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A State of the Environment Report

Pollutants in British Columbia's Marine Environment
A Status Report

SOE Report No. 89-1

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A Status Report

B.H. Kay

Environmental Protection, Pacific and Yukon Region
Conservation and Protection
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Preface

The quality of the marine environment in British Columbia has become an issue of concern. The goal of this project was to answer two questions:

- What is the current status of pollutants in the marine environment in British Columbia?
- Has the quality of the marine environment improved or deteriorated since the early 1960s?

This report answers the first question by summarizing data on the sources and levels of pollutants in the marine environment, as well as the environmental impacts of these contaminants. Our ability to answer the second question is limited by the lack of long-term studies on the marine environment.

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Units of measure

SI units used

d	day
g	gram
h	hour
L	litre
m	metre
t	tonne

Multiples of SI units

k	kilo	10^{3} (multiply by 1000)
m	milli	10^{-3} (multiply by 0.001)
μ	micro	10^{-6} (multiply by 0.000001)
n	nano	10^{-9} (multiply by 0.000000001)

Equivalent concentrations

Liquids:	1 mg/L	= 1 ppm (part per million)
	1 μg/L	= 1 ppb (part per billion)
Solids:	1 mg/kg	= 1 ppm (part per million)
	1 μg/kg	= 1 ppb (part per billion)
	1 ng/kg	= 1 ppt (part per trillion)

NOTE: Units used in original references have been changed to the appropriate equivalent concentrations shown above.

Chapter 1
Background

British Columbia's coastal resources

Protection of the marine environment is important for the preservation of habitat and species, and for the maintenance of the social, economic and cultural values associated with such an environment. The development of urban centres and the exploitation of natural resources can result in immense pressure on the environment. This report identifies and quantifies some of the major stresses to the marine environment of the Pacific coast, based on data available from the 1970s to the end of 1986. It also identifies the environmental changes or effects that have been observed.

The Pacific coast has been inhabited by indigenous peoples, such as the Haida, Kwakiutl, Nootka and Salish, for over 7 000 years. Their traditional lifestyles and spiritual values still focus on the marine environment. The availability of rich and abundant natural resources may be one reason for the longevity of these native cultures.

European settlers first came to the Pacific coast about 150 years ago. About 2.1 million people now live in British Columbia's coastal plains and mountains (defined as the Pacific Maritime Ecozone by the Canada Committee on Ecological Land Classification). Over 80% of these people live in three major urban areas — Vancouver, Victoria and Nanaimo. Of these, the vast majority live in and around Vancouver.

Canada's Pacific coast comprises some 25 700 km of shoreline, numerous islands, productive estuaries, deep fjords and bays. The continental shelf is narrow, typically less than 50 km wide, and the shoreline is complex. Numerous river estuaries support large populations of marine life and waterfowl. In contrast, fjords tend to have poorly oxygenated bottom waters and are relatively less productive. The abundant natural resources of the coast include wildlife, fish, forests and mineral deposits.

The Pacific marine environment also provides habitat for wildlife, including numerous species of seabirds and marine mammals. This area is home to 27% of the world population of Rhinoceros Auklets, 71% of the world population of Cassin's Auklets, 42% of the world population of Ancient Murrelets and 78% of the Canadian population of Tufted Puffins. The productive estuaries, saltwater marshes and bays provide important habitat for over a million migrating birds that pass through the region each spring (B.C. Ministry of the Environment and Parks 1983). Marine mammals on the coast include several species of whales, of which the Gray and Minke are the most common. Killer whales, dolphins, porpoises, sea lions and seals also inhabit the coastal waters (B.C. Ministry of the Environment and Parks 1983).

Fishing is an important industry for British Columbia. Salmon, herring and various species of groundfish, as well as prawns, crabs, shrimps, clams, oysters, mussels, abalone and geoducks, are harvested commercially and recreationally. The Pacific coast accounts for approximately 30% of the estimated dollar value of the entire Canadian fishery (Fisheries and Oceans Canada 1985). In 1984, the Pacific commercial fishery landed 169 000 t of fish with an estimated value of $233 million. The salmon fishery, which is the most valuable, accounted for over 60% of that value. The second most valuable fishery is herring, followed by groundfish (sole, halibut, etc.) and shellfish. The fastest growing fishery is molluscan shellfish. Harvests of molluscs have increased from 3 000 t in 1984 to 10 700 t in 1986. Salmon farming is becoming increasingly important. Over 500 applications for new provincial salmon farm leases were received in 1986.

The forest resources of British Columbia's coastal plains and mountains were estimated to be 2.2 billion m^3 in 1981 (Statistics Canada 1986). This represents about 30% of British Columbia's forest resources on stocked, productive forest land. Nearly 25 000 persons were employed in logging and forestry services in the coastal area in 1980.

Five of British Columbia's mining regions border on the Pacific Ocean. These regions contain deposits of iron, copper, silver, gold, lead and zinc. Total estimated reserves of these elements exceed 11 million tonnes, 90% of which are reserves of iron (Statistics Canada 1986).

Protective legislation

Water pollution in British Columbia falls under the jurisdiction of several federal and provincial acts and regulations. A good review of the legislation is presented in

"Environmental Law: British Columbia Handbook" (Ince and Edwards 1984).

International agreements, such as the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (London Dumping Convention), the International Convention for the Prevention of Pollution from Ships (MARPOL) and the United Nations Law of the Sea (UNCLOS III), are implemented domestically through Part VI of the *Canadian Environmental Protection Act* (CEPA), formerly the *Ocean Dumping Control Act* (ODCA), the *Canada Shipping Act*, the *Fisheries Act* and the Code of Recommended Standards for the Safety and Prevention of Pollution for Marine Transportation Systems and Related Assessment Procedures (TERMPOL Code). The three acts, in addition to British Columbia's *Waste Management Act*, form the legislative basis for most marine environmental controls. Table 1 presents a brief description of these acts and their attendant regulations.

The provincial *Waste Management Act* prohibits the introduction of any waste into any water without a permit or approval pursuant to the Act. If the terms of the permit or approval are complied with, there is no offence under the Act, nor is prosecution possible under any municipal by-law, permit, licence or order. Effluent discharges to B.C. marine waters require such approval by the provincial government. The provincial Ministry of the Environment and Parks refers permit applications to a variety of agencies and governments (including the federal government) so that their concerns can be considered in developing the terms and conditions of the permit.

The federal *Fisheries Act* also prohibits the discharge of deleterious substances to fish habitat. Environment Canada, which administers pollution sections of the Act, normally applies the provisions of the *Fisheries Act* by working with provincial government agencies in setting terms for provincial permits or approvals. Permit terms and conditions are based on the applicable regulations, guidelines or objectives described in Table 1 and on site-specific considerations peculiar to each discharge location.

Federal guidelines and regulations have been developed under the *Fisheries Act* for various effluent types. This is to ensure that minimum national standards for these effluents are met and to discourage the formation of "pollution havens" in provincial or territorial jurisdictions having less stringent regulations, or none at all.

In 1975, Canada joined more than 50 countries in ratifying the London Dumping Convention. The Parliament of Canada passed the *Ocean Dumping Control Act* in 1975 to fulfill part of Canada's international obligations under this convention. In June 1988, the *Ocean Dumping Control Act* was repealed and replaced by Part VI of the *Canadian Environmental Protection Act*. This Act is designed to protect human health, marine life and legitimate uses of the sea by controlling the dumping of wastes and other

Table 1
Legislation governing marine pollution control in British Columbia

Act	Jurisdiction	Regulations, objectives or guidelines
Fisheries Act (Sections 33(2), 33(12), 33(13))	Federal	Metal Mining Liquid Effluent Regulations and Guidelines Alice Arm Mine Tailings Disposal Regulations Pulp and Paper Effluent Regulations and Guidelines Metal Finishing Liquid Effluent Guidelines Guidelines on the Use and Acceptability of Oil Spill Dispersants Chlor-alkali Mercury Liquid Effluent Regulations Meat and Poultry Products Plant Liquid Effluent Regulations Petroleum Refinery Liquid Effluent Regulations and Guidelines Fish Processing Operation Liquid Effluent Guidelines
Waste Management Act	Provincial	Pollution Control Objectives for the Forest Products Industry[1] Pollution Control Objectives for the Mining, Smelting and Related Industries Pollution Control Objectives for Municipal-type Waste Discharges Pollution Control Objectives for the Chemical and Petroleum Industries Pollution Control Objectives for Food-processing, Agriculturally Oriented and Other Miscellaneous Industries
Canadian Environmental Protection Act, Part VI	Federal	Ocean Dumping Control Regulations
Canada Shipping Act	Federal	Ship Source Pollution Prevention Regulations[2]

[1] Provincial pollution control objectives were developed pursuant to the *Pollution Control Act*, which was replaced by the *Waste Management Act* in 1982.
[2] The regulations, objectives and guidelines are currently being updated to conform with current international standards.

Table 2
Categories of substances under Part VI of the *Canadian Environmental Protection Act*

Category	Coverage
Schedule III, Part I (prohibited substances)	Substances that can seriously harm the marine environment. These cannot lawfully be dumped except in trace quantities and then only for good and compelling reasons, and when the risk to marine life, and animal and human health is minimal. These substances include: • mercury and mercury compounds • cadmium and cadmium compounds • crude oil and its wastes, refined petroleum products, petroleum distillate residues and any mixtures containing any of these substances • organohalogen compounds, including PCBs • high-level radioactive wastes or other high-level radioactive materials • any substance produced for chemical or bacteriological warfare • persistent plastics and other persistent synthetic materials
Schedule III, Part II (restricted substances)	Substances that are potentially harmful, but can be dumped safely with extreme care, including: • arsenic, lead, copper, zinc, beryllium, chromium, nickel, vanadium and their compounds • cyanides and fluorides • pesticides and their by-products not listed in Schedule III, Part I • organosilicon compounds, such as water repellents • containers and scrap metals • radioactive wastes or other radioactive matter not included in Schedule III, Part I • substances that because of their bulkiness sink to the sea bottom, interfering with fishing and navigation
Schedule III, Part II (all other substances)	All substances not listed in Schedules III, Parts I and II. Factors that must be considered in granting all ocean dumping permits are also listed. • the total amount and average composition of substances dumped • toxicity • other physical, chemical and biological characteristics • location of dumpsite • method of disposal • effects of tides, winds, currents and other dispersal factors • salinity, temperature and other water characteristics • sea-bottom characteristics • possible effects on marine life and fisheries • possible effects on other uses of the sea • accumulation and biotransformation in biological materials and sediments • consideration of other waste management options

substances into the ocean. Under the Act, disposal of wastes at sea is regulated by a system of permits. The terms and conditions of permits vary with the type of substance dumped. These conditions govern such things as timing, handling, storage, loading and placement at the disposal site. Table 2 lists the three categories of substances covered by the ocean dumping control provisions of the *Canadian Environmental Protection Act*. In March 1988, the Supreme Court of Canada ruled that the *Ocean Dumping Control Act*[1] (now Part VI of CEPA) is valid legislation within B.C. coastal waters under provincial jurisdiction.

Canadian ships, aircraft, and marine structures (such as platforms) must have permits to dispose of wastes by dumping or incineration at sea. Foreign vessels also require such permits if they wish to dump wastes in Canadian waters.

The *Canada Shipping Act* regulations are now being updated in anticipation of Canada acceding to the international MARPOL Convention. The update will include new or revised regulations pertaining to oil, noxious liquid substances, harmful substances in packaged form, sewage and garbage.

Other legislation has application in specific circumstances. The provincial *Health Act* regulates minor domestic sewage discharges, and the *Land Use Act* regulates handling of waste from salmon farms. Should offshore drilling resume, the Canada Oil and Gas Lands Administration regulates rig wastes. The use of pesticides is regulated by the federal *Pest Control Products Act*.

[1] Found *ultra vires* of the federal Parliament by a 26 January 1984 decision of the B.C. Court of Appeal.

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Chapter 2

Sources of pollution

British Columbia's marine[1] waters receive inputs containing pollutants from a variety of sources. Rivers and surface runoff from inland agricultural and urban areas drain into coastal estuaries. The atmosphere can also introduce contaminants to ocean waters, but virtually nothing is known about the role of this pathway on Canada's west coast. Ships pump out oily bilge water into the ocean. The sources of pollution that this chapter focuses on are municipal and industrial wastes, ocean dumping, accidental spills of chemicals and oil, and non-point sources.

Municipal waste

British Columbia's coastal urban centres have always discharged sewage into the province's coastal waters. Wastewater treatment plants were virtually nonexistent before 1950; raw sewage was released through numerous shallow outfalls. The last 25 years have seen the installation of new sewage treatment plants or improved outfalls to accommodate increased populations and to meet more stringent environmental requirements.

The quality of sewage and municipal wastewater effluents depends on the degree to which physical, primary, secondary or tertiary treatments are applied. Other procedures, such as disinfection, are optional and not usually considered to be part of the treatment process. Physical treatment refers to the removal of gross solids and other aesthetically displeasing materials through screening or grinding. Primary and secondary treatments reduce the levels of suspended solids and bacteria. Tertiary treatment can be included, if deemed necessary, to remove nutrients and other contaminants from the effluent.

Approximately 270 marine sewage discharges are currently registered with the provincial government. Of these, 63% receive primary treatment at most, and none receives tertiary treatment. Many serve one or two businesses or small residential subdivisions and are normally treated by septic tanks or "package" sewage treatment plants. These low-volume discharges consist mostly of "sanitary" wastes. Larger-volume discharges serving major urban areas may, however, contain many other waste materials. Institutional, industrial, stormwater and numerous other wastes can enter the municipal sewer systems. Thus, the term "municipal wastewater" is applied, because the discharge consists of much more than just sanitary or domestic sewage. Potential pollution effects of municipal sewage appear in Table 3.

[1] "Marine" generally means seaward of a line across the mouths of estuaries; however, some information will be given for the lower Fraser River, which has strong saltwater influence for several kilometres upriver.

Industrial waste

Pulp and paper

The pulp and paper industry discharges process effluents containing pulping and bleaching chemicals and solids, including wood fibres and wood wastes. There are 10 pulp mills operating along the coast of British Columbia (Figure 1) that discharge effluents and solids into the marine or estuarine environments.

Table 3
Potential environmental impacts of marine sewage discharges

Environmental impacts	Contributing substances
Increased turbidity; alteration of benthic habitat	Sewage solids
Health hazards associated with bathing or shellfish consumption	Pathogenic microorganisms in liquid and solid portions of the effluent
Reduction in dissolved oxygen	High organic content (oxygen-demanding materials) in solid and dissolved form
Nutrient enrichment (eutrophication)	Nutrients containing nitrogen and phosphorus
Bioaccumulation and biomagnification of toxic substances; sediment contamination	Metals, chlorinated organic compounds (e.g., pesticides)
Acute toxicity	Surfactants, ammonia, chlorine (from disinfection)
Aesthetic Impact	Solids, floating and non-biodegradable materials

Source: Waldichuk 1984, Kay 1986.

The impact of pulp mill discharges on the marine environment varies with the quality of the effluent (determined by the pulping process and treatment methods employed), disposal location (in relation to living resources, ocean currents and wind), disposal method (surface discharge or submerged outfall) and habitat sensitivity.

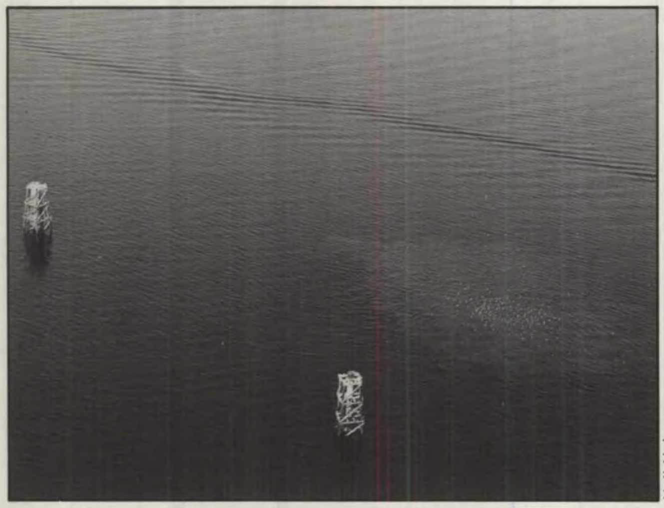
In general, environmental impacts from the marine discharge of pulp mill wastes can be classified into four broad categories, as shown in Table 4.

Table 4
Potential environmental impacts of pulp and paper effluents

Environmental impacts	Contributing substances[1]
Increased biochemical oxygen demand	Dissolved organic substances (lignins, carbohydrates, organic acids, alcohols)
Toxicity	Resin acids; chlorinated lignins, chlorinated resin acids; phenolics; unsaturated fatty acids; diterpene alcohols; juvabiones; lignin degradation products (lignosulphonates); fungicides (chlorinated hydrocarbon mixes, mercuric and zinc compounds)
Benthic habitat smothering	Suspended solids (fibre, bark residues, ash, lime, clay)
Colour	Lignin derivatives; paper dyes and fibres

Source: Pearson 1980; Waldichuk 1983.

[1] The substances listed result largely from the wood degradation process or from chemicals used in the pulping process.



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Surfacing pulp mill effluent

Problems associated with pulp mill discharges in freshwater systems, such as pH changes and foam production, are now considered minor in marine systems. This is due to the natural buffering capacity of seawater and effluent disposal methods such as submarine outfalls. Surface foam has been objectionable in the past, but current treatment limits foam production to very small amounts near points of discharge.

Mining

Base metals have been mined in the coastal areas of British Columbia since 1899, when the Britannia Copper Mine was opened in Howe Sound. In total, 10 mines have operated for varying periods of time along the coast. Only the Island Copper Mine continues to operate (locations of abandoned and existing coastal mines shown in Figure 1).

On average, the ore comprises 2% metal (e.g., copper 1.13%, nickel 1.41%, lead 2.08%, zinc 5.11%). The remaining ore is discarded as waste rock or tailings. The potential environmental impacts of the marine disposal of mine tailings are outlined in Table 5.

Table 5
Potential environmental impacts of marine disposal of mine tailings

Category	Environmental impacts
Physical	Loss of habitat, especially for bottom-dwelling organisms Increased turbidity around the point of discharge Spread of tailings and other associated contaminants
Chemical	Increased concentration of trace elements in the water column, particularly metals and certain organic compounds (mill reagents) Changes in the redox potential and pH of seawater Increase in chemical oxygen demand and possibly in biochemical oxygen demand Creation of a reservoir of contaminants in the sediments and/or tailings which may be remobilized through time into the water column
Biological	Lethal and sublethal toxic effects on plants and animals Loss of diversity and possible disappearance of life in the severely affected areas Bioaccumulation and bioconcentration of certain trace elements in biota Change in the benthic community from sensitive species to more pollution-tolerant species Decreased photosynthesis due to high turbidity levels

Source: Mining Division, Industrial Programs Branch, Environment Canada.

Figure 1
Location of abandoned and existing coastal pulp mills and mine sites in British Columbia

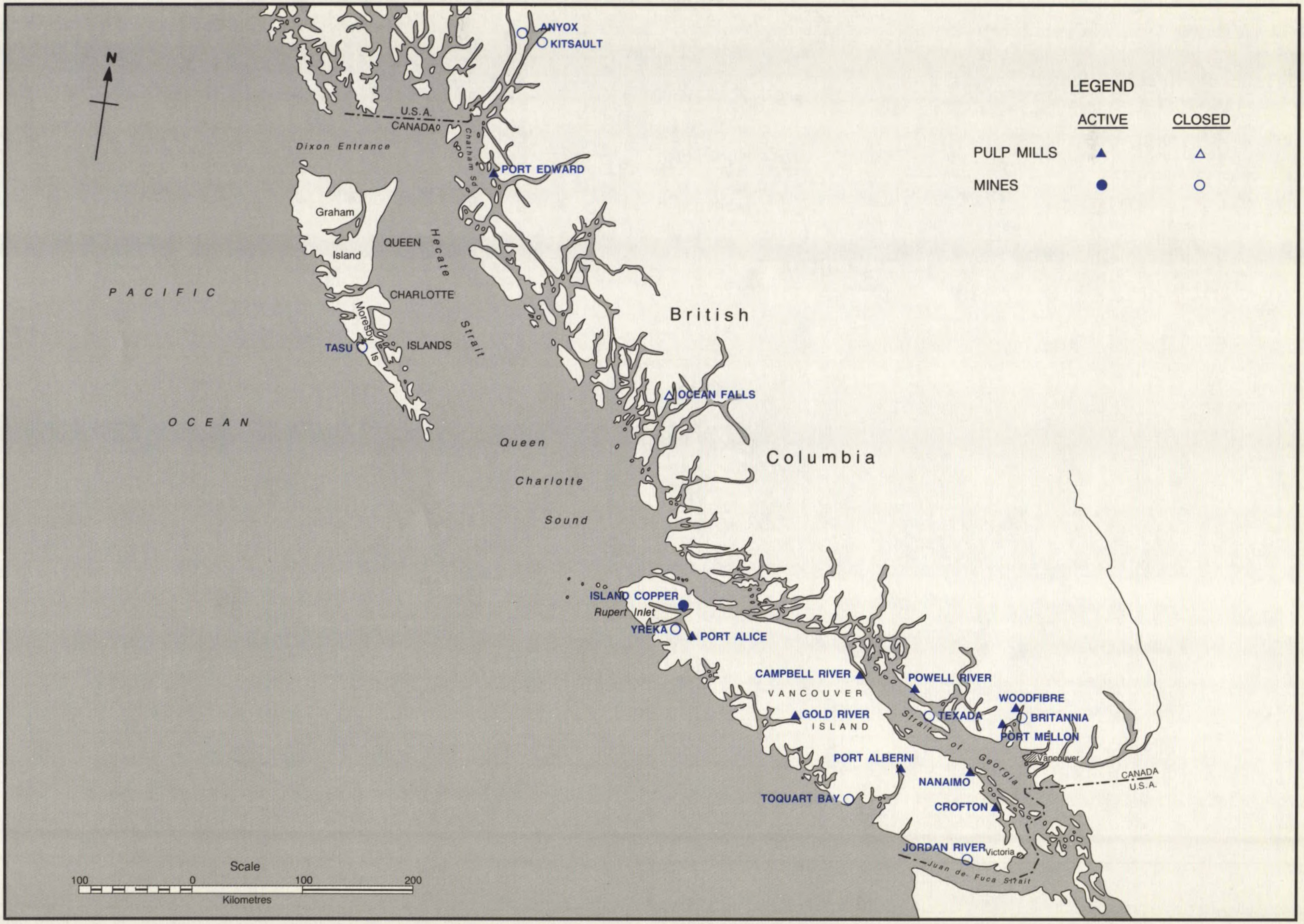
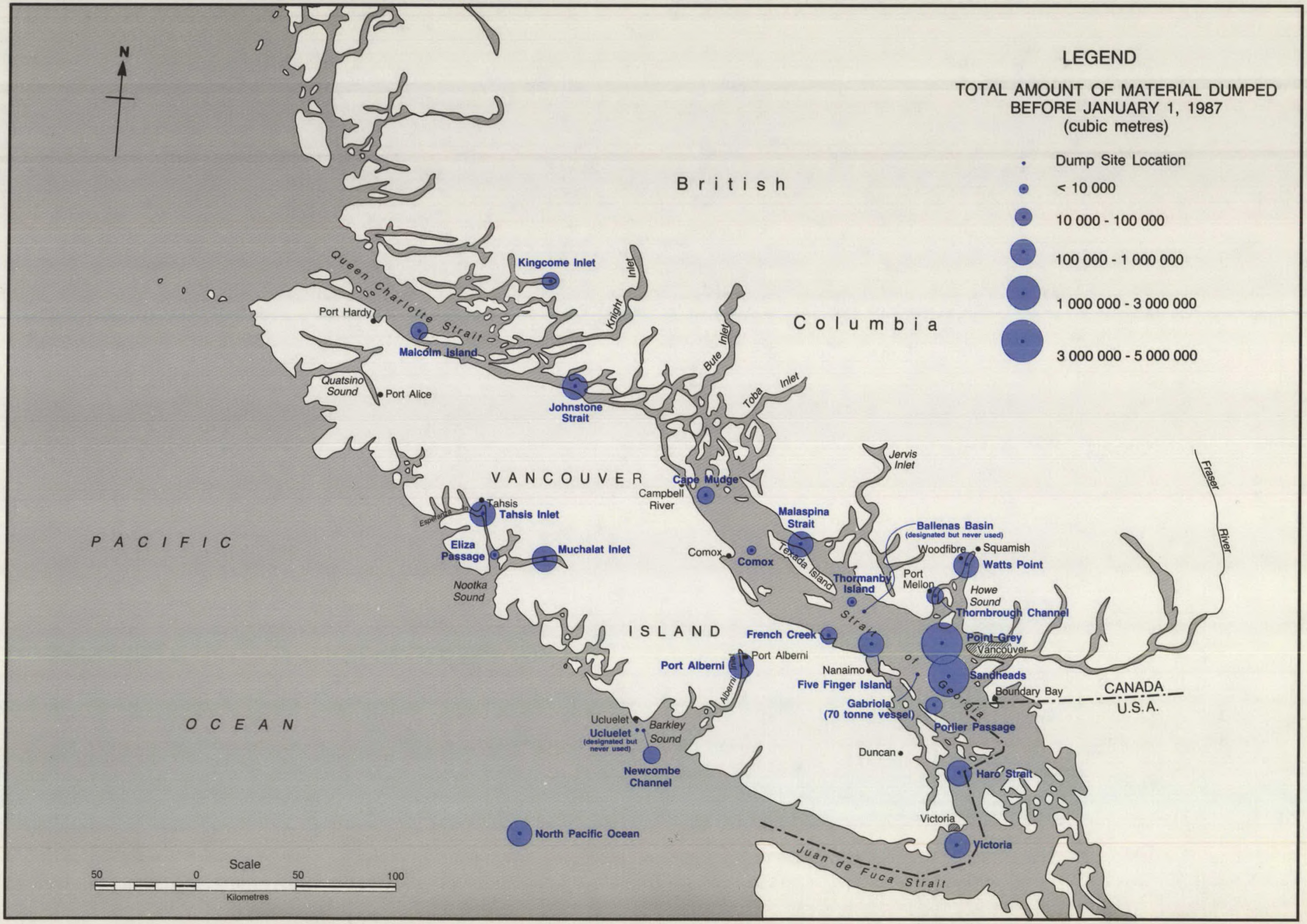


Figure 2
Active ocean dumpsites in southern British Columbia

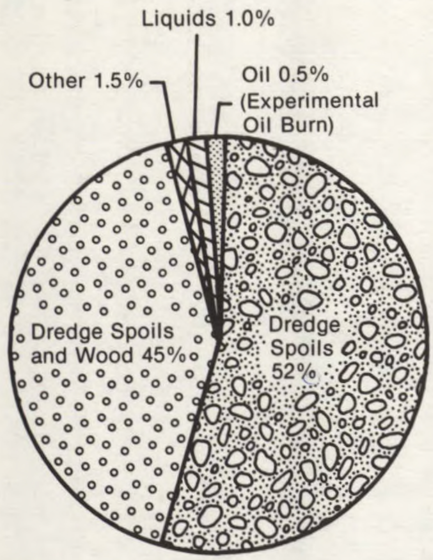


Source: Sullivan 1987.

Chemical, metal finishing and petroleum industries

Direct effluent or stormwater discharges to marine waters from the chemical, metal finishing and petroleum industries are few and are concentrated in the B.C. Lower Mainland. Most discharges from these industries enter the sanitary sewage collection systems and are treated in municipal wastewater treatment plants. Pollutants from the chlor-alkali and sodium chlorate industries include mercury (e.g., from the mercury-cell process), free chlorine, suspended solids, sulphuric acid and trace metals. Oil and grease, suspended solids and phenols have been measured in process effluent and stormwater discharges from oil refineries. In addition, sulphides and ammonia have been measured in the process effluent.

Figure 3
Type of material dumped in the ocean, 1975–1983*



SOURCE: Environmental Protection, Pacific and Yukon Region, unpublished data.

*Data from 1983 to 1986 are not tabulated, but relative quantities are unchanged.

Dredge spoil ocean dumping

Ocean dumping

Ocean dumpsites have been established at 126 locations in B.C. coastal waters (Ward and Sullivan 1980). Since 1982, most dumping has taken place at the sites shown in Figure 2. The greatest quantity of material has been dumped at the Point Grey and Sandheads dumpsites (Figure 2).

Many types of materials are considered for ocean dumping. Most dump material consists of dredge spoils (primarily sand and gravel) or dredge spoils and wood waste (usually dredged near forest operations and containing quantities of wood debris in addition to sand and gravel), primarily from Fraser River and harbour dredging and forest industry operations (Figure 3).

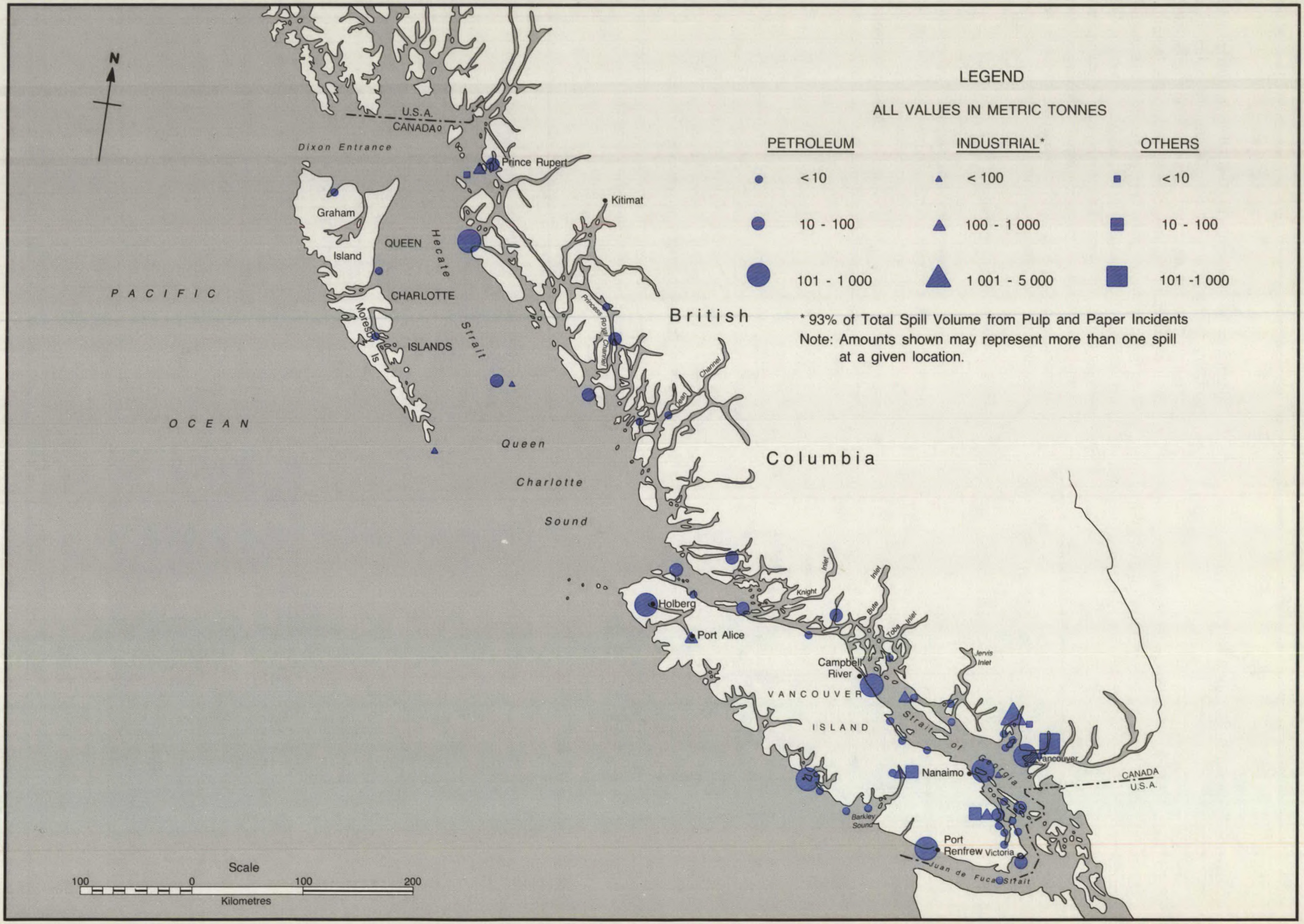
Disposal of waste materials at sea can affect the physical, chemical and biological properties of dumpsite areas, as shown in Table 6.

Table 6
Potential environmental impacts of ocean dumping

Category	Environmental impacts
Physical	Loss of habitat through smothering Creation of new habitat (artificial reefs) Alteration of bottom currents Attenuation of light in the water column through fractionation of wastes Dispersal of sediment-associated contaminants
Chemical	Increased concentrations of elements (e.g., metals) in water column and sediments Introduction of wastes containing various chemical forms of elements compared with those occurring naturally Oxygen depletion resulting from biodegradation of waste products
Biological	Lethal and sublethal toxic effects on plants and animals Bioconcentration, bioaccumulation and/or biomagnification of trace elements or organic substances

SOURCE: National Research Council of Canada 1982.

Figure 4
Significant marine spills: location of incidents, 1972–1984



Source: Environment Canada NATES Database.

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Landfill leachate drainage

Spills

Marine spills are considered to be significant when the material released exceeds 1 t, or when the spill poses a threat to sensitive areas such as bird sanctuaries and estuaries. Significant spills are recorded by Environment Canada on the National Analysis of Trends in Emergency System or NATES database. Records of all reported spills are maintained at the Environmental Protection Service regional office in West Vancouver. Significant spills make up approximately one-sixth of the total spills.

Figure 4 illustrates the distribution of marine spills along the B.C. coastline. Spill amounts may represent a single incident or several incidents that have occurred at the same location. Since 1975, the use of newer ships with segregated fuel and ballast tanks, the introduction of stiffer penalties and the implementation of the new vessel management system for harbour traffic have contributed to the reduced incidence of marine spills on the west coast. There has also been a heightened awareness of the importance of preventing pollution by the users of the sea lanes.

The environmental consequences of spills are dependent on the volume and type of material spilled, the location, weather conditions and the proximity to environmentally sensitive areas. Bird kills are often the most commonly reported consequence of oil spills. Oil disrupts the normal insulating properties of bird feathers, causing loss of body heat and buoyancy. Industrial chemical spills are sometimes toxic to fish.

Non-point sources

Pollution that cannot be traced from an identified point source is known as diffuse or non-point pollution. Diffuse pollution from land-based sources, including agriculture, forestry, landfill leachates, urban drainage and transportation, is increasing near coastal population centres. Sewage discharged from anchored vessels has caused the closure of shellfish areas in the summer. Contaminants from non-point pollution include trace metals, persistent organic chemicals, nutrients, oils and grease and bacteria. These contaminants enter the ocean through a variety of routes including rivers, storm drains and groundwater; therefore, no data are available quantifying the volumes of pollutants from these sources.

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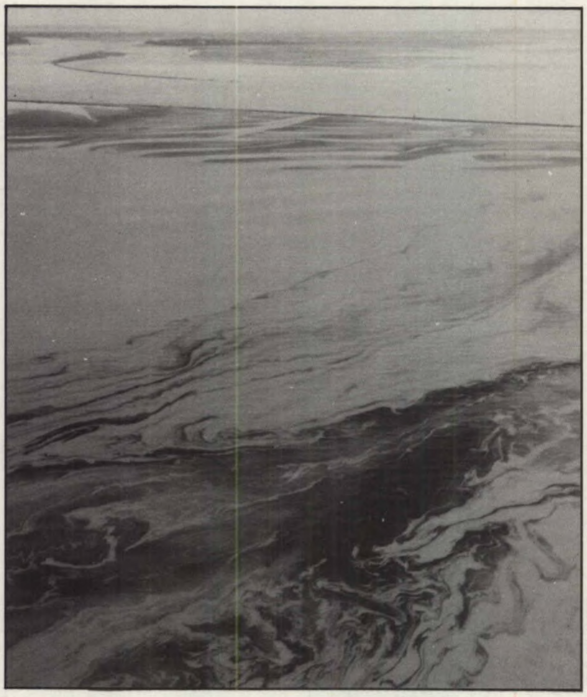
Benthic impacts in the vicinity of a pulp mill outfall



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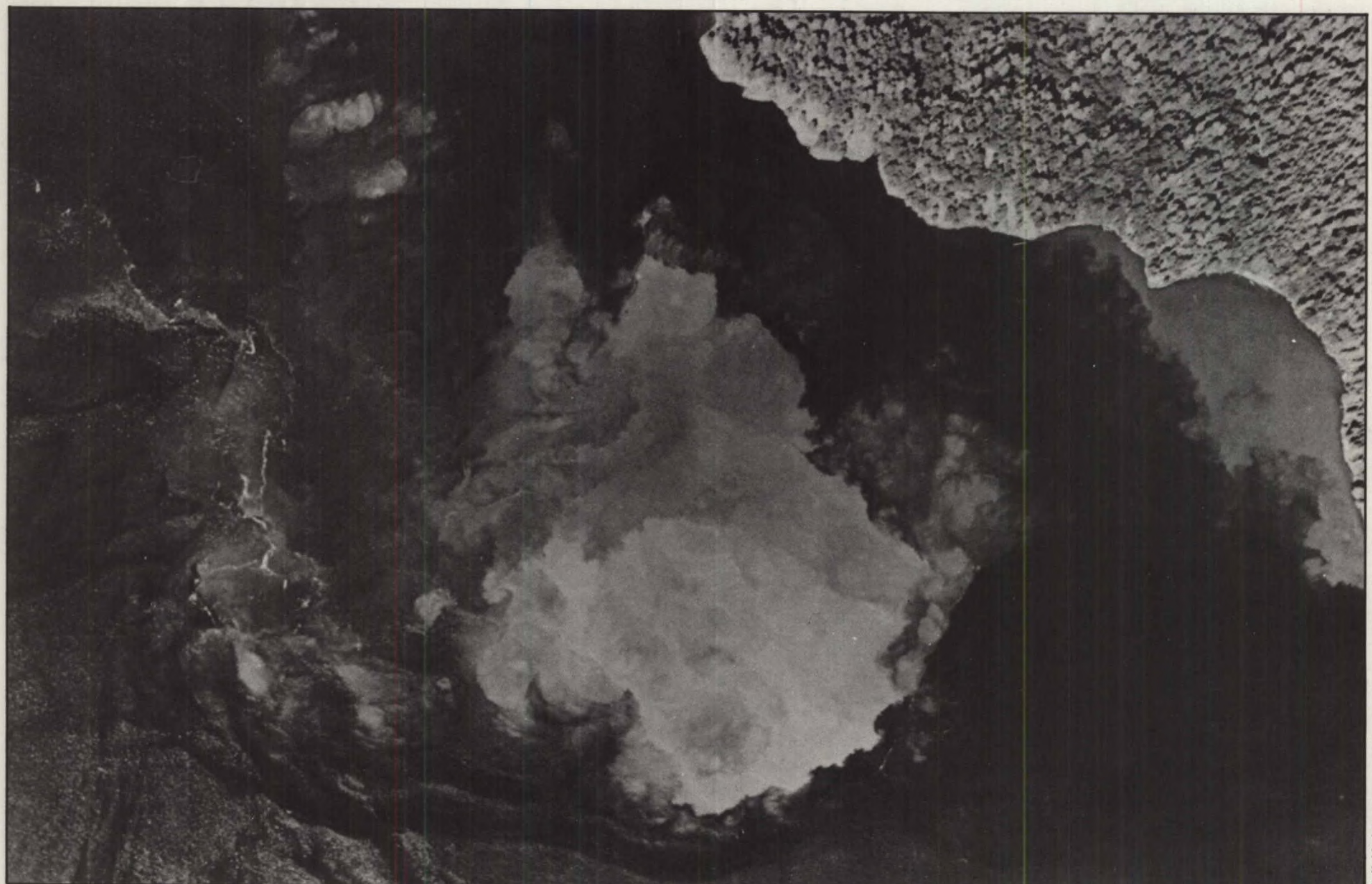
Oil spill — Fraser River Estuary



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Surfacing mine tailings

Chapter 3
Pollutant discharges and their effects on the environment

Introduction

Chapters 1 and 2 have described the sources of pollution, the legislation regulating them, and the potential effects of the pollutants on the marine environment. Chapters 3 and 4 describe the type of wastes discharged, the amount or volume of the discharge and the environmental impacts.

Effluent waste

The location and total volume of effluents discharged each day from major urban and industrial centres along the coast are shown in Figure 5. The greatest volume of effluent is discharged into the Strait of Georgia.

The number of waste discharges for which permits were issued has increased almost sixfold between 1973 and 1985 (Figure 6) and had reached a total of 400 in 1986. The number of domestic sewage discharge permits has increased substantially since 1978, whereas the number of permits for other types of waste has remained relatively constant. By 1985, domestic sewage discharge permits accounted for 67% of all marine outfall permits issued, as illustrated in Figure 7. However, discharges from the pulp and paper industry contribute more effluent volume to coastal waters (Figure 7) than do discharges from other sources.

Solid waste

Many types of solids are discharged to the marine environment. These include organic solids, such as wood wastes and sewage, and inorganic solids, such as mine tailings. Suspended solids can increase turbidity, thereby limiting light penetration and reducing the energy available for photosynthesis. Solids can also sink to the bottom, where they can smother habitat.

The effects of waste on oxygen levels in the marine environment

Marine life requires oxygen to live and grow. Oxygen is produced in the water by photosynthesis in phytoplankton and marine plants and is absorbed from the air at the surface. Oxygen can also be supplied to inlets and fjords by movement of oxygen-rich water masses from the open ocean and by surface runoff of well-oxygenated rainwater. Insufficient oxygen in marine ecosystems leads to stress or death of commercially important fish and other marine species.

Because marine microorganisms require oxygen to decompose organic wastes generated by human and industrial activities, the presence of such wastes may result in a reduction in the natural oxygen content of seawater. The amount of oxygen consumed by bacteria in this process is called the biochemical oxygen demand (BOD) and measuring the BOD at an outfall provides information on the organic content of wastewaters. The higher the BOD, the less dissolved oxygen is available for plants and marine life.

Toxicity testing

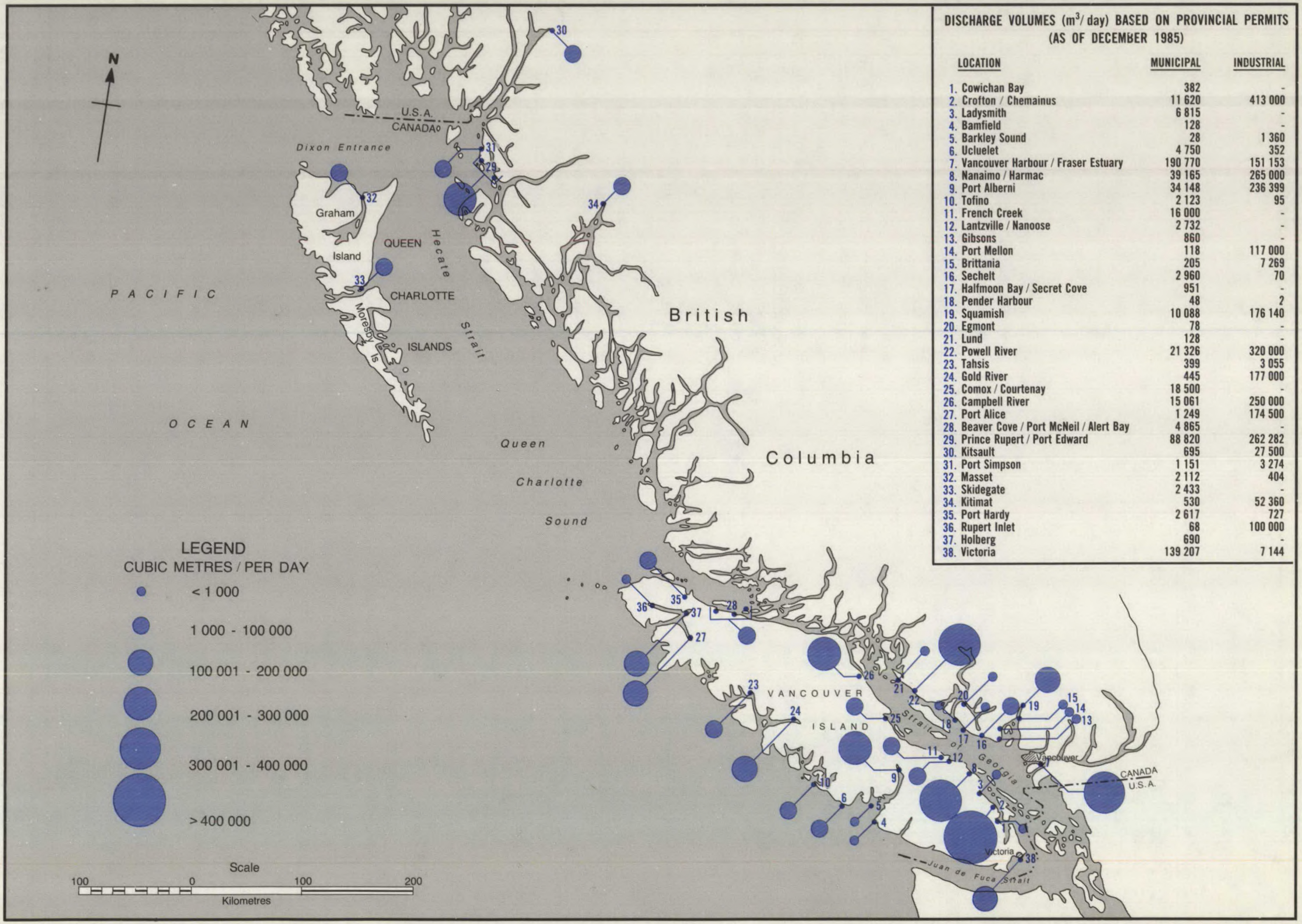
Acute toxicity of effluents is measured by determining the effluent concentration (LC_{50}) at which 50% of the test organisms die within a given period of time (usually 96 h for fish bioassays). Chronic toxicity can be measured by subtle, long-term changes in test organisms, such as behaviour modification and reproductive abnormalities.

Municipal wastewaters and effluents from the pulp and paper and mining industries are tested routinely as part of the regulatory process. Fish are usually used as the test organism. Toxicity testing measures the toxicity of the effluent as a whole and does not generally distinguish those components responsible for the toxicity.

Municipal waste

With the exception of the Iona Island sewage treatment plant, all municipal wastes are discharged to the ocean through submerged outfalls. The effluent discharge from the Iona Island sewage treatment plant, serving Vancouver and parts of Burnaby, flows through a 6-km channel dredged across Sturgeon Bank in the Fraser River estuary. The discharge of sewage from the Iona Island plant has resulted in significant and frequent oxygen depression in the effluent channel and in an area near the channel on Sturgeon Bank. Fish kills have occurred up to

Figure 5
Volume of waste discharged daily at major industrial and municipal marine outfalls, 1985

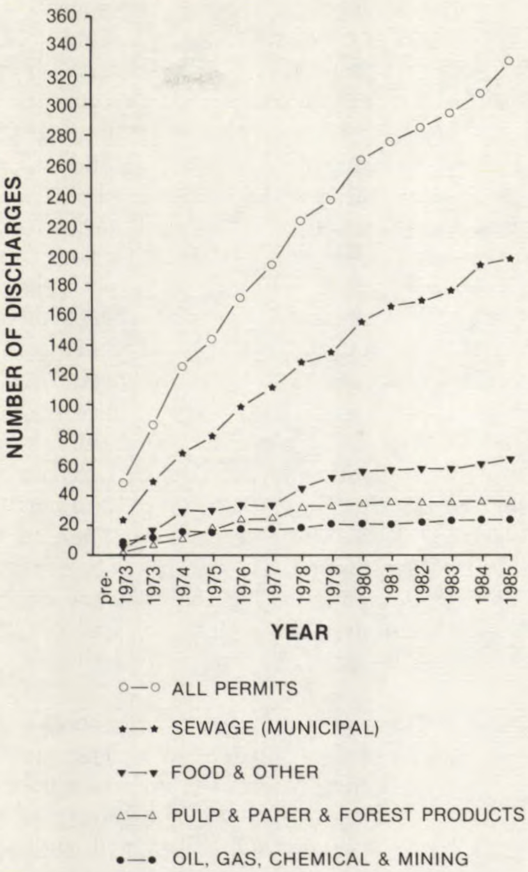


DISCHARGE VOLUMES (m³/ day) BASED ON PROVINCIAL PERMITS (AS OF DECEMBER 1985)

LOCATION	MUNICIPAL	INDUSTRIAL
1. Cowichan Bay	382	-
2. Crofton / Chemainus	11 620	413 000
3. Ladysmith	6 815	-
4. Bamfield	128	-
5. Barkley Sound	28	1 360
6. Ucluelet	4 750	352
7. Vancouver Harbour / Fraser Estuary	190 770	151 153
8. Nanaimo / Harmac	39 165	265 000
9. Port Alberni	34 148	236 399
10. Tofino	2 123	95
11. French Creek	16 000	-
12. Lantzville / Nanoose	2 732	-
13. Gibsons	860	-
14. Port Mellon	118	117 000
15. Brittania	205	7 269
16. Sechelt	2 960	70
17. Halfmoon Bay / Secret Cove	951	-
18. Pender Harbour	48	2
19. Squamish	10 088	176 140
20. Egmont	78	-
21. Lund	128	-
22. Powell River	21 326	320 000
23. Tahsis	399	3 055
24. Gold River	445	177 000
25. Comox / Courtenay	18 500	-
26. Campbell River	15 061	250 000
27. Port Alice	1 249	174 500
28. Beaver Cove / Port McNeil / Alert Bay	4 865	-
29. Prince Rupert / Port Edward	88 820	262 282
30. Kitsault	695	27 500
31. Port Simpson	1 151	3 274
32. Masset	2 112	404
33. Skidegate	2 433	-
34. Kitimat	530	52 360
35. Port Hardy	2 617	727
36. Rupert Inlet	68	100 000
37. Holberg	690	-
38. Victoria	139 207	7 144

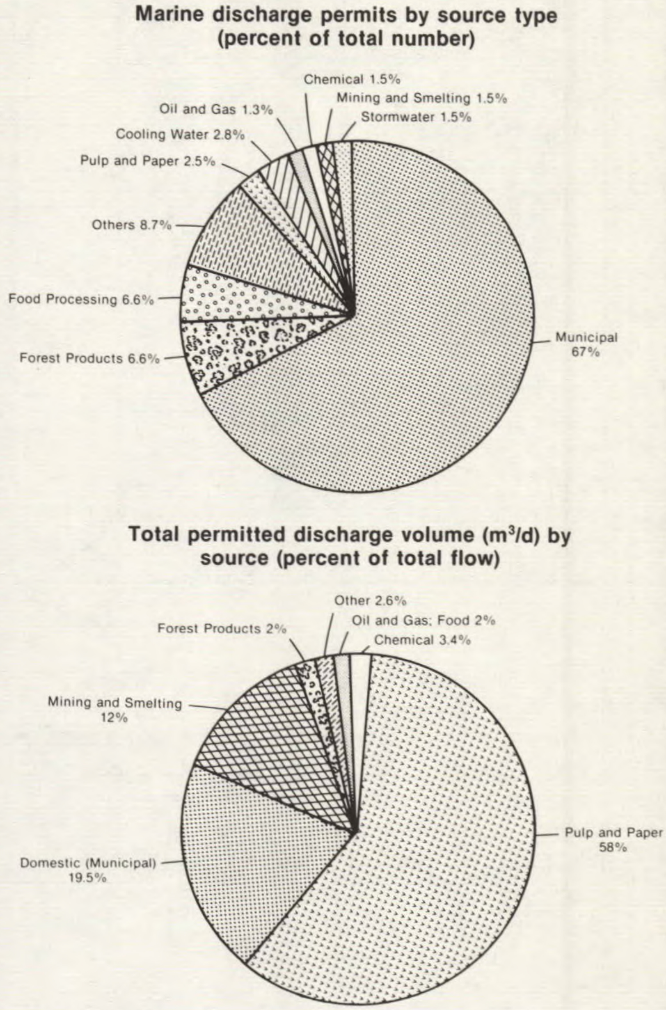
SOURCE: Discharge Inventory Database, Environmental Protection, Pacific and Yukon Region.

Figure 6
Number of permitted marine discharges, 1973-1985



SOURCE: Discharge Inventory Database, Environmental Protection, Pacific and Yukon Region.

Figure 7
Marine discharge permits and effluent discharge volume by source, 1985



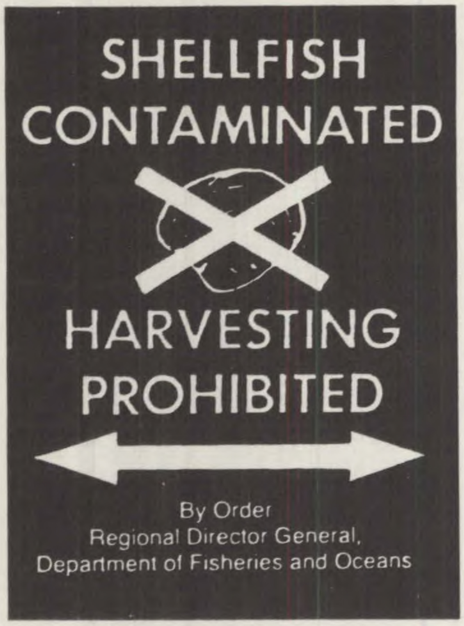
SOURCE: Discharge Inventory Database, Environmental Protection, Pacific and Yukon Region.

4 km from the outfall, usually during calm, warm weather (Birtwell *et al.* 1983). Solutions to this problem are now being implemented through improvements in primary treatment and construction of a submarine outfall to remove the effluent from the sensitive estuarine environment. Extensive monitoring will assess the impact of the new outfall.

The BOD from other municipal discharges (see Figure 13) is substantially less than the Iona Island discharge.

Laboratory bioassays of a variety of B.C. municipal wastewaters have shown most effluents to be toxic to some degree (Higgs 1977). Ammonia is responsible for the acute toxicity in fish. The levels detected in the sea around coastal outfalls to date are well below levels known to be toxic to marine species.

The organic solids discharged at sewage outfalls are more easily biodegraded than are the complex cellulose compounds discharged by pulp mills. Consequently, the zone of influence is much smaller around municipal discharges. In addition, solids from sewage (with the exception of some inorganic solids) are more likely to disperse throughout the water column than to settle out. At the Macaulay Point outfall, which discharges raw sewage from Victoria, underwater visual observations found a black organic accumulation at the end of the outfall; it began to thin out 20 m from the pipe end and was much less evi-



dent at 40 m. Similar or lesser effects have been observed at other municipal waste outfalls (Petrie and Holman 1983). Figure 8 shows the average amount of solids discharged daily from the major marine sewage outfalls.

Environmental impact of bacterial pollution

Bacteria and viruses that may be harmful to public health enter the ocean through point sources, such as municipal sewage, and non-point sources, such as urban and agricultural drainage (Hoadley and Dutka 1977). It is well established that contaminated drinking water can transmit disease. This has resulted in major efforts to safeguard drinking water. Skin, ear, eye, nose and throat infections can be caused by swimming in polluted waters.

Bacteria called fecal coliforms are used as indicators of contamination from sewage in swimming areas and areas where shellfish are harvested. Swimming areas are usually closed when the fecal coliform count exceeds 200 organisms per 100 mL. High standards for water quality are demanded in areas where shellfish are harvested. Harvesting is prohibited when the median fecal coliform count exceeds 14 per 100 mL. For example, 1 L of sewage effluent that has not been disinfected would have to be diluted by 35 000 to 71 000 L of seawater to meet the standard for shellfish growing.

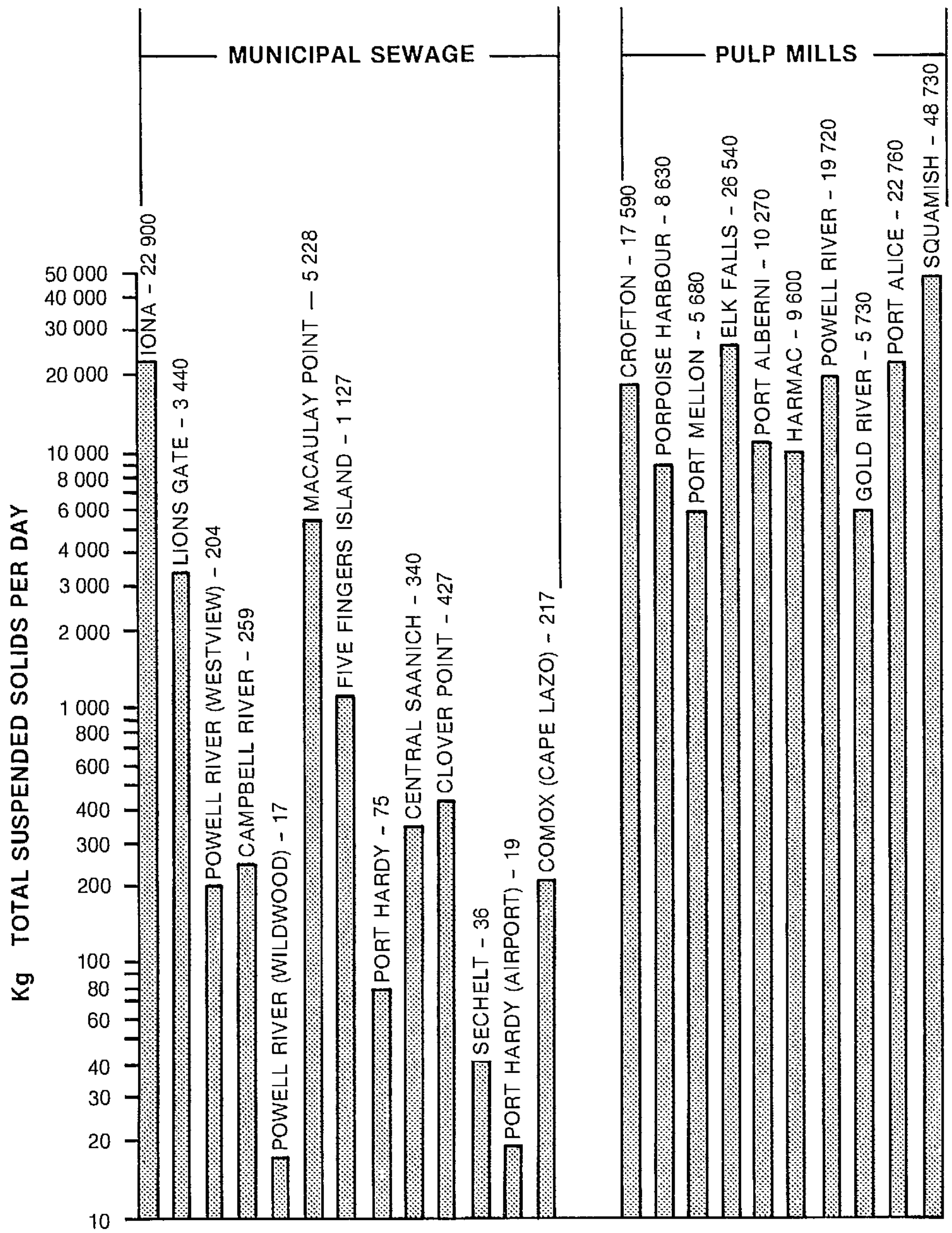
Filter-feeding shellfish such as oysters, clams and mussels can concentrate sewage bacteria in their tissues. The incidence of human disease caused by consumption of contaminated shellfish has been well documented (Hunt 1977). The danger increases for those consumers who prefer to eat oysters or other shellfish raw or only partially cooked. Although there have been no disease outbreaks in British Columbia from consumption of contaminated shellfish, there have been outbreaks of diseases such as cholera, salmonellosis (food poisoning) and infectious hepatitis in other parts of the world. Typhoid was also commonly transmitted by this route, but the last recorded North American incident was in 1954.

The impact of municipal sewage discharges on major commercial shellfish production areas is relatively minor, because most oyster and clam harvesting occurs at a considerable distance from urban centres. However, during the early 1960s, sewage pollution caused the closure of major oyster production areas at Comox, Ladysmith and Boundary Bay. In the early 1970s, most clam harvesting was prohibited in the Port Hardy area. These closures remain in effect, although Ladysmith has been partially reopened because of improvements in sewage treatment and disposal methods. Sewage pollution has also closed numerous areas to recreational shellfish harvesting.

Municipal marine discharges are the sole cause of approximately 7% of all shellfish closures. They are implicated as a major pollution source in approximately 25% of the contaminated areas, and as a minor source in a further 25%. Figure 9 shows changes in shellfish closures between 1972 and 1986. The increase in size of areas closed has been negligible (about 0.5%) since 1972. If the closed areas in highly urbanized Vancouver and Victoria are excluded from this calculation, there has even been a slight decrease (about 8%) in the total area closed. This can be attributed primarily to the reopening of Parksville Bay following the construction of the French Creek sewage treatment plant and outfall, the reopening of portions of Ladysmith Harbour following improvements in sewage collection systems and the partial reopening of Nanaimo Harbour following installation of the Five Finger Island outfall and cessation of the raw sewage discharge at Newcastle Island.

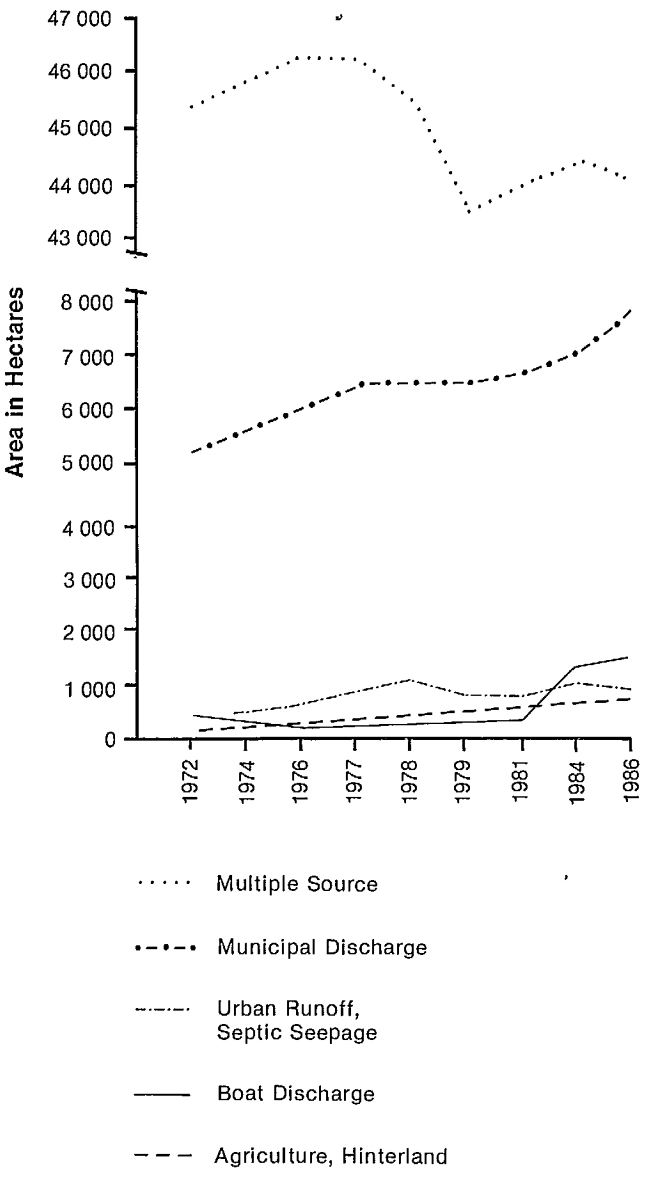
Sewage from anchored pleasure boats has caused several shellfish areas to be closed during the summer. Areas closed due to agricultural runoff have steadily increased over the past several years. Without adequate control, these transient and diffuse pollution sources will continue to encroach on shellfish growing areas. Figure 10 shows shellfish areas along the coastline that have been closed because of sewage.

Figure 8
Average amount of suspended solids (kg/d) discharged daily from major marine sewage and pulp mill discharges, 1985



SOURCE: Kay 1986; Environmental Protection, Pacific and Yukon Region, unpublished data.

Figure 9
Trends in B.C. shellfish closures, 1972–1986



SOURCE: Environmental Protection, Pacific and Yukon Region, unpublished data.

Environmental impact of nutrient pollution

The release of large amounts of nutrients (nitrogen and phosphorus) has caused excessive growth of algae and other aquatic plants (eutrophication) in freshwater systems.

In marine systems, nutrients come from sewage outfalls, agricultural runoff and other non-point sources. Increases in nutrient concentrations can stimulate the growth of phytoplankton. Evidence to date indicates that nutrients have less impact in seawater than in freshwater systems. Although nutrient levels around large municipal outfalls in southern B.C. coastal areas are sometimes elevated above background levels, no environmental effects have been documented (Lorimer 1984). Levels of nutrients recorded at sampling stations around major sewage outfalls and the background level at a reference point near Texada Island are shown in Figure 11.

Industrial waste

Pulp and paper

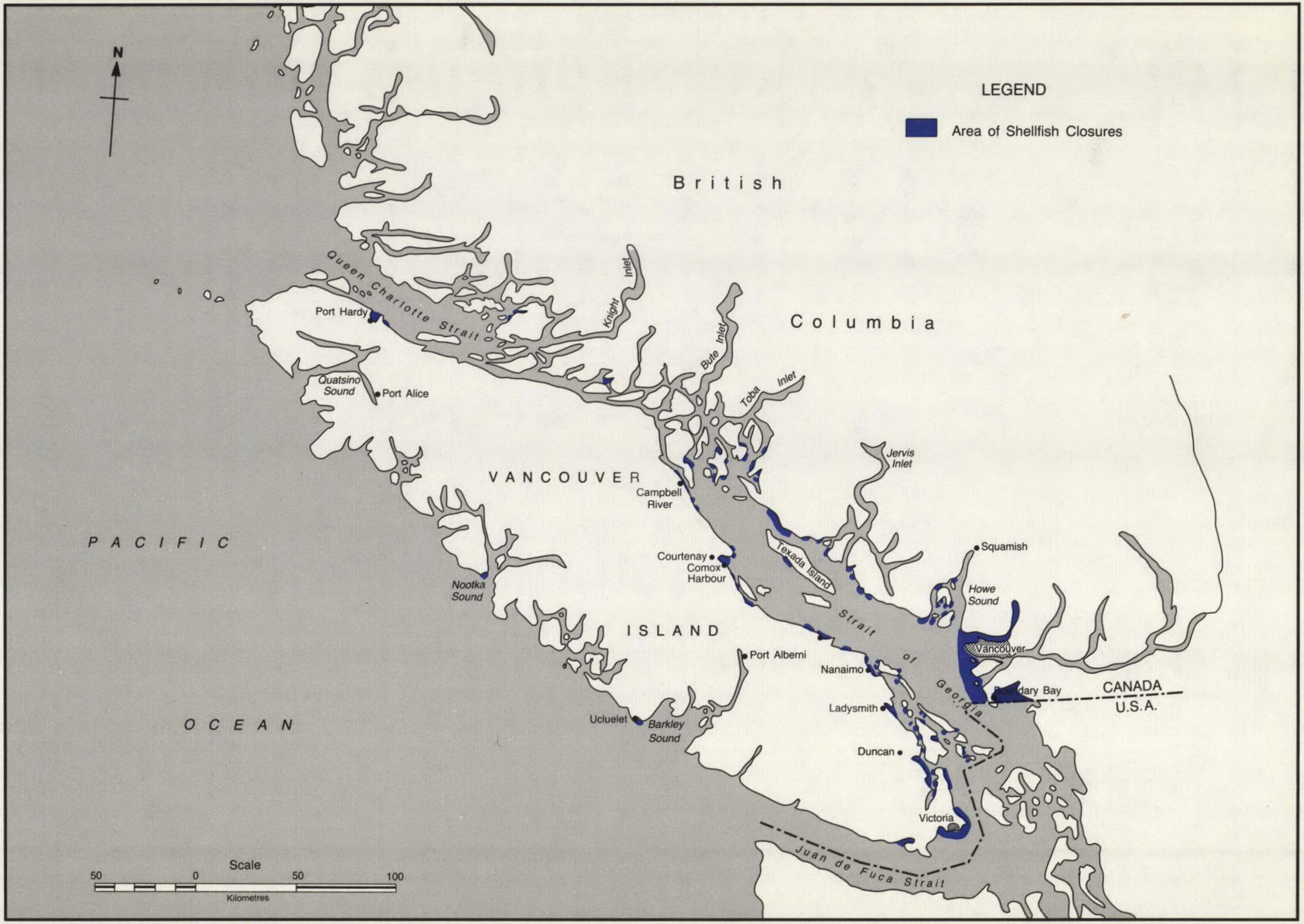
Pulp mills discharge large quantities of solid wastes, both wood fibre and wood wastes. The average total daily discharge of solids (measured as total suspended solids, TSS) from all coastal mills between 1975 and 1986 are presented in Figure 12. The greatest reduction in TSS occurred between 1975 and 1980. In 1986, approximately 125 000 kg of solids were discharged into the ocean every day (Figure 12). Figure 8 shows the average amount of solids discharged daily from each mill in 1985.

Most solids settle out, removing bottom habitat and smothering benthic organisms. The zone of measurable impact ranges from about 0.5 km to almost 5 km (Kay 1986). Insufficient data are available to determine the rate at which fibre deposition is encroaching on benthic habitat. Overall, fibre releases have stabilized since 1980, although areas of fibre deposition are increasing at some locations, including Northumberland Channel, Malaspina Strait and Porpoise Harbour (Pomeroy 1983).

Municipal sewage and pulp and paper effluents exert the greatest BOD loads on the marine environment. Environmental controls in the pulp and paper industry have substantially reduced the BOD from pulp mill effluent. BOD loading was reduced by 56% between 1975 and 1980, although recent reductions have not been as significant (Figure 12). Despite these reductions, the BOD load from the average pulp mill exceeds that in the sewage from most of our larger coastal cities (Figure 13).

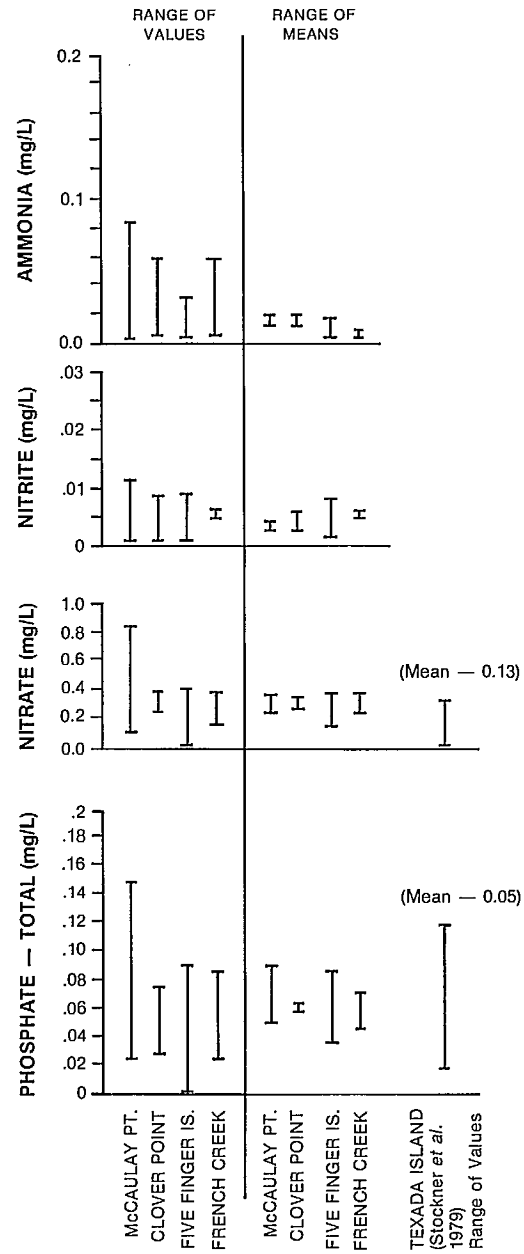
Dissolved oxygen problems persist at pulp mill operations at Port Alberni and Port Alice on Vancouver Island, even though improvements have been made in effluent treatment and disposal. Low oxygen levels have been measured, especially in summer, as a result of effluent BOD, reduced photosynthetic activity (due to effluent colour), poor water circulation and oxygen demand from slowly degrading wood fibres on the bottom. Such effects can have significant impact on migrating salmon.

Figure 10
Sanitary closures of shellfish production areas in coastal waters of southern British Columbia, 1986



SOURCE: Environmental Protection Pacific and Yukon Region.

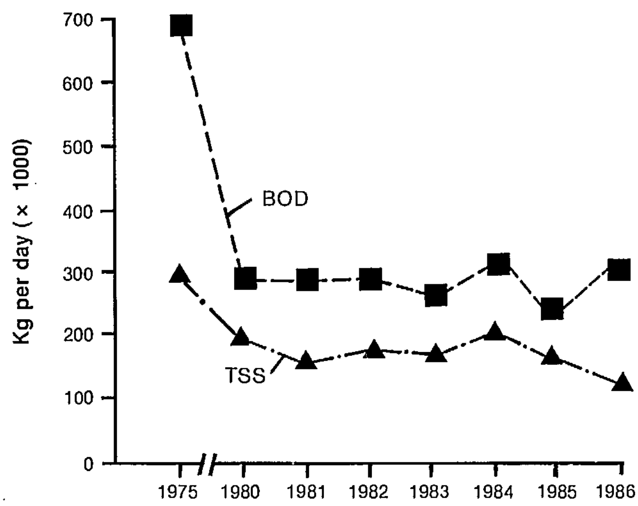
Figure 11
Range of nutrient values for selected marine waters receiving municipal wastes



SOURCE: Balch *et al.* 1976; Waters 1976; Packman 1977; Stockner *et al.* 1979; Hoff 1981; Pomeroy and Packman 1981; Vassos 1982; Goyette *et al.* unpublished; EQUIS, Data Management System, Waste Management Branch (W.M.B.), B.C. Ministry of Environment and Parks 1982; W.M.B. unpublished data.

NOTES: 1. Values at outfall sites are for all stations and all depths.
2. Values for Texada Island are for surface (0-5 m) measurements in an area free of anthropogenic nutrient inputs.

Figure 12
Biochemical oxygen demand (BOD) and total suspended solids (TSS) discharged daily from coastal pulp mills (excluding Ocean Falls), 1975–1986

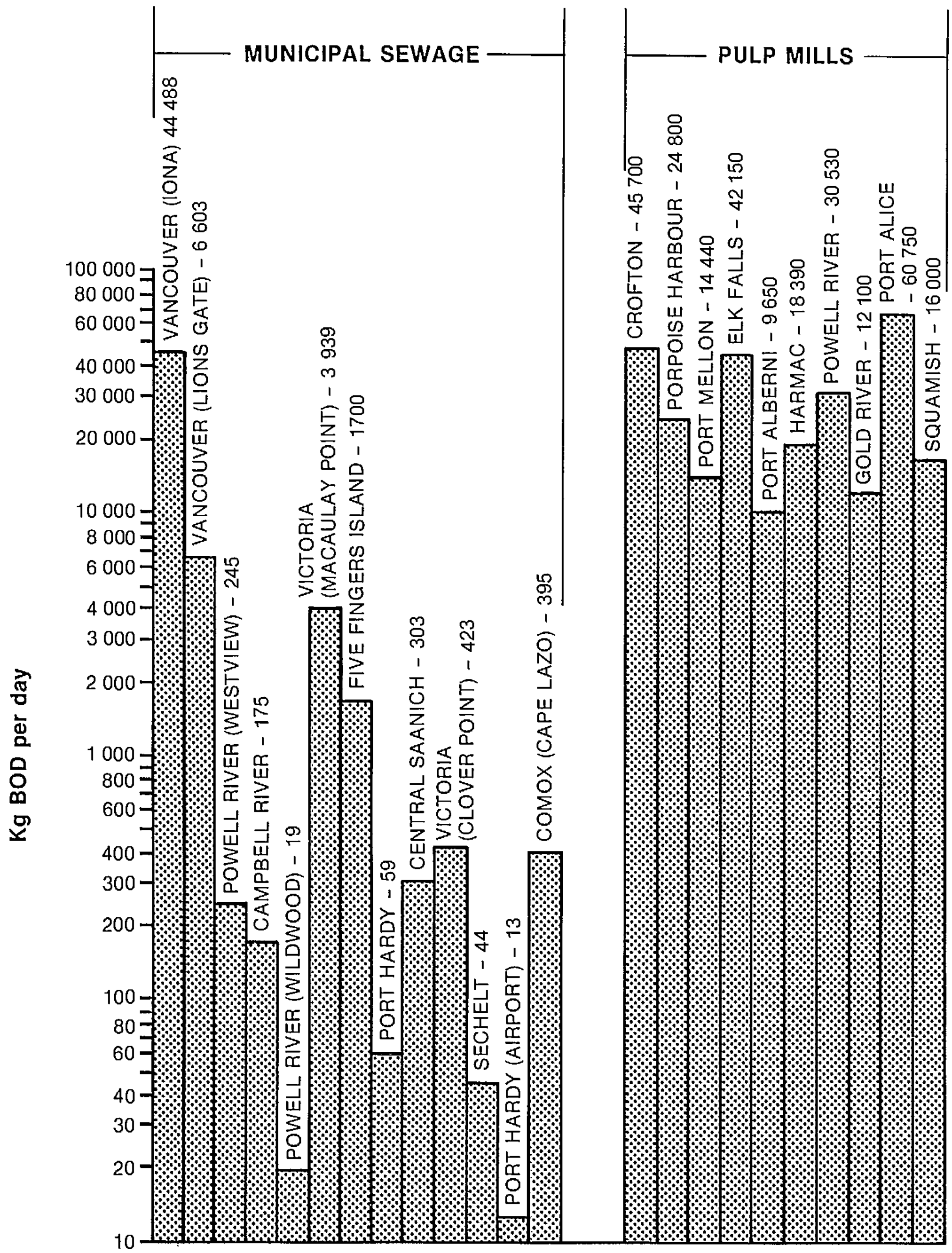


SOURCE: Kay 1986; Environmental Protection, Pacific and Yukon Region, unpublished data.

At the Port Alberni mill, the BOD discharge is adjusted according to the Somass River flow to provide sufficient oxygen levels to maintain fish life in the inlet. At Port Alice, BOD loading creates periodic oxygen depression in Neroutsos Inlet. In September 1985, dissolved oxygen levels were considered to be low enough to act as a barrier to migrating chum salmon (Colodey and Pomeroy 1985). Low dissolved oxygen levels were also found at the Ocean Falls mill (Packman 1979), which has since closed, and the mill at Porpoise Harbour near Prince Rupert (Waldichuk *et al.* 1968). In the latter case, changes in mill processes, pollution abatement technology and effluent discharge locations have resulted in a return to healthy oxygen levels.

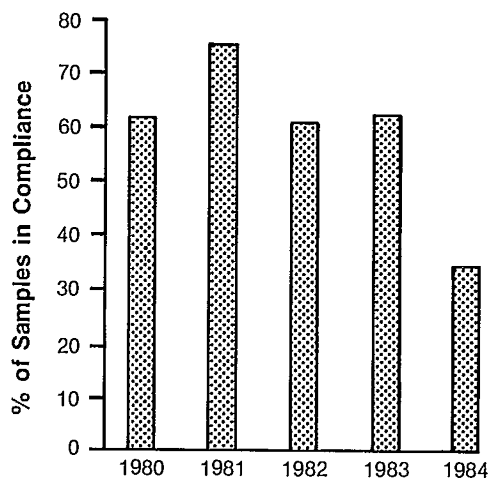
Pulp mills must measure the toxicity of their effluents to fish species to fulfill a requirement of their provincial discharge permits under the *Waste Management Act*. Both federal and provincial governments also monitor effluent toxicity to determine whether it is in compliance with environmental regulations. Toxicity is extremely variable between mills and within the same mill, and studies have found that untreated effluents are not acutely toxic about 23% of the time (Walden and Howard 1977). Toxicity requirements vary for each mill, depending on the age of the mill, pulping process, discharge location and other

Figure 13
Average biochemical oxygen demand discharged daily from major sewage outfalls and pulp mills, 1985



SOURCE: Kay 1986; Environmental Protection, Pacific and Yukon Region, unpublished data.

Figure 14
Coastal pulp mill toxicity compliance, 1980-1984



SOURCE: Kay 1986; Environmental Protection, Pacific and Yukon Region, unpublished data.

factors. Figure 14 shows the degree of compliance by all coastal mills between 1980 and 1984. There is an apparent trend to decreasing compliance; however, the data may be skewed by one or two mills having poor compliance records. Sampling frequency increases when mills have difficulty meeting their compliance levels.

It has been estimated that between 70 and 100% of the toxicity of pulp mill effluents is caused by resin acids from the wood and by chlorinated lignins and other chlorine-containing compounds formed in the bleaching process (Leach and Thackore 1977). Very few studies have examined the effects of pulp mill effluent in B.C. marine waters. Under experimental conditions, toxicity, as measured by fish mortality or avoidance reactions, has been detected up to 10 km from a surface-discharged effluent (McGreer *et al.* 1980). Prior to the installation of submerged outfalls and diffusers at most coastal mills, toxicity was also measured by the effects of mill wastes on intertidal zones. In many cases, barnacles in these areas experienced die-off cycles, and normal shorelife was absent. Such effects have been measured up to 8 km from a discharge point. Intertidal zones have recovered significantly within a few months to a year after effluent is diverted to submerged outfalls.

The chronic and sublethal toxic effects of pulp mill effluents in marine ecosystems are not well understood. Experimental studies have shown that sublethal concentrations of effluent cause stress in fish (behaviour modification, changes in temperature tolerance or alteration in feeding habits; reviewed by Kay 1986). However, there has not been any documented decline in commercially harvested finfish stocks because of pulp mill effluent effects. Chronic exposure to toxic effluents could have a negative impact on fish stocks under less favourable conditions (such as poorly flushed, sensitive environments). For example, oyster beds near the Crofton mill have become less productive, and the oysters are in poor condition (Davis *et al.* 1976).

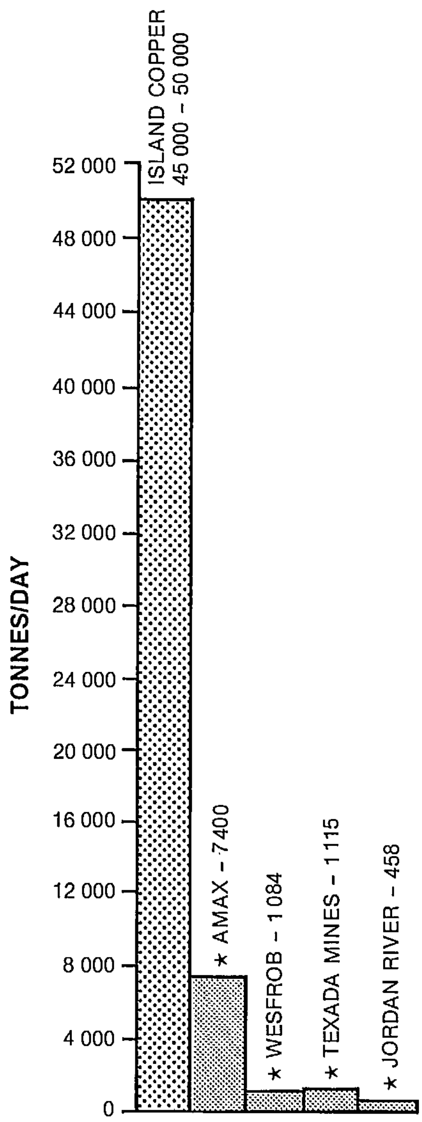
Mining

The marine disposal of mine tailings is one of the largest sources of inorganic solids from human activities. The disposal of mine and mill tailings results in a massive discharge of solids to the environment (Figure 15). The only mine currently operating on the coast discharges approximately 45 000–50 000 t of inorganic solids to Rupert Inlet on Vancouver Island each day. Other mines, operative in recent years, have discharged between 460 and 7 400 t of tailings each day. Affected areas in and around Rupert Inlet include deep trough, shallow subtidal and intertidal habitats up to 18 km from the mine's outfall. It is estimated that the depth of tailings in the trough of Rupert Inlet will reach 46 m during the life of the mine (Waldichuk and Buchanan 1980).

Tailings have been observed 3–4 km from a now-abandoned mine outfall in Tasu Sound, Queen Charlotte Islands (Harding 1983), whereas impacts have been recorded in Alice Arm (Burling *et al.* 1983) 7–10 km from the discharge point. Similar patterns have been observed at other mine sites on Texada Island (Thompson *et al.* 1979) and in Howe Sound (Levings and McDaniels 1973; Thompson and McComas 1973; Goyette 1975; Petrie and Holman 1983). Such large discharge volumes can cause extensive obliteration and loss of benthic habitat. Little is known about the long-term effects of smothering on the diversity of marine life and on commercially important fish (reviewed by Kay 1986).

Suspended solids from the discharge of mine tailings can cause increased water turbidity. An increase in water turbidity can reduce light penetration and decrease photosynthesis. However, outfalls have usually been located to lessen the chance of tailing clouds reaching the surface. In addition, salt water has been added to tailings to reduce the buoyancy of the plume. Even with such measures, tailing clouds have not always behaved as predicted. Sometimes they rise to higher levels and appear at the surface, as in the case of Rupert Inlet (Goyette and Nelson 1977; Burling *et al.* 1983). These plumes have not been shown to adversely affect photosynthesis or primary productivity.

Figure 15
Daily tonnage of tailings discharged by some past and present B.C. coastal mines



SOURCE: Kay 1986.

* Not operating

More significant impacts, including smothering and alteration of intertidal and near-shore habitat and reduced primary productivity, were caused by tailings discharged at the surface from now-abandoned operations. Intertidal habitats were affected at Jordan River, Britannia Beach, Alice Arm and Hasting Arm (also a copper smelter site) as a result of these early mines.

Neutralized mine wastes are not normally acutely toxic to test species (Hoos and Holman 1973), and toxic effects have not been observed in marine systems receiving mine tailings. However, toxicity has been found to result from acid mine drainage and slag pile leachate at two abandoned mine sites (Goyette 1985).

Ocean dumping

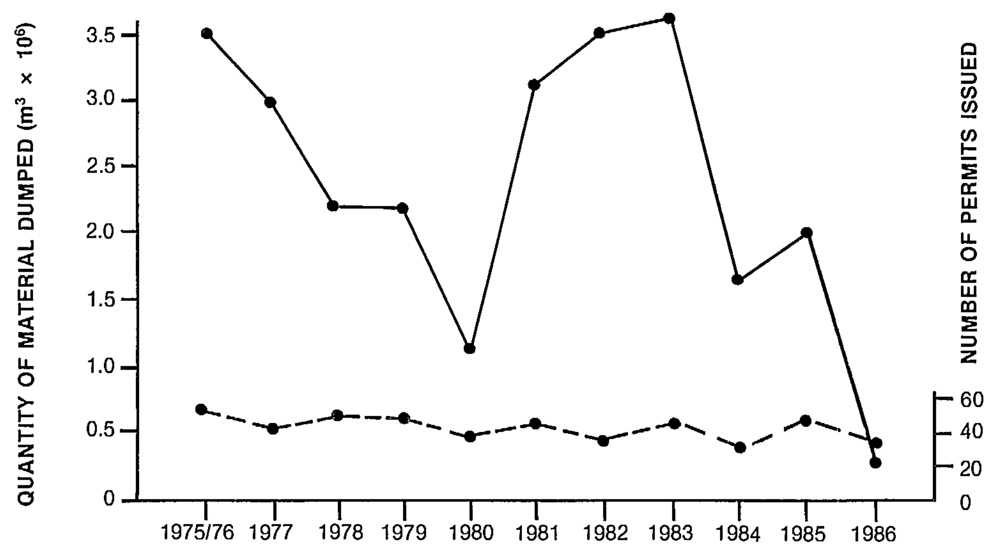
The number of ocean dumping permits issued by Environment Canada under the *Ocean Dumping Control Act* has remained relatively constant (Figure 16). Total quantities of materials dumped in the B.C. marine environment between 1975 and 1986 are also shown in Figure 16.

Information on the effect of dumping solids in the ocean has been obtained from underwater photography (still and video pictures) and benthic community studies at the Point Grey and Port Alberni dumpsites (Anderson *et al.* 1977, 1978; McDaniel *et al.* 1977; Beak Consultants 1978; EVS Consultants Ltd./Fisheries and Oceans Canada 1979; O'Connell/Dobrocky Seatech 1979; Packman 1980; Berrang 1981; Levings/EVS Consultants Ltd. 1981; Popham *et al.* 1983). Most types of material dumped in B.C. waters do not appear to adversely affect the marine community. The above authors noted that changes in species abundance, diversity and biomass had occurred. Dumped material, particularly larger objects such as concrete blocks, can provide habitat enhancement for benthic organisms if properly placed.

Spills

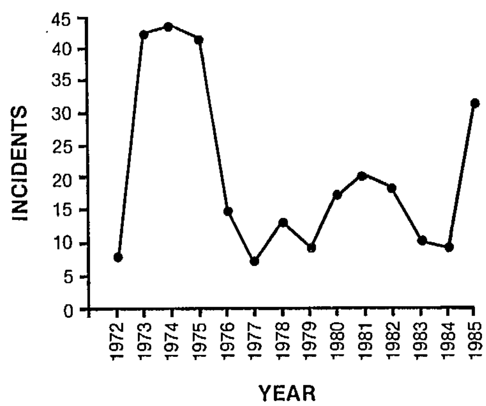
The NATES database recorded 252 significant spills in B.C. marine waters between 1972 and 1984. Figures 17 through 19 show the number of spills in a year, the source and the quantity of material dumped. Although petroleum spills make up 84% of the reported incidents, industrial chemical spills account for the largest quantities (6 839 t or 63.5%). Furthermore, 93% of industrial chemical spills involve process-line or effluent-line breaks or other accidents at pulp and paper mills.

Figure 16
Total amount of material dumped (m^3) and permits issued per year, 1976-1986



SOURCE: Environmental Protection, Pacific and Yukon Region, unpublished data.

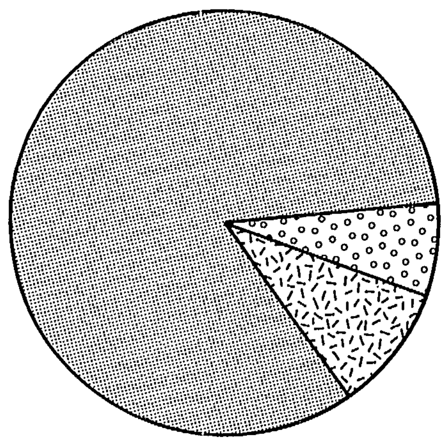
Figure 17
Significant* marine spills: yearly summary, 1972-1985



SOURCE: NATES Database — Environment Canada.

*Significant spill is where the spilled material exceeds 1 t.

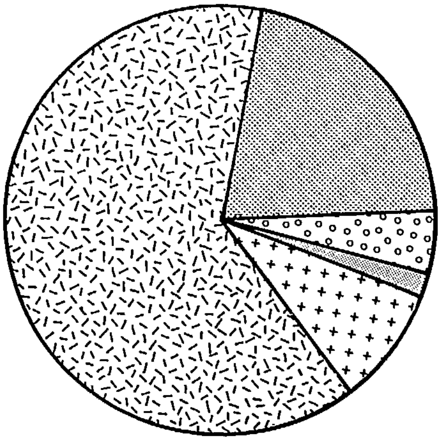
Figure 18
Significant marine spills: number of incidents, 1972-1984



	(no.)	(%)
PETROLEUM	211	83.7
IND. CHEMICAL	24	9.5
OTHER	17	6.8
TOTAL	252	100.00

SOURCE: NATES Database — Environment Canada.

Figure 19
Significant marine spills: quantity of material, 1972–1984



	(t)	(%)
PETROLEUM	2 300	21.4
IND. CHEMICAL*	6 839	63.5
BASE	955	8.9
IND. WASTE	136	1.3
OTHER	532	4.9
TOTAL	10 762	100.00

SOURCE: NATES Database — Environment Canada.

* 93% of total spill volume from pulp and paper incidents (i.e. not bulk chemical spills).

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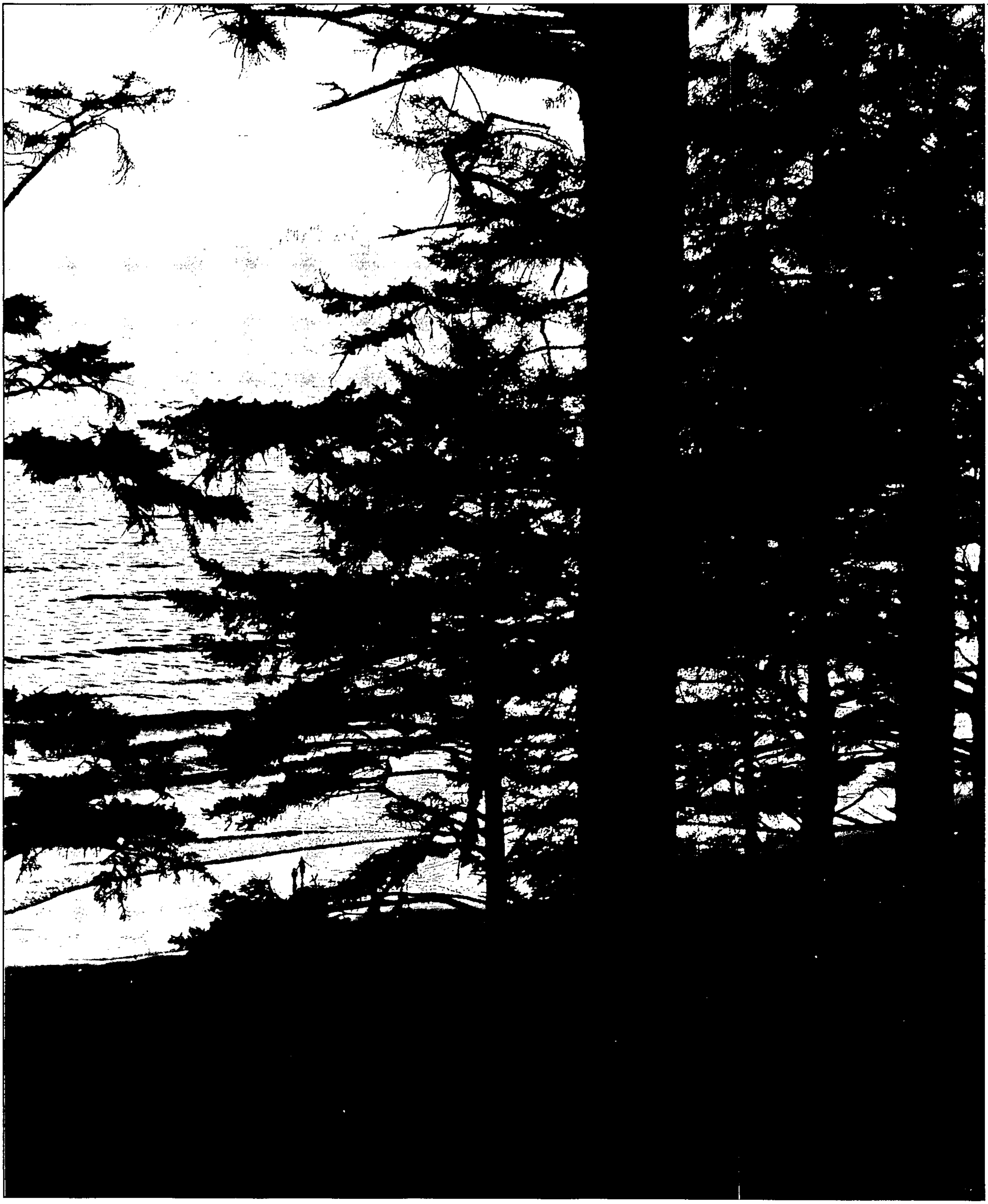


Tourism Canada

Chapter 4
Toxic substances

There is growing concern over a number of pollutants whose effects we are just beginning to understand. They are capable of causing biological damage at low concentrations and can accumulate in individual species (bioaccumulation) or through entire food webs (biomagnification). These substances, often referred to as "toxics" or "toxic chemicals," may be synthetics, such as polychlorinated biphenyls (PCBs) and dichlorodiphenyltrichloroethane (DDT), or trace metals, such as cadmium, lead, arsenic and mercury.

Toxic pollutants can cause a decrease in the abundance of sensitive species, causing an imbalance to occur in the marine ecosystem. Few public health problems related to toxic pollution in the marine environment have been documented in British Columbia. However, fishing closures have been temporarily imposed for public health protection in Boundary Bay (because of a chlorophenol spill), in Porpoise Harbour (because of a spill of PCB-containing oil) and in Howe Sound (because of high mercury levels). Few data are available on most toxic substances. The following discussion will concentrate on the most commonly measured substances: metals, chlorinated hydrocarbons, organotin compounds and petroleum hydrocarbons. Little information has been gathered on trends in bioaccumulation or long-term effects for most toxic substances in B.C. coastal waters.

Trace metals

The natural weathering of rocks, leaching of soils and vegetation, volcanic activity and forest fires introduce trace metals into the environment. People contribute to this input by mining and smelting ores, by burning coal and oil and by processing and disposing of industrial and municipal wastes. Most trace metals are transported in water (in solution or as particulates) and are deposited in river, lake or marine sediments. Although all metals are found in coastal waters, zinc, copper, lead, cadmium and mercury are the ones most commonly measured. Concentrations of these five metals in marine sediments are illustrated in Figure 20.

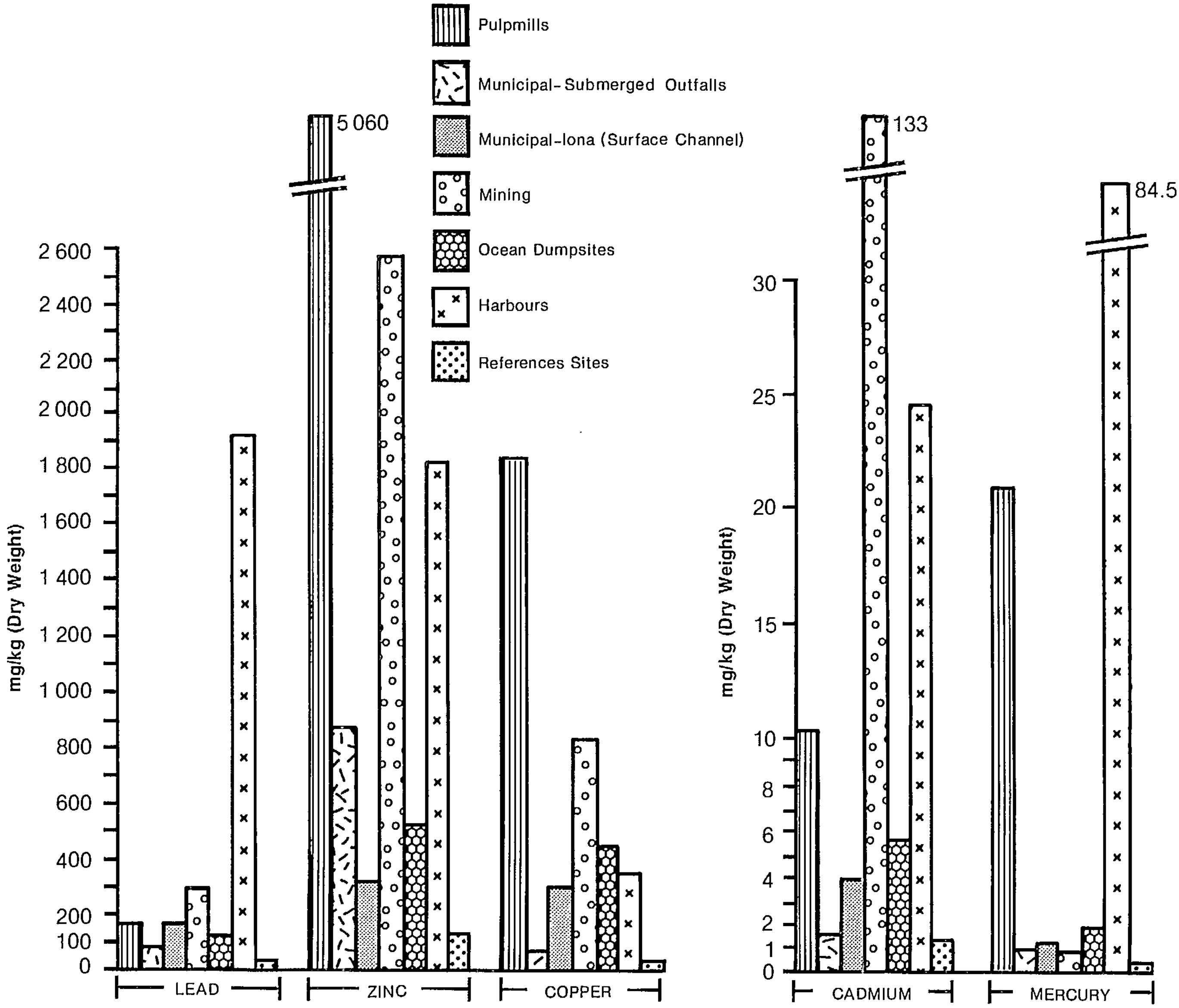
The level of trace metals may be a function of the natural mineralization of an area. The metals may be in a biologically unavailable form (e.g., bound in sediments). Chemical and biological processes may change their chemical form and make them biologically available.

Many trace metals play a vital role in plant and animal ecosystems and are required in a variety of enzyme functions. Examples of essential trace metals are selenium, chromium, copper and zinc. Lead, cadmium, mercury and aluminum, on the other hand, are referred to as non-essential metals, having no known biological function (Peereboom 1985). Their toxicity is a function of their chemical state, concentration and location within the organism. Many essential trace metals can cause toxic effects at concentrations higher than those at which they are biologically useful. They can also become poisonous after concentration in the food chain or in combination with other substances. These substances are persistent in the environment. Thus, their effects may occur many years after their initial release.

Concentrations of mercury, lead and cadmium in B.C. marine invertebrates are comparable with levels recorded in other areas of the world (Garrett *et al.* 1980; Garrett 1985*a*). Mercury is the only metal for which Health and Welfare Canada has established an acceptable limit in fish and shellfish intended for human consumption. Average concentrations are below the guideline value of 0.5 mg/kg wet weight in almost all areas. The highest concentrations of mercury (up to 13.4 mg/kg) were detected in the vicinity of a mercury-cell chlor-alkali plant in Howe Sound in the early 1970s. Mercury levels have decreased significantly in edible crab tissue and in other fish from that area following the imposition of much stricter environmental controls (Figure 21). In the Fraser River estuary, levels in crabs have been as high as 0.74 mg/kg. Mercury levels in salmon and pelagic ocean species are less than 0.5 mg/kg. Natural sources of mercury may cause concentrations in groundfish species and sharks to exceed the guideline.

Lead concentrations in various marine species are generally less than 0.5 mg/kg wet weight, but levels are notably higher in shellfish from Burrard Inlet (up to 86 mg/kg), the Fraser River estuary (3.25 mg/kg) and Alice Arm (9 mg/kg). These higher levels are associated with mining activities and industrialization in areas around

Figure 20
Maximum trace metal concentrations in sediment at B.C. coastal sites, 1975-1985



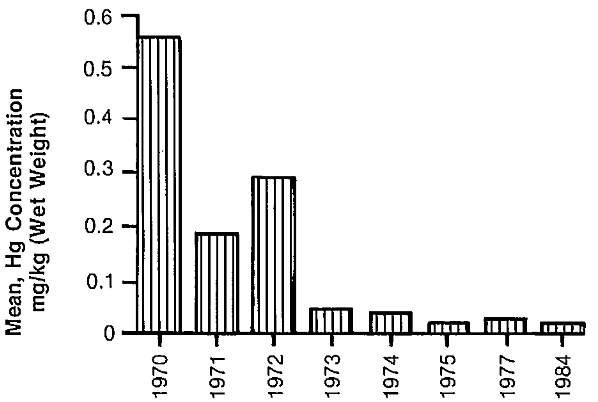
SOURCE: Kay 1986; Environmental Protection, Pacific and Yukon Region, unpublished data.

Vancouver.[1] There are currently no Canadian guidelines for lead in fish or shellfish for human consumption. The World Health Organization (WHO) has established a provisional tolerable weekly lead intake of 3000 μg (World Health Organization 1972).

Cadmium levels in invertebrates vary considerably with species, as shown in Table 7. Higher levels were found in oysters from Howe Sound and shellfish from Alice Arm, although there is no evidence of toxic effects on the organisms. No guidelines are in place for cadmium levels in fish

[1] The high level in Burrard Inlet in 1974 was recorded near a chemical plant. Early data such as these should be interpreted with caution because of different analytical techniques and quality control procedures. More recent data found the highest level to be 41 mg/kg in mussels collected near a shipyard.

Figure 21
Mean mercury levels in crab tissue, Howe Sound, 1970–1984



SOURCE: A.G. Colodey, unpublished data.

Table 7
Cadmium levels in various marine species at various B.C. locations, 1974–1985

	Concentrations (mg/kg wet weight)	
Species	Minimum	Maximum
Oysters	0.5	2
Scallops	1.87	3.6
Chiton	0.6	3.7
Limpets	0.75	8.2
Mussels	1.0	1.0
Clams and cockles	0.5	0.5
Shrimp		
Tail	0.05	0.51
Whole body	0.10	2.7
Crab		
Muscle	0.01	0.10
Viscera	0.01	25.0
Zooplankton		0.5

SOURCE: Garrett 1985*a*.

and shellfish for human consumption. The average cadmium intake from the Canadian diet is estimated to be 50–98 μg/d per person (National Research Council of Canada 1979).

Monitoring of sources of trace metals has been undertaken at several sites in B.C. near-shore coastal waters, and the results are reviewed briefly in the following sections.

Municipal waste

Street drainage, industrial wastes (such as those from the metal finishing industry), and household wastes are some of the sources of trace metals in municipal sewage. Trace metals in sediments, water and shellfish near municipal outfalls have been monitored by Environmental Protection at Comox–Cape Lazo (Colodey 1985), French Creek (Pomeroy 1982, 1984), Nanaimo (Pomeroy and Packman 1981; Pomeroy 1984), Prince Rupert, Port McNeil, Port Hardy, Ucluelet, Vancouver and Victoria (Environmental Protection, unpublished data).

Trace metal concentrations in sediments increase with time and nearness to the outfall. For example, copper and lead accumulations have been recorded at the Macaulay Point outfall. Increases in copper, zinc and manganese have been observed at French Creek. At Nanaimo, the only location for which long-term trend data are available, these metals have been steadily increasing in sediments since installation of an outfall and diffuser (Pomeroy 1984). The highest levels of trace metals were at Sturgeon Bank, near the Iona Island sewage treatment plant (Figure 20). Estimates of the daily discharge of metals from this plant are 0.6 kg cadmium, 14.7 kg lead, 50.5 kg copper and 45.9 kg zinc (EQUIS Data Management System, Waste Management Branch, B.C. Ministry of the Environment and Parks). No estimate can be made for mercury, as levels in effluent are usually non-detectable (<0.0005 mg/L).

The highest levels of lead, zinc, mercury and copper in molluscs have been reported around the Victoria area outfalls, although these levels are well below those at which there is concern for human health (Stanley Associated Engineering Ltd. 1982; Harbo *et al.* 1983).

Zinc levels in the tissues of English sole collected adjacent to the French Creek outfall increased by a factor of two between 1977 and 1980. Prawn and shrimp tail meat has shown an increase in concentrations of copper, iron and cadmium, but a decrease in the concentration of mercury (reviewed by Kay 1986).

Pulp and paper

Pulp mills are not currently considered to be major contributors of trace metals. In the past, effluents from pulp mills have contained significant levels of zinc and mercury. These two metals were used in the bleaching process and for control of slime and fungal growth. The use of zinc dithionate, a brightener, was discontinued in 1973, whereas the use of mercury-based "slimicides" was stopped around 1960.

The highest levels of mercury in sediments were recorded at the Powell River mill in 1978 and 1979 (Nelson 1979; Sullivan 1980). These results have not been duplicated during subsequent surveys, and no source has been identified.

Cadmium levels in sediments taken from the Powell River in 1981 were also substantially higher than those observed at other mills. Cadmium may have been a contaminant in zinc dithionate (zinc hydrosulphite), because test sites with elevated zinc levels also had high cadmium concentrations (Sullivan 1982). Elevated cadmium levels have also been observed at sediment testing stations adjacent to the Port Mellon, Port Alberni and Crofton mills.

Little is known about trace metals in marine plants and animals collected near pulp mill discharges. An extensive study was conducted in 1973 to determine levels of trace metals in oysters near four coastal pulp mills (Nelson and Goyette 1976). Zinc concentrations in oysters collected at the mill sites were higher than at most control sites. Copper and cadmium levels did not appear to be influenced by proximity to the mills. Further studies at Crofton have shown that zinc levels in oysters dropped by a factor of about 25 between 1973 and 1979 (Ellis *et al.* 1980).

Mercury levels in shrimp collected near the Crofton and Powell River mills ranged from less than 0.1 to 0.2 mg/kg dry weight. Cadmium levels were also low, ranging from less than 0.7 to 1.34 mg/kg dry weight (Sullivan 1980).

Mining

Levels of trace metals in seawater around tailing discharges are often below the level at which they can be detected and are below levels considered to present risks to marine life. Analyses of tissues from crabs and eulachon collected in Alice Arm found that metals from mining operations were not accumulating in the edible tissues (Futer and Nassichuk 1983), although bioaccumulation of some metals has been observed in some species of marine organisms. Trace metal concentrations found in mussels and shrimp at three mine sites are summarized in Figure 22. Levels of copper, zinc, lead and cadmium in shrimp did not differ between mine and reference sites (unimpacted areas in the same area but beyond the mine's influence), whereas levels of copper, zinc and cadmium in mussels were slightly elevated at the discharge points in comparison with those measured in mussels collected from the reference area.

Chemical industries

Marine discharges from chemical plants occur at three sites in Burrard Inlet and two sites in Squamish. The only routine sampling of the marine environment has been at the chlor-alkali plant in Squamish, because of the mercury-cell process used at this plant. Significant amounts of mercury (9 kg/d) were released from this plant to Howe Sound prior to 1970. Investigations of possible mercury contamination in Howe Sound in 1969 and 1970 resulted in the closure of commercial and recreational fishing in upper Howe Sound. The closure, imposed in April 1970, was lifted two months later for salmon, herring and trout, but continued until 1978 for groundfish, crustaceans and shellfish. In the early 1970s, action by federal and provincial environment ministries and improvements in the chlor-alkali plant operation reduced the mercury content in the effluent by approximately 99%, to 50–60 g/d. Mercury levels in crabs have declined since the improvements were made. Concentrations in most groundfish species have decreased below the 0.5 mg/kg guideline for consumption. Shellfish species in Howe Sound, including oysters, clams and mussels, have never contained mercury at levels in excess of 0.5 mg/kg (reviewed by Duncan 1984; Garrett 1985*a*).

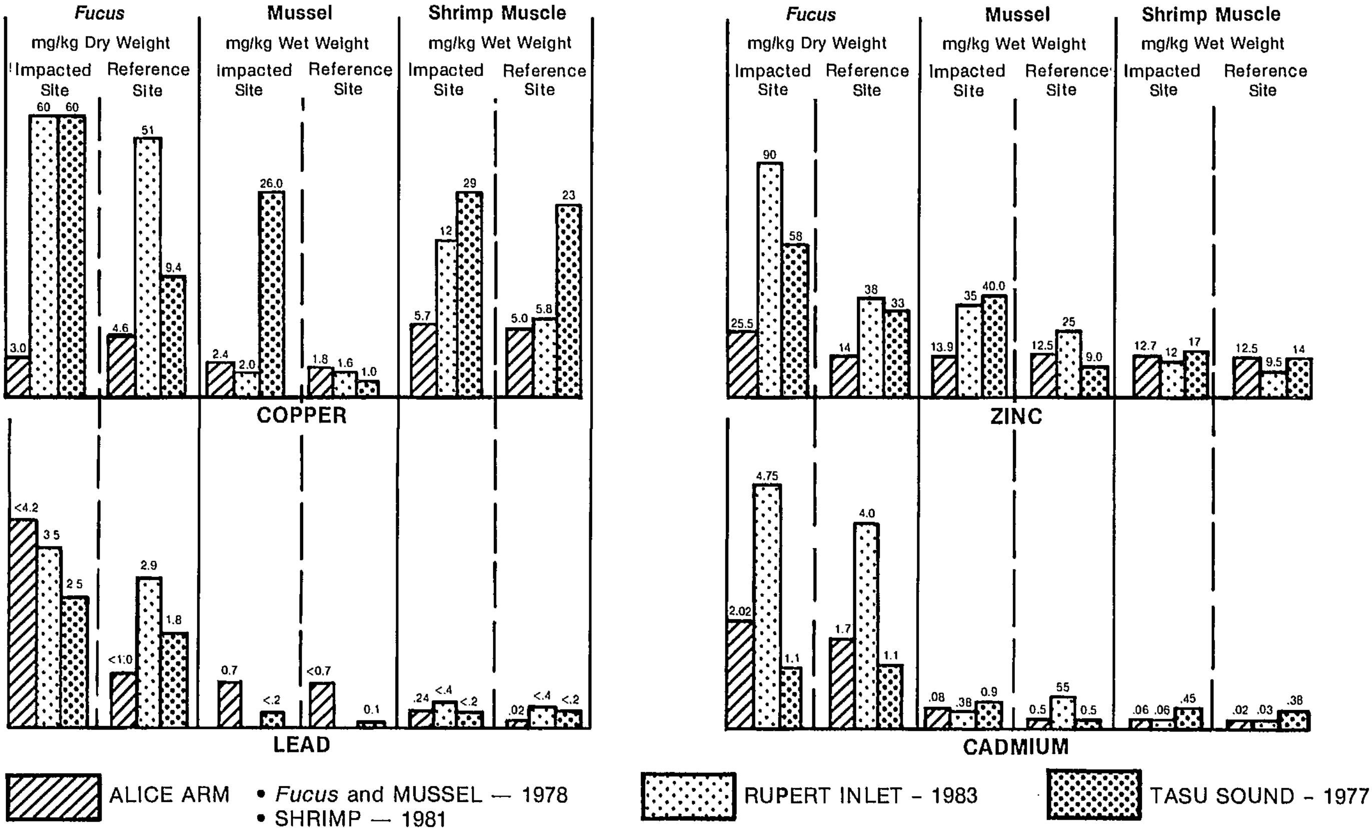
The contamination of bottom sediments in Howe Sound is confined to an area between the chlor-alkali plant and Britannia Beach, 8 km away. Recent studies have shown that mercury levels in sediments in some areas of the Squamish estuary are still high (15.7 μg/g or parts per million). These exceed levels found in most other B.C. marine locations (Moody and Moody 1985).

Ocean dumping

Schedule III, Part I, of the *Canadian Environmental Protection Act* limits the levels of mercury and cadmium permitted in materials for ocean disposal. For mercury, the dry weight concentration cannot exceed 0.75 mg/kg in the solid phase and 1.5 mg/kg in the liquid phase. For cadmium, the levels are 0.6 and 3.0 mg/kg for solid and liquid phases, respectively. A permit for dredge spoils disposal may be issued if the concentration of any substance in the dredged material does not exceed the *Canadian Environmental Protection Act*, Part VI, regulated limits for several defined substances or does not exceed the local baseline concentrations at the dumpsite. A permit may be issued if the dredged material fails these chemical screening tests, but biological tests show that dumping the dredged material will not cause acute or irreversible chronic effects in organisms typical of the marine ecosystem at the dumpsite. The company must show compliance with the overall requirements of the Act and the London Dumping Convention.

Cadmium levels in excess of 0.6 mg/kg often occur naturally at dumpsites (e.g., Tahsis Inlet, Eliza Passage, Muchalet Inlet, Port Alberni, Watts Point and Malaspina Strait). Consequently, permits may be issued if the levels in the dump material are similar to natural levels (Nelson 1985). Mean concentrations of mercury, cadmium, lead, zinc and copper in sediments at all dumpsites are shown in Figure 23.

Figure 22
Mean trace metal levels in marine life at three coastal mine sites, 1978–1984



SOURCE: Kay 1986.

NOTE: *Fucus* and mussels collected from Alice Arm in 1978 following closure of one mine and prior to opening of another.

Certain industrialized areas on the coast require maintenance dredging and disposal of dredged materials. As previously mentioned, high mercury and cadmium levels have been observed in sediments around pulp mills, notably at Powell River, Port Mellon, Gold River and Port Alberni. Major harbours in British Columbia may also contain elevated levels of substances (see Table 2) found in Schedule III, Part I. Various locations in Vancouver and Victoria harbours and False Creek that are associated with ship building and repair facilities, ore concentrate loading docks or past industrial activity contain elevated levels of trace metals. Dredging and dumping operations can cause resuspension of sediment and associated trace metals. Applications to dump dredge spoils in the ocean from these areas are often rejected, and alternative disposal options must be sought (Nelson 1985).

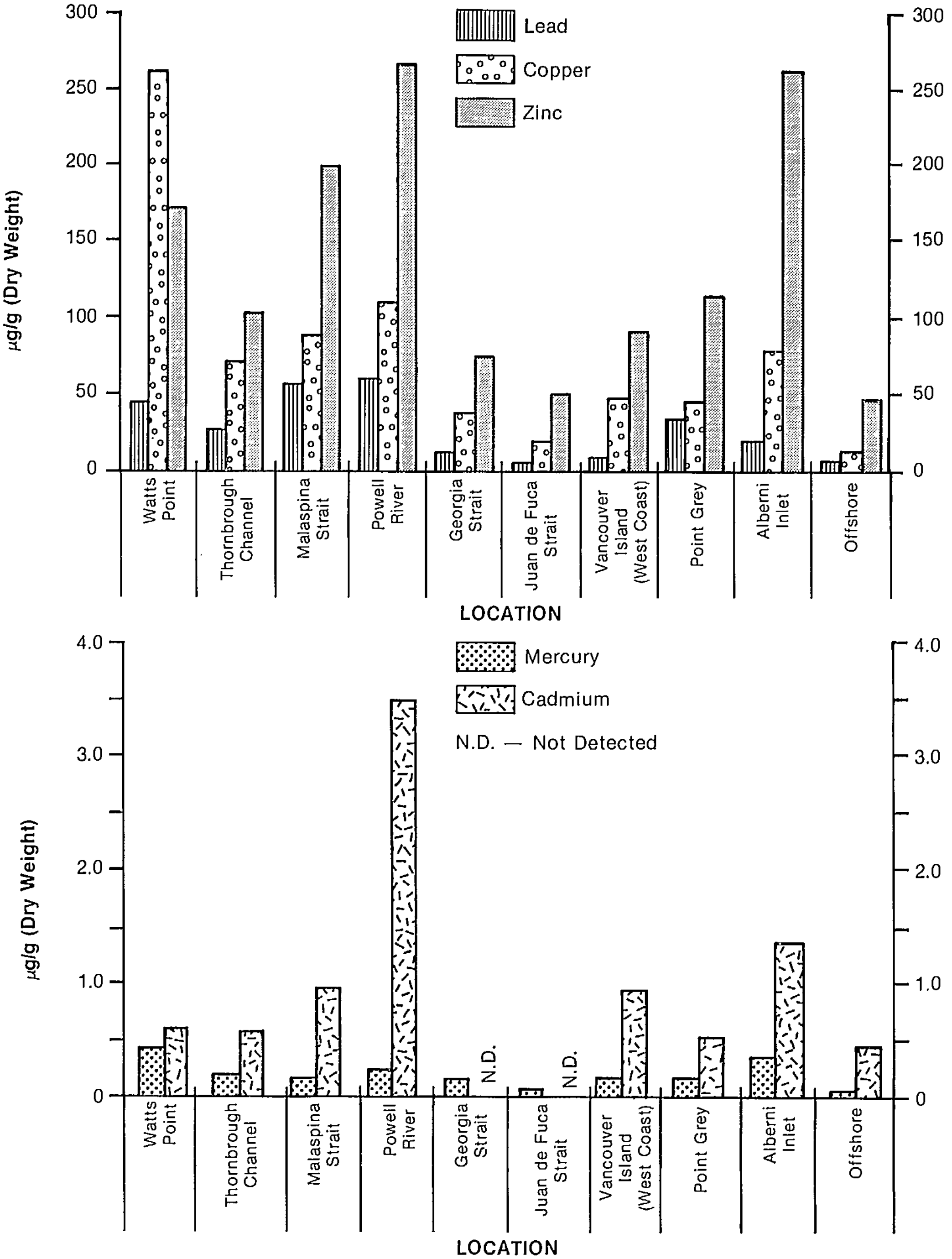
In some cases, sediments contaminated with high levels of trace metals are present in a thin layer on the ocean bottom. The surface material can be removed for disposal on land or held on a scow while the dredging site is "over-dredged." The contaminated spoils are then redeposited at the site and buried under clean material.

Fish and invertebrate samples at ocean dumpsites have been collected only at the Point Grey location. Shrimp, groundfish, crustaceans and sea cucumbers have been examined for metal content. Cadmium was generally below the limits of detection in finfish species, with higher levels measured in shrimp. Mercury levels were the highest in fish and crab tissues, but still below the 0.5 mg/kg health guidelines for food (Brothers *et al.* 1985).

Port and harbour activities

Sediments in False Creek and Vancouver and Victoria harbours have some of the highest concentrations of trace metals found in B.C. marine areas. Sources of

Figure 23
Mean concentrations of trace metals in sediments at B.C. ocean dumpsites, 1980-1984



SOURCE: Environmental Protection, Pacific and Yukon Region, unpublished data.

trace metal contamination include past and present industrial discharges, aerial emissions, marinas, marine traffic, urban runoff, ship building and repair facilities, ore concentrate loading docks and sewer discharges. No long-term studies have been undertaken to investigate the sources and distribution of metals in harbour sediments, although Environment Canada is undertaking an extensive study in Vancouver Harbour. The B.C. Ministry of the Environment and Parks also monitors levels of contaminants in the harbour.

The toxicity of sediments containing elevated levels of trace metals to marine species is of concern. Under experimental conditions, toxic effects were observed when cod larvae and invertebrates were exposed to sediments from False Creek and a ship repair facility (McGreer and Munday 1982).

Information on trace metal levels in marine organisms collected from harbour areas is incomplete and limited to Vancouver Harbour and False Creek. Levels in mussels and other invertebrates showed concentration ranges for mercury, cadmium and lead of 0.05–0.74, 0.3–0.87 and 0.5–86.0 mg/kg wet weight, respectively (Garrett 1985*b*).

Organic contaminants

Numerous synthetic organic compounds are found in marine waters subjected to industrial and urban pollution. Among these are chlorinated hydrocarbons, the organotin compounds and the petroleum hydrocarbons. They are of concern because of their toxicity, persistence and potential for bioaccumulation within organisms. There have been no comprehensive monitoring programs in British Columbia to examine long-term trends in the accumulation of such compounds in sediment and marine life. Some site-specific information that covers several types of pollutants is available.

Polychlorinated biphenyls (PCBs)

PCBs are a class of synthetic chlorinated hydrocarbons that have been used extensively in such products as plastics, inks, carbonless copy paper, paints and pesticides; and as dielectric, hydraulic, high-temperature lubricating and heat transfer fluids. The characteristics of PCBs that make them desirable for industrial applications also make them a hazard to the environment. They are accumulated at higher levels in the food chain because they are extremely stable and are not readily metabolized. Toxic effects from PCBs have been observed in birds, humans and other mammals, as well as in marine vertebrates and invertebrates. Health and Welfare Canada has established a guideline of 2 mg/kg wet weight as an acceptable level in the edible portions of fish and shellfish intended for human consumption.

PCBs have not been manufactured in North America since 1977. They are still in use, however, in British Columbia, particularly in electrical equipment. They have not been detected in most B.C. effluent discharges, except in municipal sewage. No data are available for levels in marine waters off British Columbia.

Table 8
Maximum PCB concentrations in sediments at various B.C. coastal locations and associated activities, 1976–1983

Location	Concentration (μg/kg dry weight)	Activities
False Creek	3 890	Multiple activities
Burrard Inlet	17 000	Multiple activities
Squamish	50	Multiple activities
Woodfibre	4 460	Pulp mill
Port Mellon	620	Pulp mill
Powell River	1 700	Pulp mill
Ocean Falls	380	Pulp mill
Kitimat	25	Aluminum smelter, pulp & paper mill
Port Edward — Canadian Cellulose	74 822 000	PCB spill
Gorge Harbour	12	Reference — no obvious sources
Victoria Harbour	3 640	Multiple activities
Esquimalt Harbour	2 600	Multiple activities
Crofton	60	Pulp mill
Harmac	1 500	Pulp mill
Nanaimo Harbour	90	Multiple sources
Ucluelet	43	Harbour, not highly industrialized
Alberni Inlet	5 500	Pulp mill and other activities
Gold River	170	Pulp mill
Sturgeon Bank	214	Multiple sources
Point Grey	1 050	Ocean dumpsite

SOURCE: Adapted from Garrett 1983.

Marine sediments at locations associated with industrial, urban and port activities contain some PCBs. Present sampling programs are biased towards industrialized areas. Data on background levels of PCBs in sediments in areas far from industrial activity show a range from non-detectable (<5 μg/kg) to 100 μg/kg. Much higher levels have been observed near pulp mill discharges and harbour areas (Table 8). PCBs in sediments around pulp mills are likely there as a result of leaks from PCB-containing electrical equipment. Contamination of harbour sediments probably results from sewage discharges, stormwater run-off and unreported spills from electrical and hydraulic equipment, and the past use of PCB-containing marine paints.

The forestry sector is the largest user of PCB-containing electrical equipment in British Columbia, 40% of which is found in the pulp and paper sector. B.C. Hydro is the second largest user of such equipment.

A major spill of approximately 800 L of PCBs to Porpoise Harbour near Prince Rupert in 1977 resulted in the highest levels of PCBs (75 000 mg/kg in the sediments) recorded to date in the B.C. marine environment. Levels in the sediments of Prince Rupert Harbour, Tuck Inlet and parts of Porpoise Harbour outside the spill area were much lower (<0.005–0.275 mg/kg). Contaminated sediments were capped to prevent further dispersal and contact with aquatic organisms. Annual monitoring indicates that the contamination has been contained.

PCBs have low solubility in water and tend to concentrate in sediments. The actions of currents, tides and leaching can expose marine plants and animals to PCBs contained in suspended solids. In fish, the liver retains the highest levels followed by the gills, heart, brain and muscle. PCBs can also accumulate in the hepatopancreas of shrimp and lobster.

PCBs have been detected in sediments of the lower Fraser River (Swain 1986), but they were not detected in marine intertidal sediments of the estuary in the most recent survey (Environmental Protection, unpublished data). PCBs in tissues of freshwater and estuarine species from the Fraser River estuary were surveyed in 1973, 1980 and 1985 (Garrett 1983; Swain 1986). These studies showed that the mean wet weight PCB levels were well below the 2 mg/kg Health and Welfare Canada guideline. In general, the highest levels were found in the more industrialized North Arm region. In 1980, PCB residues in muscle tissue of fish from the North Arm ranged from less than 0.1 to 0.8 mg/kg. PCB levels were below the detection limits in all species collected in other areas of the Fraser River. Samples from the outer estuary showed higher levels of PCBs in crabs and bottom fish at Sturgeon Bank than at Roberts Bank. PCB levels in crabs decreased with increasing distance from the Iona Island sewage treatment plant. Near the Iona Island discharge, the highest mean level was 0.213 mg/kg for crabs, 0.65 mg/kg for flounder and 0.044 mg/kg for salmon.

In 1985, concentrations of PCBs were below 0.1 mg/kg in all species at all stations, with the exception of one sample of polychaetes from the lower North Arm, which contained 2.5 mg/kg PCBs (Swain 1986). The highest concentrations of PCBs in tissue were recorded in plants and animals collected along the Porpoise Harbour shoreline after the 1977 spill. The levels of PCBs were as high as 72.9 mg/kg in spider crabs. Marine life in Porpoise Harbour beyond the immediate spill area contained elevated PCB levels, but concentrations of PCBs in marine life in more distant areas such as Chatham Sound were at or below detection limits (5 μg/kg). After the spill cleanup, Dungeness crab monitored annually in Porpoise Harbour until 1981 contained mean concentrations well below the 2 mg/kg Health and Welfare Canada guideline.

Shellfish samples collected in coastal areas that are removed from industrial pollution sources have not shown detectable levels of PCBs. Mussels collected from False Creek and Burrard Inlet contained maximum concentrations of 400 μg/kg. Ranges of PCBs found in various species of shellfish collected along the coast are presented in Table 9.

Dioxins

The discovery of polychlorinated dibenzo-*p*-dioxins (commonly called dioxins) in the Canadian environment and the knowledge of their extreme toxicity in animals have raised concerns over the potential risks these chemicals present to humans and the environment. The Expert Advisory Committee on Dioxins was convened by Canada's ministers of Health and Welfare and Environment in 1981 in response to these concerns. A report was published in November 1983 (Health and Welfare Canada/Environment Canada 1983). The major environmental inputs of dioxins to the Canadian environment were ranked as follows:

(1) municipal and industrial incineration sources

(2) chlorophenols, particularly in the wood preservation and treatment industries and other pesticide uses

(3) landfills containing liquid organic wastes and precipitated fly ash from municipal incinerators

(4) other combustion sources, such as wood burning, fires involving electrical equipment containing chlorinated organics, cigarette smoke and automobile exhaust

(5) pesticides synthesized from chlorophenol precursors, including phenoxy herbicides and others

(6) pharmaceutical and domestic products, including some disinfectants.

Monitoring of dioxins in the Canadian environment is limited. The largest database on dioxins in food sources is one on Great Lakes fish. In British Columbia, marine and estuarine waters have been sampled in Victoria Harbour and the Fraser River estuary. The results, however, are not yet available. Dioxins were not detected in sediment samples taken from Boundary Bay, following a large chlorophenol spill into the Serpentine River (Colodey 1986).

No dioxins were detected in the edible muscle tissue of crab, shrimp and fish from Boundary Bay, Burrard Inlet and Vancouver Harbour. Levels of 2–3 ng/kg were found in crab hepatopancreas (Colodey 1986). Health and Welfare Canada has proposed a health advisory level of 20 ng/kg in fish for human consumption.

Table 9
PCB concentrations in B.C. shellfish, 1977-1981

Location	Species	Range (μg/kg wet weight)
Sturgeon Bank	Clams	ND[1]-0.3
Roberts Bank	Clams	ND-76
False Creek	Mussels	14-17
Burrard Inlet	Mussels	400 (single sample)
Porpoise Harbour (spill)	Mussels	87-17 000
Various commercial oyster leases	Oysters	ND

SOURCE: Adapted from Garrett 1983.

[1] ND, not detectable.

Chlorophenols

The B.C. forest industry uses fungicides containing chlorophenols to protect freshly cut lumber from sapstain and mould fungi. Fungi cause unsightly staining of lumber and facilitate the invasion and damage of wood by other decay organisms. More than 80% of the lumber currently shipped overseas is unseasoned and requires chemical protection. This protection is provided by sodium tetrachlorophenate and sodium pentachlorophenate. Chlorophenols released into the environment at sawmills and lumber export terminals have been shown to be toxic to fish and other aquatic organisms.

Monitoring programs to determine levels of chlorophenols — pentachlorophenol (PCP), tetrachlorophenol (TTCP) and trichlorophenol (TCP) — in water, sediment and marine life have been confined to industrialized areas, particularly where there are forest industry operations. The most detailed study, undertaken in 1978 (Environmental Protection Service 1979), found chlorophenols in the sediment and organisms collected from all sample sites, as illustrated in Figure 24. Seawater from all but one site also contained chlorophenols. The highest concentrations in sediments were found in Gorge Inlet and Victoria Harbour. The highest levels in tissue were recorded in sculpin liver collected from the Nanaimo River estuary. Chlorophenol levels in edible crab tissue were generally low, not exceeding 20 μg/kg (TTCP). Seawater concentrations ranged from non-detectable to 7.3 μg/L (PCP).

High concentrations of PCP (225 and 2760 μg/L) and TTCP (530 and 8270 μg/L) have been found in effluents at two of four effluent sampling sites. Sampling in Ladysmith Harbour has found low chlorophenol levels in water (0.06 μg/L), sediments (17 μg/kg) and oysters (4 μg/kg) (McDougall and Boyd 1984).

Several chlorophenol spills have had measurable impacts on the marine environment in the last few years. In March 1984, about 45 000 L of PCP and TTCP spilled and entered Hyland Creek, the Serpentine River and the marine waters of Mud Bay, south of Vancouver. The greatest impacts were seen in Hyland Creek and the Serpentine River, where over 5000 fish were killed. The effect on the marine environment was less severe and appeared to be of short duration. Some estuarine fish (flounders and sculpins) were found among the dead freshwater species that had accumulated near the mouth of the Serpentine River. Maximum total chlorophenol concentrations of 22.9 μg/L were observed in marine waters, 4 days after the spill. They dropped below the detection limit ($<$0.1 μg/L) within 10 days, and total chlorophenols were never detected in sediments ($<$10 μg/kg). Clam tissue concentrations of chlorophenols were low, decreasing from a maximum of 108 μg/kg to below detection limits ($<$10 μg/kg), two months after the spill (Colodey 1986).

Chlorophenol sampling programs begun in 1983 have concentrated on the Fraser River estuary and Vancouver Island near wood treatment facilities (Garrett 1985*b*).

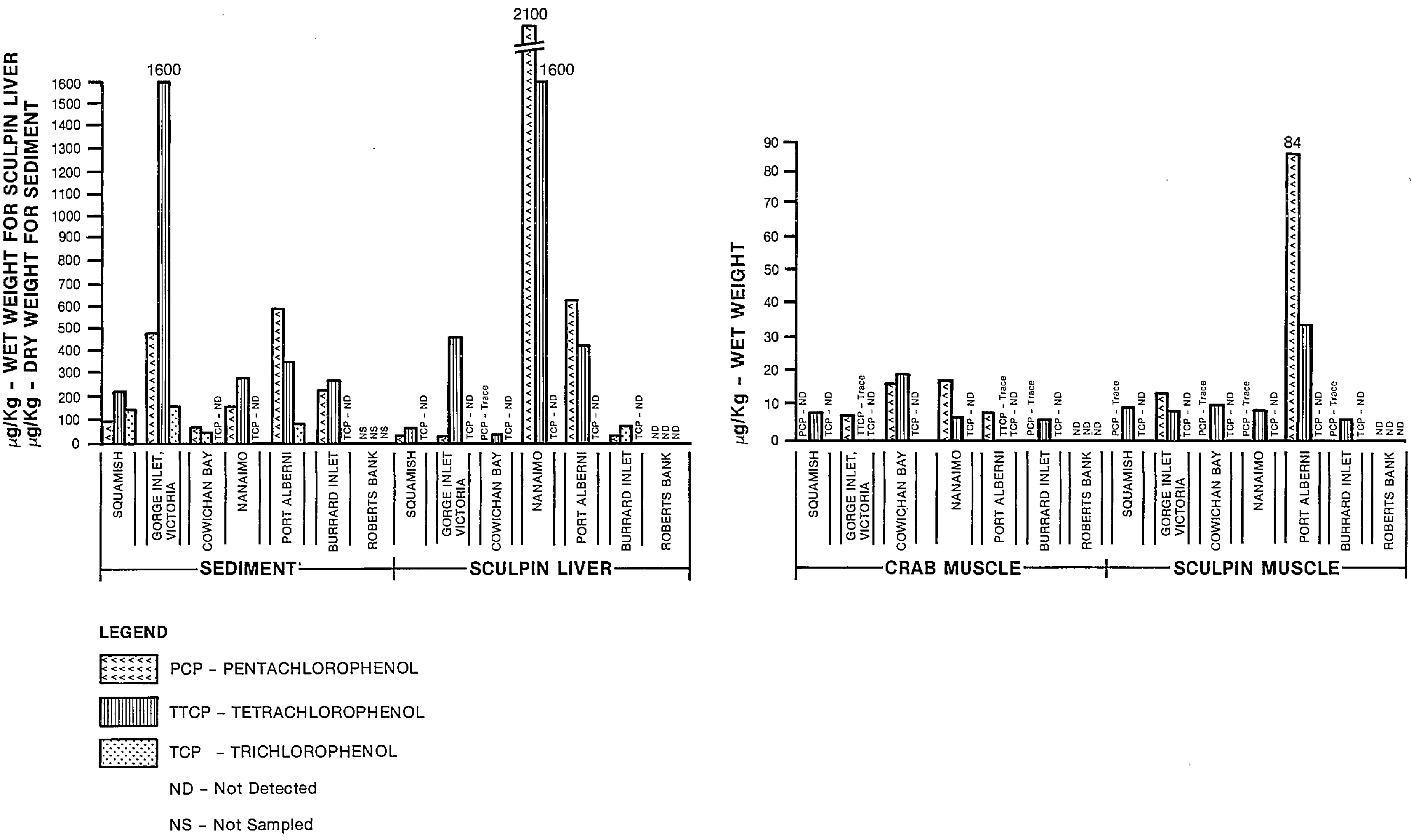
Other chlorinated hydrocarbons

Other toxic, persistent or bioaccumulative substances (including a variety of pesticides, phthalate esters (used in the production of polyvinyl chloride), solvents and chlorinated benzenes) enter our coastal waters by way of industrial, municipal and storm discharges. Studies on the presence of such toxic chemicals have been limited to the lower Fraser River and its estuary and, to a lesser extent, False Creek, Burrard Inlet and McMicking Point, near Victoria. Low levels of various pesticides have been detected in Fraser River fish. Fifty-seven trace organic compounds were identified in a survey of three Vancouver area sewage treatment plants. Work is continuing to improve the identification of the types and quantities of these organic contaminants in water, sediment and fish, and to evaluate the impacts on the marine environment, in the Lower Mainland areas.

Organotin compounds

Organotin compounds (including tributyltin or TBT) are used in the production of polyester resins, polyvinyl chloride plastics and antifouling marine paints. They are toxic to larval forms of marine life, notably oysters. In adult oysters, they cause shell thickening and stunt growth. Sediments collected from various ship building and repair facilities and bulk loading terminals in Vancouver, Victoria and Esquimalt harbours and the lower Fraser River estuary in 1984 and 1985 showed a considerable range of contamination. The highest concentration of TBT (10.78 mg/kg) was found in Vancouver Harbour, near a

Figure 24
Maximum chlorophenol concentrations in sediment and tissue from B.C. coastal sites, 1978



SOURCE: Adapted from Environmental Protection Service 1979.

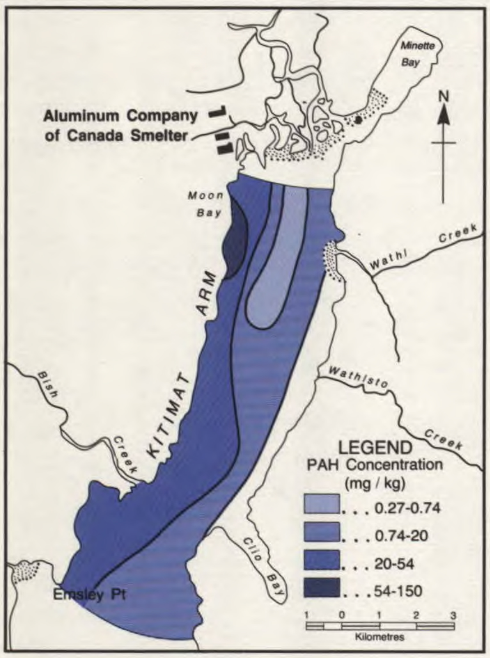
shipyard. Of 256 sites examined in Canada, the 10 highest concentrations of TBT were found at various sites in Vancouver Harbour (Maguire *et al.* 1985).

Further study is required to assess the effects of organotin compounds on the environment. The use of organotin compounds for the antifouling treatment of fish farm nets has caused so much concern that their use in aquacultural operations (primarily finfish) has been prohibited. Further study of the biological availability of sediment-bound organotins and their bioaccumulation potential is needed. Toxic effects (such as abnormal growth and shell malformation) have already been documented in cultured oysters. More work is required to determine the ecological impact of organotin compounds on shellfish.

Petroleum hydrocarbons

Sources of hydrocarbons in coastal environments include municipal wastewaters, refinery wastewaters, urban runoff, spills and natural seepage. The long-term effects of oil pollution on marine ecosystems are not well understood. There is a considerable body of information that shows oil products are toxic to a wide variety of marine organisms. Much less is known about the response of ecological communities to oil spills. It is likely that certain local environments (particularly harbours) in British Columbia that are exposed to chronic discharges of petroleum compounds are experiencing adverse effects.

Figure 25
PAH distribution in sediments of Northern Kitimat Arm



Source: MacDonald, 1983.

Polycyclic (or polynuclear) aromatic hydrocarbons (PAHs) are of particular concern because some have been shown to be carcinogenic in animals and humans. Sources of PAHs in the marine environment are fossil-fuel combustion, aluminum smelting, forest fires, refuse burning and creosote-treated wood products used in the construction of docks and wharves. Certain marine organisms, such as molluscs, are known to readily accumulate PAHs from the environment. They do not rapidly excrete or metabolize these compounds.

Shellfish samples from several commercial growing areas in British Columbia have been found to contain low levels of PAHs. The level of benzo-(a)-pyrene (B(a)P), the most carcinogenic PAH, in geoducks from the Courtenay area was below 0.9 μg/kg. This contrasts with a level of 42.8 μg/kg found in mussels from Burrard Inlet. Concentrations of B(a)P in sediments also show wide ranges between harbour and non-harbour sites, with average levels in harbour sites being about 260 times higher (105 μg/kg versus 0.4 μg/kg) (Duncan 1984; Waters 1985).

Sediment PAH levels were also measured in Kitimat Arm, near an aluminum smelter, during 1978 and 1979. B(a)P was not included in the analysis. The overall PAH distribution pattern, as illustrated in Figure 25, suggests four distinct zones of PAH concentration. The highest levels were detected near the smelter and had a mean of 9 300 μg/kg. The smelter company has reported significant reductions in PAH discharges since 1978.

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Chapter 5
Environmental concerns

Impact on fisheries

The protection of fish habitat is of paramount concern to the departments of Fisheries and Oceans and Environment. Habitats can be physically altered or damaged by harbour developments, forestry and mining operations and urban and industrial foreshore developments. The environmental effects of physical disruption can be substantial. However, pollution in marine waters has not had such obvious impacts. As pointed out in the 1982 report of the Commission on Pacific Fisheries Policy (Pearse 1982), it is virtually impossible to quantify the long-term impact of past damage on fish stocks.

The effects of pollution, domestic sewage in particular, have been detrimental to shellfish in inshore coastal waters. Closures, imposed during the 1950s and 1960s, eliminated many traditional shellfish areas from active production. Since 1972, however, the number of closed shellfish areas has decreased slightly (by about 8%). Landings of oysters have increased 190%, and landings of clams have increased 222% during the period from 1982 to 1984. These numbers are encouraging, but likely reflect the shellfish industry's relocation of growing areas to waters well removed from pollution, rather than any significant cleanup of polluted areas.

Pollution affects local fish populations. To our knowledge, commercial harvest of fish stocks has not been reduced. Toxic chemical spills and the sewage discharge from Iona Island have resulted in fish kills. Low dissolved oxygen levels have led to interruption of salmon migrations in Neroutsos Inlet. Temporary fishing bans have been imposed in Howe Sound, Boundary Bay and Porpoise Harbour. In heavily industrialized areas, such as the Lower Mainland, fish are continually exposed to a wide variety of toxic contaminants, albeit at very low concentrations. Fish in these areas contain elevated levels of some metals and organochlorines and have shown evidence of tissue abnormalities (skin and liver lesions). Further studies are necessary to determine the impact of toxic chemicals on fish and their habitats.

Impacts in specific areas

Despite the limitations in determining long-term trends in marine environmental quality based on the site-specific information that has been collected, it is clear that some B.C. coastal areas have significant pollution problems and deserve further study. These areas (Figure 26) include many of those identified in 1982 by Environment Canada's Pacific and Yukon Region Toxic Chemicals Committee, and much of the following is excerpted from its report (Garrett 1982).

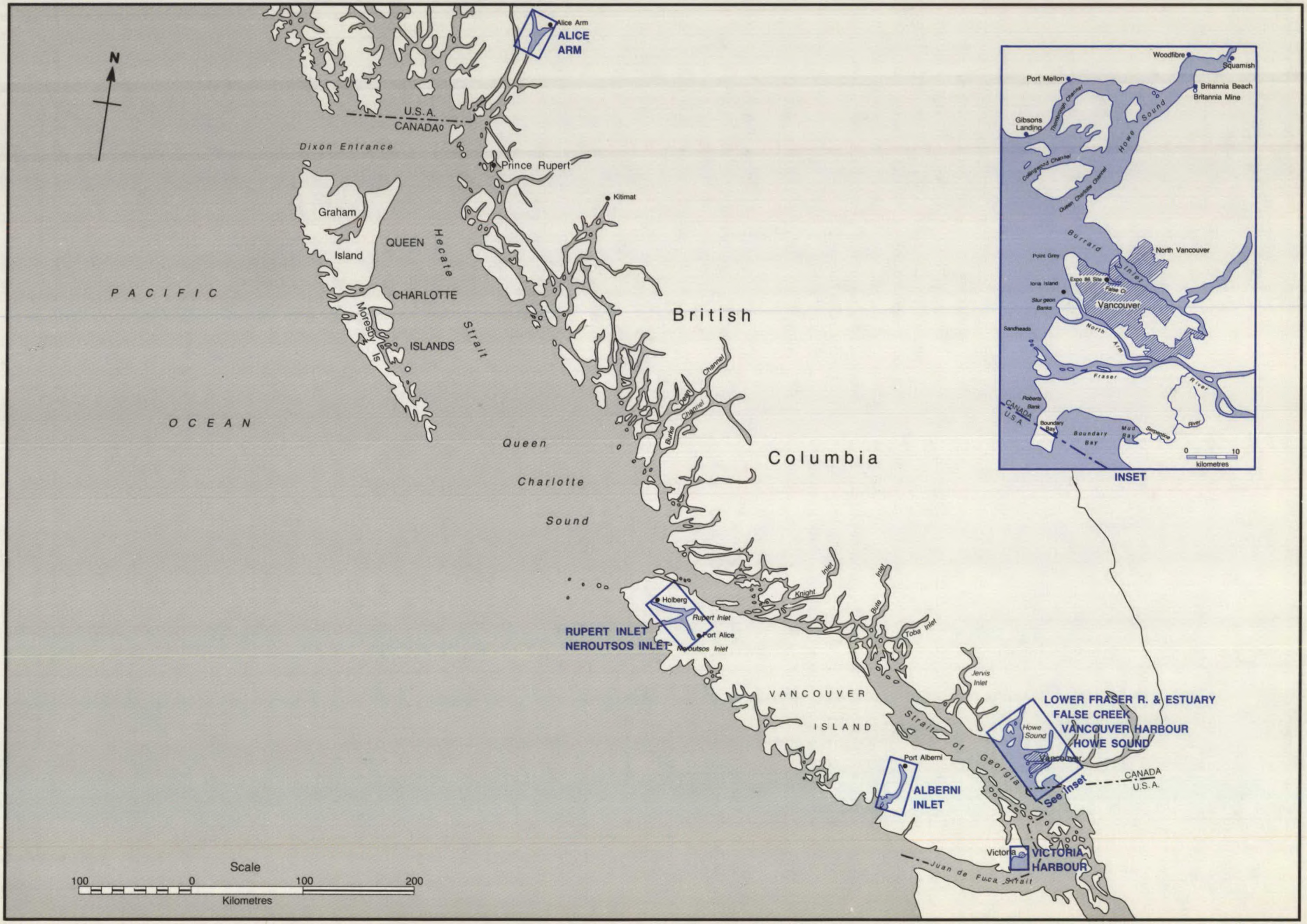
The lower Fraser River and its estuary

The lower Fraser River, which flows through the most heavily urbanized and industrialized area in British Columbia, is a source of contaminants in the marine environment. PCBs have been detected in low but measurable quantities in the sediment and living organisms of almost all industrial areas of the Fraser River and its estuary. PCBs and dioxins have also been detected in heron eggs from areas around the University of British Columbia.

Monitoring of industrial and municipal wastes indicates that although significant amounts of organic contaminants have been discharged to the lower Fraser River, the levels have been reduced in recent years. For example, PCBs have largely been removed from paper recycling plant effluent. PCB and TTCP losses have been reduced, following the introduction of codes of practice for handling of these chemicals.

Significant levels of chlorinated phenols have been detected in sediments and marine life collected near wood treatment plants along the Fraser River. Extensive creosote contamination has been identified at one of the plants. Phthalate esters and PAHs are also present in sediments, plants and animals from the Fraser River. Low levels of various organochlorine pesticides and metabolites and higher levels of dichlorodiphenyldichloroethylene (DDE, the major breakdown product of DDT) have been detected in some fish from the Fraser River.

Figure 26
Coastal areas of special concern



Waste processing and waste disposal sites, such as sewage treatment plants, incinerators and landfills, are probably important sources of organic contaminants entering the lower Fraser River. A survey of three Vancouver-area sewage treatment plants found a total of 57 trace organic compounds in the effluents. These plants discharge low but measurable amounts of PCBs, hexachlorobenzene (HCB), chlorinated phenols and phthalate esters, as well as other compounds. PCBs were detected most frequently. Sampling of sanitary storm sewers and street surface sediments in the Greater Vancouver area indicates that these sources also contribute measurable amounts of PCBs and other organic contaminants to the Fraser River system. PCBs and chlorinated phenols have been detected in leachate from local landfills.

Various surveys have shown the presence of trace metals in sediments and organisms from the Fraser River and have indicated that, in some locations, the concentrations of certain metals exceed background levels. Elevated levels of several metals have been reported near the Iona Island sewage treatment plant in the estuary. Levels of lead and zinc are significantly higher in the North Arm than elsewhere in the river because of the large load of industrial effluents and stormwater discharges.

The levels of most metals in fish from the Fraser River are not of immediate concern, although levels of mercury in some species periodically exceed the Health and Welfare Canada guideline value of 0.5 mg/kg wet weight. Some accumulation of other metals has also been noted in marine life from the estuary region.

Releases of metals to the Fraser River have been studied in detail. Several sources have been identified, including a cement company, metal finishing and fabricating plants, landfill leachates, sewage treatment plants and stormwater discharges.

Vancouver and Victoria harbours and adjacent areas

Toxic chemicals enter Vancouver Harbour (English Bay, Burrard Inlet, Port Moody Arm) in sewer wastes, atmospheric pollution, effluent discharges, runoff and wastes from extensive marine traffic. Elevated levels of certain metals, organotin compounds and PCBs have been detected in several locations in Burrard Inlet, particularly in the vicinity of terminals and ship building or repair facilities. Very high levels of contaminants have been detected in the sediments of Coal Harbour. This contamination is probably a result of the chemicals (including metals, PCBs and organotin compounds) used in the antifouling and anticorrosive paints required by the shipping industry. These chemicals enter the receiving waters by leaching and from paint application and removal.

High concentrations of zinc, copper and cadmium have been detected in the sediments adjacent to an ore concentrate loading facility. These are a result of direct spillage and stormwater runoff through storm drains.

False Creek has been the site of a wide variety of industrial activities for many years. At one time, it was one of the most highly contaminated water systems in British Columbia. Likely sources of toxic chemicals include numerous past industrial discharges and aerial emissions, marinas, marine traffic, urban runoff and sewer outfalls. Elevated levels of several metals (including mercury, lead, cadmium, arsenic, copper and zinc) and PCBs have been discovered throughout False Creek. As a result of the development of the Expo '86 site, large volumes of contaminated sediments were removed to a deep ocean dumpsite, and others were capped *in situ* with clean sediments. Further sampling is expected to show that pollutant levels in sediments have been reduced.

Victoria Harbour receives inputs similar to those described for Vancouver Harbour, but on a smaller scale. Sediments collected in the inner harbour have contained elevated levels of PCBs and several metals, including mercury, lead, cadmium, copper and zinc.

Howe Sound

Potential sources of toxic chemicals in Howe Sound include effluent and aerial emissions from a chlor-alkali plant, a ship and barge terminal, a sawmill, two bleached-kraft pulp mills, a sodium chlorate plant, an abandoned copper and zinc mine, two sewage treatment plants, a landfill, storm sewers and a resin glue extender manufacturing plant.

Mercury levels in marine life of Howe Sound have returned to acceptable levels in recent years, and the closure on fishing has been lifted. Levels of mercury in sediments in some areas remain very high.

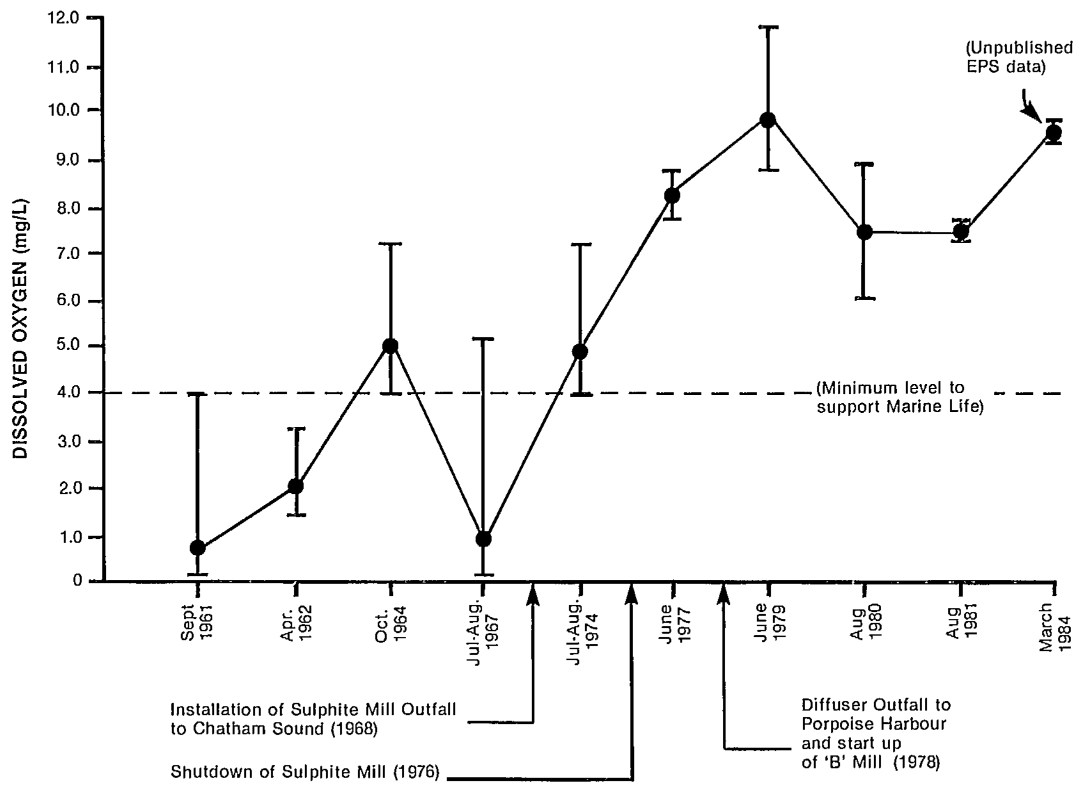
Very high levels of cadmium and elevated levels of lead and PCBs have been detected in sediments adjacent to the Port Mellon pulp mill. High levels of PCBs and mercury were present in the sediments off Woodfibre.

The copper and zinc mine located at Britannia closed in 1974. Monitoring in the vicinity of this mine still reveals elevated copper and zinc levels in surface waters and sediments.

Other coastal inlets

The discharge of approximately 45 000 – 50 000 t/d of copper mine tailings to Rupert Inlet since 1972 has resulted in significant alteration of the ecosystem. Changes

Figure 27
Changes in dissolved oxygen concentrations in Porpoise Harbour, 1961-1984



SOURCE: Waldichuk *et al.* 1968; Packman 1977; 1979; Pomeroy 1983.

NOTE: Mean Concentration and Range for all Depths (0-20m) is plotted.

in habitat have been observed up to 18 km from the mine's outfall. It is estimated that the depth of tailings in the trough of Rupert Inlet will reach 46 m during the life of the mine. The short-term effects of this discharge appear to have been smothering of benthic organisms and minor bioaccumulation of trace metals in some organisms, notably seaweed and mussels. Similar effects have been observed in Alice Arm from early and recent mining operations, although there is no mining activity at present. Long-term impacts are unknown.

On the west coast of Vancouver Island in 1986, approximately 87 000 m^3 of sulphite pulp mill effluent were discharged daily to Neroutsos Inlet, and 159 000 m^3 of kraft mill effluent were discharged daily to Alberni Inlet. At certain times of the year, these discharges reduce dissolved oxygen concentrations to levels insufficient to sustain marine life. At Alberni Inlet, the oxygen depression is severe only in deeper waters of the inner harbour, whereas in Neroutsos Inlet, the problem is more extensive and occurs throughout the water column.

The restoration of Porpoise Harbour[1]

Porpoise Harbour, near Prince Rupert, is one of several areas along the B.C. coastline that have experienced significant pollution problems due to high-BOD discharges from coastal pulp mills. In the past, these discharges have caused oxygen depression in the water column, fish kills and reduced biological productivity. Because of concern about environmental quality in this area, there have been changes in mill processes, pollution abatement technology and effluent discharge locations, resulting in significant improvements in dissolved oxygen levels (Figure 27).

[1] Source: Kay 1986.

The sulphite mill was established in 1950, and, until 1967, all effluent from the mill was discharged into the Wainwright Basin. In 1967, when the "red liquor" discharge was relocated to Chatham Sound, dissolved oxygen levels in Porpoise Harbour and Wainwright Basin began to improve markedly. Levels ranged from 3.3 to 9.7 mg/L. However, breaks in the new pipeline located across the bottom of Porpoise Harbour caused oxygen depressions and consequent fish kills. The pipe was replaced in 1974. A new kraft mill, now referred to as 'A' mill, started operation alongside the sulphite mill in 1965 and discharged its bleach plant effluent into Wainwright Basin.

The original sulphite mill was closed in 1976, and a new kraft mill, now referred to as 'B' mill, began operation in 1978. At this time, effluent from both the existing and new kraft mills was rerouted to the diffuser outfall discharging into Porpoise Harbour. Between 1976 and 1978, when effluent was being discharged into Wainwright Basin, dissolved oxygen levels returned to normal in Porpoise Harbour.

The present operation at Porpoise Harbour includes two bleached-kraft mills, which discharge their combined effluents through a 17-m-deep diffuser outfall. Pollution problems associated with the original sulphite mill resulted in part from the surface discharge of effluent and the poor bottom flushing characteristics of Porpoise Harbour and nearby Morse and Wainwright basins. Dissolved oxygen levels below the minimum level required to support aquatic life (4 mg/L) were recorded throughout the entire water column, with levels approaching 0 mg/L at many locations.

Since 1978, discharges from the diffuser outfall in Porpoise Harbour have resulted in slightly reduced dissolved oxygen levels in its immediate vicinity. However, overall oxygen levels have improved throughout the Wainwright Basin - Porpoise Harbour system. Intertidal life has also recovered, and juvenile salmon have been netted in the area. However, a buildup of pulp fibre has been noted in Porpoise Harbour, and additional pollution abatement work may be necessary to prevent further deterioration of the ocean-bottom habitat.

Organochlorine contaminants in Pacific coast seabirds[2]

Organochlorine pesticides, industrial chemicals and heavy metals have been found in organisms in all parts of the world. Seabirds, as predators near or at the top of the marine food chain, can accumulate these environmental contaminants. By monitoring selected seabird species for the presence and levels of these substances, we can determine whether pollutant levels in the marine environment are stable, increasing or decreasing.

Several million birds, representing more than 40 species, breed or winter along this coast. Beginning in the 1960s, selected populations of seabirds along the Pacific coast have been monitored by the Canadian Wildlife Service (Figure 28). The monitoring program determines levels of contaminants in tissues and eggs of seabirds.

Sources of organochlorines

Organochlorines, including DDT and DDE, are extremely persistent chemical pesticides whose use in Canada began in the late 1940s, peaked in the mid-1960s and then declined due to restrictions. In British Columbia, they were used mainly between 1946 and 1962. At that time, over 90 000 kg of DDT were applied to control forest insects. Endosulfan and lindane were also used for insect control during this period. Agricultural and industrial uses are not well documented, but the use of organochlorines was probably high in the heavily industrialized, intensively farmed Lower Mainland. Although the use of organochlorines is restricted, large amounts are still present in the environment because of the extreme persistence of these compounds. Thus, they are available to seabirds and other organisms.

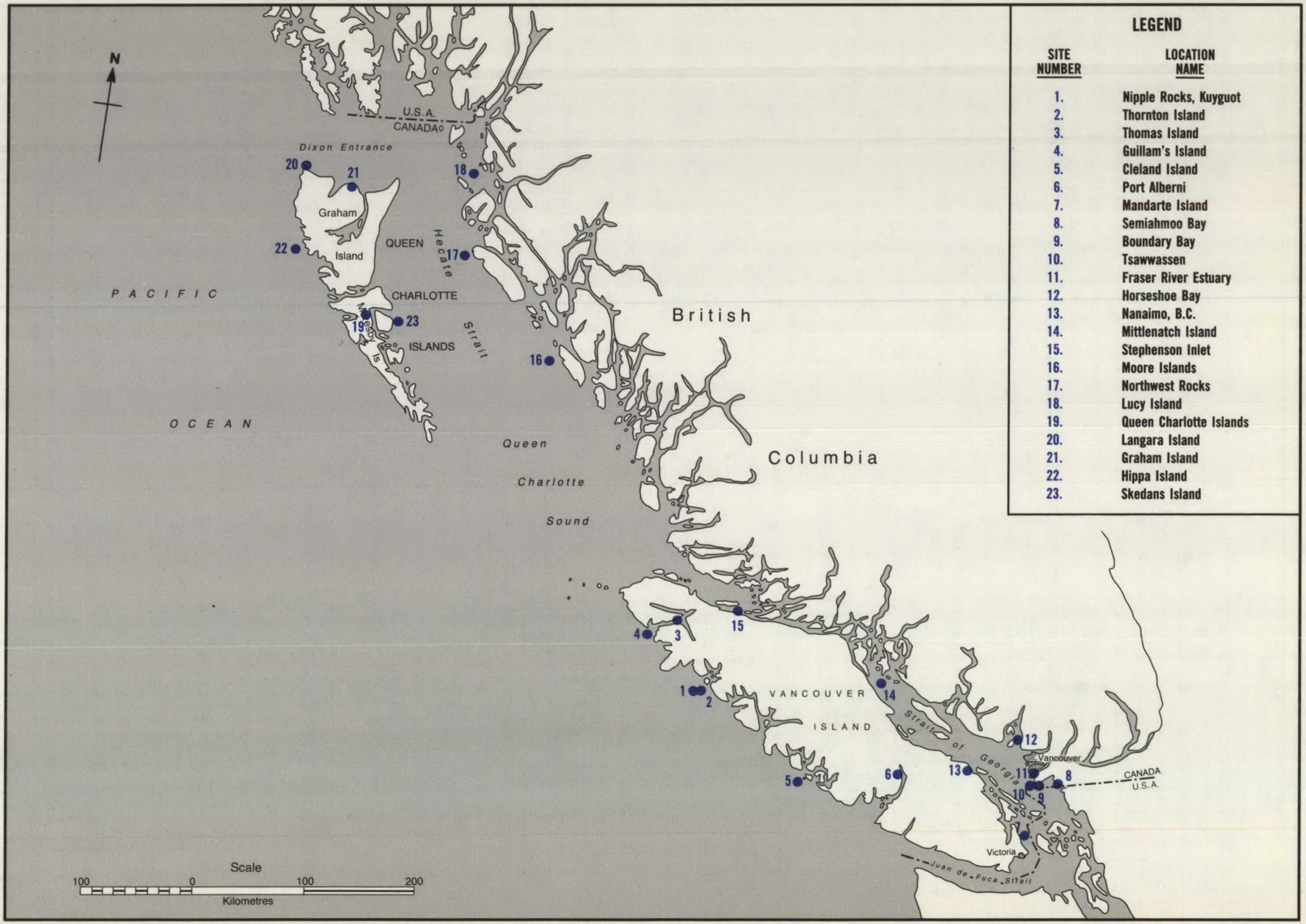
Organochlorines were used extensively in other areas frequented by seabirds, such as the U.S. Pacific Northwest. They are still used in some parts of Latin America, and seabirds migrating south may pick up contaminants in their wintering areas. Pesticides used in these areas may eventually reach Canadian waters via ocean currents or atmospheric transport.

Levels detected in Pacific coast seabirds

Data collected between 1968 and 1976 showed the presence of organochlorine compounds in tissues of several species of seabirds from various locations. DDE and DDT were found in all seabird tissues analysed. The levels ranged from 0.029 mg/kg DDE in the brain tissue of Glaucous-winged Gulls taken from Boundary Bay in 1968 to 10.7 mg/kg DDE in the fat tissue of the same species taken from Langara Island in 1969. PCBs have been detected in all samples since 1969. The levels range from 0.04 mg/kg in brain tissue of Leach's Storm-Petrel taken from Graham Island in 1976 to 16.4 mg/kg in the fat tissue of Ancient Murrelet taken from Langara Island in the same year. Other organochlorine compounds detected in various species, tissues and locations included dieldrin, endrin, heptachlorepoxide, chlordane compounds, hexachlorocyclohexane and hexachlorobenzene (HCB). Dieldrin,

[2] Much of this material is taken from Noble and Elliott 1986.

Figure 28
Geographical locations of seabird specimens collected from the Pacific region of Canada, 1968-1985

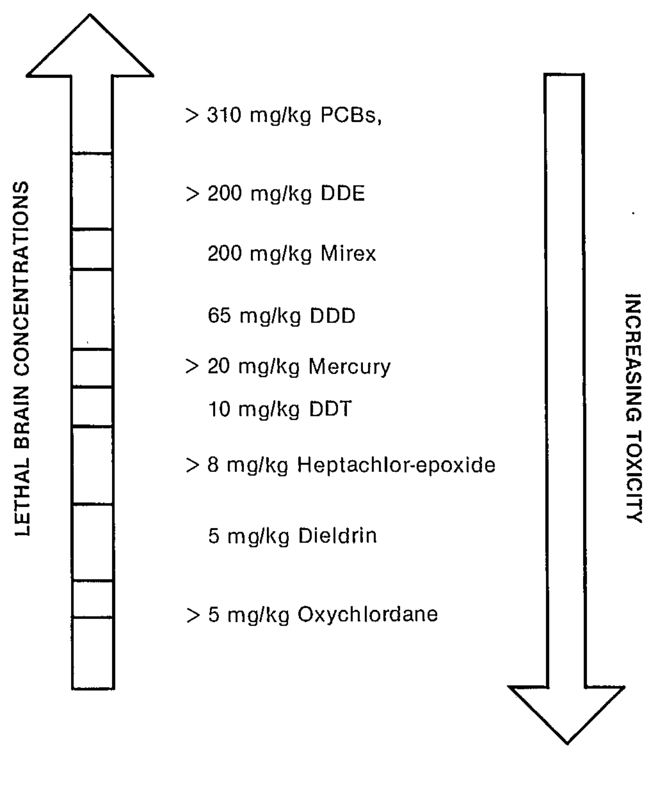


heptachlorepoxide, oxychlordane and HCB at concentrations between 0.01 and 0.2 $\mu g/g$ were present in all of the species sampled.

Direct exposure of birds to organochlorines can be fatal. Almost all experimental work on the acute toxicity of organochlorines to birds has been with typical laboratory species (doves, quail, blackbirds, cowbirds and starlings) rather than seabirds. Testing for acute toxicity usually means calculation of the LC_{50} (concentration needed to kill 50% of the experimental birds). As the toxic effect is on the nervous system, concentrations of the chemical in the brain of the dead birds provide estimates of lethal levels. To date, brain levels are still the only criterion for attributing the cause of death.

The concentrations of commonly detected organochlorines in the brain that are associated with death are listed in Figure 29. The most toxic organochlorines are the cyclodienes (endrin, dieldrin and chlordanes), some of which may be lethal at levels as low as 0.8 mg/kg (Stickel *et al.* 1969). DDT compounds were generally less toxic, with DDE likely to cause death at brain levels greater than 250 mg/kg (Stickel 1973). Polychlorinated biphenyls were the least acutely toxic to birds, with lethal brain residue levels of 500–3 000 mg/kg in laboratory species (Heath *et al.* 1972). Studies by Koeman *et al.* (1973) imply that seabirds may be more sensitive, with PCB brain levels of 130 mg/kg associated with cormorant mortality. Families of birds differ widely in their response to organochlorines as a result of differences in biochemical pathways and physiology (Walker and Knight 1981). It is possible that the lethal brain levels in seabirds differ from the values shown in Figure 29 (Noble and Elliott 1986).

Figure 29
Comparative toxicities of selected environmental contaminants



SOURCES: Heath and Spahn 1973; Ohlendorf *et al.* 1981; Porter and Wiemeyer 1972; Scheuhammer 1988; L.F. Stickel *et al.* 1979; W.H. Stickel *et al.* 1969, 1970, 1984; Stickel and Stickel 1969.

Geographical differences

The data on geographical trends in contaminants in seabirds are based on the analysis of seabird eggs. Concentrations of organochlorine contaminants in seabirds of British Columbia were intermediate between higher levels in Oregon and California to the south, and lower levels in Alaska to the north. DDE and PCB levels were generally higher in birds nesting in the Strait of Georgia than in other coastal areas. The highest PCB levels were found in Double-crested and Pelagic cormorants in the Strait of Georgia. In a 1970 survey, levels of dieldrin were also highest in the Strait of Georgia (in Glaucous-winged Gull eggs), whereas levels outside the strait were lower and exhibited no clear geographical pattern. The highest HCB levels were found in eggs of the same species from Cleland Island (Noble and Elliott 1986).

Temporal trends

DDE, PCB, dieldrin and heptachlor levels in eggs of the Double-crested Cormorant, Pelagic Cormorant and Glaucous-winged Gull in the Strait of Georgia declined between 1970 and 1985. Other compounds measured in eggs from this area did not show any consistent trends. Between 1970 and 1985, oxychlordane concentrations increased slightly in eggs of Double-crested Cormorants, and HCB levels increased in the eggs of Glaucous-winged Gulls. Concentrations of DDE and PCBs, but not HCB, declined in eggs of Rhinoceros Auklets from Lucy Island over the same time period. Data on long-term trends of contaminant levels in samples from the west coast are limited. Few conclusions can be drawn, but there has been an overall decline in the levels of most contaminants (Noble and Elliott 1986).

Contaminant effects and the status of seabird populations

The impact of sublethal levels of organochlorines in seabirds is often difficult to isolate from other environmental and human-induced factors. Various researchers around the world have associated contaminants with effects such as eggshell thinning, embryotoxicity, teratogenicity, dermal lesions, weight loss, immunotoxicity, liver enlargement and reproductive disorders (Koeman *et al.* 1968; Blus *et al.* 1971; Nettleship 1975). Contaminants can contribute to such phenomena as seabird wrecks (large bird kills), nestling mortality and decreasing populations. Seabird wrecks often appear to be associated with decreased food availability. Starvation may result, causing the birds (including young chicks) to metabolize internally stored fats (where contaminants tend to accumulate). Contaminant concentrations increase in target organs and can reach lethal levels.

Eggshell thinning occurred in Northern Gannet eggs during the late 1960s at Bonaventure Island, Quebec. Researchers found eggs so thin that the egg was virtually a bag of jelly held together by a membrane. High DDE levels are thought to have contributed to this phenomenon. Productivity was low (30%), and the Northern Gannet population declined. By 1984, DDE levels had decreased, eggshell thickness had increased and productivity had risen to 75%.

Present levels of organochlorine contaminants found in most Pacific coast seabirds do not appear to threaten their survival. Contaminant levels in some species have sometimes been a cause for concern. Stable or increasing populations of Double-crested and Pelagic cormorants, Glaucous-winged Gulls, Common Murres and Rhinoceros Auklets (except at Langara Island, where the colony disappeared between 1952 and 1970) would indicate that contaminants are not a factor affecting these species at the population level. Insufficient data on population status and trends preclude any discussion of contaminant effects on other species such as Fork-tailed and Leach's storm-petrels, Pigeon Guillemots, Marbled Murrelets and Cassin's Auklets (Noble and Elliott 1986).

Two seabird species on Canada's Pacific coast have recently experienced population declines. Organochlorine contamination (as well as low food availability) may have contributed to a decline in the Ancient Murrelet population at Langara Island in the Queen Charlotte Islands. Considering the low residue levels, this was not a direct toxic effect. Tufted Puffins disappeared from several locations near Langara Island and have recently suffered almost complete reproductive failure at Triangle Island in three out of five years of studies (reported in 1979). The reason for these declines remains unclear, but Tufted Puffins are vulnerable to food shortages. This may result in elevated contaminant levels in food-deprived chicks (Noble and Elliott 1986).

The future

This report has summarized the data on sources and levels of contaminants, as well as the impact of contaminants on the marine environment. Past studies of B.C. coastal waters have demonstrated the impact of localized waste discharges. Urban and industrial development will continue to exert pressure on the marine environment.

Most studies have not monitored long-term changes in the environment. Comparison of various studies is often inappropriate because collection of the data and its analysis have not been standardized. Thus, it is not yet possible to answer the question, "Is the quality of the marine environment improving or deteriorating?"

Monitoring must begin with adequate background data. Long-term sampling programs must be established that include monitoring the effects of new industries on the marine environment (over a 10- to 15-year time period). The distribution and fate of toxic chemicals must be examined more closely. There must be increased efforts to determine the impact of contaminants on fish and wildlife and their habitats. It is equally important that increased efforts are made to reduce the number of effluent discharges and to control the release of toxic chemicals.

Environment Canada will redirect its marine studies in the coming years to address some of these issues. Work already begun on the lower Fraser River and estuary by municipal, provincial and federal researchers will provide the kind of information necessary for continued protection of this important river.

The B.C. Ministry of Environment and Parks is establishing water quality objectives for marine areas under the greatest urban and/or industrial pressures. Thus, the program has focused on the Lower Mainland regions.

The challenges we are facing are enormous. We know very little about the effects associated with human exposure to pollutants. Nor do we adequately understand how these pollutants enter and react with the marine food web. We must accept these challenges with enthusiasm and encourage others to participate in this vital work.

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