 0.052	ND - 0.005	ND	ND
Benzo(a)pyrene	ND	ND	ND	ND	ND	ND - 0.021	ND - 0.005	ND	ND
Indeno(1,2,3-c,d)pyrene	ND	ND	ND	ND	ND	ND	ND	ND	ND
Dibenzo(a,h)anthracene	ND	ND	ND	ND	ND	ND	ND	ND	ND
Benzo(g,h,i)perylene	ND	ND	ND	ND	ND	ND	ND	ND	ND
TOTAL HPAH:	ND	ND	ND	ND - 0.21	ND	0.053 - 0.602	ND - 0.05	ND	ND
TOTAL PAH:	ND	ND - 0.903	ND - 0.038	ND - 0.996	0.011 - 0.02	0.148 - 1.24	0.025 - 0.169	ND	ND

ND = <0.02 $\mu g/g$ except for Indeno(1,2,3-c,d)Pyrene, Dibenzo(a,h)Anthracene, Benzo(g,h,i)Perylene which is <0.06 $\mu g/g$

As briefly discussed in Section 4.1.2.2, a number of the HPAH compounds are potentially carcinogenic (National Academy of Sciences, 1972). The International Agency for Research in Cancer (IARC) (1987) has classified carcinogenic agents into 4 Groups as follows:

Group 1 - significant evidence of carcinogenicity in humans to define the agent as carcinogenic to humans.

Group 2A - limited evidence of human carcinogenicity and sufficient evidence of carcinogenicity in animals, suggest that the agent is probably a human carcinogen.

Group 2B - based on inadequate evidence of carcinogenicity in humans and sufficient evidence of carcinogenicity in animals, the agent is defined as a possible human carcinogen.

Group 3 - insufficient human and limited animal data does not justify the classification of the agent as a possible human carcinogen but the evidence suggesting the lack of carcinogenicity is missing.

Group 4 - there is evidence, both human and animal, suggesting that the agent is probably not carcinogenic to humans.

Of the PAH compounds measured, benzo(a)anthracene and benzo(b)pyrene fall under Group 2A; benzo(b)fluoranthene, benzo(k)fluoranthene and indeno(1, 2, 3-c,d)pyrene, under Group 2B. Group 3 compounds consist of anthracene, benzo(g,h,i)pyrene, chrysene, phenanthrene and pyrene.

In terms of human risk assessment, no distinctions are made between Groups 1, 2A, and 2B. Experimental evidence does not allow quantitative risk assessment of several Group 3 substances. Taking the most recent data set (Table 10), only the samples from False Creek contained Group 2A and 2B PAH compounds. Results suggest that relatively high sediment PAH concentrations are required to cause a measurable increase in crab tissues PAH concentration. However, considering the limited sample size, more intensive sampling in the harbour is required. This should include crab and other important species (e.g. bivalves) to determine the significance of tissue PAH concentrations from both a biological and human health standpoint. According to Uthe (1979), allowable levels of total PAH in the edible portions, if set, would likely be about 0.1 µg/g, (or 0.001 µg/g, benzo(a)pyrene), the highest PAH levels naturally observed in foodstuffs. These values were exceeded in some crab tissue samples from 1988, in particular the hepatopancreas in crabs from False Creek, Port Moody (IOCO) and Coal Harbour.

4.2.4 Flatfish Tissue Abnormalities

4.2.4.1 External Abnormalities. Evidence of fin erosion and skin papillomas has been found in various fish species including flatfishes. Skin papillomas are thought to be caused by a protozoan (amoeba) infection but the higher percentages found around urban centres suggest a possible link to environmental conditions. Although found in remote, nonurban areas (Nigrelli et al., 1965; Wellings et al., 1976; Stich et al., 1977), they appear to be more prevalent around urban centres (Stich et al., 1976). Stitch et al. (1977) reported frequencies ranging from 7.0 - 58.6% at various urban centres along the Pacific Coast, including the Vancouver area. The upper limit was observed in flatfish from the Fraser River estuary. Nonurban areas were less than 1%. More recent studies in the Fraser estuary have reported skin papillomas up to 92% in Rex sole (Fanning et al., 1989).

During the Vancouver Harbour surveys, all flatfish caught were examined visually for external lesions (approximately 10,000 fish). Some individuals had external parasites, abnormal red colouration and skin papillomas. The number of fish affected by skin papillomas, however, was low (<5%) (Goyette et al., 1988), predominantly English and rex soles. The latter species was found mainly in the outer harbour (Station PEI).

4.2.4.2 Liver Lesions. In the present study, the number of English sole (Parophrys vetulus) affected by idiopathic (non-parasitic, non-infectious) liver lesions was significant. Prevalence of the lesions was strongly dependent on the area of capture. Idiopathic lesions have been linked primarily with exposure to anthropogenic chemical in the sediments, in particular, the polycyclic aromatic hydrocarbons (PAH) (Malins et al, 1988). Since liver lesions were shown to be more prevalent in fish from polluted urban areas compared with nonurban areas, they have been used as indicators for the end point effect of xenobiotic chemicals. Much of this data has come from the Puget Sound area (Malins et al. 1984, 1985, 1988; McCain et al. 1988; Myers et al. 1987). Malins et al. (1985) concluded that environments which induce liver lesions (or neoplasia) in fish are likely responsible for a number of other changes at the organism and ecosystem level, many of which have yet to be recognized.

Three types of idiopathic liver lesions are important because of their morphological similarities to lesions found in laboratory mammals and fishes following exposure to toxic chemicals. They include preneoplastic lesions (foci of cellular alteration - clear cell, basophilic and eosinophilic foci); neoplastic lesions (liver cell adenoma, hepatocellular carcinoma); and a degenerative condition (megalocytic hepatosis) (Myers et al., 1987). Preneoplastic lesions, particularly the basophilic and eosinophilic foci, are generally considered precursors to tumor development. The presence of preneoplastic and neoplastic lesions in fish from nonurban or undisturbed coastal areas is very low or non existent.

In September 1986, English sole samples were collected at various stations in Vancouver Harbour and examined histologically for idiopathic lesions. Detailed results with descriptions of the lesion types observed have been reported by Goyette et al. (1988). The study was repeated in 1987 including Loughborough Inlet as a reference site. Additional histochemical analysis (PAS for glycoproteins and mucopolysaccharides; Prussian Blue for ferric iron) was also included for verification of the histological observations.

Detailed results of the 1987 study are included in Appendix G. The percentage of English sole affected by neoplastic and preneoplastic liver lesions for the two studies are summarized in Table 11 and illustrated in Figure 25. The three types of idiopathic liver lesions are compared by station in Table 12 and illustrated in Figure 26.

In 1986, the prevalences of preneoplastic and neoplastic lesions in English sole ranged from 8.3 to 58.8% (Brand, 1987; Goyette et al., 1988). The highest occurred in Port Moody Arm where sediment hydrocarbon, PAH, and certain trace metals levels were relatively high. In the outer harbour (Station PEI), 13.3% of the fish were affected by both types of lesions. Along the south (Coal Harbour) and north shores (Burrard Yarrows) of the inner harbour, percents were 10 and 30%, respectively. The lowest prevalence (8.3%) occurred in the centre of the inner harbour.

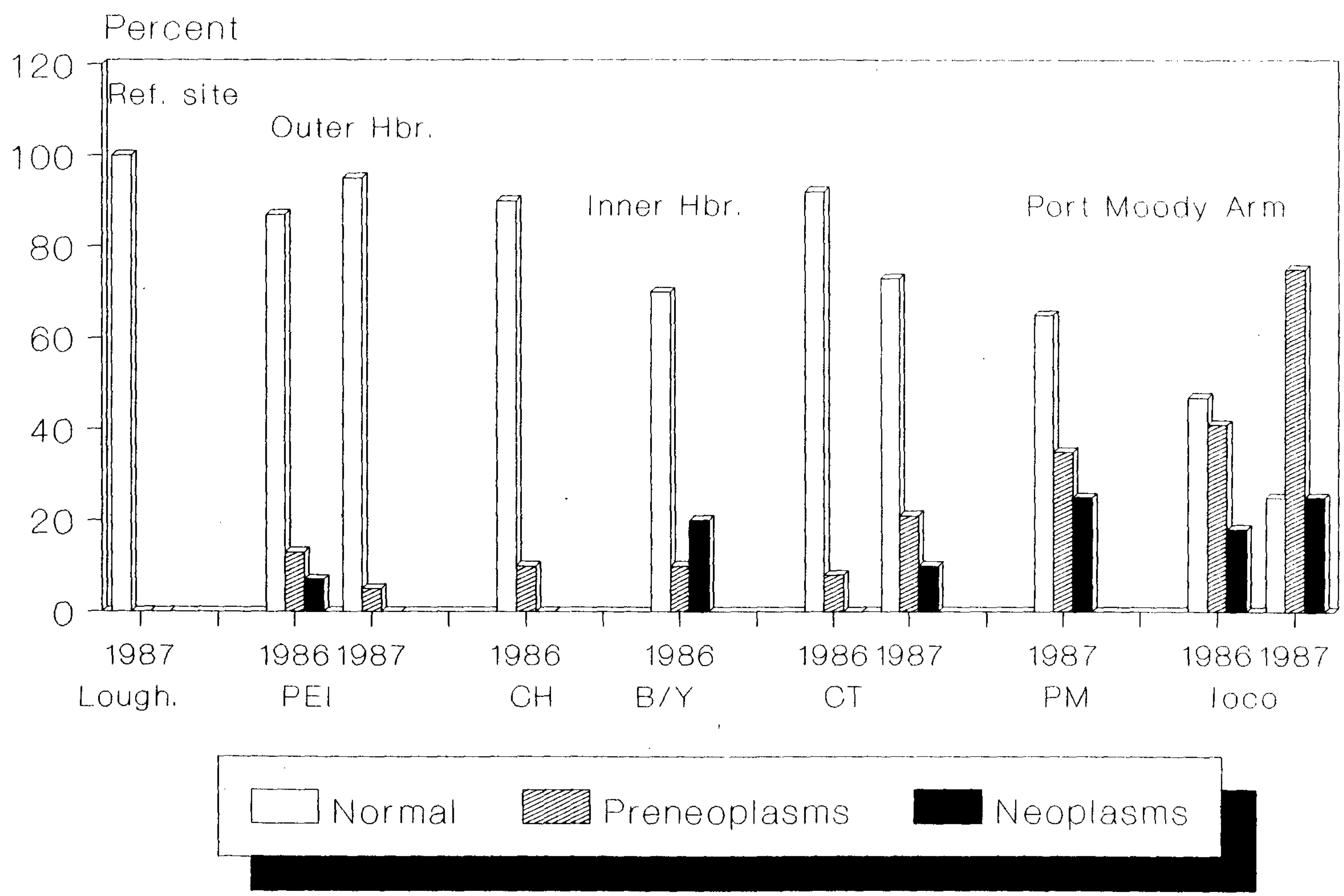
In 1987, percentages ranged from 5.0 to 75.0%. Similar to 1986, the maximum percentage was observed in Port Moody Arm, near the Ioco refinery (Ioco). Visually, livers from fish caught in Port Moody Arm appeared unhealthy, many showing distinct black lines radiating through the tissue, external nodules, and some obviously severely affected by numerous lesions. Prevalence of preneoplastic and neoplastic liver lesions from the inner harbour (Center Channel) and entrance to Port Moody Arm (Port Moody) were 31.6 and 35%, respectively. Particular to the Ioco samples, was the number of fish affected by the different types of idiopathic lesions and the frequency of co-occurences (Figure 26). Co-occurence patterns have been used to indicate the relationships of various preneoplastic lesions to the neoplastic lesions (Myers et al., 1987).

Hepatocellular carcinomas, not observed in 1986, were found in 5.5% of the fish from the Ioco sampling site in 1987. No idiopathic lesions were found in sole from Loughborough Inlet in 1987 (Appendix G). Megalocytic hepatosis, a degenerative liver condition suspected as a precursor to preneoplasms and common in English sole from Puget Sound, did not occur frequently in sole from Vancouver Harbour. The reason for this difference is unclear.

TABLE 11 THREE GROUPS OF IDIOPATHIC LIVER LESIONS (MEGALOCYTIC HEPATOSIS, PRENEOPLASMS AND NEOPLASMS) IN ENGLISH SOLE (PAROPHRYS VETULUS) FROM VANCOUVER HARBOUR - 1986 AND 1987

STATION	N	MEGALOCYTIC HEPATOSIS N (%)	PRENEOPLASTIC LESIONS: CLEAR CELL FOCI N (%)	PRENEOPLASTIC LESIONS: EOSINOPHILIC FOCI N (%)	PRENEOPLASTIC LESIONS: BASOPHILIC FOCI N (%)	NEOPLASTIC LESIONS: LIVER CELL ADENOMA N (%)	NEOPLASTIC LESIONS: HEPATOCELLULAR CARCINOMA N (%)
PEI							
1986	15	0 (0)	2 (13)	0 (0)	1 (7)	1 (7)	0 (0)
1987	20	0 (0)	0 (0)	0 (0)	1 (5)	0 (0)	0 (0)
Burrard Yarrows							
1986	10	0 (0)	0 (0)	2 (20)	0 (0)	2 (20)	0 (0)
1987	NS	-	-	-	-	-	-
Coal Harbour							
1986	10	1 (10)	0 (0)	1 (10)	0 (0)	0 (0)	0 (0)
1987	NS	-	-	-	-	-	-
Centre Harbour							
1986	12	0 (0)	1 (8)	0 (0)	0 (0)	0 (0)	0 (0)
1987	19	1 (5)	0 (0)	3 (16)	2 (11)	2 (11)	0 (0)
Port Moody							
1986	NS	-	-	-	-	-	-
1987	20	0 (0)	1 (5)	6 (30)	6 (30)	5 (25)	0 (0)
Ioco							
1986	17	1 (6)	2 (12)	1 (6)	5 (29)	3 (18)	0 (0)
1987	16	0 (0)	2 (12)	10 (62)	10 (62)	4 (25)	3 (19)
Loughborough Inlet (Reference Site)							
1986	NS	-	-	-	-	-	-
1987	6	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)

NS - Not Sampled



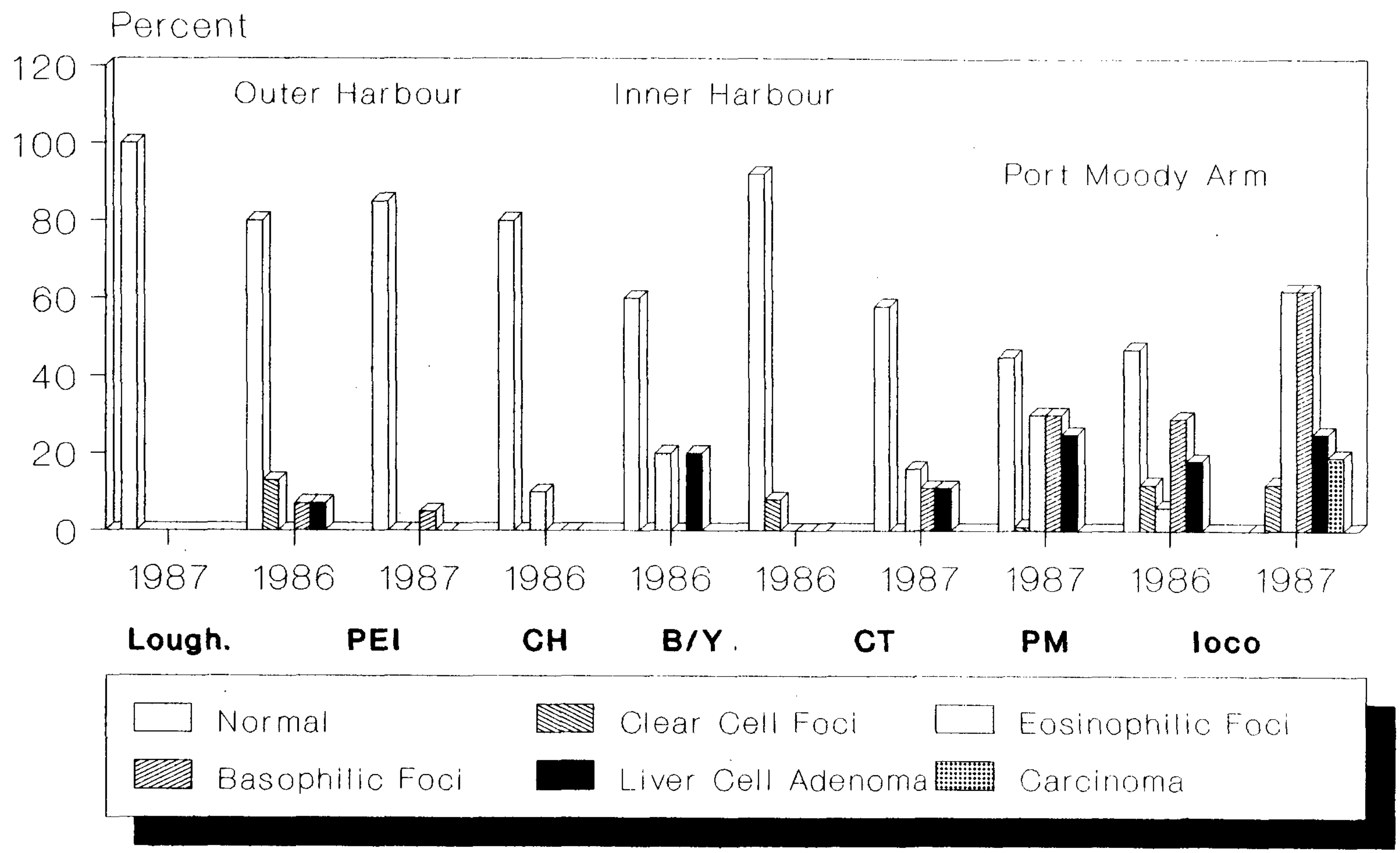
PEI = Pacfic Environment Institute.
CH = Coal Hbr. B/Y = Burrard Yarrows
CT = Centre Channel. PM = Port Moody.
Lough. = Loughborough Inlet (reference site)

FIGURE 25. PERCENT NORMAL VS. NEOPLASTIC AND PRENEOPLASTIC LIVER LESIONS IN ENGLISH SOLE (<u>PAROPHRYS VETULUS</u>) FROM VANCOUVER HARBOUR (1986 AND 1987) AND LOUGHBOROUGH INLET (1987).

TABLE 12. PREVALENCE OF PRENEOPLASMS AND NEOPLASMS IN THE LIVER OF ENGLISH SOLE (*Parophrys vetulus*) FROM VANCOUVER HARBOUR - 1986 AND 1987

STATION	N	PRENEOPLASMS N (%)	NEOPLASMS N (%)	PRENEOPLASMS/NEOPLASMS EITHER N (%)	PRENEOPLASMS/NEOPLASMS CO-OCCURENCE N (%)
PEI					
1986	15	2 (13)	1 (7)	2 (13)	1 (7)
1987	20	1 (5)	0 (0)	1 (5)	0 (0)
Burrard Yarrows					
1986	10	2 (20)	1 (10)	3 (30)	1 (10)
1987	NS	-	-	-	-
Coal Harbour					
1986	10	1 (10)	0 (0)	1 (10)	0 (0)
1987	NS	-	-	-	-
Centre					
1986	12	1 (8)	0 (0)	1 (8)	0 (0)
1987	19	4 (21)	2 (11)	5 (26)	1 (5)
Port Moody					
1986	NS	-	-	-	-
1987	20	7 (35)	5 (25)	7 (35)	5 (25)
Ioco					
1986	17	7 (41)	3 (18)	9 (53)	1 (6)
1987	16	12 (75)	4 (25)	12 (75)	4 (25)
Loughborough Inlet (Reference Site)					
1986	NS	-	-	-	-
1987	6	0 (0)	0 (0)	0 (0)	0 (0)

NS - Not Sampled



PEI = Pacific Environment Institute
CH = Coal Harbour B/Y = Burrard Yarrows
CT = Centre Channel PM = Port Moody
Lough. = Loughborough Inlet (Reference site)

FIGURE 26. COMPARISON OF INDIVIDUAL NEOPLASTIC AND PRENEOPLASTIC LIVER LESIONS OBSERVED IN ENGLISH SOLE (<u>PAROPHRYS VETULUS</u>) IN VANCOUVER HARBOUR (1986 AND 1987) AND LOUGHBOROUGH INLET (1987).

Areas within Puget Sound have been rated according to the prevalence of neoplasms, preneoplasms and megalocytic hepatosis (Evans-Hamilton and D.R. Systems, 1987). Myers et al. (1987) has shown a significant link between megolocytic hepatosis and preneoplastic lesions (foci of cellular alteration) suggesting the former as an early indication of hepatocarcinogen-hepatotoxin exposure. Areas of primary concern are those having >5% neoplasms, >15% preneoplasms and >15% megalocytic hepatosis in the target species, English sole. Secondary areas are those with 2.5 - 5% neoplasms, 5 - 15% preneoplasms and 5% to 15% megalocytic hepatosis. Percentages of neoplasms and preneoplasms in English sole from the various sampling locations in Vancouver Harbour in 1986 and 1987 are shown in Table 11. Megalocytic hepatosis in fish from Vancouver Harbour was very low (1.3 - 1.9%) compared to Puget Sound (up to 86%) (Evans-Hamilton and D.R. Systems, 1987). Percentages of each type of lesion are provided in Table 12. The types of neoplastic and preneoplastic lesions in English sole from Vancouver Harbour were similar to those found in urban embayments in Puget Sound. All sampling locations in the harbour fell within either the primary or secondary areas of concern established for Puget Sound.

Hepatic lesions in English sole, living in direct contact with the bottom, have been linked to sediment-associated aromatic hydrocarbons which includes PAH (Malin et al., 1984, 1985, 1988; Myers et al., 1987). PAH metabolites can bind to proteins and nucleic acid (DNA) resulting in molecular deformation, cell damage and eventually in mutations, cancer or teratogenic effects (Knutzen, 1987, Neff, 1979). As little as 1 µg/g, total sediment PAH is required to cause biochemical effects in winter flounder (Pseudopleuronectes americanus) (Payne et al., 1988). A number of idiopathic lesions have been found in wild fish from PAH contaminated areas and reproduced in the laboratory through intermuscular and embryo micro-injections of sediment extracts (Black et al., 1988; Metcalfe et al., 1988). Krahn et al. (1986) found high concentrations of aromatic compound metabolites in English sole bile from Eagle Harbour and Duwamish Waterway, two areas in Puget Sound containing high sediment PAH levels. Concentrations in reference fish were at least 20 times lower.

While the exact cause/effect relationship between sediment contaminants and liver lesions in English sole remains uncertain and other contaminants besides PAH can cause or promote tumor development in fish, PAH appear to play a major role. For example, percentages of neoplastic and preneoplastic lesions in English sole from Eagle Harbour, site of a creosote plant, were 32% and 52%, respectively (Evans-Hamilton and D.R. Systems, 1987). Sediment HPAH concentrations in Eagle Harbour ranged from 10.4 - 63.9 µg/g. In Everett Harbour (HPAH, 0.74 - 56.0 µg/g), prevalences of the two types of hepatic lesions were 12% and 25%. In Commencement Bay (HPAH, 0.057 - 10.2 µg/g), prevalences were 8% and 27%, respectively. In Sinclair Inlet, where HPAH levels averaged 6.7 µg/g (2.0 - 29.0 µg/g) along the shoreline, the prevalences of preneoplastic lesions in fish caught offshore ranged from 1.7 - 30%. Percentages of neoplastic lesions ranged from 0 - 6.7%. In Budd Inlet, an area where HPAH levels were low (0.35 - 0.69 µg/g), neoplastic and preneoplastic lesions were not detected in English sole.

Although English sole exhibit seasonal migrations, studies indicate that they have strong homing instincts. From tagging studies, Day (1976) found that fish caught in Puget Sound rapidly returned to their area of capture. Sharp contrasts between the high prevalences of liver lesions in fish from contaminated embayments in Puget Sound and nearby offshore areas (Evans-Hamilton and D.R. Systems, 1987) also suggests that English sole occupy relatively small territories. In Vancouver Harbour, the distance and geographical restrictions between Port Moody Arm and the inner harbour, coupled with the strong tidal currents, suggests that the English sole population in Port Moody Arm is relatively isolated from the remainder of the harbour. If one assumes that: PAH are the primary cause of the liver lesions in English sole from Vancouver Harbour and those fish in Port Moody Arm belong to distinct populations which are exposed only to local sediment PAH concentrations then, sediment HPAH concentrations of 3.3 - 4.4 µg/g (1987), result in a 35% prevalence of preneoplastic and neoplastic lesions and 4.5 - 18.8 µg/g in a 75% prevalence. Throughout Port Moody Arm, HPAH levels in 1987 ranged from 3.0 - 32.0 µg/g (mean, 7.5 µg/g) (Table 6).

In the rest of the harbour, where the movements of English sole and levels of PAH exposure are more difficult to predict, sediment HPAH concentrations of 1.1 - 5.5 µg/g (Station 14 and 19, respectively) were associated with lesion prevalences of 10 - 30%. HPAH levels in the foreshore areas along the south shore of the inner harbour, away from the area of capture (Station 22A), were 6.6 and 9.9 µg/g in 1985/86 and 1987, respectively.

More information on the movements of English sole in Vancouver Harbour and the cause/effect relationships between sediment associated PAH and prevalences of English sole liver lesions is required before definite conclusions can be drawn. However, data from Vancouver Harbour and elsewhere, suggest that the sediment PAH concentration required to cause liver lesions in English sole are 3 - 4 µg/g, or possibly lower.

4.2.5 Benthic Infauna

In October 1987, macrobenthic infauna sampling was conducted at 28 sites by the Institute of Ocean Sciences (Burd and Brinkhurst, in prep.), in conjunction with the current program. No historical information is available which predates industrial and urban development to evaluate what constitutes a normal or "healthy" benthic community in Vancouver Harbour. However, preliminary analysis of the data shows a much healthier infauna community in the inner harbour than would be expected based on the levels of contaminants. Several stations in Port Moody Arm were severely depauperate.

A cluster analysis showed some obvious differences between groups of stations. One group in particular included a small group of stations on the north shore near Vancouver Wharves (Stations 1 - 4A) and one south shore station (Station 25B). Another groups consisted of the remaining stations in the inner harbour (Stations 11B, 15, 16, 19, 22D, 22E, 25D and 25E). At three Port Moody Arm stations fauna, were essentially absent (Stations 41B, 45 and 46). The reference station (Station PEI) appeared to cluster with the stations in the middle of the inner harbour, away from the nearshore stations. All of these groups are statistically significant (Burd and Brinkhurst, in prep.) but have yet to be tested for agreement between clusters based on chemical data or sediment type and those derived from benthic studies. A preliminary inspection of the data shows that there is a richer fauna, in terms of number of individuals, and even some stations with more species at some inner harbour stations, than the reference site (PEI). Chemical analysis of surface sediments from Station PEI during the present study, however, indicates some contamination, particularly with respect to copper (see Section 4.1.1.4).

4.3 Sediment Toxicity

4.3.1 Amphipod Bioassays

Sediment toxicity test using the amphipod (Rhepoxynius abronius) have been conducted for a number of coastal areas in B.C., including Vancouver Harbour, under Ocean Dumping Research Funding (Chapman and Barlow, 1984; Chapman et al., 1988, 1989). Although the purpose was to evaluate the tiered testing approach using the Sediment Quality Triad (sediment toxicity, sediment chemistry and benthic infauna) results provided a measure of the sediment toxicity at the various locations in the harbour. Percent survival was determined from 20 amphipods exposed to sediment samples for 10 days. Based on three separate studies, these varied from 0% to 18.6 $\pm$ 1.5%. The most toxic sediments came from sites near Vancouver Wharves (Stations 1, 2, and 3B) and Pacific Coast Terminals (Stations 45 and 46). Survival ranged from 0% to 7.8 $\pm$ 2.3% for these stations (Chapman et al., 1989). The centre of the inner harbour (Station 15), south shore (Station 22B, 25B), and Port Moody Arm (Stations 36B, 40, 41A, and 41B) ranged from 17.0 $\pm$ 3.9% to 18.6 $\pm$ 1.5% survival. Only Stations 22B, 25B and 36B of the latter group were significantly different from the controls. Using the current data, high toxicities did not always correspond to the highest concentrations of measured contaminants. However, the samples were not collected concurrently with the sediment bioassay samples nor was the full spectrum of chemical contaminants analyzed.

4.3.2 Macoma Bioassays

Toxicity tests using the bivalve, Macoma sp. have also been conducted by the Provincial Waste Management Branch on sediment samples from Port Moody Arm (B. Moore, pers. com.). Mortalities ranged from 0 - 29% in samples taken along the north shore near the Ioco refinery and townsite. Along the south shore, near Pacific Coast Terminals, the percent mortalities ranged from 5 - 39%.

4.4 Conclusions

Overall, the results from this study do not suggest that the environment in Vancouver Harbour is severely degraded. The harbour continues to support a variety of epibenthic species along with a relatively rich infaunal community. There was no evidence of significant metal uptake in selected benthic species captured in areas offshore from the more heavily contaminated foreshore areas. Nevertheless, sediments in a number of areas of the harbour are seriously contaminated with trace metals and certain organic chemical contaminants associated with urban and industrial activities. This has resulted in the pathological effects to some segments of the bottomfish populations in the harbour, raising questions concerning biota survival and level of chemical carcinogens in the marine environment. As well, sediments from some locations are highly toxic to test organisms and results of studies show that the benthic community occurs in distinct groups or clusters implying alterations to the community structure which requires further investigation.

5.0 Remedial Actions

As a result of this and other studies, a number of remedial measures are presently being implemented to address environmental concerns in Vancouver Harbour. In cooperation with Environment Canada, B.C. Waste Management Branch, and other regulatory agencies, Greater Vancouver Regional District (GVRD) has undertaken a study to identify short-term and long-term actions necessary to improve environmental conditions in Vancouver Harbour. The provincial Ministry of Environment is presently drafting Water Quality Objectives for Burrard Inlet (Vancouver Harbour). Current legislation under the Ocean Dumping provisions of the federal Canadian Environmental Protection Act (CEPA) and evaluation of various chemical substances under the CEPA Priority Substance List will govern the dredging and disposal of contaminated material from the harbour. An interim screening limit of 2.5 µg/g, total PAH has been proposed for ocean disposal while a more detailed assessment is carried out.

As of March 1989, treated process water from the Esso Petroleum Ioco Refinery, which was discharged directly to Port Moody Arm, has been diverted to the GVRD sewer system. In addition, the company has undertaken a detailed wastewater chemical characterization and stormwater segregation program. Similar wastewater characterization programs are either underway or proposed for other refinery operations in the harbour. Wastewater from the sulphur storage area at the Pacific Coast Terminals operation in Port Moody Arm has also been diverted to the GVRD sewer system, along with facility modifications to prevent waste seepage into the harbour. Vancouver Wharves, which was identified as a major source of metal contamination in the inner harbour, removed a significant quantity of the contaminated material from the loading dock area in September 1989 to increase the draft for deepsea vessels. Further inspection is required to assess this source of metal contamination in the inner harbour.

Steps to control spillage during the loading and unloading of bulk commodities and the treatment of stormwater and combined sewer overflows will be needed. Further information is also required on the relationships of sediment contaminants, in particular PAH, to pathological effects on a number of species in the harbour and on tissue contaminant levels and risks to human health through consumption of seafood.

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