ERRATA

West Coast Marine Environmental Quality:
Technical Reviews
Regional Program Report 86-01

Page 16, last paragraph. Should read "...problems associated with the mill have resulted from the poor bottom flushing characteristics..."

Page 132, figure 3.14. Metal values for *Pandalus borealis* are given as
mg/kg wet weight, not dry weight as indicated.

ENVIRONMENT CANADA
CONSERVATION AND PROTECTION
ENVIRONMENTAL PROTECTION
PACIFIC AND YUKON REGION

WEST COAST MARINE ENVIRONMENTAL QUALITY: TECHNICAL REVIEWS

Regional Program Report 86-01

By

B.H. Kay

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ABSTRACT

Environmental surveillance programs spanning the period 1970-1985 at British Columbia coastal pulp mills, municipal waste discharges and mines are reviewed. Historical environmental problems, environmental improvements and current problems are discussed.

The review summarizes data obtained for receiving water, biota and sediment contaminant levels, physical habitat disruption, toxicity, aesthetic and microbiological pollution.

The review concludes that significant improvements have been made in some problem areas, such as the impact of pulp mill discharges. Bioaccumulation of contaminants from industrial and municipal effluents and the obliterative effects of mine tailings discharges require further study.

RÉSUMÉ

Les programmes de surveillance environnementale des moulins à papier côtiers de la Colombie Britannique, des décharges municipales, et des mines, pour ont été révsés la période de 1970 à 1985. Les problèmes environmentaux historiques, les améliorations environnementales et les problémes courants y sont discutés.

La revue résume les données obtenues pour les eaux réceptrices, le matériel biologigue et le niveau des contaminants sédimentaires. La description physique des habitats, la toxicité, l'esthétique et la pollution microbiologique, y sont aussi discutés.

La revue conclue que des améliorations significatives dans certaines regions problèmes, comme par exemple l'impact des décharges de moulins à papier, la bioaccumulation des contaminants d'effluents industriels et municipaux et l'effet détouffement des déversements de résidus miniers nécessitent de plus amples études.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

LIST OF TABLES

LIST OF TABLES (Continued)

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

PREFACE

This report is one of a three part series which examines the status of knowledge of British Columbia's marine environmental quality. It reviews information describing the quality of marine water, sediments and biota in relation to the three main discharge types: pulp and paper, mining and municipal sewage. Findings from government, university and industry monitoring and research programs conducted between 1971 and 1985 are summarized. The characteristics of the major effluent discharges and their regulatory requirements are also discussed.

Where possible, trends in EPS data have been discussed, although generally there was insufficient information to establish any trends. This was due in part to the lack of time-series sampling regimes and inconsistencies in laboratory analysis and reporting. (Appendix I provides information on quality assurance procedures used in EPS analytical tests.)

For each of the three sections of the report a brief summary is provided, highlighting the major findings and identifying information gaps.

The other reports in this series include: "West Coast Marine Environmental Quality - Bibliography" (EPS Regional Program Report 86-02) and "West Coast Marine Environmental Quality: Summary Report" (EPS Regional Program Report 86-04).

1 PULP AND PAPER

Ten pulpmills presently discharge effluent to estuarine or marine waters along the British Columbia coast (Figure 1.1). The Ocean Falls mill was closed in 1980.

The pollution problems associated with each mill differ, depending upon the effluent discharge location, the manufacturing process, the volume of effluent being released and the degree of treatment being used. In general, pollution effects from the marine discharge of pulp mill wastes can be separated into four broad categories as shown in Table 1.1 and as reviewed by Pearson (1980) and Waldichuk (1983). Other problems associated with pulp mill discharges in freshwater systems, such as pH changes and foam production, are usually considered minor in marine systems due to the natural buffering capacity of seawater and the effluent disposal methods i.e. submarine outfalls.

The magnitude of impact of pulp mill discharges on the marine environment is determined by various factors including

- the effluent quality as determined by the pulping process utilized and the treatment methods employed
- the location of effluent disposal, specifically in relation to living resources, physical factors such as tides and wind, and sensitive habitats such as estuaries
- the method of effluent disposal utilized - surface discharge _vs_ submerged outfalls

The kraft, or sulphate, chemical pulping process is used by all coastal mills in the province except the Western Pulp Ltd. Partnership mill at Port Alice, which uses the sulphite process. Three mills also have mechanical pulping systems in addition to the kraft process. The kraft process is an alkaline chemical process, the caustic chemicals used in the digestion of the wood in the production of pulp being recycled, which reduces the pollution potential of this process. Most kraft mills now have associated with them bleach plants to provide some degree of bleaching for

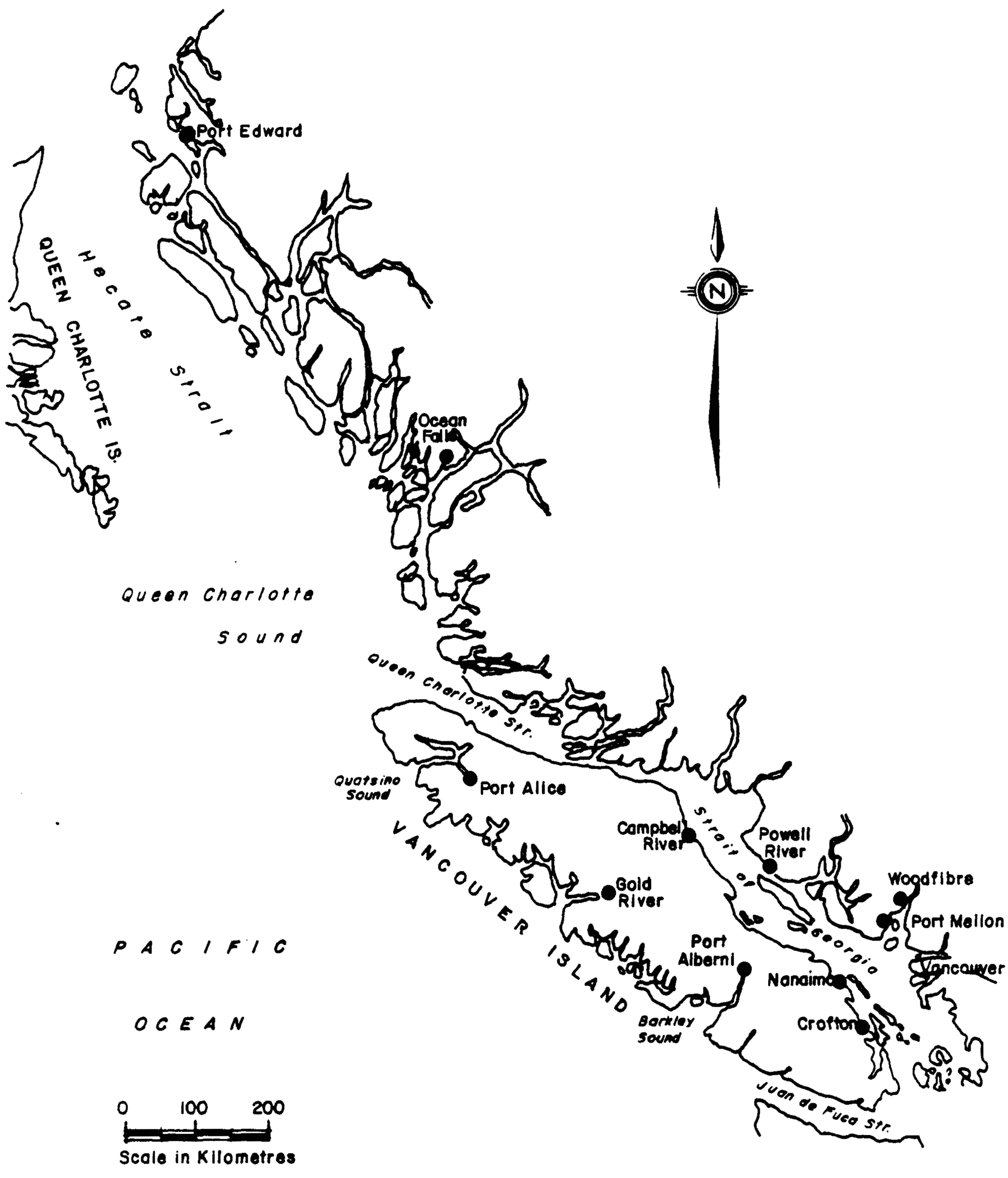


FIGURE 1.1 LOCATIONS OF HISTORIC AND EXISTING COASTAL PULPMILLS IN BRITISH COLUMBIA

the pulp. In most cases the first bleaching stage is chlorination followed by caustic extraction, which dissolves out the various coloured constituents bonded to the fibre. Caustic extraction is usually the effluent stream giving total pulpmill effluent most of its colour. Following treatment with chlorine and caustic extraction, other chemicals (e.g. chlorine dioxide and sodium hypochlorite) provide the degree of bleaching or brightening desired. These chlorine-containing streams are acidic and are often mixed with the alkaline effluent streams to provide some measure of neutralization (Waldichuk, 1983; G. Tanner, pers. comm.).

TABLE 1.1 CATEGORIES OF POLLUTION EFFECTS IN THE PULP AND PAPER INDUSTRY (from Pearson, 1980 and Waldichuk, 1983)

POLLUTION EFFECT	SUBSTANCES CONTRIBUTING TO IMPACT
Biochemical Oxygen Demand from 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 e.g. lignosulphonates; fungicides e.g. chlorinated hydrocarbon mixes, mercuric and zinc compounds
Benthic smothering	suspended solids e.g., fibre; bark residues; ash; lime; clay
Colour	lignin derivatives; paper dyes and fibres

The sulphite chemical pulping process differs from the kraft process in two major respects. Firstly it is an acidic chemical process rather than alkaline. Secondly, chemical recovery or recycling is not traditionally practised, resulting in the discharge of the spent chemicals, referred to as spent sulphite liquor (SSL). Sulphite mills have generally caused greater water pollution problems than kraft mills due to the lack of chemical recovery and higher effluent BOD per unit of production.

Mechanical pulping, or groundwood production, is used for the manufacture of newsprint at three of the coastal mills producing kraft pulp. Chemicals are not used in this process and the effluents produced are usually discharged with the kraft effluent, generally following solids and fibre removal in a clarifier.

In addition to these major effluent streams resulting from the pulping process, pulp and paper mills discharge effluents from a variety of other sources and activities in the mill, including the woodroom (hydraulic debarker), steam plant and sanitary wastes. Table 1.2 summarizes the various process and effluent characteristics of the coastal pulpmills.

1.1 Control of Water Pollution

Both the federal government and Province of British Columbia have regulations or objectives which prescribe levels of pollutants in the waste streams from pulp and paper mills. The federal regulations, which are promulgated under Sections 33 and 34 of the federal Fisheries Act, (Environment Canada, 1971; Environment Canada, 1972) prescribe levels for three deleterious substances or measurements in pulp mill effluent:

- total suspended solids (TSS)
- biochemical oxygen demand (BOD)
- toxicity

Total suspended solids and biochemical oxygen demand levels are allowed to vary under the federal regulations depending upon the size and type of mill (sulphite, kraft or mechanical) and the year of construction, alteration or expansion. Toxicity is measured using a fish bioassay and is

TABLE 1.2 PROCESS AND EFFLUENT CHARACTERISTICS OF BRITISH COLUMBIA COASTAL PULPMILLS

PLANT INFORMATION			EFFLUENT CHARACTERISTICS				
COMPANY	LOCATION	PULPING PROCESS(ES)	EFFLUENT STREAM	DAILY EFFLUENT DISCHARGE (m^3)	EFFLUENT TREATMENT	EFFLUENT DISPOSAL METHOD	DISPOSAL LOCATION
British Columbia Forest Products	Crofton, Vancouver Is.	kraft (sulphate), groundwood TMP-thermochemical pulping	kraft pulp/TMP, groundwood	230,000	primary clarifier; biological oxidation for TMP	submarine diffuser	Stuart Channel
			woodroom	15,900	settling ponds	foreshore	Stuart Channel
			sanitary	18	secondary treatment	submarine outfall	Stuart Channel
MacMillan Bloedel - Harmac Pulp Div.	Harmac, Vancouver Is.	kraft (sulphate)	kraft pulp, woodroom & sanitary	265,000	recaust clarifier, woodroom clarifier, sanitary-chlorinated secondary	submarine diffuser	Northumberland Channel
- Alberni Pulp Div.	Port Alberni, Vancouver Is.	kraft (sulphate) groundwood	groundwood, woodroom, extraction, bleach, news machines, pulp machines	209,000	clarifier and biobasin	surface outfall	Somass River estuary
			kraft bleach plant acid sewer, digester area, recaust area		none	surface outfall	
- Powell River Pulp Div.	Powell R.	kraft (sulphate) refiner groundwood	woodroom, steam plant, mechanical pulpmill & papermachine	220,000	clarifier	surface discharge via tailrace	Malaspina Strait
			kraft pulp	100,000		submarine diffuser	
Canadian Forest Products - Howe Sound Pulp Div.	Port Mellon	kraft (sulphate)	kraft pulp sanitary	117,000	sanitary-biological treatment	submarine diffuser	Thornborough Channel
Crown Forest Industries - Elk Falls Pulp Mill	Campbell R.	kraft (sulphate) groundwood	kraft pulp, groundwood and sanitary	250,000	recaust sanitary clarifier	submarine diffuser	Discovery Passage
CIP Forest Products Inc., Tahsis Pacific Region	Gold R.	kraft (sulphate)	kraft pulp, woodroom and sanitary	177,000	clarifier	submarine diffuser	Muchalat Inlet
Westar Timber Ltd. - Skeena Pulp Div.	Prince Rupert	kraft (sulphate) - 2 mills	kraft pulp woodroom	218,000 15,900	screening	submarine diffuser surface discharge	Porpoise Harbour
Western Pulp Partnership - Squamish Pulp Div.	Howe Sound	kraft (sulphate)	kraft pulp, woodroom sanitary	136,588	clarifier none	submarine diffuser	Howe Sound
- Port Alice Pulp Div.	Port Alice	sulphite (NH_3 base)	sulphite pulp	174,500	SSL recovery-incineration and 3 day retention spill pond	submarine diffuser	Neroutsos Inlet

determined by observing the fish survival in a 65% effluent concentration over a 96 hour period.

Provincial requirements for effluent quality are on a site specific basis, allowing levels of pollutants prescribed in an effluent permit issued under the provincial Waste Management Act. In developing the terms and condition of the effluent permit, the provincial Waste Management Branch (WMB) follows a set of "Pollution Control Objectives for the Forest Products Industry of British Columbia", published in 1977 (Pollution Control Board, 1977). These objectives provide "for the use of the environments' assimilative capacity within limits which do not lead to unacceptable conditions". In so doing, they include objectives for both effluent quality and receiving water quality, as shown in Tables 1.3 and 1.4 respectively. These objectives have been developed for all pulp mill discharges and some parameters may not apply to marine discharges.

Since all of B.C.'s coastal mills existed prior to the promulgation of the federal regulations, the mills were not required to comply immediately with the effluent quality criteria. Instead, compliance timetables are negotiated with individual mills, the terms of which are usually applied through provincial regulatory mechanisms (i.e. Waste Management Branch discharge permit).

The provincial effluent permit requirements for each of the ten coastal pulp mills are summarized in Table 1.5.

1.2 Environmental Monitoring Programs

The impact of pulp mill effluents on the receiving environment has been assessed by EPS at least annually at most coastal mills since the early 1970's. Generally these monitoring programs have been designed to evaluate four major environmental impacts noted in Table 1.1.

These "effects monitoring" programs are consistent with the pollutants which are limited by permit in the effluent discharge - BOD, suspended solids and toxicity. When unacceptable deterioration in environmental conditions is observed, negotiations are opened with

TABLE 1.3 EFFLUENT OBJECTIVES FOR PULPING PROCESSES (Kraft, Sulphite, and Mechanical)

CHARACTERISTIC	UNIT	LEVEL		SUGGESTED MONITORING FREQUENCY
		A	B	
Total suspended solids	kg/t (lb./ADT)	10 (20)	17.5 (35)	Daily composite three times per week.
BOD_5 -				
Kraft	kg/t (lb./ADT)	7.5 (15)	30 (60)	Daily composite once per week.
Sulphite: paper grades	kg/t (lb./ADT)	50 (100)	113 (225)	Daily composite once per week.
dissolving grades	kg/t (lb./ADT)	75 (150)	175 (350)	Daily composite once per week.
Mechanical	kg/t (lb./ADT)	7.5 (15)	20 (40)	Daily composite once per week.
Temperature	°C	35	35	Daily.
pH range[1]	--	6.5 - 8.0	6.5 - 8.0	Continuous.
Dissolved oxygen[2]	mg/L	2.0	--	Daily.
Zinc (mechanical only)	kg/t (lb./ADT)	--	1 (2)	Once per week.
Toxicity[3 4]	% effluent volume	100	30	Monthly[5].

[1]Applicable only to fresh waters. Where background pH of receiving water is outside the designated range, effluent pH shall not differ from background by more than ± 0.2 pH units.
[2]Applicable to effluents after secondary treatment.
[3]In the case of bleached kraft mills the tabled values are based on water usage of 150 m^3/ADT (30,000 gal/ADT.)
[4]96-hour TLm static bioassay on salmonid species giving 50 per cent survival over 96 hours. Tabled values are effluent dilutions (by volume) in which tests are to be conducted. For marine discharges, toxicity tests are to be carried out on neutralized samples.
[5]If failure detected, frequency to be every two weeks until objective met.
- Pollution Control Board (1977)

TABLE 1.4 RECEIVING WATER QUALITY OBJECTIVES[1]

CHARACTERISTIC	OBJECTIVE	CHARACTERISTIC	OBJECTIVE
Dissolved oxygen	negligible change[4]	Primary production[3]	negligible change
Toxicity	no increase	Tainting, edible organisms	no change
pH	negligible change	Colour (APHA units)	negligible increase
Residual chlorine	below detectable limits (amperometric method)	Suspended solids	negligible increase
		Phenol	negligible increase
Turbidity (APHA units)	negligible change	Mercaptans	negligible increase
Oil	none visible on water surface	Sulphides	negligible increase
Floatable solids, scum	negligible increase	Resin acids (total)	negligible increase
Temperature (°C)	no measurable change	Biocide additives	no measurable increase
Foam	no increase	Woodwaste leachates	negligible increase
Nutrients[2]	negligible change in site specific productivity limiting parameters	Aesthetic	no decrease

[1]Not applicable in the initial dilution zone.
[2]Nutrients - Limiting parameters will normally be taken as phosphates and/or biologically assimilative nitrogen compounds.
[3]Primary production - Biological growth directly dependent on sunlight.
[4]A negligible change (increase or decrease) is one which does not lead to a polluted condition in receiving water quality and can therefore be disregarded.
- Pollution Control Board (1977)

TABLE 1.5 SUMMARY OF PROVINCIAL PERMIT REQUIREMENTS FOR COASTAL PULP MILL EFFLUENT DISCHARGE (as at May 28, 1986)

COMPANY	LOCATION	PERMIT NUMBER	PERMIT REQUIREMENTS						
			TSS ($kg.day^{-1}$)	BOD ($kg.day^{-1}$)	TOXICITY[1]	pH	TEMPERATURE	COLOUR	OTHER
British Columbia Forest Products	Crofton	PE-114	27,500	48,000	30 %	-	-	See Note 1	-
MacMillan Bloedel	Nanaimo (Harmac)	PE-1214	12,000	27,000	30 %	-	35°C	See Note 1	-
	Port Alberni	PE-266	16,500	16,500	80 %	6.5-8.5	35°C	See Note 1	-
	Powell River	PE-153	30,500	44,500	34 %[3]	-	35°C	See Note 1	-
Canadian Forest Products	Port Mellon	PE-1149	10,150	17,400	30 %	-	35°C	See Note 1	-
Crown Forest Industries	Campbell River	PE-1164	29,000	43,500	30 %	-	35°C	See Note 1	-
CIP Forest Products Inc.	Gold River	PE-318	13,300	25,300	30 %	-	35°C	See Note 1	fecal coliforms
Westar Timber Ltd.[2]	Prince Rupert	PE-1157 (Skeena)	25,000 compliance	55,000 based on monthly	12.5 % average	-	40°C	-	-
Western Pulp Partnership	Port Alice	PE-1240 (variance order)	90 kg/Adt	177 kg/Adt	30 %	-	35°C	See Note 1	-
	Squamish (Woodfibre)	PE-1239	0.17 kg/m^3	0.28 kg/m^3	30 %	6.5-8.5	35°C	-	mercaptens: < 2 mg/L sluphides: < 1 mg/L residual chlorine: < 0.1 mg/L

[1]Toxicity expressed as percent effluent which is permitted to cause death in 50 percent of the test fish in 96 hours (LC_{50}). Effluent concentrations must not be less than that shown. All effluent samples are neutralized.
[2]Westar Timber. Two pulpmills discharge to 2 common outfalls.
[3]Receiving waters outside the initial dilution zone must not have greater than 0.05 toxic units (100 percent ÷ LC_{50}).

Note 1. No maximum levels are prescribed however the mills must measure colour in the effluent, usually weekly.
Note 2. Receiving water monitoring program are required for most mills to determine the zone of impact or influence. The specifics of each program are not included in the permit.

regulatory authorities to adjust effluent quality accordingly. Other environmental effects which are less routinely monitored but which may have a greater long term environmental threat include sub-lethal or chronic toxicity and metal uptake and bioaccumulation. Sublethal or chronic stress has been measured experimentally in a number of ways in fish including effects on blood characteristics, circulation, cough response, avoidance behaviour, growth and swimming performance. These effects are rarely seen in receiving environments and are difficult to measure. Metal pollution from pulpmills is not normally regarded as a significant environmental threat due to the low concentrations in the wood or processing chemicals. Mercury and zinc have historically been metals of concern due to their presence in slimicides and brightening agents although their uses have been discontinued - mercurial slimicides since 1960 and zinc dithionite since 1973 (Waldichuk, 1983). Cadmium has been noted in sediments near several coastal mills, probably associated with zinc in bleaching processes no longer used.

Environmental monitoring programs are undertaken by the various mills as a requirement of their provincial discharge permit and by the federal government, through the Environmental Protection Service and Department of Fisheries and Oceans, as a means of assessing compliance with, or the adequacy of, the Federal regulations. The details of these monitoring programs are provided elsewhere (Kay, 1986).

1.3 Biological and Environmental Impacts

As a general statement, the environmental impacts of pulp mill discharges have changed during the past 10-15 years due to improved mill processes (e.g. chemical recovery) and treatment, and the replacement of surface discharges with submarine diffusers at many of the mills. In many cases these changes have resulted in measurable improvements in water quality and biological productivity. However the installation of submarine diffusers has led to a different environmental problem, that of fibre deposit in deeper waters resulting in habitat removal and potential toxicity (Pomeroy, 1983a).

The total discharge levels of TSS and BOD in relation to production at all coastal mills is shown in Figure 1.2, while Figure 1.3 presents the average total of TSS and BOD discharge ($kg.day^{-1}$) for all coastal mills

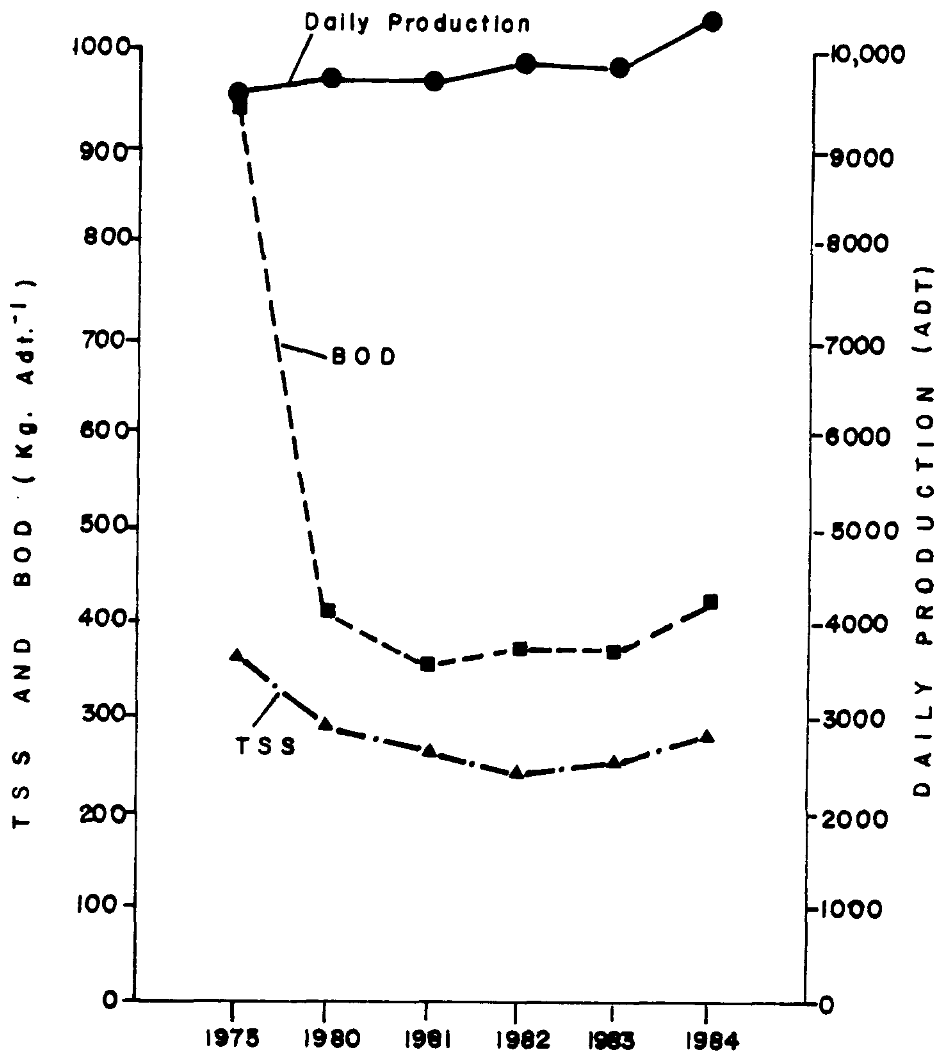
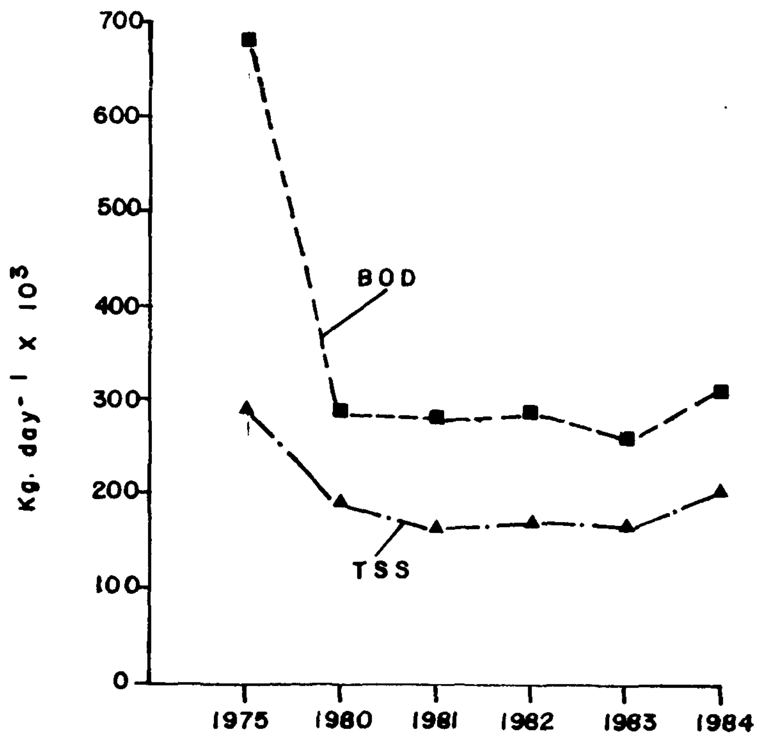


FIGURE 1.2 TOTAL PRODUCTION (Adt.day^{-1}) AND TSS / BOD RELEASES (Kg.Adt^{-1}) FOR ALL COASTAL PULP MILLS, 1975-1984



YEAR	BOD	TSS
1975	682971	298811
1980	298811	198161
1981	287719	164312
1982	295562	174194
1983	269941	171233
1984	311010	202461

FIGURE 1.3 AVERAGE TOTAL OF TSS AND BOD DISCHARGE (Kg$\cdot$day^{-1}) FOR ALL COASTAL PULPMILLS, 1975-1984 (EXCLUDING OCEAN FALLS)

between 1975 and 1984. The efforts of industry and government in limiting the discharge of BOD and TSS are readily evident between 1975 and 1980, when an overall 56% reduction in BOD and 34% reduction in TSS was achieved. Since 1980, average daily production levels and BOD/TSS discharges have stabilized, with a slight increase evident in 1984. These data do not take into account mill shutdowns, which would result in decreased annual loadings, nor do they reflect the success of specific abatement programs which may have been instituted at individual mills between 1980 and 1984.

Environmental and ecological concerns from pulp mill discharges have previously been categorized in Table 1.1. They are common to all pulp mills although the degree of environmental impact will vary. In the following discussion, these pollution categories are reviewed to provide a general overview of the problems and solutions at the various coastal mill locations. Detailed descriptions of the many studies undertaken by researchers, consultants, forest companies and government agencies are provided elsewhere (Kay, 1986).

1.3.1 **Dissolved Oxygen.** The BOD loading from pulp mill effluents has caused serious dissolved oxygen deficiencies in the receiving waters of Alberni Inlet, Neroutsos Inlet, Cousins Inlet and Porpoise Harbour/Wainwright Basin.

A long history of investigations exists for Alberni Inlet and has recently been reviewed by Waldichuk (1983) and Morris and Leaney (1980). Oxygen levels in Alberni Inlet have been of concern since the construction of the kraft pulp mill in 1949. This concern is related primarily to the abundant salmonid resources of the Somass River. The Somass River system supports all five species of Pacific salmon and was one of the first areas in British Columbia where an artificial spawning channel was constructed for salmon (Morris and Leaney, 1980). The estuary is also important habitat for wintering waterfowl populations, including Trumpeter Swan. The vulnerability of this estuarine system to pollution and other manifestations of industrialization prompted large scale environmental monitoring and effluent treatment and improvement programs.

Between 1949 and 1956, mill effluent was discharged through the marshes of Lupsi Cupsi Point into the northern corner of Alberni Harbour. After extensive studies of oceanographic processes pointed to a chronic oxygen depression below the halocline which had developed since installation of the mill, a decision was taken to relocate the discharge into the Somass River current, which would quickly disperse it seaward in the surface layer. In 1956 the discharge was directed to the mouth of the Somass River. Subsequently a flume was built to convey the effluent along the deep sea wharf to the present discharge point where it could be swept into the seaward flow of the jet stream from the Somass River.

However, the low oxygen problem persisted through 1970, when MacMillan Bloedel established a pollution abatement program to upgrade the quality of the effluent. This included the construction of a clarifier and aeration lagoon (biobasin) to remove 22,675 kg/day of both suspended solids and BOD from the effluent streams.

Although these improvements resulted in an increase in surface dissolved oxygen levels, the amount of oxygen available to satisfy fish requirements and the BOD of the waste effluent varied significantly with the Somass River flow. Consequently, the company was required to control the TSS and BOD discharge according to river flow in order to maintain sufficient D.O. levels. Beginning in 1983 the company was required to reduce TSS and BOD discharges to 16,500 kg/day and continue monitoring the Somass River flow daily from November 1 to February 28.

Dissolved oxygen data collected by Sullivan (1981, 1982) in 1980 and 1981 shows levels ranging from 7.7-10.5 $mg.L^{-1}$ in surface waters nearest the discharge point. However, levels drop quickly with depth, with ranges of 2.5-7.5 $mg.L^{-1}$ at 5 meter depth and 1.3-7.1 $mg.L^{-1}$ at 10 m depth. The high D.O. values of 7.5 $mg.L^{-1}$ and 7.1 $mg.L^{-1}$ at the 5 and 10 m depths respectively were recorded on March 4 and 5, 1982 and indicate conditions in Alberni Harbour are periodically environmentally acceptable. The dissolved oxygen values observed below the halocline (which varies between 2 and

5 metres depending on river flow and season) have not shown significant improvement despite the pollution abatement facilities installed in 1970. The continued low dissolved oxygen values result from several factors, including the BOD of the mill effluent, the extensive discolouration of the water reducing natural phytoplankton productivity below the halocline (see discussion on primary productivity, Section 1.3.4) and oxygen demand of anaerobically decomposing organic debris in benthic substrates. Figure 1.4 shows the comparions of dissolved oxygen data collected at a station nearest the outfall during several studies between 1965 and 1982.

Dissolved oxygen depletion has also been a major concern at the Western Pulp Ltd. Partnership (formerly Rayonier Canada) sulphite mill at Port Alice. Early studies conducted in the late 1950's and 1960's (Waldichuck et al., 1968) showed depressed oxygen levels at the entrance to Neroutsos Inlet, approximately 10.4 km from the outfall. During the summer, D.O. levels in the surface waters (0-4 m) of Neroutsos Inlet were generally below 4 $mg.L^{-1}$. Levels decreased in both surface and depth (15 m) waters with a range of 1.7-2.8 $mg.L^{-1}$ at a station closest to the outfall.

Between 1973 and 1977 mill monitoring showed the dissolved oxygen levels in the surface waters were improved and held to an average 4.0 $mg.L^{-1}$ base level at the mouth of the inlet. However, D.O. levels near the discharge point continued to be extremely low during the summer months, with values ranging from 0.3-4.1 $mg \cdot L^{-1}$ in the top 2 metres (Davis et al., 1977). During this period, the mill was required to reduce BOD and TSS discharges through the installation of a recovery system for spent sulphite liquor (SSL) and biological treatment. In fact, SSL was barged for ocean dumping between 1974 and 1976. In 1977 an SSL incineration system was installed together with a three day retention SSL spill pond, although biological effluent treatment has not yet been installed. With the completion of the SSL recovery system, Rayonier Canada embarked on an environmental monitoring program to assess the impact of the effluent discharge on the physical, chemical and biological properties of the receiving waters and fish resources through toxicity and preference/avoidance testing and salmon migration and escapement studies. A series of reports detailing these studies have been published by the Company and summarized in

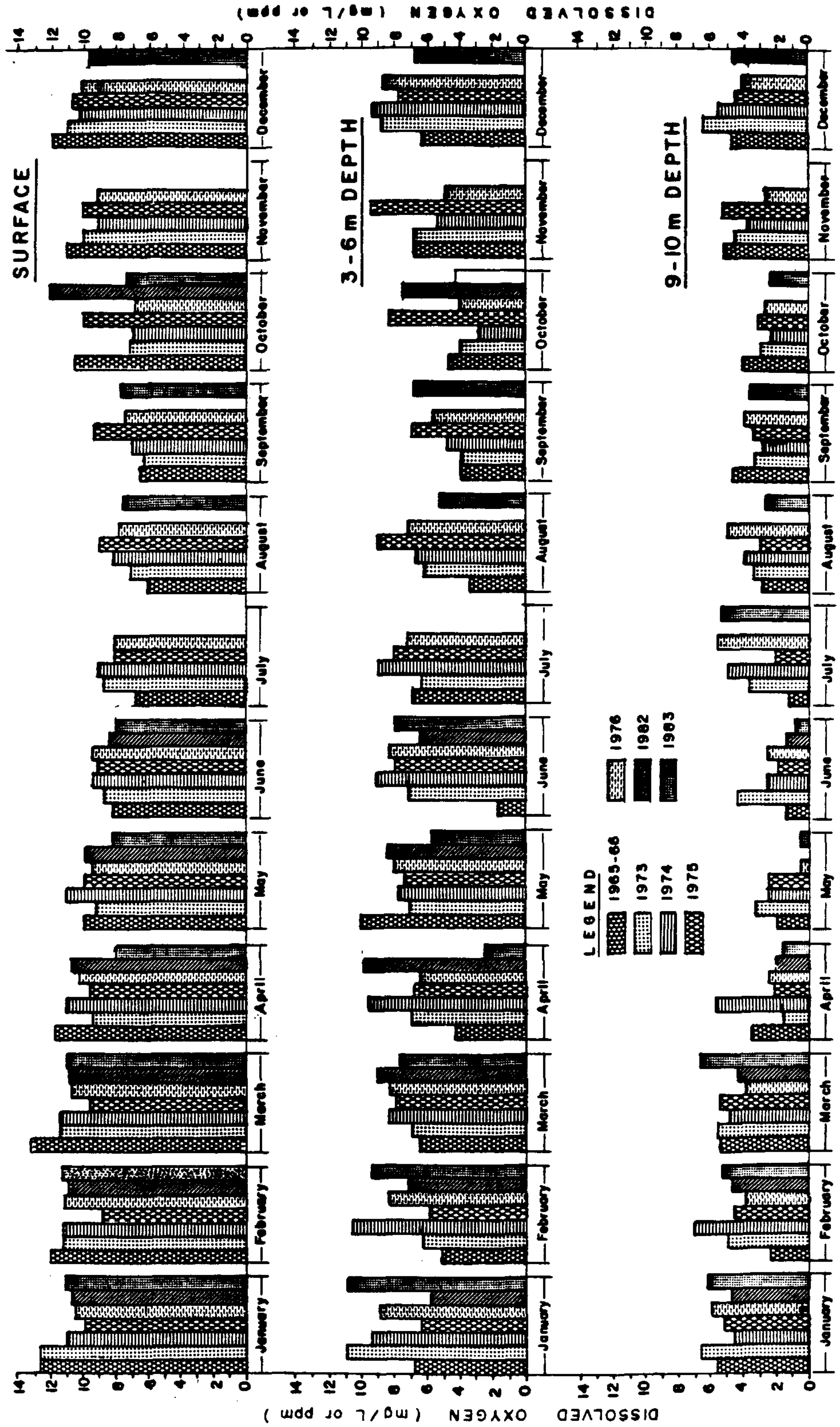


FIGURE I.4 MEAN DISSOLVED OXYGEN LEVELS - HOHM ISLAND - BY THE MONTH three volumes (Tollefson and Tokar, 1978; Tokar and Tollefson, 1980; Tollefson, 1982).

Improvements in D.O. levels in surface waters reported by the Company between 1969 and 1978 are reflected in the simplified diagram presented in Figure 1.5. The 1980 an 1981 water quality monitoring programs gave similar results (Tollefson, 1982).

Oxygen data collected in 1984 during a 9 day operation, 5 day shutdown cycle, indicate that oxygen recovery during the 5 day period was sufficient to cope with the BOD demand during the 9 day operation period for critical fry migration periods. This implies that the BOD loading under full operation was near the assimilative capacity of the Inlet (Pomeroy, EPS memorandum, 1984). Dissolved oxygen data for 1983-1985 is shown in Figure 1.6 for a sample station located mid-inlet off the mill site. Severe oxygen depletion was noted from June to October in 1985 due to several factors including (i) a switchover in the mill to a high BOD product, (ii) an increase in production, (iii) a combination of warm weather and low freshwater discharges to the inlet (Colodey and Pomeroy, 1985). The re-direction of the effluent to a 37 m deep diffuser in October 1985 appeared to have alleviated the surface D.O. problems, although D.O. at depth now appears to be depressed, as shown in the November 1985 data in Figure 1.6. Preliminary data showed a recurrance of severe oxygen depletion during the spring of 1986, when large numbers of herring were killed. Further data collection will be necessary to assess the impact of the new diffuser discharge on Neroutsos Inlet.

In Porpoise Harbour near Prince Rupert, changes in mill processes, pollution abatement technology and effluent discharge locations at the Westar Timber Ltd. (formerly Canadian Cellulose) operation have resulted in significant improvements in D.O. levels in the surrounding waters. The present operation includes two bleached kraft mills which discharge their combined effluents through a 17 m deep diffuser outfall into Porpoise Harbour.

Historically, pollution problems associated with the mill have resulted from the poor flushing characteristics of Morse Basin, Wainwright Basin, and Porpoise Harbour, when Wainwright Basin received effluent from a sulphite mill located on Watson Island between 1950 and 1966.

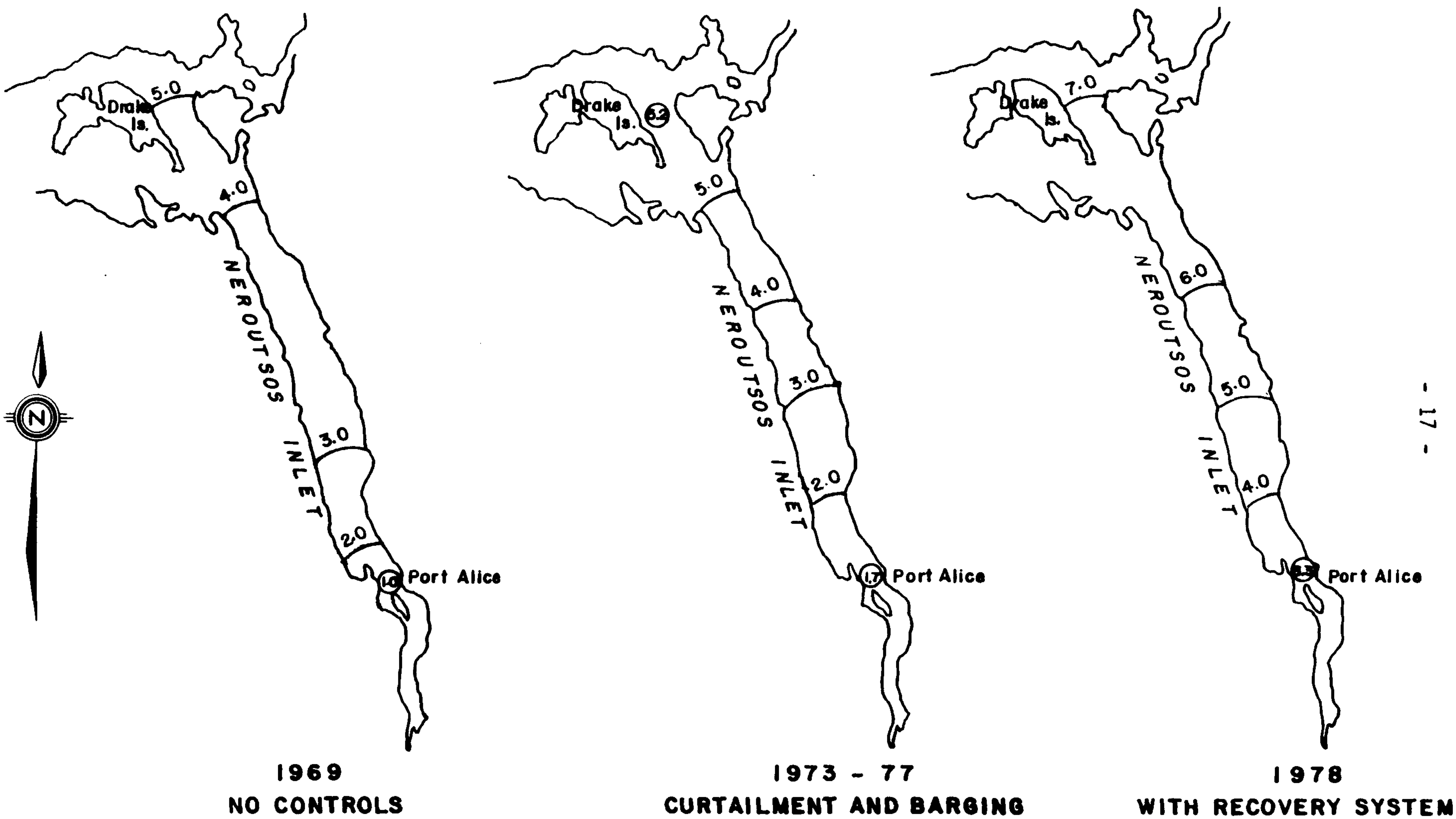


FIGURE 1.5 IMPROVEMENT IN WATER QUALITY - NEROUTSOS INLET DISSOLVED OXYGEN MEAN VALUES - July, August, September, October ppm - Top 2 metres (After Tollefson and Tokar, 1978)

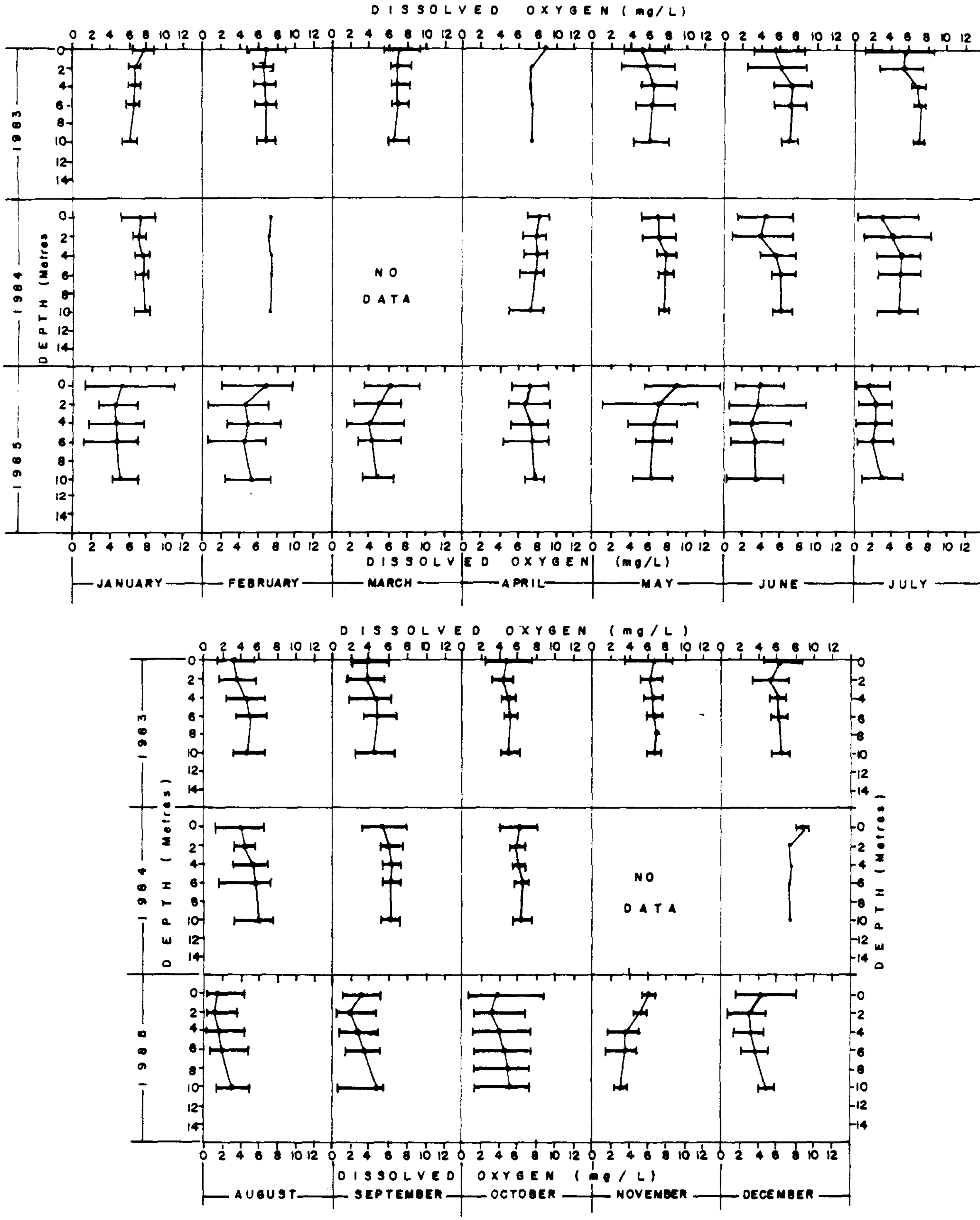


FIGURE 1.6 MONTHLY DISSOLVED OXYGEN PROFILES (MEAN AND RANGE) AT SAMPLE STATION 8, NEROUTSOS INLET, 1983 - 1985

Dissolved oxygen concentrations in Porpoise Harbour and Wainwright Basin declined continually from the time the sulphite mill was built in 1950 until the SSL line was moved to discharge into Chatham Sound in 1967. In 1961, Waldichuk (1962) recorded values of < 4 $mg \cdot L^{-1}$ through the entire water column (25 m depth) in Porpoise Harbour, with levels approaching zero at many locations (Figure 1.7).

In 1967 the SSL was diverted to a new outfall discharging into Chatham Sound on the northwest corner of Ridley Island.

After this relocation to Chatham Sound the D.O. levels in Porpoise Harbour and Wainwright Basin improved markedly. In surveys conducted by EPS in 1974, Packman (1977) found dissolved oxygen concentrations ranging from 3.3 $mg \cdot L^{-1}$ to 9.7 $mg \cdot L^{-1}$ in Porpoise Harbour. Oxygen depression continued to occur in Porpoise Harbour however, due to breaks in the SSL pipeline resulting in fish kills (reviewed by Packman, 1979c).

Concurrent with this diversion, a new kraft mill was constructed on Watson Island with effluent discharging into Wainwright Basin. In 1976 the sulphite mill was permanently shut down and in 1978 a new kraft mill was brought on-line. With the completion of the new mill, effluent from both kraft mills was rerouted to the diffuser outfall discharging to Porpoise Harbour. After the shutdown of the sulphite mill in 1976, dissolved oxygen concentrations in Porpoise Harbour returned to normal levels as recorded by EPS in 1977 and 1978 (Packman, 1979c).

Studies conducted by EPS between 1979 and 1982 (Pomeroy, 1983b), and again in 1984, following the installation of the diffuser in Porpoise Harbour concluded dissolved oxygen concentrations in the immediate area of the diffuser were depressed in comparison to stations farther removed and reflect an effluent effect. However, levels still remained higher than previously measured, with the lowest value recorded at the outfall site being 5.7 $mg \cdot L^{-1}$ at a depth of 20 m. Average dissolved oxygen concentrations at a station sampled in Porpoise Harbour (P-12) between 1961 and 1984 are shown in Figure 1.8.

In Wainwright Basin, dissolved oxygen levels measured at two stations by Westar Timber during 1985 (Dwernychuk, 1986) ranged from 6.9 $mg \cdot L^{-1}$ (15 m depth) to 10.4 $mg \cdot L^{-1}$ (10 m depth). D.O. concentration at the deepest sampling point (30 m) ranged from 7.0 $mg \cdot L^{-1}$ to 10.1 $mg \cdot L^{-1}$.

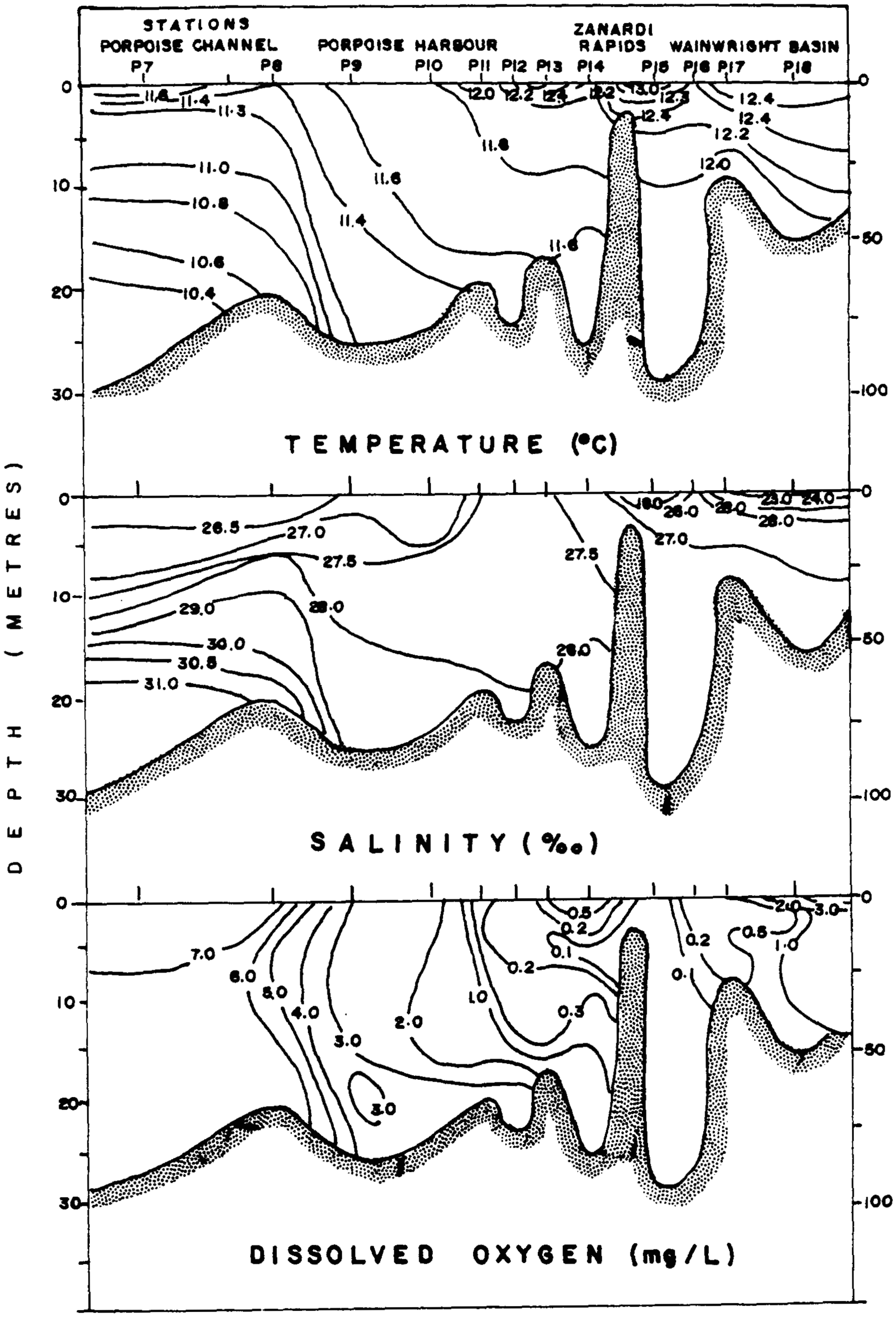
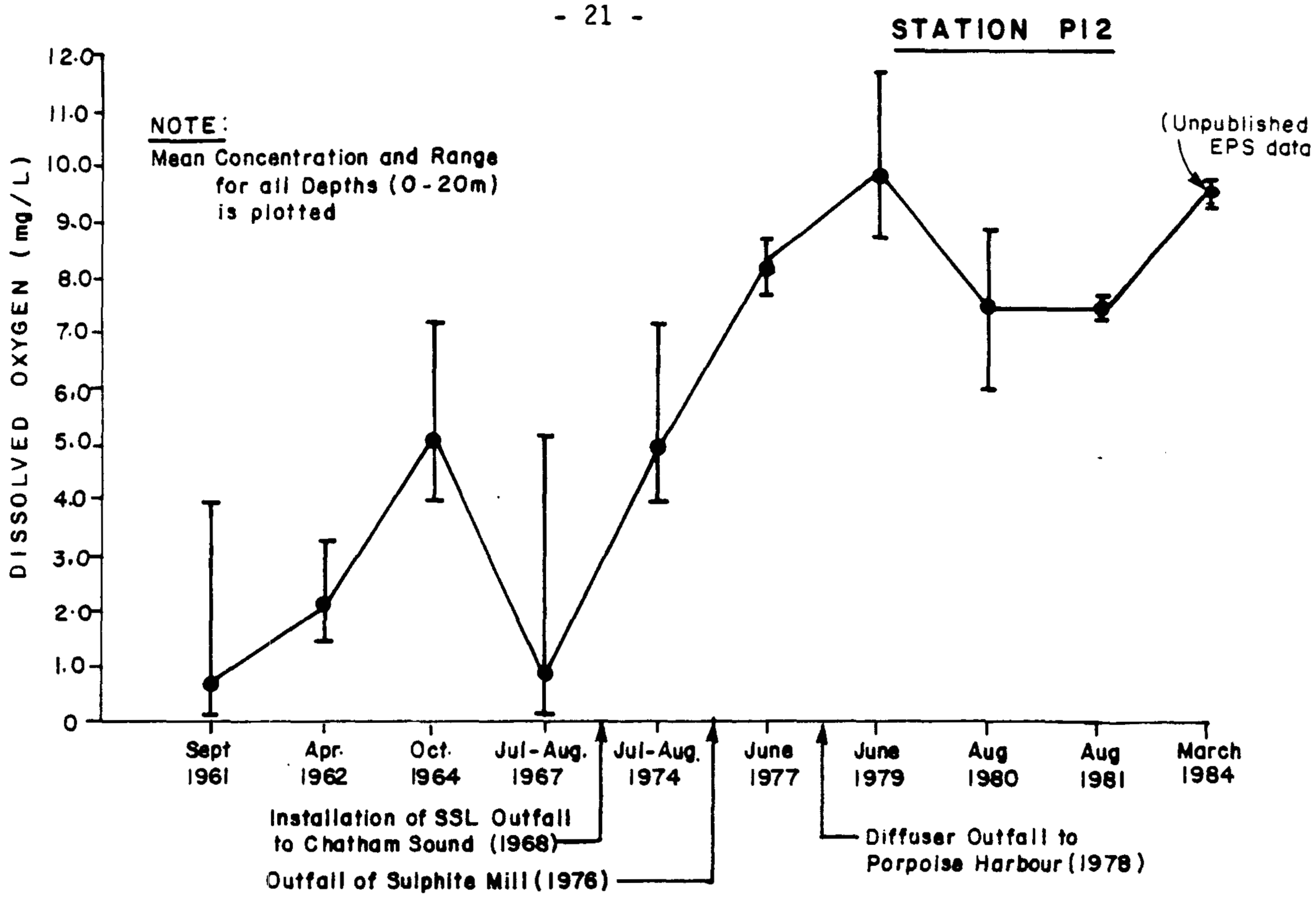


FIGURE 1.7 WATER COLUMN PROFILES (PORPOISE HARBOUR - WAINWRIGHT BASIN) (Waldichuk, 1962)



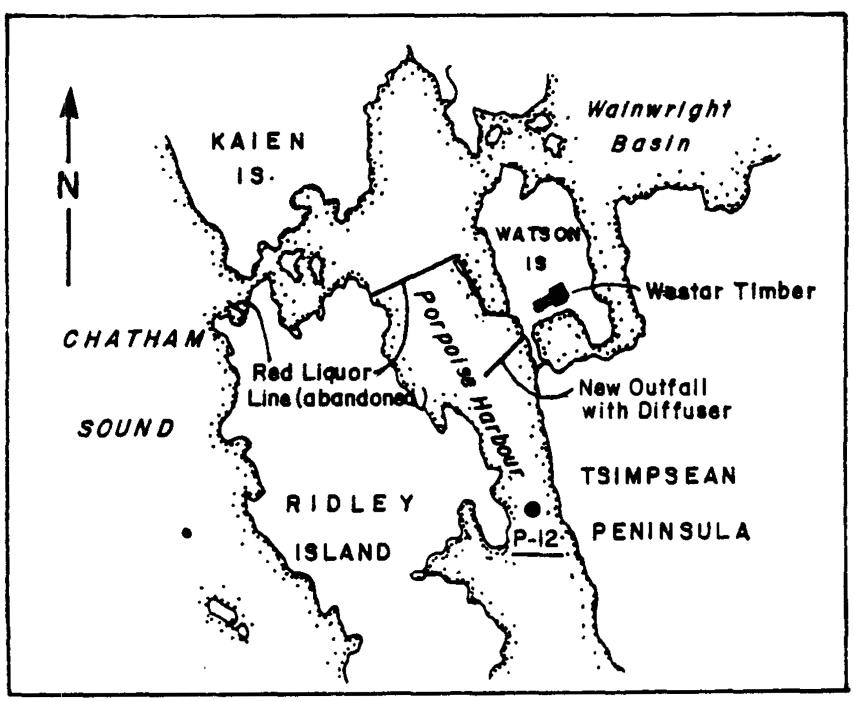


FIGURE 1·8 CHANGES IN DISSOLVED OXYGEN CONCENTRATIONS IN PORPOISE HARBOUR, 1961 - 1981 (Waldichuk et. al, 1968; Packman, 1976; Packman, 1979; Pomeroy, 1983)

At the head of Cousins Inlet where the Ocean Falls mill operated until 1981, dissolved oxygen concentrations were significantly reduced in bottom waters due to the surface effluent discharge. The low dissolved oxygen values were attributed to the oxygen demand resulting from accumulated fibres contained in the surface discharge (Packman, 1979a). The cessation of chemical pulping in 1967 resulted in significant improvements in bottom and surface dissolved oxygen concentations although levels recorded in 1974 were still as low as 1.5 $mg \cdot L^{-1}$ in October. This mill was permanently closed in 1981 and further work investigating water quality rehabilitation has not been conducted.

1.3.2 Toxicity. The toxicity of pulp mill effluents to fish species is routinely monitored at all coastal pulp mills and an upper limit of toxicity is prescribed in all provincial discharge permits (Table 1.5). Table 1.6 presents compliance data (pass/fail) for all coastal mill effluent monitoring programs since 1975.

In general, pulp mill effluents have variable toxicity, even over very short term periods (i.e. minutes) during the pulping operation. Poole et al. (1978) have summarized toxicity data collected from a variety of regulatory test procedures and the results are presented in Table 1.7.

In a study of seven B.C. mills over a 40 day period, Walden and Howard (1977) concluded that toxicity varied up to 500% and effluents were non-toxic without treatment about 23% of the time. Their study showed that untreated neutralized BKME commonly had 96 hr LC_{50} values ranging from 15-50% v/v. Walden (1976) reviewed data on the effect of whole mill effluent and black liquor on invertebrates and fish involved in food chains, including phytoplankton, zooplankton (brine shrimp), blue mussels, crustaceans, crabs and seaworms and concluded the threshold level for toxicity of whole mill outfalls was approximately 5 % v/v. In other words, the concentration of pulp mill effluent at which acute toxic effects were observed was approximately 5 %.

Leach and Thackore (1977) examined pulp mill effluents from Canadian mills to determine the major toxic components. They found that 70-100 % of the toxicity resulted from resin acids, and chlorinated lignins

TABLE 1.6 **PULPMILL TOXICITY COMPLIANCE SUMMARY, 1975-1984**

MILL:	CROFTON		SKEENA		PT. MELLON		ELK FALLS		ALPULP		HARMAC	
YEAR	LC_{50}	P/F	LC_{50}	P/F	LC_{50}	P/F	LC_{50}	P/F	LC_{50}	P/F	LC_{50}	P/F
1975	30	4P/3F	30	1P/1F	30	1F	30	1P/2F	90	9P	65	1F
1976	30	1P/5F	30	1P/8F	65	1P/4F	65	6F	90	8P	65	1P/9F
1977	30	2P/1F	65	6F	65	1P/5F	65	6F	90	9P/2F	30	3P/2F
1978	NR	NR	NR	NR	NR	NR	NR	NR	90	7P/3F	30	NR
1979	NR	NR	NR	NR	NR	NR	NR	NR	90	6P/3F	30	NR
1980	30	4P	30	1P/2F	12.5	NR	30	NR	90	5P/3F	30	4P
1980	30	2P/1F	30	2F	30	NR	30	NR	90	7P/1F	30	3P
1980	30	7P/5F	30	2P/5F	30	NR	30	NR	80	3F	30	1P
									25	3P	30	
1983	30	10P/5F	30	2P/6F	30	1P/3F	30	3F	80	4P	30	4P
1984	30	4P/6F	30*	1P/22F	30*	1P/1F	30*	2F	80	4P	30	3P

MILL:	POWELL		TAHSIS		PT. ALICE		WOODFIBRE		OCEAN FALLS	
YEAR	LC_{50}	P/F	LC_{50}	P/F	LC_{50}	P/F	LC_{50}	P/F	LC_{50}	P/F
1975	30	1P	30	1P/2F	30	1F	12.5	1P	NR	NR
1976	65	6F	65	5F	65	8F	65	6F	65	5F
1977	65	1P/4F	65	6F	65	7F	65	3F	65	7F
1978	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
1979	30	NR	30	NR	30	NR	12.5	NR	30	NR
1980	30	2P	30	2P/4F	30	1P/3F	12.5	NR	30	NR
1981	30	3P	30	1P/1F	30	2P/1F	12.5	NR	-	-
1982	34	4P	30	4P	30	NR	12.5	2P	-	-
1983	34	4P	30	4P	30	2P/2F	12.5	1P	-	-
1984	34	3P	30	3P	30*	7F	12.5	1P/1F	-	-

KEY: P/F = Pass/Fail
LC_{50} = Percent concentration of effluent tested (not necessarily permit values) to obtain pass or fail result
* = incomplete data
NR = No Record

TABLE 1.7 REGULATORY BIOASSAY TESTS WITH SALMONID UNDERYEARLINGS AND WHOLE PULP AND PAPER MILL EFFLUENTS (after Poole et al. (1978))

EFFLUENTS	TEST ORGANISM	TEMP. (°C)	pH	96-HR LC_{50} EFFLUENT CONCENTRATION (v/v)
KRAFT MILL EFFLUENT				
Whole	*Oncorhynchus nerka*	15	7.0 - 7.4	12.2
Neutralized	*O. nerka*	15	7.0 - 7.4	34.2 - 64.1
BLEACHED KRAFT MILL EFFLUENT	*O. tshawytscha*	9 - 15	7.4 - 7.8	1.9 - 3.6
	O. kisutch	9 - 15	7.4 - 7.8	3.1 - 67.0
	O. nerka	10 - 13	7.0	> 22
	O. kisutch			
	O. gorbuscha			
	Salmo salar	15	7.0 - 7.2	12.0 - 25.0
SULFITE WASTE LIQUOR				
Fresh	*S. salar*	16 - 18	6.5 - 6.7	2.0 - 2.4
Oxidized	*S. salar*	16 - 18	6.5 - 6.7	2.8
Ammonia base	*S. gairdneri*	14 - 18	7.7 - 8.5	0.82
	Salvelinus fontinalis	8 - 12	?	8.7 - 25.0
Soda base				11.6 - 60.0
Groundwood	*Salmo gairdneri*	12	6.4 - 7.0	2.5
Fine paper	*S. gairdneri*	?	6.1 - 7.5	55.0 - 65.0

and other chlorine-containing compounds formed by the bleaching process. Approximately 30 compounds were identified as toxic contributors to pulp mill waste.

Sublethal effect studies were reviewed by Davis (1976). The average sublethal concentration of whole kraft mill effluent for all species of salmon studied was 0.16 of the 96-h LC_{50}, and varied between 0.06 to 0.33. Neutralized kraft mill bleach plant effluent yielded a slightly higher sublethal average concentration of 0.375 of the 96-h LC_{50}, with a range of 0.05-0.8. The most sensitive sublethal thresholds appeared to involve behaviour, temperature tolerance and cough frequency. Davis (1976) recommended the establishment of a discharge dilution criteria of 0.02 96-h LC_{50} for neutralized whole BKME to protect against sublethal toxic effects.

Receiving water studies to assess acute and chronic sublethal toxicity of pulp mill effluents have been few in British Columbia. The most extensive study has been conducted at the Port Alice sulphite mill in conjunction with a multidisciplinary study to assess the recovery of Neroutsos Inlet following installation of SSL recovery in 1978. The studies began in 1978 and continued for three years.

The first study was conducted in 1978 (Vigers et al., 1978) and included in situ toxicity and avoidance/preference tests for juvenile chum, juvenile herring and coho smolts and laboratory studies to determine chronic effects of sulphite mill effluent on the growth and behaviour of juvenile chum salmon. The in situ effects are presented in Figure 1.9. In the vicinity of the mill where SME was present at a high concentration in the surface waters, the juvenile fish preferred subsurface waters, and substantial mortality was encountered up to 0.4 to 0.8 km from the mill outfalls in the preference/avoidance chambers. From these distances, to beyond 2 km from the mill outfall, mortalities were reduced or non- existent, although a preference for subsurface waters was still observed. Beyond 0.8 km from the outfalls, fish increasingly preferred the surface meter of the water. Significant positive correlations were found between the distribution of chum and coho salmon in the surface meter of water and the distance from the mill outfall and consequent changes in mill effluent parameters. Decreased fish survival and increased fish avoidance were also associated with elevated Pearl Benson Index (PBI - a measure of the presence

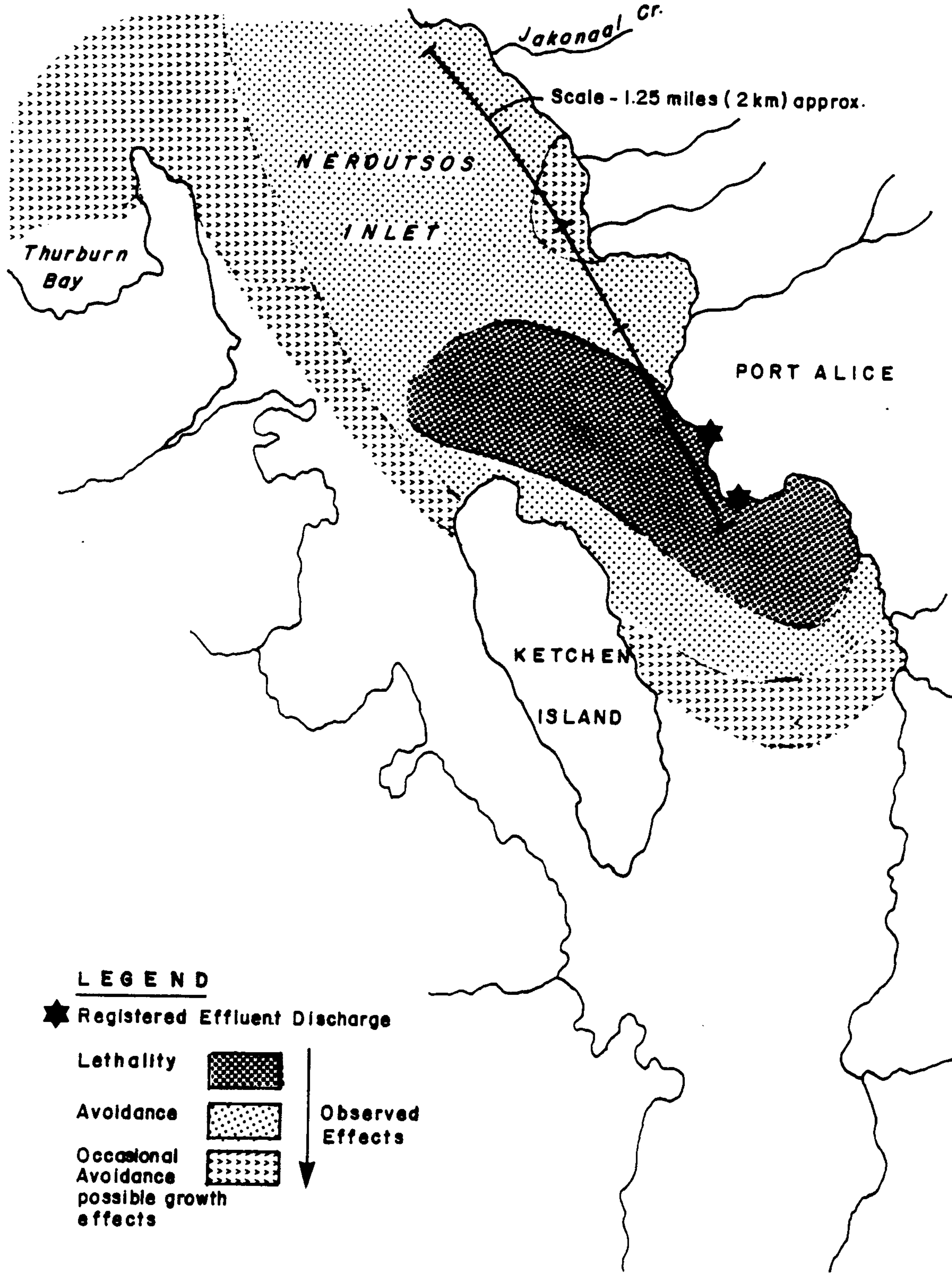


FIGURE 1.9 POSTULATED ZONE OF INFLUENCE FROM THE PORT ALICE MILL SHOWING THE MAXIMUM EXTENT OF OBSERVED EFFECTS FROM IN SITU FISH BIOASSAYS (Vigers et al., 1978)

of SSL), elevated temperature and decreased pH and salinity values. The study was unable to determine a precise relationship between effluent levels and avoidance reaction.

Chronic effects of the effluent were demonstrated in laboratory studies (Vigers et al., 1978). Exposure of chum fry to effluent concentration of 0.1 and 0.25 of the 96-h LC_{50} resulted in a reduction in biomass even though growth rates remained equal. It was concluded that reduced biomass production at a higher food ration was the result of reduced metabolic efficiency in the conversion of food to body mass.

Acute lethal bioassays (Vigers et al., 1978) of the mill effluent (using the residual oxygen bioassay) conducted concurrently with the in situ studies showed toxicity averaged 11.3% with a range of 0.6-100% v/v. Toxicity was generally pH dependent but was shown to vary by a factor of 20 for any one pH value. Based on these bioassay results, it was calculated that the dilution that might be expected to achieve the threshold for no effect ranged from a low of 18:1 to a high of 16,667:1.

In the second year of the study (1979), research efforts were directed primarily at assessing the zones of influence of the sulphite mill effluent with respect to fish preference/avoidance behaviour (McGreer et al., 1980). The study concluded that the influence of the mill as measured by preference/avoidance and acute lethality extended out to 10 km north of the mill, although avoidance reactions at this site were observed only on an ebb tide. An analysis of the measured water quality parameters indicated that pH, dissolved oxygen and percent saturation of dissolved oxygen were statistically significant determinants for chum salmon vertical distribution in the cages. As in the first study, chum fry showed a preference for the top 1 m of water except in the presence of SME. This data is summarized in Figures 1.10 and 1.11.

Fish mortality was observed at all test sites, with the highest percentage noted in traps closest and northward of the mill (52.5% and 44.2% respectively).

The third and final year of the study (1980) concentrated on examining the zone of effect in close proximity to the mill at various stages in the tidal cycle (McGreer et al., 1982). Results from this study concluded

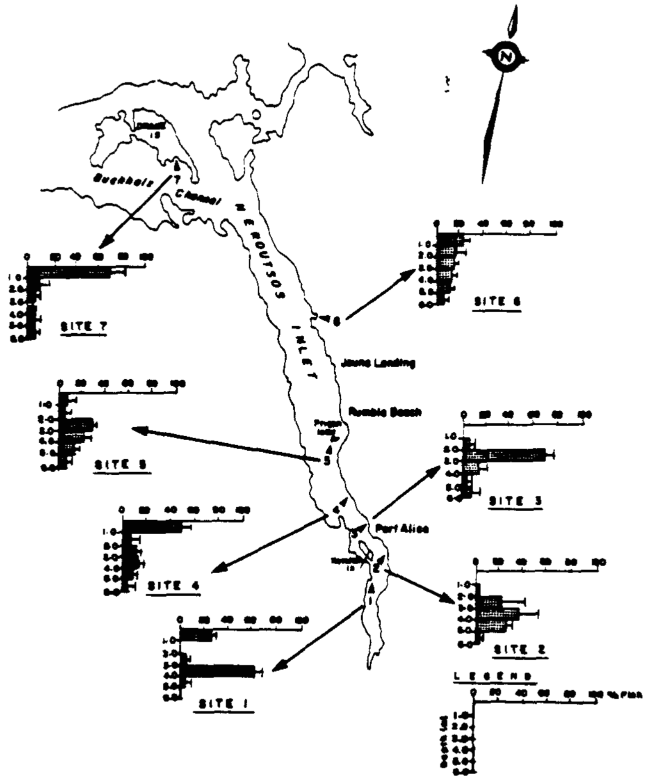


FIGURE 1.10 SUMMARY OF CHUM FRY AVOIDANCE AT NEROUTSOS INLET EBBING TIDE (McGreer et al., 1980)

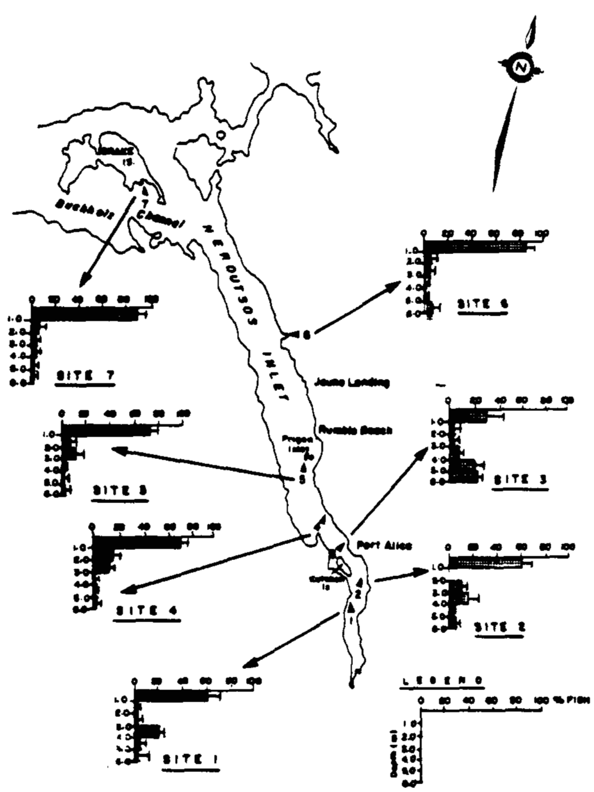


FIGURE 1.11 SUMMARY OF CHUM FRY AVOIDANCE AT NEROUTSOS INLET FLOODING TIDE (McGreer et al., 1980)

that fish avoidance behaviour was not as pronounced as that observed in 1979 and was strongly affected by the state of the tide. A reduction in the toxicity of the sulphite mill effluent from 1979 was also shown by an increase in the 96-h LC_{50} for SME in laboratory bioassays with rainbow trout. Mortalities in surface waters of Neroutsos Inlet during 24 h acute toxicity studies with juvenile chum salmon were recorded up to 0.5 km from the mill site, representing a reduction in the size of the acute lethal zone from 1979. Water quality had improved over the 1979 test and, although a statistical significance was found between fish vertical distribution in the cages and water quality parameters, it was much weaker than in 1979.

In addition to these studies, fisheries studies were also conducted between 1978 and 1980 to examine the migratory behaviour of juvenile salmonids originating from the Cayeghle/Colonial creek system at the head of Neroutsos Inlet. Poulin and Rosberg (1978) concluded that the seaward migration of juvenile chum peaked in mid April and was virtually complete by the end of May. In the vicinity of Port Alice, east side migrants were absent from nearshore areas and did not reappear until 2.0-2.5 km down-inlet. These findings were essentially repeated by Poulin and Rosberg (1980) in the 1979 studies and suggested large numbers of fry were successful in moving seaward of the mill along both the eastern and western shoreline. During both the 1978 and 1979 studies, no significant correlation between chum catch and water quality parameters was observed outside of the gross response of fry to surface water conditions within the mill vicinity. Further work conducted in 1980 (Poulin and Oguss, 1982) comprising fluorescent dye marker/recapture studies indicated that chum fry from Cayeghle Creek move rapidly and freely throughout Neroutsos Inlet. Tagged fry released at the head of the inlet dispersed within 4 or 5 days to the entrance of the inlet, near Quatsino Sound. The demonstrated ability of the chum fry to cross the inlet freely above and below the mill, and their presumed ability to avoid the mill effluent plume suggested to the authors that it was unlikely large numbers of fry were trapped in the zone of influence and exposed to acutely toxic concentrations of effluent. The study concluded that the impact of the mill consisted primarily of the possible loss of approximately 2 km of nearshore habitat plus a localized reduction in water quality adjacent to the mill.

More recently however the spawning patterns of returning chum salmon were significantly disrupted during severe oxygen depression observed in 1985. Avoidance reaction to the reduced oxygen values resulted in a significant delay returning to spawning grounds which may have resulted in unsuccessful spawning and/or death. There was no visual evidence of dead salmon however there was a positive correlation between abundance of salmon netted and ambient D.O. (Colodey and Pomeroy, 1985).

The MacMillan Bloedel Harmac mill was also the subject of toxicity studies in 1977 (EVS Consultants, 1977) to assess the effect of its effluent on larval and juvenile herring. The study concluded that herring larvae were 2-3 times as sensitive as other routine test fish to BKME in the 96 hour acute toxicity LC_{50} test. However, at <u>in situ</u> concentrations of the Harmac effluent (concentrations up to 0.05 96-h LC_{50}) it was postulated the effluent would have minimal impact on herring larvae development. Similarly no significant effects on growth, appetite or conversion efficiency were observed in juvenile herring exposed for 36 days to effluent at <u>in situ</u> concentrations. Chronic exposure to 0.001 to 0.005 of the 96-h LC_{50} of Harmac BKME would not introduce a stress which would exclude herring from Northumberland Channel nor would it have a direct effect on growth, feeding or food conversion efficiency.

Toxicity studies using oysters and salmon at the Canadian Forest Products Mill at Port Mellon have been reviewed by Nelson (1979a). Oysters placed in a cage 200 m from the alkaline outfall all died within one year and were heavily fouled with fibre and lime mud. Oyster condition improved and mortality decreased with increasing distance from the mill. Results of this study suggested a zone of influence extending 0.5 to 0.8 km south of the mill. Avoidance reactions by juvenile chinook and chum salmon were noted in surface waters (1.5 m) in the vicinity of the mill. This work was performed prior to the installation of the submarine diffuser.

Davis et al. (1976) studied <u>in situ</u> physiological effects of the B.C. Forest Products Crofton mill discharge on coho underyearlings. Although inconclusive, they found evidence of reduced metabolic activity when fish were exposed to water 0.24 km from the mill outfall. Toxic effects of this discharge, as measured by condition factor (i.e. plumpness) in oysters were noted at a station 1.9 km northwest of the outfall. This poor condition factor has persisted for some years.

1.3.3 Effects on Intertidal Community Structure. The toxic effects of pulp mill effluents have been evaluated at a number of coastal mills using qualitative and quantitative studies of the nearshore habitat. These studies examine the abundance and diversity of invertebrate populations within the intertidal ecosystem as a measure of the pulp mill effluent zone of influence. Generally, intertidal effects are most significant at mills having surface, rather than submarine, outfalls. These studies have also been valuable in assessing the rate and degree of recovery of intertidal habitat following the replacement of a surface discharge with a submarine outfall diffuser.

Packman (1979b) has reviewed the impact of the Harmac pulp mill effluent both prior to and following the installation of a submarine diffuser in Northumberland Channel in January 1976. Studies conducted by the mill prior to 1976 noted that the effluent appeared to have the greatest effect on larval and juvenile life stages of fauna which settled in the intertidal zones during April to October. Periods of heavy barnacle die-off and poor periphyton growth were noted in the mill zone of influence. These detrimental effects were noted in varying degrees over a distance of some 5000 m north and south of the mill. Following installation of the diffuser, a definite increase in species and numbers of animals was noted in the intertidal zone within the previous zone of influence. Qualitative assessments of the intertidal biological communities conducted by the mill at four stations within Northumberland Channel have shown that intertidal biological trends have not changed significantly since 1976 (Young, 1983). The study recommended the intertidal program be discontinued.

Similar intertidal improvements have been observed at other coastal mills following the installation of submarine diffusers. Beak Consultants (1978) found recoveries at previously affected sites following the installation of the diffuser at the Elk Falls mill in 1977. Prior to diffuser installation, intertidal areas within the foam containment boom were denuded of their normal complement of shorelife and the impact was measureable approximately 150 m in a southerly direction (Beak Consultants, 1974).

Surface-discharged effluent from the Powell River mill exerted an influence on intertidal ecology up to 8 km northward with the prevailing currents. Effects to the south were minimal, although intertidal growth restrictions were noted at a station on Harwood Island (Young, 1978). With the installation of a submarine diffuser in 1980, intertidal impacts have been alleviated (Sullivan, 1982). However, a new fibre bed and consequent benthic habitat alienation have been recently observed near the diffuser (Pomeroy, unpublished).

The impact of the Port Mellon mill surface discharge has been reviewed by Nelson (1979a). Severely depressed intertidal communities were observed in the vicinity of the pulp mill and the zone of influence was concluded to extend 1 to 2 km south of the mill outfalls. The recent (1982) installation of a submarine diffuser has removed effluent from the shoreline. Recovery studies of the intertidal communities have not yet been reported, but water quality studies by the mill have concluded that temperature, dissolved oxygen, salinity and pH profiles in general were not significantly different from values observed at the control stations. Colour was shown to indicate the presence of effluent in surface waters south, but not north of the diffuser (Dupree and Nieminen, 1985).

Perhaps the most extensive studies on intertidal community structure changes resulting from pulp mill discharges were conducted at the Western Pulp Limited Partnership Sulphite Mill at Port Alice as part of the multi-disciplinary study investigating environmental improvements at Neroutsos Inlet. The study was developed and implemented through 1978 and 1979 and has been reported by Cross and Ellis (1981). Measurement techniques were designed to evaluate biological changes in areas exposed to different concentrations of sulphite mill effluent. The pollution influence of the discharge was measured by finding the location of maximum abundance of an amphipod, Allorchestes anagusta. This location was shown to move closer to the discharge source and indicated decreased pollution over the course of the study. Analysis of the shoreline flora and fauna data illustrated a tendency of the sulphite effluent to affect the east side of Neroutsos Inlet for approximately 7 km and to have less of an effect on the west side.

1.3.4 **Effects on Primary Productivity.** The dark brown colour of mill effluents can present severe ecological problems under certain circumstances. The inhibiiton of sunlight penetration can reduce or retard photosynthesis by phytoplankton, seaweed and rooted aquatic vegetation. This in turn reduces the amount of food available to the food chain and can also diminish or even eliminate a source of oxygen to the water. This can be particularly problematic in areas already experiencing depleted oxygen levels.

Primary productivity studies have been incorporated into the monitoring programs of several coastal mills including Port Alice (Sullivan, 1979a), Port Alberni (Sullivan, 1978) and Gold River (Sullivan, 1979b). In addition, research programs have been conducted at the Port Mellon and Squamish (Woodfibre) mill sites in Howe Sound (Stockner et al., 1975). These latter programs, conducted in 1973 to 1975, concluded that the strong light attenuating properties of KME were the major cause of reduced primary productivity rather than effluent toxicity adjacent to British Columbia coastal mills. Mills situated in areas of rapid tidal flushing showed practically no effect of KME (e.g. Harmac, Elk Falls) while those located in inlets with little flushing showed the greatest inhibition (Port Alice, Porpoise Harbour, Wainwright Basin). The study also showed that primary production adjacent to the mills was restored to near normal levels during mill shutdowns resulting from a labour dispute between July and October 1975. For example, primary production adjacent to the Port Mellon mill in Howe Sound increased 56 times after 14 days of mill closure, as compared with a 1.7-fold increase at a control site. At the head of Howe Sound light attenuation caused by the Woodfibre mill effluent reduced productivity, but this effect is masked in the natural effect of high turbidity from the Squamish River.

Sullivan (1979a) examined the impact of the Port Alice sulphite mill effluent on phytoplankton productivity in Neroutsos Inlet prior to the installation of the spent sulphite recovery system. Areal production rates between a control station in Quatsino Sound and a station at the mill differed by a factor of 20-40 times, depending on the time of year. Mill effects as measured by reduced productivity were seen at a station near the entrance to Neroutsos Inlet, some 18 km from the discharge. During a mill shutdown, differences in production between the control and mill site were reduced to 2-3 fold. The study concluded the reduced phytoplankton productivity was related to light attentuation.

Primary productivity studies continued at the Port Alice mill during the environmental monitoring program from 1979-1980. These data, summarized by Tollefson (1982) continued to show depressed primary productivity at the mill site and for some distance down the inlet during April to September studies.

Studies in Alberni Inlet conducted by EPS (Sullivan, 1978) during 1974-1976 concluded that lower phytoplankton productivity in the harbour as compared to a control area down inlet resulted from several factors, either operating singly or in combination. Of particular note in this study was the frequent absence of nitrate in the upper zone of the water column at both control and test sites. This phenomenon, combined with the light attenuation resulting from the pulp mill discharge and possible reduced phytoplankton standing crops, were considered probable causes of the reduced phytoplankton productivity in the harbour.

1.3.5 **Effects on Benthic Habitat.** The large daily releases of suspended solids by surface or submarine outfalls can seriously degrade benthic habitats. A large portion of the discharged effluent consists of wood fibres which settle out, resulting in direct removal of bottom habitat and smothering of organisms. The high oxygen demand of these deposits can result in low dissolved oxygen concentrations near the bottom. The estimation of the oxygen demand of these deposits is not necessarily reflected by the BOD tests on the effluent, since the microbiologial breakdown of cellulose occurs over a longer time period than that measured by the test.

Besides causing oxygen deficiency in waters overlying the sediment/water interface, pulp mill effluent solids degrade benthic habitat by turning sediments anoxic under anaerobic decomposition of wood fibres, and by production of toxic hydrogen sulfide (H_2S).

The Environmental Protection Service has examined the benthic habitat in the vicinity of many coastal mills, using both qualitative measurements and direct visual observations with the PISCES IV submersible. Pomeroy (1983a) has reviewed these studies for the mills at Porpoise Harbour, Ocean Falls, Harmac and Woodfibre. McGreer (1984) analysed marine benthic invertebrate data collected by EPS at eight coastal mills during 1981-83.

The zone of influence on the benthic habitat is variable and can depend on the method of effluent disposal, water exchange and surface and subsurface currents, and the length of time the effluent has been discharging. Table 1.8 summarizes the measured zones of influence at various coastal mills.

Pulp mill deposit patterns are similar among the various mills. Sampling sites adjacent to the discharge are often devoid of life due to physical smothering, toxicity due to hydrogen sulphide gas, and anoxia. With increasing distance from the outfall, a 'transition zone' is encountered wherein marine life becomes more abundant. Measurement techniques for determining the extent of the zone of influence include species abundance and diversity, organic carbon determinations and analysis for specific pulp mill effluent components (e.g. resin acids).

Insufficient data are available to determine the rate of encroachment on the benthic habitat of fibre deposition. Overall, fibre releases (as measured by TSS) from coastal mills have stabilized since 1980 (Figure 1.2). Despite this stabilization, areas of fibre deposition are increasing at some locations e.g. Northumberland Channel (Harmac), Malaspina Strait (Powell River) and Porpoise Harbour (Pomeroy, 1983a) while at other locations (e.g. Stuart Channel) the fibre deposits although extensive, appear to have reached their maximum size (Sercombe and Hincks, 1981).

Perhaps the most severe environmental impact related to fibre deposition occurred at the now-closed Ocean Falls mill in Cousins Inlet. During the 69 years of mill operation, a large deposit has been formed up to 3.5 km from the mill. Adjacent to the mill itself the deposit was estimated to approach 15 m thick, decreasing to isolated thin patches in a 'transition

TABLE 1.8 SUMMARY OF BENTHIC EFFECTS OF COASTAL MILLS

PULP MILL	DISCHARGE LOCATION	YEARS OF DISCHARGE	MEASURED ZONE OF IMPACT	REFERENCE
Ocean Falls	Cousins Inlet	69	4.8 km	Packman, 1979a
Woodfibre	Howe Sound	72	1 - 1.5 km	Nelson, 1979b
Harmac	Northumberland Channel	11[a]	0.8 - 1.0 km	Packman, 1979b
Westar	Porpoise Harbour	7[b]	0.3 - 0.75 km	Pomeroy, 1983b
Crofton	Stuart Channel	28	1.6 - 3.2 NW & SE 0.3 km offshore	Sercombe and Hincks, 1981 Pomeroy (EPS _in. lit._, 1984)
Elk Falls	Discovery Passage	8[c]	0.5 km	Pomeroy (EPS _in. lit._, 1984)
Port Alice	Neroutsos Inlet	68[d]	0.5 - 1.0 km	Pomeroy (EPS _in. lit._, 1984
Port Alberni	Alberni Inlet	38 (15 yrs (with treatment)	1.9 km	Pomeroy (EPS _in. lit._, 1984)
Powell River	Malaspina Strait	8[e]	0.5 km	Pomeroy (EPS _in. lit._, 1984)

[a] installation of submarine diffuser in 1976
[b] installation of submarine diffuser in 1978
[c] installation of submarine diffuser in 1977
[d] SSL recovery installed in 1979
[e] submarine outfall installed in 1977 for kraft mill

zone' extending an additional 1.3 km, for a total impact distance of some 4.8 km. In the heavy impact benthic zone the deposit is strongly reducing, with bubbles of H_2S gas being released and portions of the deposit being brought to the surface. No obvious life was present in this area with the exception of sea anemones and polychaete worms utilizing logs projecting from the deposit. Increases in organic content and some heavy metals in the sediments were evident with proximity to the mill, with zinc levels increasing approximately 6 fold between the entrance to Cousins Inlet and the mill site.

An example of recovery can be seen in Wainwright Basin, which previously received effluent from the Canadian Cellulose sulphite mill. Large intertidal and subtidal fibre deposits had formed in the Basin by 1966, and dissolved oxgen levels reached near zero due to the very poor flushing rates. Benthic fauna was virtually non-existent and intertidally restricted to some worms, crustaceans and poorly developed algae. Large mats of fibre frequently appeared on the water surface, raised by H_2S gas accumulations on the bottom. Intertidal habitat and shallow (< 25 m) water quality recovery occurred quite quickly with the diversion of the effluent discharge first to Chatham Sound, then to Porpoise Harbour. However, EPS has now identified a fibre deposit forming in the vicinity of the new outfall and diffuser in Porpoise Harbour (Pomeroy, 1983b).

Studies have been conducted by the B.C. Forest Products mill at Crofton to determine the extent of the fibre deposition. Ellis (1970) determined that the fibre bed extended in Stuart Channel from 1.6 to 3.2 km northwest and southeast of the outfalls, with the coarse fraction extending to approximately 305 m offshore to a water column depth of about 46 metres. The area of accumulated coarse fibre extended about 0.4 km on each side of the outfalls and formed a mat 10-15 cm or more thick. In 1978, underwater PISCES examination by EPS revealed areas of soft substrate covered with patches of white bacterial or fungal slime. Shrimp populations, abundant at 100 m depth, declined with decreasing depth and were not seen above 35 m. From 50 to 35 m the dominant benthic organisms were sole (Nelson, 1979c). More recent studies by the mill (Sercombe and Hincks, 1981) have concluded that the affected areas around the outfalls has not enlarged compared to previous mill surveys between 1974 and 1979. The fibre had not been found extend more than 1.8 km northwest or southeast of the outfalls, nor more than 0.45 km offshore.

During 1982-83 EPS surveyed benthic infaunal communities at eight coastal pulp mills. McGreer (1984) analysed the data and compared them with results of surveys in 1978 and 1981. The following notes are excerpted from his report.

Porpoise Harbour

Reduced numbers of taxa were reported for all sites north of the outfall and for sites within 1500 m south of the outfall compared to the reference site. The same pattern was not reflected in the total abundance data. In 1981, abundance was similar at most stations. Abundance per sample appeared to be much greater in 1981 than in either 1978 (approx. 100) or 1983 (approx. 300) at the same sites. This was solely due to the increased abundance of the polychaete *Capitella capitata* in samples analysed.

At some sites there was an apparent reduction in the number of species and abundance from 1978 to 1983. This trend appears to indicate a deterioration in benthic communities in Porpoise Harbour and this site warrants further investigation.

Port Alberni

Decreased numbers of taxa compared to other stations are most apparent at sites within 750 m of the mill. Only two or three taxa are generally found near the outfall. The numbers of taxa are highest (25 species) between 1000 and 2500 m from the point of effluent discharge, then appear to decrease at stations farthest from the outfall. This pattern was similar for all three years sampled. Changes in abundance per sample followed closely the pattern for total numbers of taxa with highest values (1,283 at station 7) being recorded at stations 1500-2500 m from the outfall. Total abundances showed an apparent increase between 6- and 20-fold between 1980 and 1982 at these stations. Abundances were highly variable from one year to another at all stations. Amphipod species were noticeably absent from most samples.

Port Mellon

The total numbers of taxa in 1980 were highest (13) at a site located 600 m from the mill. This increase in species suggests a response due to organic enrichment. A reduction in the number of taxa compared to site 3 was observed at sites 2, 5 and 6. As the stations sampled represented both shallow and deeper water sites, characterization of communities due to mill influence is difficult with such a small number of samples. Sites sampled in 1980 were not sampled in 1981, so comparison with the subsequent years' data cannot be made.

The abundance data also appear to be related to organic enrichment showing higher values at sites near the mill. In general, both the total numbers of taxa and organism abundance are relatively low compared to non-polluted stations at other sites. More intensive sampling near the mill and along transects running north and south in Thornbrough Channel is required to adequately characterize the benthic communities in the area, and to permit an adequate assessment of effects of the mill effluent.

Port Alice

The lowest number of taxa was recorded at a site approximately 250 m down-inlet from the mill. Sites further away (approximately 750 and 1250 m from the mill) showed an increase in the number of taxa compared to any of the other sites, suggesting a response due to organic enrichment. The total abundances per sample were also highest at sites closest to the mill (approximately 300 per sample), apparently due to organic input. Both numbers of taxa and abundance per sample were much reduced at sites more distant than 1250 m from the mill. The sites sampled at Port Alice appear well situated for monitoring changes in benthic communities from year to year. Replicate samples collected at each site would allow determination of within site variability and use of statistical methods for comparing data.

Harmac

Compared to other mill sites Harmac shows a more complex pattern of changes with increasing distance from the mill. The highest number of taxa (20) was found at a site approximately 1000 m from the outfall. Between 1000 and 2000 m, there was a sharp decrease in the number of taxa at all sites, followed by a second peak between 2000 and 2500 m from the outfall. Changes in total abundance followed a pattern of increasing and decreasing values similar to that for the numbers of taxa. The overall range of abundance per sample (3-64 individuals) was one of the lowest reported for any mill site sampled. The reason for the complex changes observed in benthic data off Harmac are unknown. The changes may reflect interactions between organic enrichment and effluent or sediment toxicity. Further sampling is required to confirm the unusual pattern apparent in the 1981 benthic set.

Ocean Falls

Numbers of taxa are reduced at sites within 3 km of the previous discharge compared to sites farther down Cousins Inlet. This pattern is similar to that shown by Fournier and Levings (1982) in their study of polychaete species in this area. Dominant polychaete species identified in the previous study (Fournier and Levings, 1982), for example *Sigambra tentaculata*, *Nephyts cornuta franciscana*, *Lumbrinereis* sp., *Cassura* sp., *Capitella capitata* and *Heteromastus filobranchus*, were also reported as common species in the EPS benthic data which was dominated by polychaete worms.

The total abundance of individuals per sample was lowest at site 10, closest to the mill. The highest number of individuals per sample (128) at one site (B) contained a large number of *Nemertea spp*. (94) in the sample. If this group of worms is excluded, the numbers at this site are similar to those from the other sites in proximity to the mill. Abundance at sites more distant from the mill appeared to be highly variable. Replicate sampling to assess differences in abundance in relation to the mill is required. With respect to future monitoring at this site, it is of interest to note that Fournier and Levings (1982) suggested that the potential for benthic recolonization in this area is poor.

Crofton

As only three samples were collected offshore from the Crofton mill, it is not possible to determine the extent of effects due to the mill discharge from the present data. In general, the range in values for the number of taxa (3-6) and abundance per sample (4-7 individuals) was very low and indicative of a disturbed community. Additional sampling over a larger area is required to separate changes due to the mill discharge from natural benthic communities in the area. The dominance of *Paraonis gracilis* and *Diplodonta orgbellus* in the samples suggests the presence of organic enrichment due to wood waste.

Woodfibre

Four sediment samples collected in close proximity to the Woodfibre mill were completely devoid of benthic invertebrates. Additional sampling at greater distances from the mill is required to assess the zone of impact for benthic communities at this site.

1.3.6 **Metal Levels in Sediments and Biota.** The Environmental Protection Service collects sediment in the vicinity of coastal pulp mills for a variety of analyses, including trace metals, particle size and percent organic matter. Figure 1.12 shows ranges of these levels for mercury, cadmium, lead, copper and zinc. The data represents the range of results for all samples sites at a given mill.

Although not now generally considered significant contributors of trace metals, pulp mill effluents in the past have contained significant levels of zinc and mercury. The two metals were used in compounds involved in the bleaching process (zinc) and controlling slime and fungal growth (mercurial slimicides). Zinc, as zinc dithionate, was discontinued as a brightener in 1973, while the use of mercury based slimicides was stopped around 1960.

The highest values for mercury in sediments were recorded by Nelson (1979d) in 1978 at the Powell River mill. A level of 21.0 $mg \cdot kg^{-1}$ dry weight was observed in a core sample collected immediately offshore from the breakwater. The high level persisted in 1979 with a maximum value of 9.49 $mg \cdot kg^{-1}$ dry weight being recorded by Sullivan (1980). These results have not been duplicated during subsequent surveys and no source has been identified.

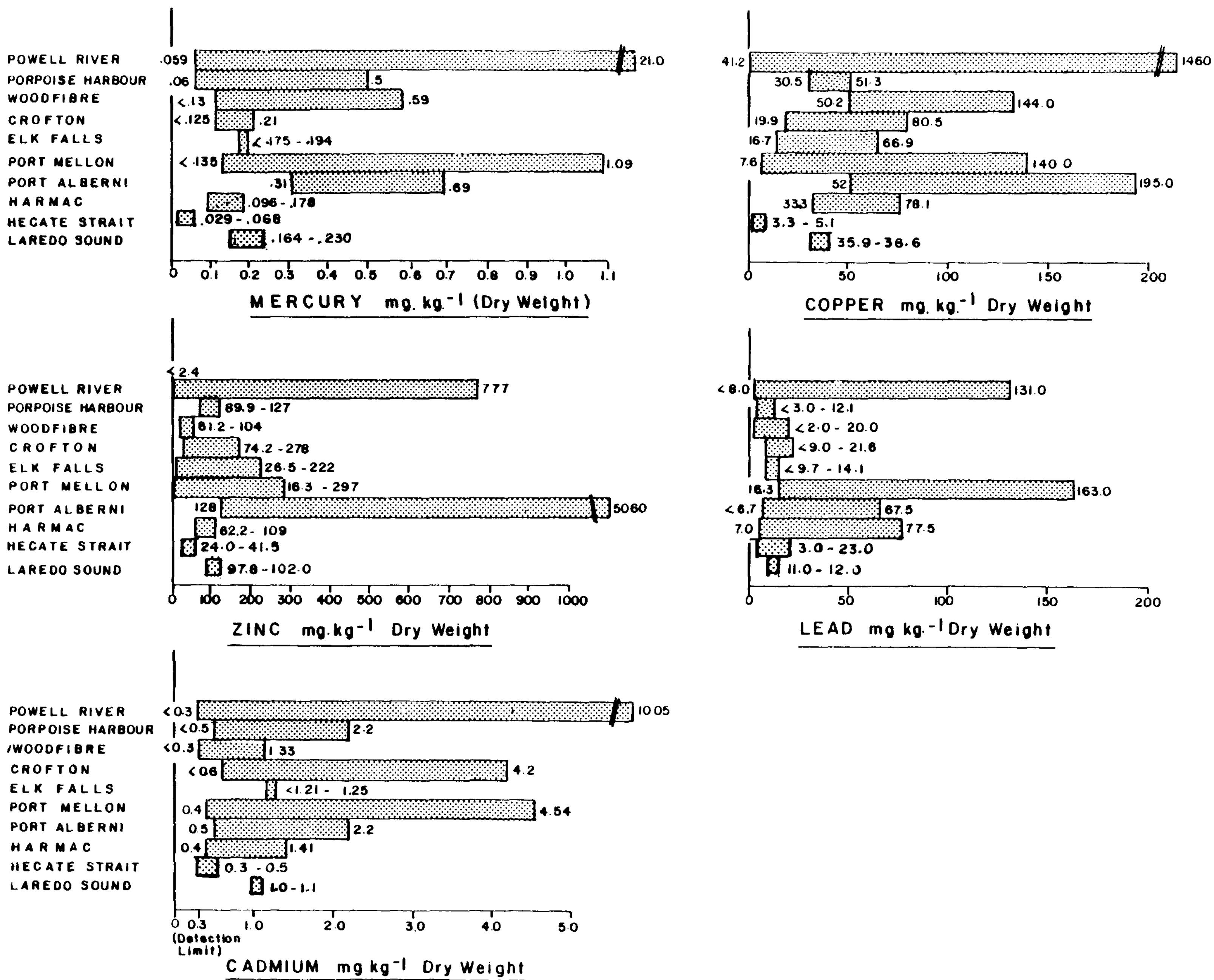


FIGURE 1-12 RANGE OF TRACE METAL CONCENTRATIONS FOUND IN SEDIMENT AT COASTAL PULPMILLS
[illegible]

Cadmium levels in the Powell River sediments are also substantially higher than those observed at other mills. The highest value of 10.5 $mg \cdot kg^{-1}$ (dry weight) was recorded in November 1980. The lowest value of 2.92 $mg \cdot kg^{-1}$ (dry weight) recorded during this survey was still substantially higher than most other coastal mills. High levels continued to be observed in 1981 (Sullivan, 1982) and it was surmised that the cadmium may have been a contaminant in zinc dithionate (zinc hydrosulphite), since zinc concentrations were correspondingly high at stations with elevated cadmium. The cadmium levels indicate a continuing concern associated with dredging and dredge spoils disposal from this site.

Elevated cadmium levels have also been observed at sediment stations adjacent to the Port Mellon (4.54 $mg \cdot kg^{-1}$), Port Alberni (2.2 $mg \cdot kg^{-1}$) and Crofton (3.46 $mg \cdot kg^{-1}$) mills.

Sullivan (1980) has briefly discussed the expected levels of cadmium and mercury in natural, unimpacted marine sediments. Literature values cited for the development of levels for cadmium and mercury for Schedule I of the Ocean Dumping Control Act suggest that cadmium levels in "unpolluted" areas would range from 0.04-1.9 $mg \cdot kg^{-1}$ and mercury levels would range from 0.015-0.17 $mg \cdot kg^{-1}$. Levels stipulated in the Ocean Dumping Control Act are 0.75 $mg \cdot kg^{-1}$ for mercury and 0.60 $mg \cdot kg^{-1}$ for cadmium in the solid phase of the waste. Upper levels of cadmium in sediments around pulp mills generally fall outside of the ODCA level, while mercury values are generally within the limits of the act. Recent sediment data collected by EPS in 'unpolluted' areas along the west coast of Vancouver Island (Hecate Strait, Masset Inlet) show mercury levels ranging from 0.029-0.261 $mg \cdot kg^{-1}$ (dry weight) and cadmium levels ranging from $<$ 0.3-2.5 $mg \cdot kg^{-1}$ (dry weight).

Very limited trace metal analysis has been undertaken on biota collected in the vicinity of pulp mill discharges. The most extensive study was conducted in 1973 to determine the levels of zinc in oysters near four coastal pulp mills (Nelson and Goyette, 1976). Figure 1.13 gives ranges of zinc, copper, and cadmium levels in oysters levels collected at mill and control sites. Zinc concentations in oysters collected at the mill sites were generally higher than control sites although high levels of zinc were noted at Gambier Island. Copper and cadmium levels did not appear to be

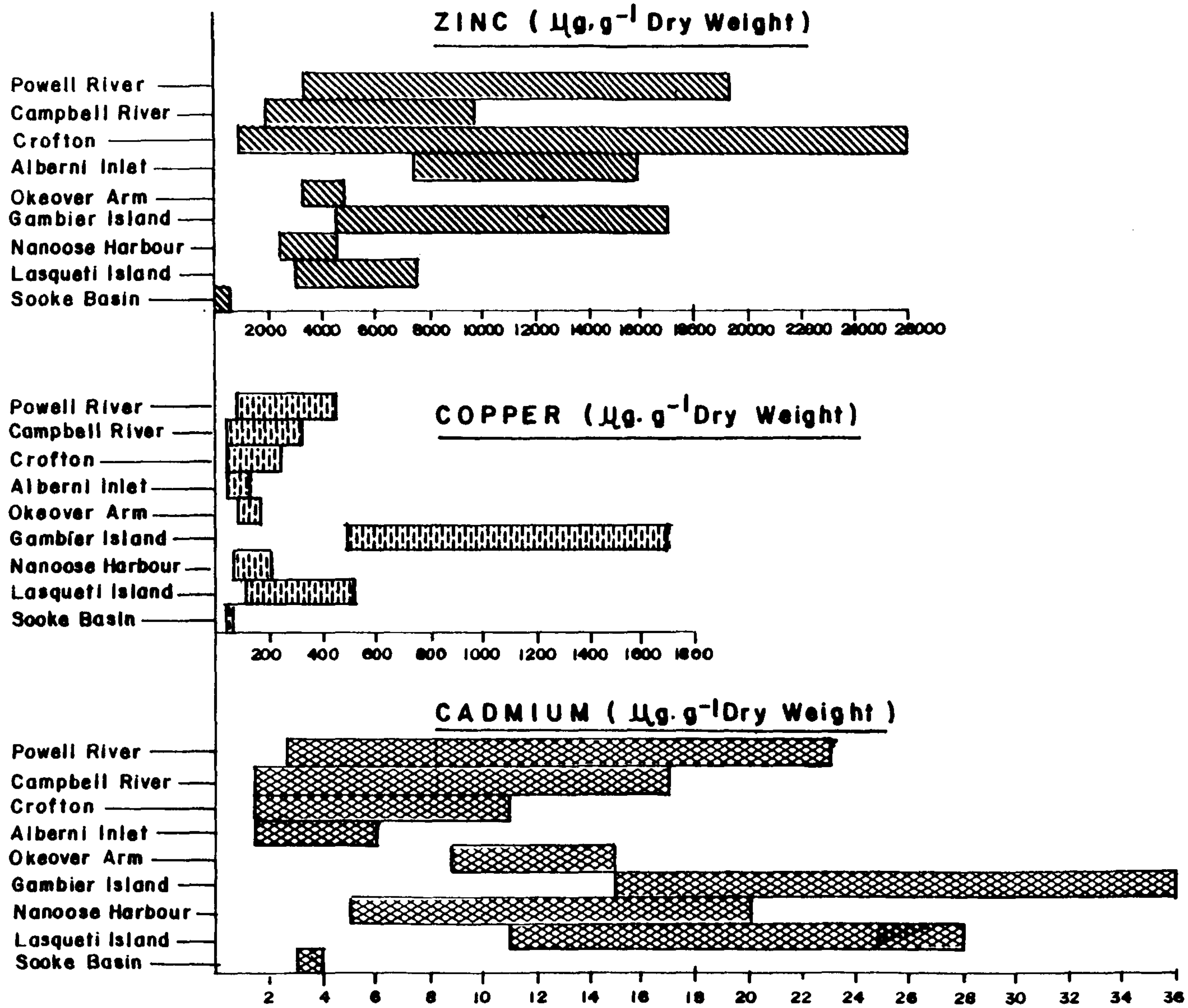


FIGURE 1.13 RANGE OF ZINC, COPPER AND CADMIUM LEVELS IN OYSTER COLLECTED AT PULP MILL SITES (Nelson and Goyette, 1976)

influenced by proximity to the pulp mills, with the control station at Gambier Island showing the highest levels of any sample sites. This most probably results from the heavy mineralization in the Gambier Island - Howe Sound areas and consequent elevated background levels of metals. Ranges of copper and cadmium levels collected at Lasqueti Island, which more likely approximates general background conditions in Georgia Strait, were similar to those observed at the pulp mill sites. Zinc and copper levels in bivalve molluscs other than oysters did not indicate significant contamination from the pulp mills. Mean zinc concentrations in mussels and clams ranged from 70 $ug \cdot g^{-1}$ (dry weight) at Crofton to 500 $ug \cdot g^{-1}$ (dry weight) at Powell River and Campbell River. Nelson and Goyette (1976) concluded that the zinc concentrations in oysters corresponded to known or anticipated effluent flow patterns.

Ellis et al. (1981) have investigated the recovery from zinc contamination in oysters stocks at Crofton and have shown oysters reduced their zinc levels from 14,400 $ug \cdot g^{-1}$ (dry weight) in 1973 to 570 $ug \cdot g^{-1}$ (dry weight) in 1979. However, the condition factor of the oysters has not improved indicating zinc was not the cause of poor condition factor.

Few data exist for benthic biota collected near pulp mills largely because trawl nets are usually filled with wood debris or torn by sunken logs. Sullivan (1980) has reported mercury levels in shrimp collected off the Crofton and Powell River mills ranged from < 0.096 to 0.2 $mg \cdot kg^{-1}$ (dry weight). Cadmium levels were also low, ranging from < 0.714 to 1.34 $mg \cdot kg^{-1}$ (dry weight).

1.4 Pulp and Paper Summary

Major advances in pollution control were made in the early to mid 1970's. These included conversion of the Port Edward (Porpoise Harbour) mill from sulphite to kraft, installation of a biological treatment pond at Port Alberni, clarifiers at six of the 10 mills, and recovery of spent sulphite liquor at Port Alice. Excluding Ocean Falls, these improvements resulted in an average reduction of 58% in biochemical oxygen demand and 45% in suspended solids discharged to B.C. coastal waters. However, since 1981 the total amount of both of these pollutants has gradually increased, coincident with production increases.

By 1986 all mills except Port Alberni had relocated their outfalls to discharge through submarine diffusers to provide improved dilution and dispersion of effluent.

These changes resulted in recovery of water quality and intertidal habitat, although recovery has been difficult to document in recent years. Despite the improvements, however, degradation of marine environmental quality remains a feature of coastal pulp and paper operations.

Measured zones of benthic impact extend from 0.5 to 4.8 km, and up to 7.0 km for intertidal impact. Major impacts are (1) creation of fibre beds and wood debris deposition, (2) hypoxia of receiving water, and (3) depauperate intertidal communities. All of these impacts reduce the amount of suitable habitat available for fishery resources. Fibre beds and areas of wood debris deposition cause well-defined, but local, alienation of habitat for benthic resources such as sole, crab and shrimp. Pulp mills with areas of documented benthic degradation include those at Alberni Inlet, Neroutsos Inlet, Stuart Channel, Northumberland Channel, Malaspina Strait and Howe Sound (Woodfibre).

In contrast, water column hypoxia causes less easily quantifiable damage but, depending on site-specific conditions of bathymetry and event/season-specific conditions of weather and oceanography, can and does seriously impair the ability of fishery resources such as salmon to rear in and migrate through areas of degradation. Worst cases are at Alberni Inlet and Neroutsos Inlet. At these locations, summer low freshwater runoff and warm temperatures can combine with oceanographic stratification and stability to reduce the amount of oxygen available. In both cases, seasonal oxygen deficits are exascerbated by thick and extensive beds of wood fibre and debris overlying anoxic sediments. A third location, the inner basin of Howe Sound, also has multi-annual hypoxia which results in widespread death of benthic animals; however, this is thought to be at least partially natural, and it is not known if the pulp mill is a contributing factor. The other mills are sufficiently well flushed by tidal currents and annual oceanographic events that their liquid wastes are usually adequately degraded, and may even contribute to marine phytoplankton productivity by supplying essential nutrients.

Minor sources of marine environmental quality degradation associated with coastal pulp mills are organic and inorganic contaminants. The known inorganic contaminants are heavy metals which occur at trace levels in the sediments near some mills, notably those at Alberni Inlet and Malaspina Strait. They probably derive from historic (no longer practiced) use of certain brightening or bleaching agents, and are not now discharged at significant levels. While some of these metals--such as lead, cadmium and mercury--are known to be toxic, and to accumulate in tissues of some marine organisms, the levels are too low to be of serious concern to marine ecosystems.

Of the organics, little is known: more research is required on toxicity to marine organisms and biochemcial reactions and transformations in seawater.

1.5 Pulp and Paper References

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1.6 Pulp and Paper Glossary

BOD_5 Biochemical Oxygen Demand. The amount of dissolved oxygen required to stabilize the oxygen demand of decomposible organic matter during an incubation period of 5 days at 20°C.

TSS Total suspended solids or total residue. Nonfilterable residue present in an effluent.

SSL Spent sulphite liquor

D.O. Dissolved oxygen

BKME Bleached kraft mill effluent

SME Sulphite mill effluent

2 SEWAGE

2.1 Introduction

Sewage has been discharged to British Columbia coastal waters since the early development of urban centers. Prior to 1950, there were virtually no treatment plants, with sewage generally being discharged raw through numerous shallow outfalls. In the intervening years, new sewage treatment plants have been built, or longer outfalls have been installed to accomodate the increased populations and to meet more stringent environmental requirements (Figure 2.1).

Approximately 256 marine sewage discharges are presently registered with the provincial government, of which 63% have primary treatment or less (Discharge Inventory Database, Environmental Protection). Many are low volume, serving one or two businesses or small residential subdivisions. These smaller discharges are generaly treated by septic tanks or "package" sewage treatment plants, and contain little or no non-sanitary waste. However, larger volume discharges from major urban areas can contain many other waste materials, in addition to sanitary or domestic sewage. Institutional, industrial, stormwater and other non-domestic wastes enter the municipal sewer system. Thus the term "municipal wastewater" is generally applied, since it consists of much more than just sanitary or domestic sewage.

The quality of municipal wastewater effluents depends on the degree of treatment applied. Treatment can be categorized as physical, primary, secondary or tertiary. Additional processes, such as disinfection, can also be applied. Physical treatment refers to the removal of gross solids and other aesthetically unpleasing materials through the processes of screening or comminution (grinding). Further treatment (primary, secondary) can be applied to reduce the suspended solids, biochemical oxygen demand and bacteria levels. Still more treatment (tertiary) can be included if necessary to remove nutrients from the effluent. There are no tertiary treatment plants discharging to B.C. marine waters.

The general effects of sewage in the marine environment have recently been reviewed by Waldichuk (1984) and Lorimer (1984).

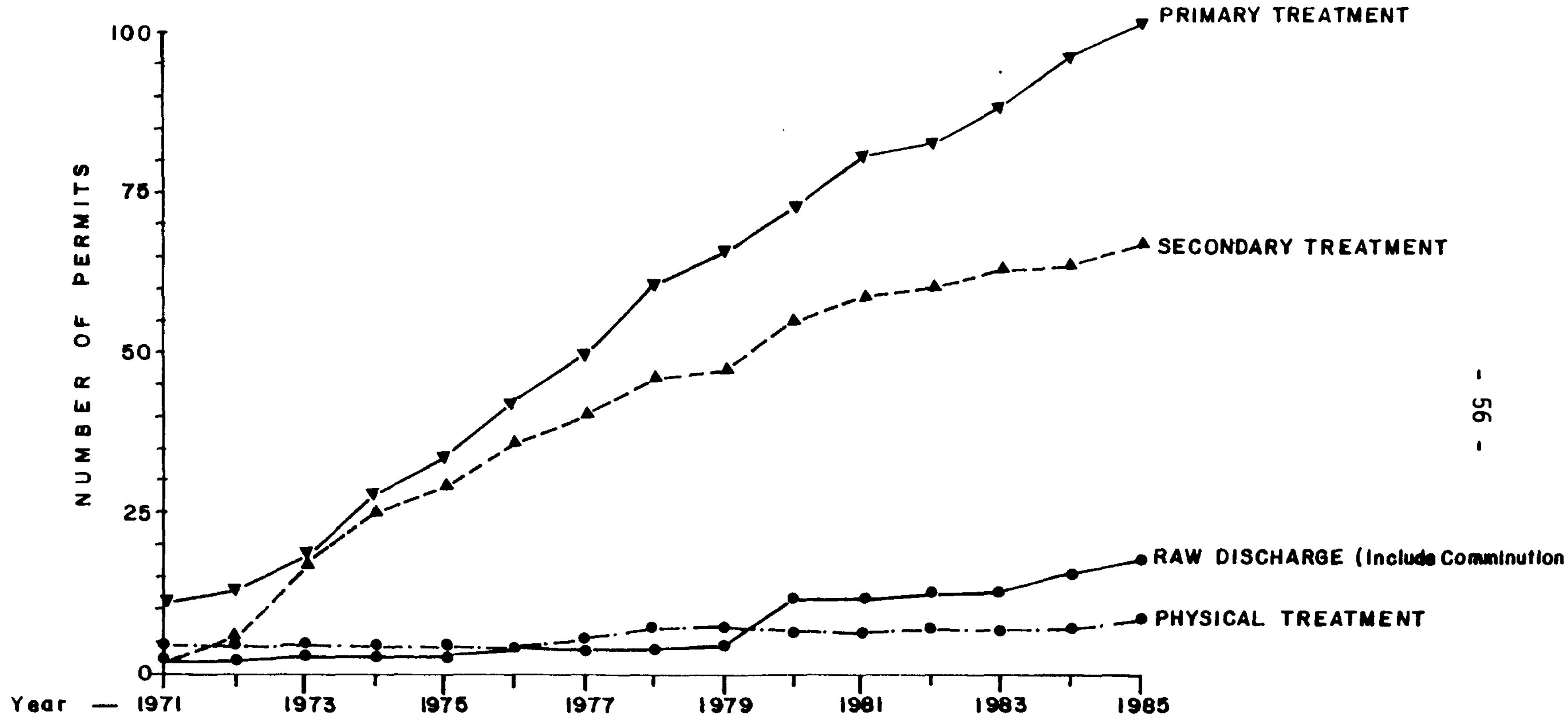


FIGURE 2.1 NUMBER OF MARINE MUNICIPAL DISCHARGES BY TREATMENT CATEGORY, 1971-1985

2.2 Control of Water Pollution

In 1973 the Province of British Columbia conducted a public inquiry to develop objectives for effluent and receiving water quality for municipal wastewater discharges (Department of Lands, Forests and Water Resources, 1975). The major threats to the receiving environment were identified as those listed in Table 2.1. Further, the assimilative capacity of the marine environment was considered an appropriate treatment within limits, and the objectives allow an initial dilution zone in the immediate vicinity of the point of discharge wherein receiving water quality objectives need not be met. Receiving water quality objectives outside the initial dilution zone are given in Table 2.2.

The effluent quality objectives for marine discharges were developed on the basis of outfall depth-distance combinations and apply to flow rates up to three times the average dry-weather flow (DWF). The objectives allow for a lesser degree of treatment when outfall length and depth are increased. More restrictive effluent requirements, or conversely longer outfall distance-depth combinations are required for discharges to shellfish waters or embayed areas. As shown in Table 2.3, components in marine wastewater discharges which are generally regulated in provincial discharge permits include: biochemical oxygen demand, suspended solids, total phosphorus and chlorine residual. Other effluent constituents such as trace metals, oils and grease, phenols and methylene blue- active substances have upper concentration limits set by the objectives but they are rarely included in operating municipal discharge permits for marine waters.

There are no specific federal regulations pertaining to municipal wastewater effluent quality, although guidelines have been developed for effluent quality and wastewater treatment at federal establishments (Environmental Protection Service, 1976). These guidelines set limits for biochemical oxygen demand (20 $mg \cdot L^{-1}$), suspended solids (25 $mg \cdot L^{-1}$), fecal coliforms (400/100 mL, after disinfection), residual chlorine (0.5-1.0 $mg \cdot L^{-1}$), pH (6-9), phenols (20 $ug \cdot L^{-1}$), oils and greases (15 $mg \cdot L^{-1}$) and total phosphorus (1.0 $mg \cdot L^{-1}$). The guidelines do not recommend any receiving water quality objectives, but do recognize the concept of a mixing

TABLE 2.1 CATEGORIES OF POLLUTION EFFECTS FROM MARINE SEWAGE DISCHARGES

POLLUTION EFFECT	CAUSATIVE SUBSTANCES
Increased turbidity Alteration of benthic habitat	Sewage solids.
Health hazards associated with bathing, shellfish consumption	Pathogenic microorganisms in liquid and solid portions of the effluent.
Reduction in dissolved oxygen	High organic content in solid and dissolved form.
Nutrient enrichment, eutrophication	Nitrogen- and phosphorous-containing nutrients.
Bioaccumulation and biomagnification; sediment contamination	Metals, chlorinated organic compounds (e.g. pesticides).
Toxicity	Surfactants, ammonia, chlorine (from disinfection.
Aesthetic impact	Solids, non-biodegradable and floatable materials.

TABLE 2.2 RECEIVING WATER QUALITY MAINTENANCE OBJECTIVES FOR MUNICIPAL WASTEWATER DISCHARGES

PARAMETER	OBJECTIVE
Dissolved Oxygen	Decrease not to exceed 10%
Residual Chlorine	Below detectable limits (amperometric method)
Nutrients	No dectable increase in site-specific productivity-limiting parameters (2) (5)
Coliforms - receiving waters	(3)
- shellfish meat	(3)
Toxicity	No increase above background (4)
Settleable Solids	Negligible increase
Flotable Solids	Negligible increase
Oil	None visible on water surface
Organisms	No change in productivity or development of nuisance conditions (5)
Heavy Metals	Negligible increase

EXPLANATORY NOTES

(1) These objectives are for the maintenance of background receiving water quality, generally expressed in terms of the maximum allowable change for specified parameters. They are not applicable within the intial dilution zone.
(2) Limiting parameters will normally be taken as phosphates and/or nitrogen forms.
(3) In general, total coliform levels are not to exceed a median MPN of 1000/100 ml or a fecal coliform median MPN of 200/100 ml and in shellfish waters are not to exceed a fecal coliform MPN of 14/100 ml and shellfish meats may not show a fecal coliform level greater than MPN of 230 per 100 gm.
(4) As measured in a 96 hour TL_m static bioassay test.
(5) The following nuisance conditions are typical of those to be considered:
At sea or in estuaries, presence of sludge beds with reduced species diversity and a restricted range of predominant organisms such as Capitella capitata.

(Department of Lands, Forests and Water Resources, 1975)

TABLE 2.3 EFFLUENT QUALITY OBJECTIVES FOR MUNICIPAL WASTEWATERS (including storm overflows)

	MARINE (1)		PARAMETER (Numerical values in mg/l)
	Open	Embayed	
AVERAGE DWF ≥ 45 m^3/day			
Effluent quality required for all flows up to 3 times AVG.DWF	130 130 Yes No 0.5-1.0 -	45 60 Yes No 0.5-1.0 1.5 (2)	BOD_5 SS DISINFECTION DECHLORINATION Chlorine Residual Total Phosphorus
Requirements for all flows greater than the multiple of AVG. DWF shown	none	screening (3)	Treatment of overflow Multiple of avg. DWF
Effluent quality required for intermediate DWF multiples (6)	- - - -	130 130 Yes 0.1-1.0	BOD_5 SS Disinfection Chlorine Residual
AVERAGE DWF ≤ 45 m^3/day			
All flows	typical septic tank effluent (4)	45 60 Yes 0.2-1.0	BOD_5 SS Disinfection Chlorine Residual

EXPLANATORY NOTES

1. The effluent quality objectives for marine discharges for flows up to 3 times avg. DWF are based on outfall depth-distance combinations. Visual evidence of the discharge should normally not be noticeable. Where quality better than the tabulated values is provided and for any portion of flow exceeding 3 times avg. DWF, outfall lengths may be reduced.

2. The total phosphorus requirement for effluents may be waived if it can be reasonably shown from a site-specific study that the receiving waters would not be subject to an undesirable degree of increased biological activity because of the nutrient input.

3. Where intermediate DWF multiples are passed through the treatment plant, the overall effluent quality objective shall be the flow-weighted average of the value shown and the value for the under 3 DWF portion of the flow. Chlorination and dechlorination shall be provided as required for the "up to 3 DWF" portion of the flow.

4. Septic tanks must have a hydraulic capacity of at least two times the design average daily flow for the effluent to meet requirements.

(Department of Lands, Forests and Water Resources, 1975) zone. At the time of writing, these guidelines were under review (T. Tevendale, pers. comm.).

In addition to these guidelines, the Environmental Protection Service has broader regulatory powers under the Fisheries Act. Municipal wastewater discharges which are shown to be deleterious to fish, fish habitat, or the use of fish by man can be subject to federal regulatory action. Bacteriological water quality monitoring of bivalve molluscan shellfish areas is also a responsibility of the federal government, with waters exceeding specific bacteriological limits being closed to shellfish harvesting.

All applications for provincial marine sewage discharge permits are evaluated by federal and provincial agencies on a site-specific basis and the effluent and receiving water quality requirements are developed from this assessment. Factors which determine the necessary degree of effluent quality include proximity to shellfish harvesting areas, ocean currents and density profiles, existence of other discharges in the immediate vicinity, discharge location (e.g., an embayment), and socio-economic factors. Generally, BOD_5 and suspended solids are the only regulated parameters in most provincial effluent permits although for larger discharges other parameters may be added.

The type and degree of treatment, design of the discharge system, and constituents of the sewage influent, determine effluent characteristics. Treatment and discharge systems for major B.C. municipal outfalls are shown in Table 2.4.

2.3 Receiving Water Monitoring Programs

Receiving water monitoring programs which have been conducted at British Columbia coastal municipal wastewater discharges fall into two categories:

1) monitoring programs required under the discharge permit to assess environmental changes,
2) monitoring programs conducted to assess the impact of the discharge in terms of specific water quality criteria, e.g. bathing, shellfish harvesting.

TABLE 2.4 SUMMARY OF PERMITS AND OUTFALL AND DIFFUSER DIMENSIONS OF SELECTED MARINE MUNICIPAL OUTFALLS IN BRITISH COLUMBIA (Lorimer, 1984)

SITE	DATE	PERMIT NO.	PERMIT FLOWS m^3/day	DIAMETER (mm)	TOTAL LENGTH (m)	LENGTH BELOW LWL (m)	DEPTH (m)	TREATMENT	CONFIGURATION	DIFFUSER LENGTH (m)	DIFFUSER DEPTH (m)	DISCHARGE	POPULATION SERVICED
Macaulay Point	17/Dec/75	PE-270	54,552	914	1717	1669.7	60.8	Comminution only	Tapered and ported at 508 mm centres	153	61	Juan De Fuca Strait	75,258
Clover Point	20/Jun/73	PE-1877	63,000	1067	1106	932	57.6	Comminution only	Straight ported at 3500 mm centres	196	67	Juan De Fuca Strait	55,000
McMicking Point				1050	232	222	19.5	Comminution only	Single port 150 mm diameter		19.5	Enterprise Channel	20,000
Finnerty Cove	04/Jun/68 20/Oct/81	PE-231	6,800 13,000	610	634	466	15.5	Comminution Chlorination	Single port 61 mm diameter		15.5	Hard Strait	25,000
Sidney	07/Oct/77	PE-136	5,900	457	662	524	11.5	Activated sludge Roto-strainer	Tapered and ported 76 mm diameter at 4.6 m centres	86.3	12.3	Sidney Channel	8,452
Five Finger Island		PE-338	average 27,274					Primary with Chlorination	"Y" shaped. Each arm 9.15 m long. 7.62 cm diameter ports every 1.83 m. Total no. ports is 104	2030	70	Georgia Strait	49,347
Comox-Courtenay (Cape Lazo)	23/Jul/85	PE-5866	18,500	860		3000	63	Secondary Conventional activated sludge	60 ports over 148 m	148	63	Georgia Strait	16,000
French Creek	May/75	PE-4200				2438.4	61	Digester Secondary				Georgia Strait	7,000
Campbell River	21/Dec/64 May/74	PE-109 PE-109	average 6818 as of 24/09/73	304.8 533.4		182.9 115.8	11.0 6.9	sludge, Aerobic Clarifier, Grit removal, Activated	No diffuser No diffuser			N. Georgia Strait Discovery Passage	16,411

Continued...

TABLE 2.4 (Continued)

SITE	DATE	PERMIT NO.	PERMIT FLOWS m^3/day	DIAMETER (mm)	TOTAL LENGTH (m)	LENGTH BELOW LWL (m)	DEPTH (m)	TREATMENT	CONFIGURATION	DIFFUSER LENGTH (m)	DIFFUSER DEPTH (m)	DISCHARGE	POPULATION SERVICED
Powell River Westview	24/Jun/63	PE-73	average 5454	610	518			Barminuter Activated sludge extended aeration	No diffuser			Malaspina Strait	13,305
Town Site	10/Jan/67	PE-171	average 6818	1270	305			Mechanical screens Hige rate activated sludge	No diffuser			Malaspina Strait	
Prince Rupert* Outfall I	10/Sep/80	PE-5572-01	17,000	610		392	64	Comminution				Prince Rupert Harbour	16,786
Outfall G	10/Sep/80	PE-5577-02	4,500	400		32	18	None				Prince Rupert Harbour	
Outfall H	10/Sep/80	PE-5577-03	394,000	1,200		46	24	None				Prince Rupert Harbour	
Outfall J	10/Sep/80	PE-5577-04	11,200	400		107	26	None				Prince Rupert Harbour	
Outfall L	10/Sep/80	PE-5577-05	5,700	450		180	52	Comminution				Prince Rupert Harbour	
Outfall K	10/Sep/80	PE-5577-06	5,900	300		35	21	None				Prince Rupert Harbour	
Outfall A	11/Dec/80	PE-5577-07	27,700			50	21	None				Prince Rupert Harbour	
Outfall B	11/Dec/80	PE-5577-08	16,200			560	45	Comminution				Prince Rupert Harbour	
Outfall C	11/Dec/80	PE-5577-09	35,500			50	21	None				Prince Rupert Harbour	
Lions Gate	17/Feb/59	PE-30	102,000 as of 22/Feb/79									Burrard Inlet	

*Prince Rupert sewer consolidation not complete. Not all outfalls operating as specified.
Distance from the shoreline at mean sea level
tSource: Statistics Canada. Estimations of Oct. 1983 populations based on 1981 census

Programs in the first category are designed to examine the interaction of the effluent discharges with the marine ecosystem (Figure 2.2) and have been limited to the larger volume discharges serving Victoria, Nanaimo, Comox-Courtenay and Vancouver.

Programs in the second category have been extensive, specifically with respect to assessing the sanitary quality of shellfish areas.

Monitoring programs associated with marine municipal wastewater outfalls have been extensively reviewed by Lorimer (1984). The following summarizes her major findings of pollution effects as categorized in Table 2.1.

2.3.1 Solids. The impact of solids on the marine environment becomes more evident as the degree of sewage treatment is reduced. Solids in sewage, consisting of fecal matter, plastics, paper and floatables, are aesthetically offensive, particularly in cases where the effluent plume reaches the water surface and shoreline areas. The extent of benthic habitat disruption resulting from solids deposition around the outfall also is determined by the degree of treatment. Thus raw, or physically treated sewage, will have a greater impact on the benthos than primary or secondary treated effluent discharged in similar volume.

Monitoring programs to examine solids impacts have not been included as part of "permit required" studies per se. Much of the work is qualitative, relying on visual observations obtained during underwater surveys using the Pisces IV submersible studies. The Environmental Protection Service has undertaken such studies at the Macaulay Point, Clover Point, French Creek and Five Fingers Island sewage outfalls (Petrie and Holman, 1983) and more recently at Prince Rupert and Powell River (Holman, pers. comm.). Areal visual impacts have not been large at the outfalls studied. At the Macaulay Point outfall, which discharges raw sewage, the bottom directly opposite the end of the outfall consisted of a black organic accumulation devoid of an epifaunal community except for large numbers of hermit crabs. However, sewage debris was observed to thin out at approximately 20 metres from the pipe end, with some evident at 40 metres from the discharge point. Water column turbidity impacts from this outfall

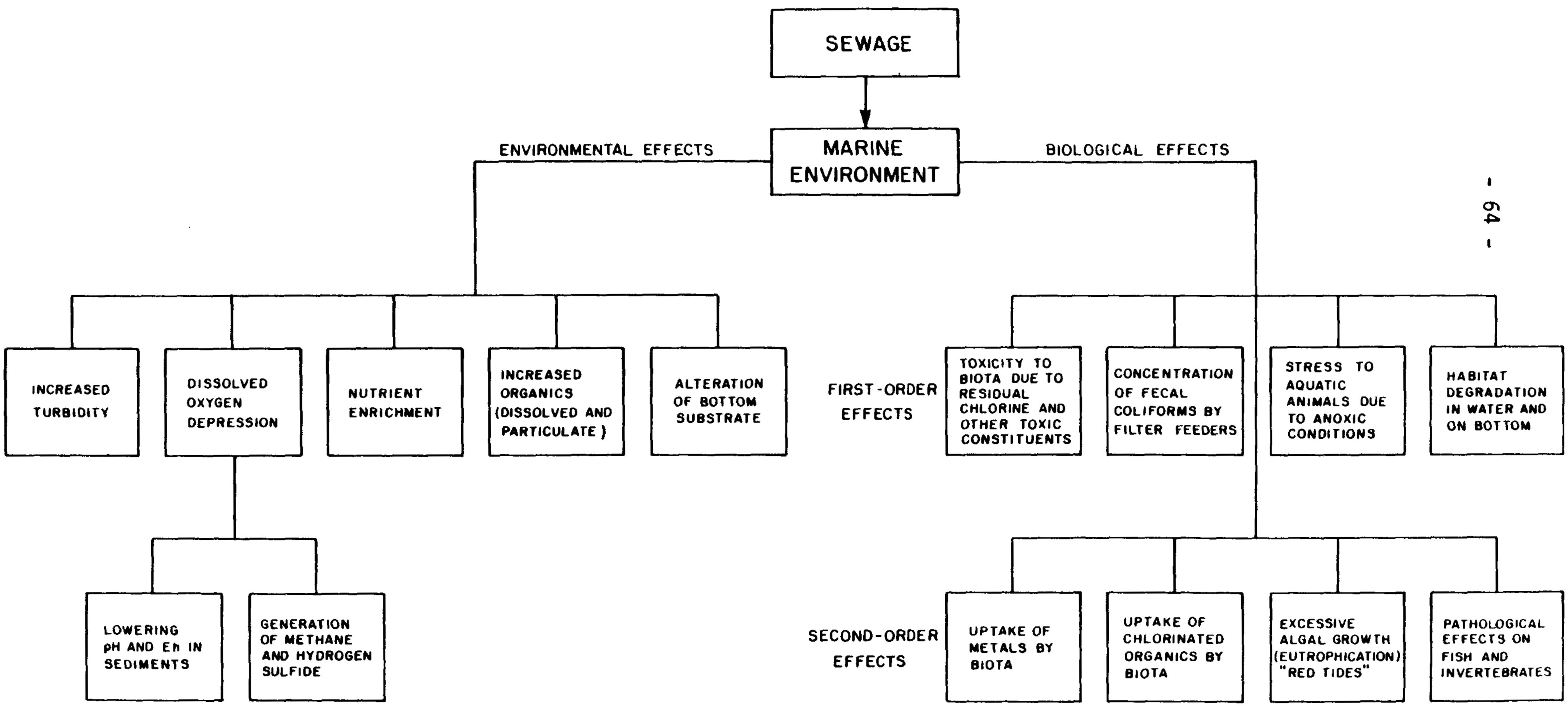


FIGURE 2.2 SCHEMATIC DIAGRAM ILLUSTRATING THE EFFECTS OF SEWAGE IN THE MARINE ENVIRONMENT (Waldichuk, 1984)

are difficult to assess since the effluent is discharged on an intermittent (pumped) basis.

Underwater observations at the Five Finger Island outfall diffuser, which discharges effluent from Nanaimo and surrounding areas, has shown an increasing impact between 1978 and 1983. In 1983 turbidity in the area of the diffuser was very high with a visibility less than 1 metre. Non-biodegradable materials extended an estimated 10 metres from the pipe, while in previous years little accumulation was noted. An increase in fish and invertebrates over the surrounding water was also evident in the area of the diffuser and for varying distances from the pipe (Pomeroy, 1984).

The benthos in the vicinity of the French Creek outfall, which discharges secondary treated effluent from the communities of Parksville and Qualicum Beach, has had minimal impact to date with little evidence of non-biodegradable debris. Due to the relatively young age of this discharge, there is not sufficient data available from which to draw any conclusions about the effect on species composition (Pomeroy, 1984).

In reviewing the effects of domestic wastes on the species composition of marine communities, Lorimer (1984) concluded that, although composition may have changed, the impact of the effluent was slight. One exception was the low diversity of animals in the immediate area of the McMicking Point outfall, a shallow outfall discharging raw sewage (Ellis, 1980).

2.3.2 **Dissolved Oxygen.** The average daily biochemical oxygen demand from the major marine sewage outfalls is shown in Figure 2.3. Depression of dissolved oxygen levels is not common around submarine municipal outfalls. Environmental Protection Service studies (Pomeroy and Packman, 1981; Pomeroy, 1982, Pomeroy, 1984) at the French Creek and Five Finger Islands outfalls have not demonstrated any general effluent effect on water quality, the lowest concentration (3.5 $mg \cdot L^{-1}$) being recorded immediately adjacent to the French Creek diffuser. However, significant dissolved oxygen depression is frequent at the Iona Sewage Treatment plant discharge. Unlike the other marine outfalls studied, the discharge for Iona primary-treated effluent is not submerged, but rather flows through a 6 kilometre dredged channel across

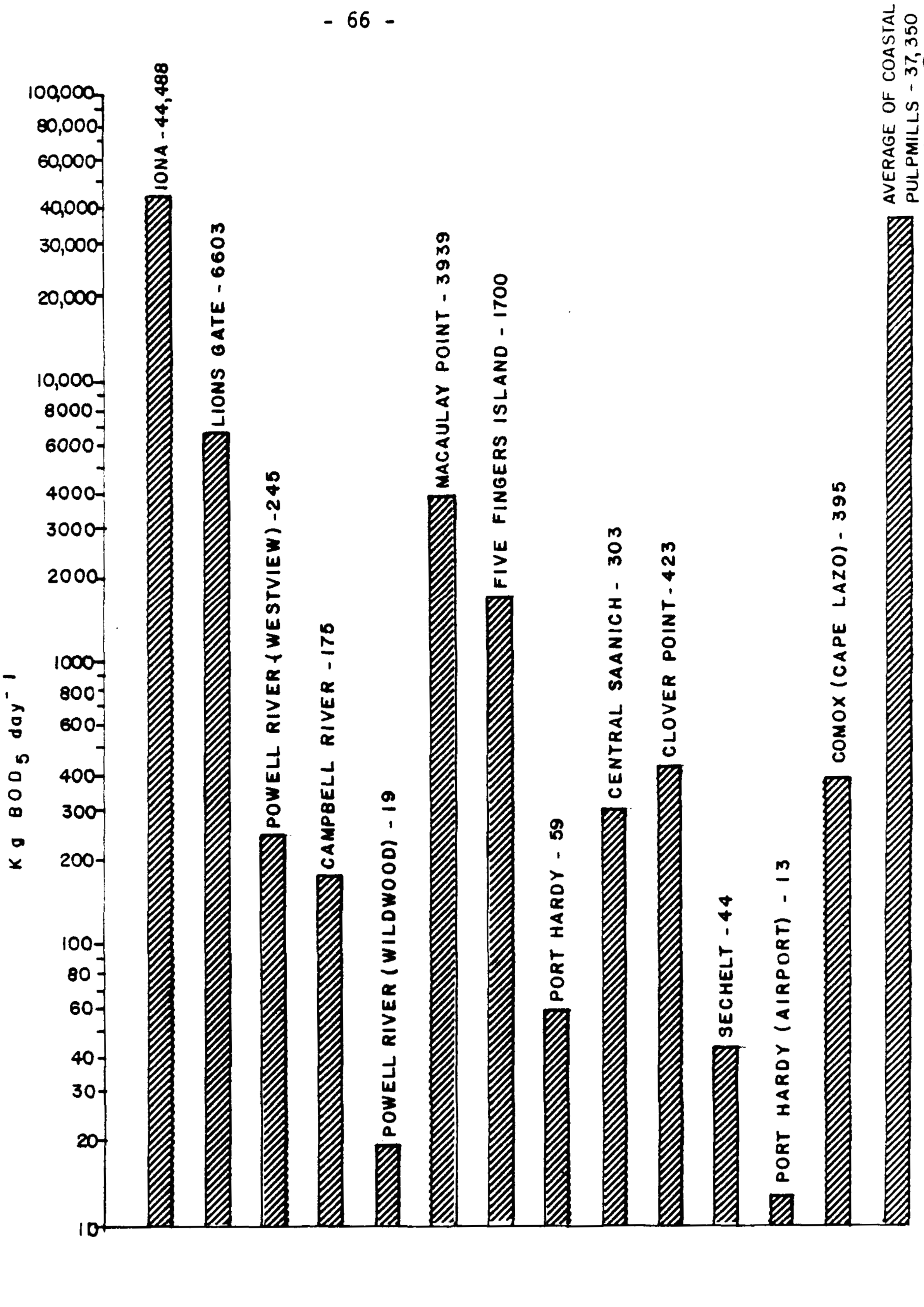
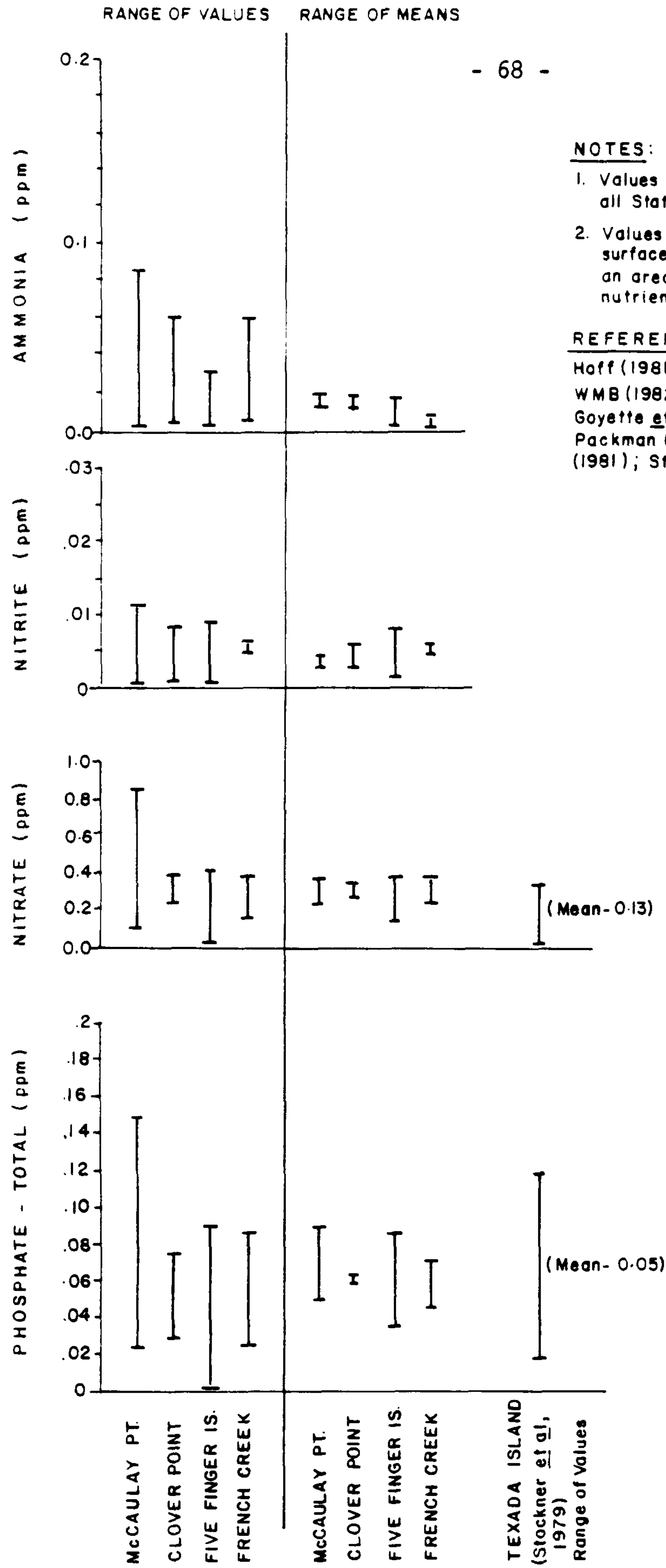


FIGURE 2.3 AVERAGE DAILY BOD_5 LOADING ($Kg.day^{-1}$) FROM MAJOR MARINE SEWAGE DISCHARGES

Sturgeon Bank in the estuary of the Fraser River. Studies conducted in 1980 (Birtwell et al., 1983) showed mortality of juvenile chinook salmon to occur at all experimental in-situ bioassay sites within 4.4 km from the outfall. Mortality often was rapid and on one occasion all the test fish placed 2.2 kilometres from the outfall died within 9 minutes. During calm and warm weather, receiving waters overlying part of Sturgeon Bank became depleted of oxygen. This event was often associated with fish stress, mortality and extensive predation by gulls and herons. The study suggested that the frequent mortality of large numbers of fish could have a deleterious effect on fish stocks in the Fraser River.

2.3.3 **Nutrient Levels.** Sewage contains a relatively high concentration of both nitrogen- and phosphorus-containing nutrients. It is particularly high in urea, ammonia, nitrates and other nitrogenous constituents. Extensive nutrient measurements have been undertaken by the Capital Regional District in the receiving waters around Victoria. Nutrients are also routinely measured during EPS environmental assessments and were measured during initial start-up of the Five Finger Islands discharge. Sporadic measurements have been made by the Greater Vancouver Sewerage and Drainage District at the Lions Gate sewage treatment plant outfall site. These studies (reviewed by Lorimer, 1984) suggest there is little nutrient enrichment of consequence in marine waters receiving sewage effluent from submerged outfalls. Pomeroy (1984) has reported increases in phosphate, nitrate and ammonia values during the past eight years within 0.5 kilometres of the Five Finger Islands diffuser, although the levels are not considered significant with respect to nutrient enrichment.

Figure 2.4 presents data on the range of values and range of means for total dissolved ammonia, nitrite, nitrate and phosphate levels recorded at receiving water monitoring stations for four major B.C. municipal marine outfalls. Data for nitrate and phosphate levels at a reference station near Texada Island (Stockner et al., 1979) is also included for comparison. Generally, the highest values of all four nutrients were recorded at the Macaulay Point raw discharge, although ranges of mean values for the four outfalls studied did not vary substantially between sites. Mean nitrate and



NOTES:

1. Values at Outfall Sites are for all Stations and all Depths
2. Values for Texada Island are for surface (0-5m) measurements in an area free of anthropogenic nutrients outputs.

REFERENCES

Hoff (1981); EQUI3; Vassos (1982); WMB (1982); Balch et al (1976); Goyette et al (unpublished); Waters (1976); Packman (1977); Pomeroy and Packman (1981); Stockner et al (1979)

FIGURE 2.4 RANGE OF NUTRIENT VALUES FOR SELECTED MARINE MUNICIPAL OUTFALL RECEIVING WATERS phosphate levels were slightly higher than observed at the Texada Island reference site as might be expected.

There has been considerable debate about increasing nutrient levels due to sewage discharges in the Strait of Georgia (Stockner et al., 1979, 1980; Parsons et al., 1980; Clark and Drinnan, 1980). Nutrient enrichment has not conclusively been identified as causing eutrophication in local waters and various reviewers now consider this unlikely (Waldichuk 1983, 1984; Harrison, et al., 1983). Since primary productivity is often nitrogen limited in marine waters, biological effects of all but the very highest sewage-related nutrient concentrations are probably positive (Harrison, 1985).

2.3.4 Trace Metals. Trace metals in sediments near municipal outfalls have been monitored by EPS 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 (EPS unpubl). These and other sources of information, summarized by Lorimer (1984), are shown in Figure 2.5. Trace metals often associate physicochemically with organic matter, and where organic content of sediments increases, trace metals content also is expected to increase if there is a source available, such as contaminants in municipal effluent. Trends of increasing trace metals with both time and proximity to the outfall have been observed in most of the locations monitored. For example, copper and lead accumulations have been recorded at the Macaulay Point outfall, while increases in copper, zinc and manganese have been observed at French Creek and Nanaimo. At Nanaimo, the only location where good, long term trend data are available, these metals have been increasing progressively in sediments since installation of the diffuser (Pomeroy, 1984). The highest levels of trace metals of all municipal outfalls monitored, from a May 1985 survey (EPS unpubl. data), were at Sturgeon Banks, near the Iona Island sewage treatment plant: 4.05 ppm cadmium, 303 ppm copper, 1.27 ppm mercury, 162 ppm lead and 330 ppm zinc (higher levels of some of these metals were measured at Prince Rupert, but since the source was found to have been mine concentrates washed into city sewers by firemen when a warehouse caught fire, rather than municipal waste water, they have not been included).

Since spacial patterns of trace metal build-up vary with differences in oceanography, bathymetry, hydrology (of the outfall), and physicochemical properties of both the effluent and the local environment, increases have been observed by examining the highest level at any station, compared to a reference site (Figure 2.6). The reference site in Laredo Sound, although far removed from any known pollution source, had higher levels of some metals (e.g., mercury, copper, cadmium) than other reference sites, and therefore represents the high end of the range of natural variability on this coast.

There are several pathways by which trace metals from municipal waste water can enter, and affect, marine organisms: directly through the gills or other tissues from the dissolved state (this is not usually significant because, in general, upon entering a highly buffered medium like sea water, dissolved metals precipitate out of solution rapidly and become incorporated into bottom sediments), ingestion with suspended particles by filter-feeders, ingestion with sediments by deposit feeders, and ingestion with plant or animal tissues by other animals.

The highest level of lead in molluscs was from Clover Point: 11.7 ppm (dry weight) reported by Harbo et al. (1983). McMicking Point and Finnerty Cove outfalls discharged effluent which had a mercury content slightly higher than the British Columbia Ministry of Environment recommended level (Stanley Associates, 1982). Mercury in shellfish tissue from both outfalls areas was above the mean level in molluscs from southern British Columbia, as reported by Harbo et al. (1983).

The highest levels of zinc and copper observed in molluscs in the areas considered were collected from the Clover Point and Finnerty Cove outfalls which had six to seven times greater copper, cadmium and zinc levels than for samples obtained from the McMicking Point outfall terminus (Stanley Associates, 1982). Although the levels of zinc presented by Stanley Associates (1982) appear high (845-915 ppm, dry weight), levels of 100-1000 ppm (dry weight) are not uncommon for bottom dwellers such as molluscs (Stanley Associates, 1982). The Pacific oyster (*Crassostrea gigas*) is known to concentrate zinc at higher levels than in most shellfish (Harbo et al., 1983). The mean dry weight contents of zinc in *C. gigas* taken from

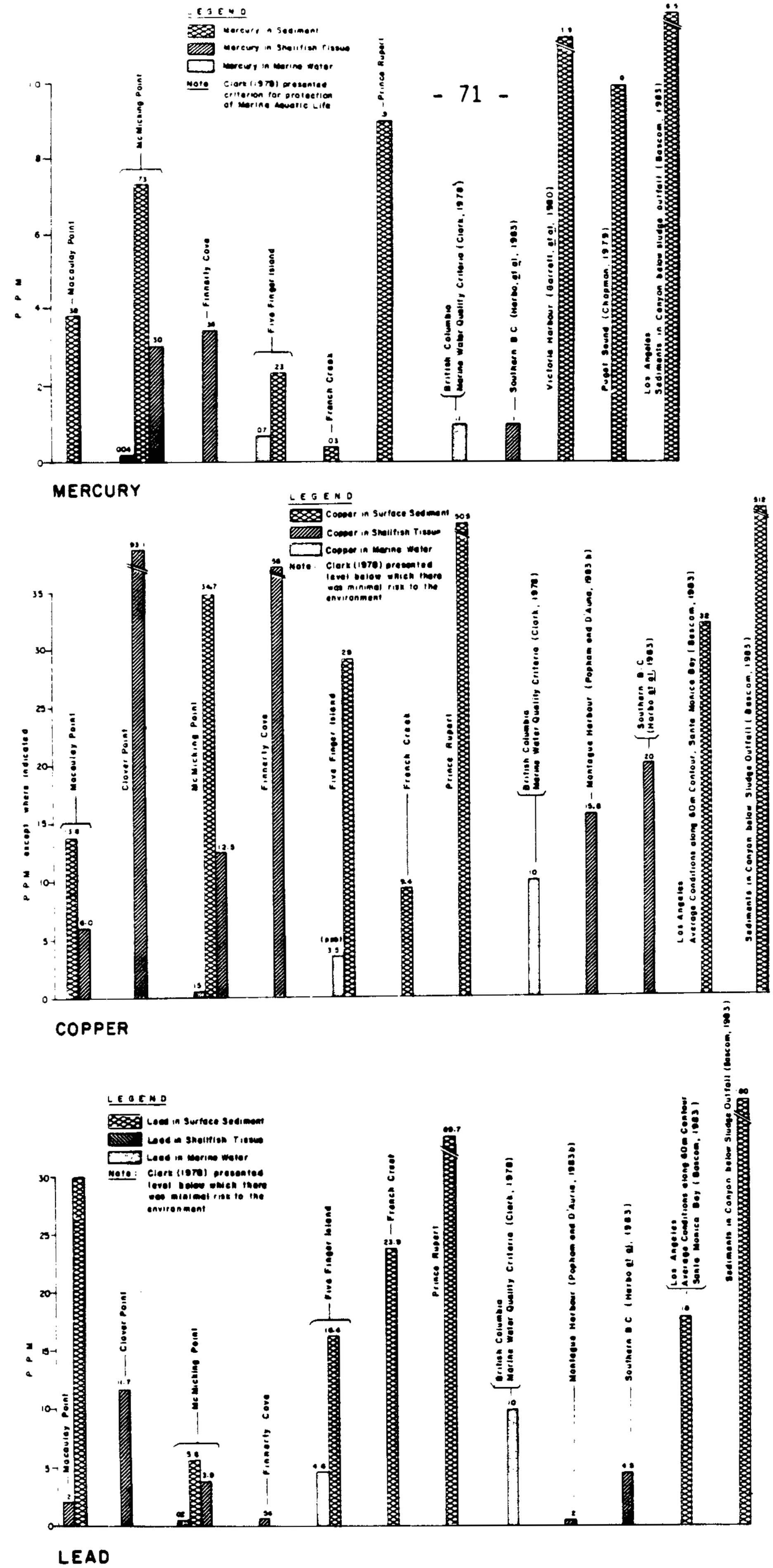


FIGURE 2.5 COMPARISON OF MEAN TRACE METAL CONCENTRATIONS IN MARINE WATER, SURFACE SEDIMENT AND SHELLFISH TISSUE FOR SELECTED MUNICIPAL OUTFALL AREAS (Lorimer, 1984)

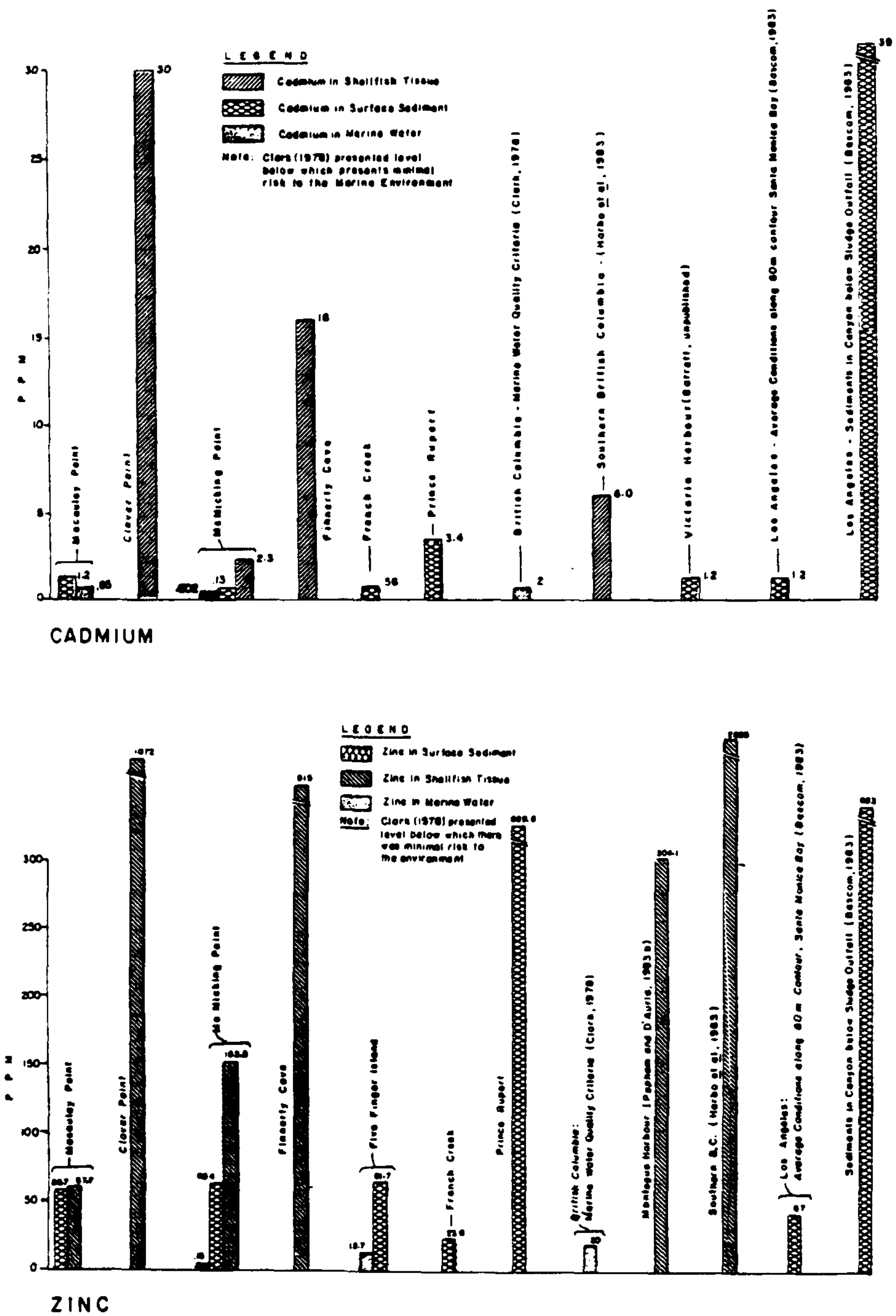


FIGURE 2.5 (con't.) COMPARISON OF MEAN TRACE METAL CONCENTRATIONS IN MARINE WATER, SURFACE SEDIMENT AND SHELLFISH TISSUE FOR SELECTED MUNICIPAL OUTFALL AREAS (Lorimer, 1984)

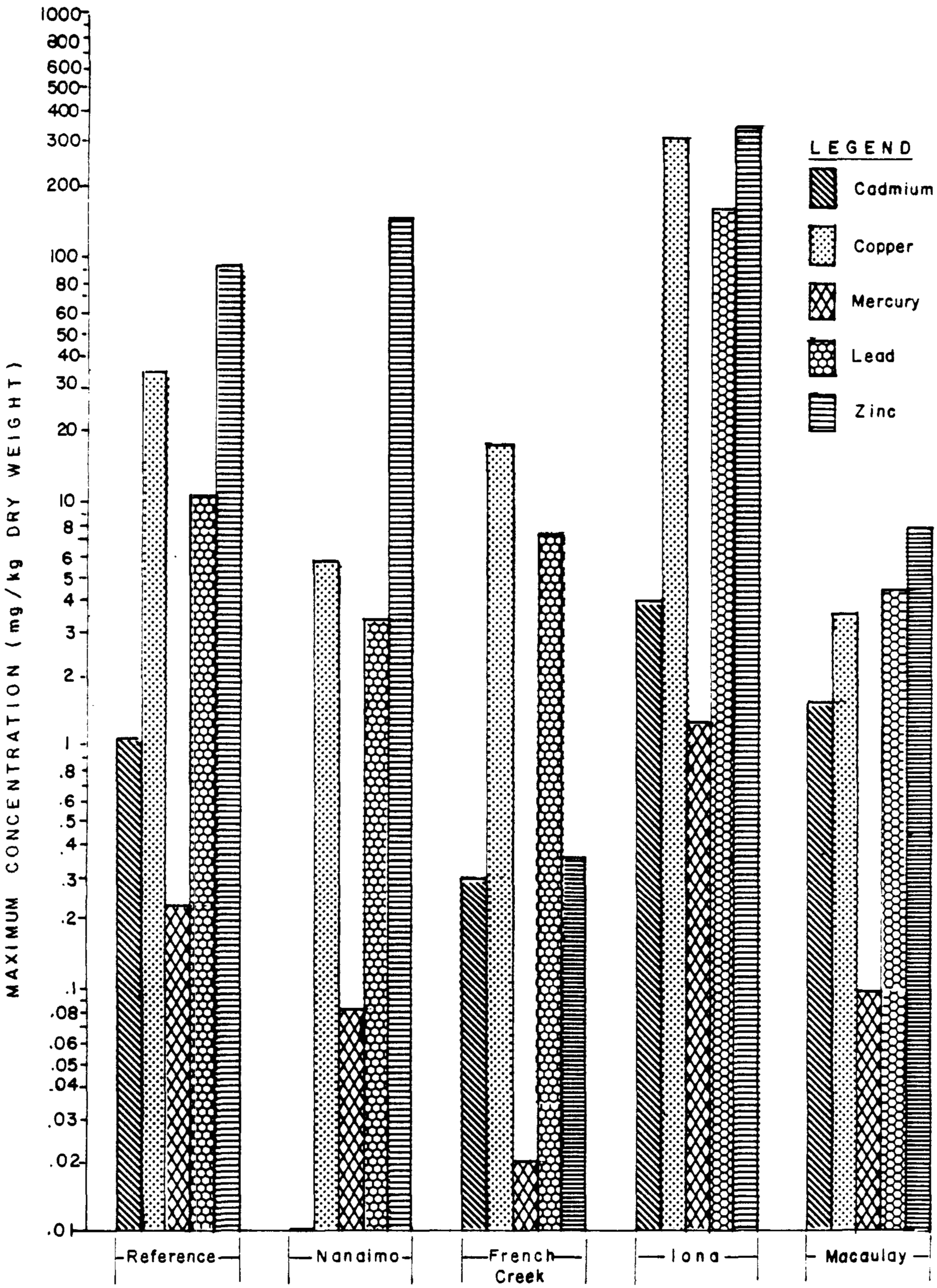


FIGURE 2.6 MAXIMUM SEDIMENT METALS AT SELECTED MUNICIPAL OUTFALLS (EPS DATA)

Southern British Columbia waters were recorded as 2886 ± 4117 ppm (Harbo et al., 1983). The Finnerty Cove mussel samples which contained between 845 and 915 ppm were therefore not extreme.

In tissue metal levels in English sole (Parophrys vetulus) collected during trawls adjacent to the French Creek outfall between 1977 and 1980 the zinc content of tissue apparently increased by a factor of two (Pomeroy, 1982), although direct comparison is difficult due to different laboratory instruments and analytical procedures. Prawn and shrimp at the Five Finger Island outfall have shown an apparent increase in tail meat trace metal levels for copper, iron and cadmium between 1977 and 1980, while mercury levels have apparently decreased (Pomeroy and Packman, 1981). The levels, which range from 18-123 ppm (dry weight) for copper, 12-321 ppm (dry weight) for iron, 49-65 ppm (dry weight) for zinc, < 1.0-3.89 ppm for lead (dry weight), < 0.5-1.02 ppm for cadmium (dry weight) and 0.043-1.38 ppm for mercury (dry weight) suggest a bioaccumulative process for some metals.

2.3.5 Organic Chemicals. The concentrations of organic compounds in sewage effluents is dependent upon the nature of the sewerage area (i.e. residential, industrial) and the waste management bylaws of the municipality. It is therefore difficult to make generalizations as to the potential environmental danger arising from organic chemicals in sewage.

Organic chemicals have been detected in sediment and mussels adjacent to the Macaulay Point and McMicking Point raw sewage outfalls. Levels of polychlorinated biphyenyls (PCB's) for example, ranged from non-detectable to 8.5 ppb in sediment at the Macaulay Point outfall. At McMicking Point, PCB levels in mussel tissue ranged from non-detectable to 127 ppb (dry weight) at sites 200-300 metres from the outfall. Lorimer (1984) reports the sediment PCB levels noted at Macaulay Point are far below levels measured at other British Columbia marine sites. PCB's in sediments at the French Creek outfall averaged 10 ppb in the study area (Pomeroy, 1984).

Rogers et al. (1984) have identified 15 compounds in Iona sewage treatment plant effluent which are known to be toxic to fish, and fish captured in the effluent channel have shown low but detectable concentrations of chlorinated pesticides and PCBs (McGreer and Konasewich, 1984). However, none of the contaminants approached recommended maxima for human consumption and it was concluded that the levels observed would not be sufficient to be of concern for human health (ibid). On the other hand, a high percentage of soles near the Iona outfall had external papillomas and other skin abnormalities (Popham, 1984). These diseases are often associated with organic chemical pollution, although a direct cause-effect relationship has not been established (Konasewich et al., 1982).

2.3.6 Toxicity. Toxic-to-fish compounds in sewage include un-ionized ammonia, surfactants in detergents, metals, organic compounds and chlorine (if disinfection is practised). The toxicity of effluent depends a great deal on the degree of treatment, particularly with respect to ammonia removal. Laboratory bioassays of a variety of B.C municipal wastewaters have shown most effluents to be toxic to some degree, with 96 hr-LC_{50} concentrations ranging from non-toxic (i.e. > 100%) to 26% (Higgs, 1977). Lethal and sublethal effects on biota in the water column near submarine outfalls have not been observed although little work has been done. A test of toxicity of Iona (City of Vancouver) sewage effluent to eggs and larvae of Pacific Herring concluded that egg hatchability was adversely affected compared to controls in concentrations of sewage effluent as low as 10% (Coastline, 1984). However, the same study concluded that an initial dilution of 50:1 for the effluent tested would provide protection of herring spawn from lethal and sublethal effects. Similar findings were made by the Study Group investigating alternatives to treating Iona sewage effluent (Tevendale, 1984).

Levels of ammonia in receiving waters around submarine diffusers also support the observation of minimal or no toxic effects from this source. Clark (1980) has noted that levels of un-ionized ammonia less than 0.01 $mg \cdot L^{-1}$ present minimal risk to marine biota while levels exceeding 0.4 $mg \cdot L^{-1}$ constitute a hazard. Receiving water concentrations of ammonia reported herein measure total dissolved ammonium ion (NH_4^+) rather than the more toxic un-ionized form (NH_3) and therefore direct comparisons are not possible. However, since un-ionized ammonia concentrations are much less than total dissolved ammonia (generally 1-6%, M. Pomeroy, pers. comm.), and since total dissolved ammonia levels recorded around B.C. sewage outfalls have not exceeded 0.1 $mg \cdot L^{-1}$ (see Figure 2.4), toxic effects are not expected.

2.3.7 <u>Bacteriological Impacts</u>. Apart from the dramatic ecological effects noted at the Iona sewage treatment plant discharge, and the aesthetically displeasing evidence of raw sewage discharges and resultant swimming closures noted periodically on some Vancouver and Victoria beaches, the most obvious and widespread impact of sewage contamination is the closure of beaches to shellfish harvest. The sewage may originate from nonpoint sources, such as urban and agricultural runoff, or it may originate from point sources, such as sewage discharges of raw or treated effluent.

Shellfish closures are imposed when the median fecal coliform concentrations in the growing waters exceeded 14/100 mL or when more than 10% of the water samples exceed 43/100 mL. These levels are extremely stringent and demand high water quality for areas utilized for shellfish harvesting. For example, a secondary treated effluent which has not been disinfected would require a dilution of 35,000- to 71,000-fold to meet the shellfish growing water quality standards. (The actual dilution required may be less, depending upon the bacterial die-off rate, behaviour of the effluent plume in the receiving waters and other factors).

The positive relationship between sewage pollution of shellfish growing areas and enteric disease was not realized until the early part of the 20th Century, when a typhoid epidemic broke out during the winter of 1924-25 along the United States eastern seaboard (Hunt, 1977). Epidemiological studies soon indicated that sewage-polluted oysters were responsible. Following this epidemic, the U.S. Public Health Service undertook the development of a control program to prevent further outbreaks of communicable diseases attributed to shellfish. The program now in place in Canada parallels the United States' program, as required in a bilateral agreement between the two countries signed in 1948. The importance of this program, both with respect to protection of public health and protection of the environment, is reinforced by the extensive survey work undertaken along the British Columbia Coast by the Environmental Protection Service. Between 1972 and 1984 water quality sampling along 700 km of the coastline, including all commercial and many recreational harvesting areas, has been completed or is ongoing.

The impact of municipal sewage discharges on major B.C. commercial shellfish production areas is limited simply because most oyster and clam harvesting occurs a considerable distance from urban centres. However, during the early 1960's, sewage pollution caused the closure of major oyster production areas at Comox, Ladysmith and Boundary Bay. Additional closures in the early 1970's prohibited most of the clam harvesting in the Port Hardy area. These closures remain in effect, although Ladysmith has been partially re-opened due to improvements in sewage treatment and disposal methods.

Marine municipal discharges are the sole cause of approximately 7% of all shellfish closures and are implicated as a major contributing pollution source in approximately 25% of the contaminated areas, and as a minor contributing source in a further 25% of contaminated areas. Figure 2.7 shows changes in shellfish closures between 1972 and 1984. Overall, the increase in closed area size (hectares) has been a negligible (about 1/2 percent) since 1972. If the closures imposed in the highly urbanized areas of Vancouver and Victoria are excluded from this calculation, there has been a slight decrease (about 8%) in the total area under closure. This decrease can be attributed primarily to the re-opening of Parksville Bay following the construction of the French Creek sewage treatment plant and outfall (Kooi et al., 1980), re-opening of portions of Ladysmith Harbour following improvements in sewage collection systems (Cooper and Kay, 1975) and a partial reopening of the Nanaimo Harbour area following the installation of the Five Finger Islands outfall and cessation of the raw sewage discharge at Newcastle Island (Kay and Ferguson, 1978).

The extent of bacteriological impact from municipal discharges on shellfish growing areas is dependent upon the distance of the shellfish area from the discharge point, the oceanographic characteristics of the discharge point (e.g. stratification, tides, currents), the degree of treatment afforded to the effluent, the operation of the sewage treatment plant

Pollution Source Type	Year of Closure (Area in Hectares)						
	1972	1976	1977	1978	1979	1981	1984
Multiple Source	45407.2	46232.7	46212.6	45654.2	43540.2	44017.9	44457
Municipal Discharge	5211.2	5981.3	6439.1	6466.3	6466.3	6881.2	7090
Urban Runoff, Septic Seepage	438.8	638.7	969.2	1097.1	840.3	789.2	1184
Agriculture, Hinterland	145.8	272.0	369.2	503	503	630.4	609
Boat Discharges	452	301.3	315.4	301.4	344.1	344.1	1387
TOTAL (Hectares)	51655.0	53426	54305.5	54022	51693.9	52462.8	54727

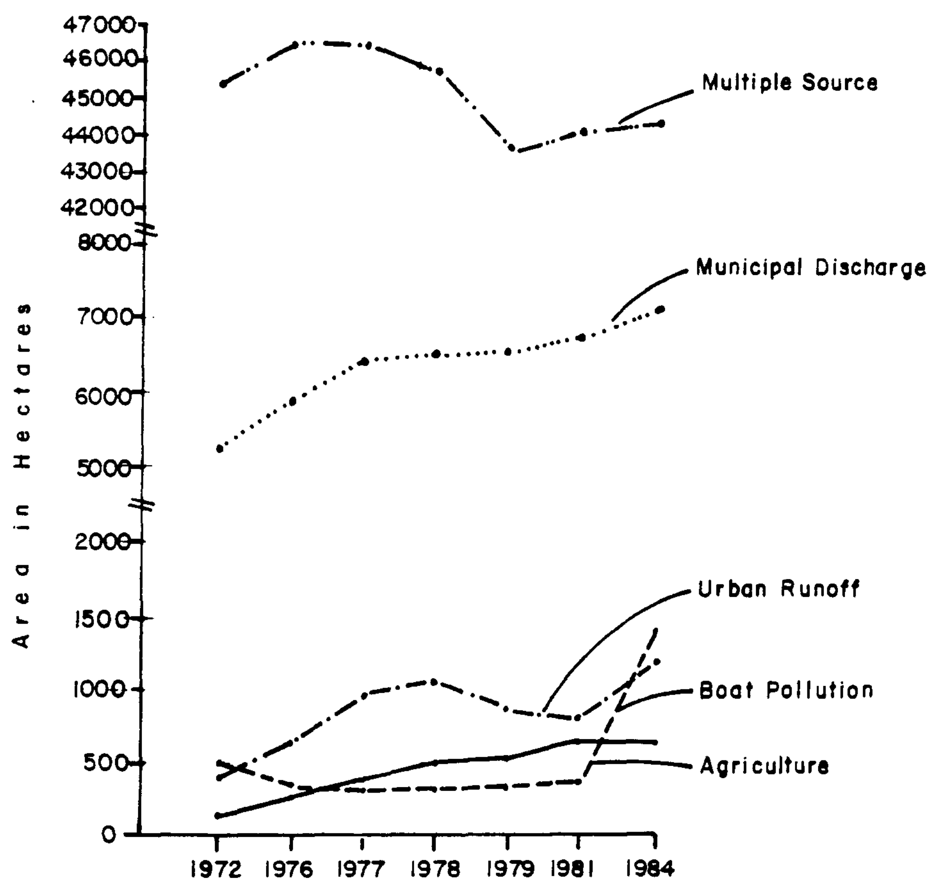


FIGURE 2.7 TRENDS IN BRITISH COLUMBIA SHELLFISH CLOSURES

including the hydraulic capacity, and the integrity of the sewage collection system. The closure of shellfish areas does not necessarily require the fecal coliform levels in the water to exceed 14/100 mL. Consideration is also given to the potential pollution effects which can occur in the event of operational malfunctions (e.g. disinfection failure) or hydraulic overloading at a sewage treatment plant.

Shellfish sanitary surveys have been conducted by the Environmental Protection Service at all south coastal municipal discharges where commercial and recreational quantities of shellfish occur. In particular, studies at Port Hardy, Campbell River, Comox, French Creek, Nanaimo, Ladysmith, Saanich Peninsula, Powell River and Ucluelet Inlet are relevant to this discussion and are summarized here.

2.4 Shellfish Sanitary Survey Case Studies

2.4.1 Port Hardy. Studies to determine the impact of the Port Hardy "Tsulquate" sewage treatment plant on nearby clam beaches showed that significant intrusion of the effluent into shellfish growing areas could occur. Dye tracing of the effluent plume and fecal coliform monitoring of the marine waters supported this conclusion. Fecal coliform levels ranged from < 2/100 mL to 79/100 mL in the vicintiy of the outfall. Although the effluent from the sewage treatment plant was chlorinated, the plant was unable to produce a high quality effluent consistently due to hydraulic overloading and carry-over of solids to the final effluents. This variable operation together with shallow depth of the outfall (6 m) and the proximity to the Tsulquate River estuary clam beaches required the maintenance of a closure (Kay and Ferguson, 1979).

2.4.2 Campbell River. Bacteriological impacts from the Campbell River Water Pollution Control Centre were not evident during studies conducted by Arney and Kay (1976). A concurrent dye study of the effluent discharge showed the sewage field to remain submerged with little lateral dispersion. During a flood tide the sewage field remained parallel to the foreshore approximately 200 metres offshore for a distance of 4 km then moved towards the centre of Discovery Passage. It was concluded that the effluent would have little impact on bacteriological water quality due to the rapid tidal action at the discharge point (Higgs, 1976a).

2.4.3 **Comox - Cape Lazo.** The discharge of 2230 $m^3 \cdot day^{-1}$ of raw sewage through an 838 m outfall into Baynes Sound was not detected at foreshore and surface water samples taken by the Environmental Protection Service during a study of Comox Harbour in 1974 (Kay and Tevendale, 1974). Maximum fecal coliform levels of 14/100 mL were recorded at stations around the outfall (Kay and Tevendale, 1974). The installation of a new sewage treatment plant with an outfall extending 2750 m offshore from Cape Lazo replaced this raw sewage discharge and a lagoon effluent discharge to the Courtenay River in 1984. Recent studies by EPS have been unable to demonstrate a bacteriological (EPS unpubl.) or biological (Colodey, 1985) impact from this discharge.

2.4.4 **Parksville.** A similar discharge south of Comox at Parksville was shown to have a pollution effect on the receiving waters of Parksville Bay. Prior to 1978, the Town of Parksville discharged unchlorinated septic tank effluent to Parksville Bay through a 21 m deep outfall, 640 m offshore. The volume of sewage discharged per day was approximately 1728 m^3.

During a study conducted by EPS in 1975 (Cooper, 1976), significant fecal pollution was observed at an outfall shore station on the flooding tide. However, fecal coliform levels in the surface waters near the outfall terminus were generally much lower. Within a 1000 m radius of the outfall surface water fecal coliform levels ranged from < 2/100 mL to 1600/100 mL, with a median value of 5/100 mL and a 90 percentile value of 85.3/100 mL. Sample stations outside a 1000 metre radius of the outfall terminus had fecal coliform levels ranging from < 2/100 mL to 49/100 mL, with a median value of 2/100 mL and a 90 percentile value of 9.8/100 mL.

2.4.5 **French Creek.** In 1978, sewage from the Town of Parksville was diverted to the French Creek Water Pollution Control Centre and discharged via a new outfall, 2438 m offshore of the French Creek Boat Basin in 61 m of water. A resurvey of the Parksville Bay area in 1979 (Kooi et al., 1980) showed significant improvement in water quality. Sampling at 10 surface water stations showed low levels of fecal contamination and there was no evidence of sewage reaching the beaches from the new French Creek outfall. During the 1979 sampling, the effluent from the French Creek plant had an average fecal coliform value of 1.9 x 10^4/100 mL. Surface and depth sampling in the vicinity of the French Creek outfall was also conducted by the Nanaimo Regional District as a condition of their Waste Management Branch permit prior to and following the installation of the new outfall. These data indicate the effluent could not be detected by the fecal coliform test, even when the discharge was untreated, as was the case during the plant construction. Following the 1979 EPS survey (Kooi, et al., 1980), and after a review of the bacteriological data generated by the Regional District of Nanaimo, the shellfish closure of Parskville Bay was lifted. In addition a large closure of the Qualicum Beach area was reduced to two smaller closures. The diversion of sewage from the Village of Qualicum Beach to the French Creek plant eliminated the contamination problems of septic tank seepage along the foreshore of Qualicum Beach.

2.4.6 **Nanaimo.** Bacteriological studies by Kay and Ferguson (1978) in the vicinity of the Five Finger Island outfall at Nanaimo concluded the discharge was having no appreciable effect at shoreline stations in the Hammond Bay area. During the survey, which was conducted in March and April of 1978, three marine sampling stations at Lagoon Head had fecal coliform concentrations ranging from < 2 to 11/100 mL. Earlier studies (Cooper, 1978) conducted in 1977 showed fecal coliform ranges of < 2 to 22/100 mL at eight foreshore sampling stations. During both these studies, effluent was chlorinated and had low (< 1000/100 mL) fecal coliform concentrations. The reduced bacteriological impact is also evident in sediment samples collected around the outfall with fecal coliform levels of 50/100g and 80/100g being recorded at two stations (Pomeroy and Packman, 1981). The installation of the Five Finger Islands outfall and cessation of raw sewage discharges through two outfalls located at Duke Point and Newcastle Island in 1975 appears to have resulted in a significant improvement in Nanaimo Harbour bacteriological water quality, although comparative data is not available prior to 1975. Kay and Ferguson (1978) sampled 24 marine stations in Nanaimo Harbour, of which all met the criteria for approved shellfish harvesting. Fecal coliform levels ranged from < 2 to 130/100 mL indicating occasional sewage pollution, likely from the shipping and industrial activity. Considering the utilization of the foreshore for commercial and industrial purposes, the high water quality is extraordinary.

2.4.7 **Ladysmith.** South of Nanaimo, the Town of Ladysmith discharges primary treated, chlorinated effluent from a plant located at Holland Bank. A maximum daily discharge of 3200 m^3 is permitted from the treatment facilities and an additional discharge of up to 54,000 m^3/day is permitted through treatment plant overload bypass facilities installed in 1982. The overload bypass does not receive any treatment other than coarse screening and is not disinfected. Treated and non-treated effluents discharge through separate outfalls located side by side, 366 m offshore at a depth of 11 m.

In addition to sewage, sludge from the treatment facility is occasionally wasted through the outfall with prior approval from the Waste Management Branch under specific tidal and wind conditions.

Prior to the installation of the overload bypass outfall, the Environmental Protection Service conducted bacteriological and dye tracer studies of the outfall plume during October 1981. Bacteria in the marine sediments around the outfall were also sampled.

Surface and depth water samples were collected for Rhodamine dye concentration and fecal coliform analysis (Kay, 1981; Shepherd, 1982). Effluent surfacing at the outfall plume rapidly dispersed, and was below the detection limit of 0.02 ppb within 400 m of the outfall. Similarly, fecal coliform levels in surface and deep waters also decreased rapidly with distance from the outfall. A comparison of dilutions determined by dye concentrations and fecal coliform concentrations showed a positive, but not high degree of correlation, with a correlation coefficient of 0.7 (Shepherd, 1982). The poor correlation was likely due to (i) variable effluent fecal coliform levels (ii) insufficient numbers of analyses of the effluent

(iii) variable solids levels in samples and the corresponding effect on bacteria levels and (iv) varying effluent dye concentrations due to manual control of dye injection and imprecise flow measurement. Initial dilution, as calculated by the OUTPLM computer dilution model, was in the range of 70-170, compared to over 200 as determined by bacteria concentration. This agrees with the fact that in general, mathematical plume dispersion models tend to be conservative (Shepherd, 1982). Fecal coliform densities in sediment around the outfall decreased to < 200/100g limits within 400 m of the outfall.

On October 7, 1981, sludge wasted through the outfall was followed visually. The sludge surfaced and was wind-directed towards Burleith Arm. Water samples were collected at 0, 3 and 6 m and analysed for fecal coliforms and 35°C total plate counts. Fecal coliform levels approaching the shellfish growing water standard were detected up to 1400 m from the outfall plume. Sampling was discontinued at this point due to navigational hazards.

Additional monitoring of this outfall following the construction of the overload bypass discharge is continuing. Recent data collected by EPS in 1983 (Kay and Walker, 1985) suggests that bacteriological water quality in some of the intertidal habitats of the outer Harbour may not be adversly affected by the bypass of untreated combined storm and sanitary wastewater. Despite visual evidence of the plume surfacing, fecal colifform densities in surface waters dropped to acceptable shellfish growing water standards within about 650 m of the plume.

2.4.8 <u>Saanich</u>. The intertidal area along the east coast of the Saanich Peninsula from Tsehum Harbour to Telegraph Cove was surveyed by EPS in 1979 (Kay, 1980). At that time, 4 sewage outfalls discharged to the receiving waters, and there were numerous storm drains and sewage lift station emergency overflow pipes along the coastline. The bacteriological quality of the marine waters was generally poor, and demonstrated the impact of the Sidney, Bazan Bay and Finnerty Cove discharges. Fecal coliform levels ranged from 2/100 mL to > 1600/100 ml at stations around the Sidney plant, 2/100 mL to 240/100 mL at stations around the Bazan Bay plant and 2/100 mL to > 1600/100 mL at stations around the Finnerty Cove outfall. The impact from the Central Saanich sewage treatment plant discharge was not as dramatic, with fecal coliform pollution exceeding the approved shellfish standard at only two stations.

In total, 93 marine stations were sampled representing 640 samples. Twenty-nine percent of the stations did not meet the approved shellfish standard.

The bacteriological water quality observed during this survey fairly reflected the conditions during periods of low runoff and limited infiltration to the collection sytems. The fecal coliform levels at the shoreline near the Sidney treatment plant outfall were likely higher than would be expected under dry conditions due to a 3 day by-pass of effluent from this plant. Data collected by the Capital Regional District and the Waste Management Branch have shown that fecal coliform levels can be higher than those observed in the EPS study.

In determining the extent of the shelfish closure along the Saanich Peninsula, a number of factors were evaluated including (1) the bacteriological quality of the water - both current and historical data (2) the performance of the treatment plants and the frequency of bypasses and hydraulic overloads (3) the location of lift station emergency overflows and the types of warning systems associated with the lift stations (4) the impact of stormwater drains and septic tank seepage on receiving water quality. On the basis of these considerations, considerably larger portions of the coastline were closed than would have been closed on the basis of bacteriological water quality data alone.

2.4.9 Powell River. Sewage discharges from the Sliammon Indian Reserve sewage treatment plant, Powell River Water Pollution Control Centre and Westview Water Pollution Control Centre were identified as major causes of bacterial pollution in the Powell River area during a November, 1975 EPS survey (Kay, 1976; Higgs, 1976b). Median fecal coliform values in the receving waters ranged from 13-90/100 mL at Sliammon and 22-75/100 mL at Westview. The combined influence of these discharges, and to a lesser extent some non-point souces, caused contamination of approximately 11 km of coastline. The pollution was localized to the foreshore surface waters, with offshore (3 km) stations showing little or no contamination. Higgs (1976) found that raw sewage bypasses due to hydraulic overloading from the Powell River and Westview plants were the most significant contributors of fecal contamination. Poor operation and disinfection malfunctions at the Sliammon plant resulted in extensive pollution of clam and oyster habitat fronting the reserve. Subsequent sampling of this area following a 128 m extension of the outfall showed water quality continued to be degraded to levels unacceptable for shellfish harvesting (Kay, 1981).

2.4.10 Ucluelet. The negative impact of raw sewage discharged through shallow outfalls into a sheltered area is best documented by the 1982 EPS study of Ucluelet Inlet (Kay et al., 1982). At the time of the survey the Village of Ucluelet discharged raw sewage through six outfalls into Ucluelet Inlet. Additional sewage discharges included raw outfalls from individual residences and a submerged outfall discharging septic tank effluent from an Indian Reserve. Forty-four sample stations were sampled in Ucluelet Inlet, with only six meeting the shellfish standard. Fecal coliform levels ranged from < 2 to > 1600/100 mL. The highest levels (median = 79/100 mL) were observed along the western shoreline of the inlet, with decreasing levels at surface stations along the centre line (median = 25/100 mL) and eastern shoreline (median = 23/100 mL). These data were consistent with the known sources of pollution, most of which were along the western shoreline within the boundaries of the Village of Ucluelet. Kay et al. (1982) also noted tidal influences on water quality particularly along the eastern shoreline. During ebb tides stations were minimally contaminated whereas during flood and high slack tides this shoreline did not meet shellfish standards. Along the western shoreline, fecal pollution exceeded the shellfish standard during all tides sampled.

To remove the sewage discharges from the inner inlet area and transport the sewage to a site where better dilution and disperson can be achieved, the Village of Ucluelet has constructed a lagoon treatment system and outfall with diffuser to discharge to a point near the entance of the inlet. Preliminary bacteriological sampling of the inlet suggests a significant improvement in water quality has occurred (EPS, unpublished).

2.4.11 **Other.** Shellfish bacteriological surveys have also examined the impact of marine sewage discharges from Tofino (Kay et al., 1982), Village of Gibsons (ibid), Village of Sechelt (Cooper and Tevendale, 1974), City of White Rock (outfall now abandoned) (EPS unpublished, 1973) and several smaller sewage treatment systems for residential and/or commercial developments. A complete reference list of these studies is provided by Kay et al. (1986).

2.5 Health Hazards Associated with Marine Sewage Discharges

The preceding section has reviewed the bacteriological impacts of sewage discharge, particularly as they relate to pollution of shellfish areas. In some cases the impacts have been well documented, but in others the dilution and dispersion patterns of the effluent are not well understood, and the resultant impacts on water quality in the foreshore area are less clear. In all cases, however, the degree of sewage pollution is measured quantitatively using fecal coliform organisms. These organisms, predominately Escherichia coli, are normal inhabitants of the gut and intestinal tract of all warm-blooded animals, including man. They are excreted in large numbers and are used as an indicator organism for the presence of sewage. Detection of fecal coliforms therefore is evidence of the potential presence of other disease-producing (pathogenic) microorganisms which may be discharged into the sewer systems. Thus standards for shellfish harvesting and swimming suitability have been established using fecal coliforms as indicators.

There is considerable controversy over the use of fecal coliforms as being adequate indicators of health hazards. On the one hand, British studies (U.K., 1959) showed there was no epidemiological basis for the transmittal of the serious and sometimes fatal diseases such as typhoid, cholera and polio through bathing in sewage-contaminated waters. More recently, however, studies conducted along the U.S. eastern seaboard (Cabelli et al., 1976) and in the Mississippi River (Rosenberg et al., 1976) have shown that bathing in polluted waters can result in gastrointestinal infections, and in the latter case, Shigellosis. The U.S. Environmental Protection Agency has recently (Federal Register, 1986) adopted swimming water standards using the enterococci groups of bacteria as indicators of sewage pollution in marine waters. Dufour (1984) has reported a direct linear relationship between swimming - related gastroenteritis and the density of enterococci.

In the case of shellfish growing waters, the relationship between fecal coliform indicators and virus levels in shellfish is being questioned. In the U.S. Gulf Coast states virological studies in approved shellfish areas show the potential for consistent virus isolations (Ellender and Cook, 1980). The investigators further concluded that bacterial indicators of the quality of shellfish growing waters and shellfish tissues were not good predictors of viral contamination in shellfish.

In British Columbia, no studies have been conducted to assess the effectiveness of the fecal coliform indicator in determining actual health hazards. Provincial epidemiological records have not shown any disease outbreaks associated with shellfish consumption (Dr. T. Johnstone, pers. comm.). However, in terms of reported cases throughout the world, Verber (1983) has shown a dramatic increase in gastroenteritis outbreaks during the first three years of this decade. Thus although fatal and near-fatal disease-causing organisms have declined to low levels, it appears that other, lower-grade maladies are on the increase world wide. It is doubtful if this trend will be seen in British Columbia due to the distance of most approved shellfish harvesting areas from urban centres.

2.6 Sewage Summary

Environmental effects associated with the marine disposal of sewage presently appear to be confined to bacteriological impacts on swimming and shellfish water, aesthetic impacts and, in the case of the Iona surface discharge, significant toxic effects to fish. Limited benthic habitat degradation and alteration has been observed at most outfall sites and levels of trace metals in sediment and biota have been shown to increase near those sites monitored. The highest levels of trace metals in sediment were found at the Iona plant outfall area.

Recent studies on organic contaminants in municipal effluents (Rogers et al., 1984) and the occurrence of abnormalities in the tissues of bottom-dwelling fish near the Iona discharge and other industrialized areas (Popham, 1984) suggest more research is required to determine the long-term bioaccumulative, mutagenic and carcinogenic impacts of municipal wastewater discharges.

The increasing controversy over the adequacy of the fecal coliform test in assessing the public health safety of swimming and shellfish waters must be addressed for British Columbia waters. Levels of pathogenic bacteria and viruses should be examined at specific sites and compared with past and existing fecal coliform data.

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3 MINING

3.1 Introduction

Mining in British Columbia dates from the waning years of the fur trade, when the Hudson's Bay Company mined coal on Vancouver Island. The obvious impacts of mining on B.C.'s environment can be traced to 1858, with the first gold rush into the Interior. Beginning around the turn of the century, lode gold - gold from the hard rock of underground mines - and silver began to dominate. In the years immediately following World War I, diversification was evident everywhere with copper, gold and lead-zinc deposits being mined extensively. Although the depression years saw a renewal of placer gold mining, by World War II demand for gold gave way to an intense search for "war" metals - chromium, molybdenum, mercury and tungsten. Following World War II the technology of the industry changed profoundly. Bulldozers, power shovels and massive trucks opened up an entirely new world of open pit mining. The new technologies revolutionized the structures of British Columbia mining, shifting it from an industry dominated by lead and zinc to one dominated by copper and molybdenum (Gunn, 1978).

Coastal ore bodies have been mined in British Columbia since 1899, when the Britannia copper mine was opened in Howe Sound. Nine mines with marine discharges have operated for varying periods of time along the coast (Figure 3.1).

3.1.1 Mining and Metallurgical Process. Metallic deposits are concentrations of normally diffuse metals which are generally bound chemically to other elements to form metallic minerals. Metallic minerals are found interspersed with non-metallic minerals or rock matter called "gangue". The "ore" consists of metallic minerals and gangue from which one or more metals may be extracted at a profit. Metallic minerals occur as native metals (e.g. gold) or as a combination of the metals with sulphur, oxygen, silicon or other elements. The non-metallic gangue materials are usually discarded in the treatment of ore. The most common gangue minerals are oxides (quartz), carbonates, sulphides and silicates.

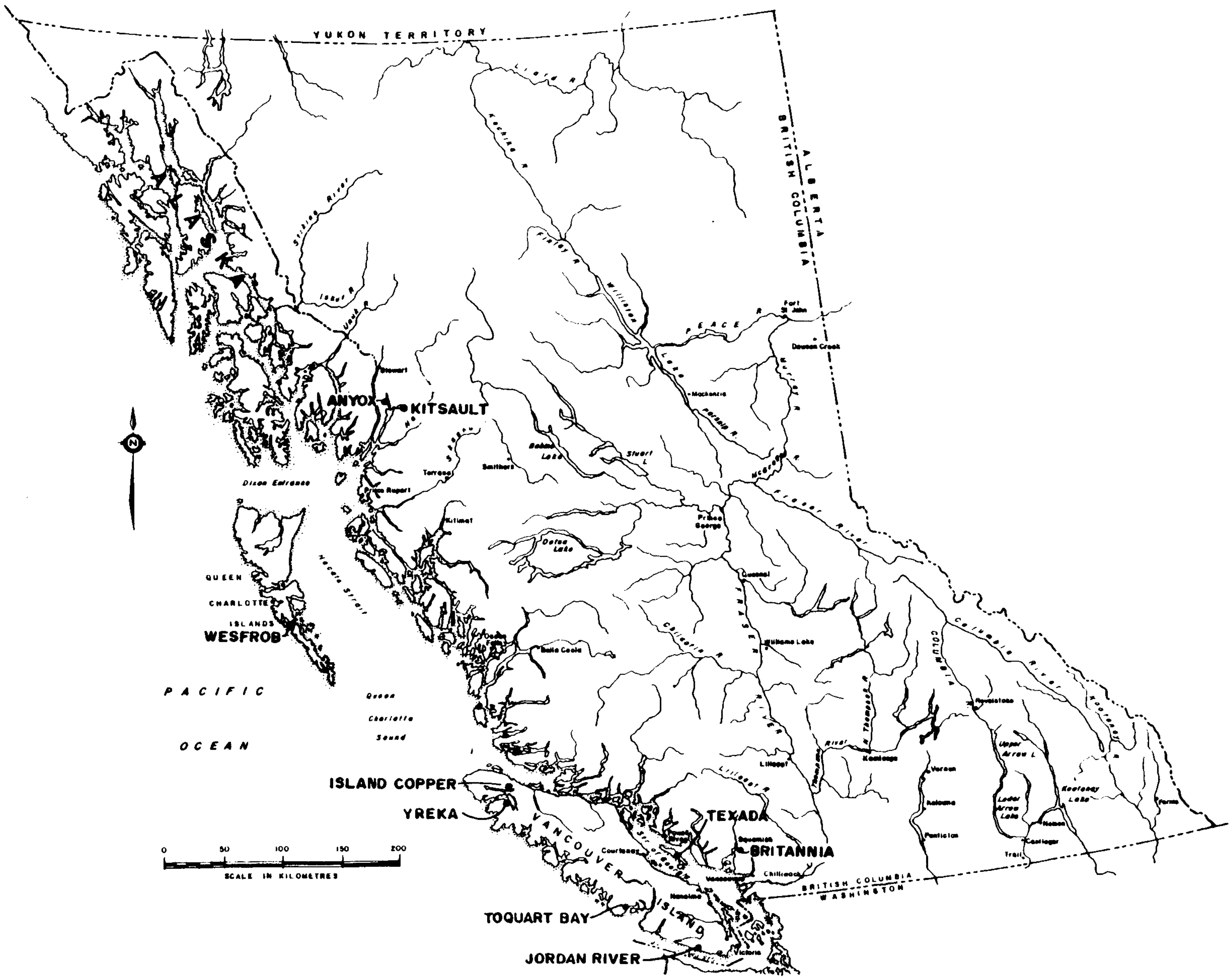


FIGURE 3.1 COASTAL MINE SITES IN BRITISH COLUMBIA

The major stages in the mining process are shown in Figure 3.2. Since coastal B.C. mines do not refine metals but ship ore concentrates elsewhere for further processing, the gangue, overburden, and mine/mill tailings constituents are the major environmental concerns in coastal mining. Characteristics of these mineral wastes are given in Table 3.1.

On the average, only two percent of ore extracted contains desired minerals. Examples are copper 1.13%, nickel 1.41%, lead 2.08%, and zinc 5.11%. The remainder is discarded as waste. Since mines must process large amounts of ore to profitably extract the metals, the unconfined disposal (i.e. without tailings impoundment) of mine and mill tailings can result in massive discharges of solids to the environment.

3.1.2 **Control of Water Pollution.** Both the federal and provincial governments exert regulatory authority over mining operations in British Columbia. The federal Parliament passed the "Metal Mining Liquid Effluent Regulations" under the Fisheries Act in 1977. These regulations apply to new, expanded (i.e. production rate increase exceeding 30% of its reference mine production rate) and reopened metal mines (other than gold mines), and define limits for prescribed deleterious substances (Table 3.2). In addition to these prescribed substances, guidelines for effluent toxicity are also included. The objective for undiluted effluent is that no more than 50% of the fish die in a composite sample within 96 hours (i.e. 96 hr LC_{50} = 100%).

Mines in commercial production prior to the promulgation of the regulations and which operated for at least two months of the 12 months preceding this date are not subject to the regulations. Guidelines have been prepared for such mines which are basically the same as the regulations. Since all of the coastal mines in British Columbia except the Kitsault molybdenum mine were in production prior to the promulgation of these regulations, they are not subject to the federal regulations. In the case of the Kitsault mine, special regulations entitled "Alice Arm Tailings Deposit Regulations" were passed on April 4, 1979, permitting the discharge of unconfined mine tailings to Alice Arm. This case will be discussed in detail later.

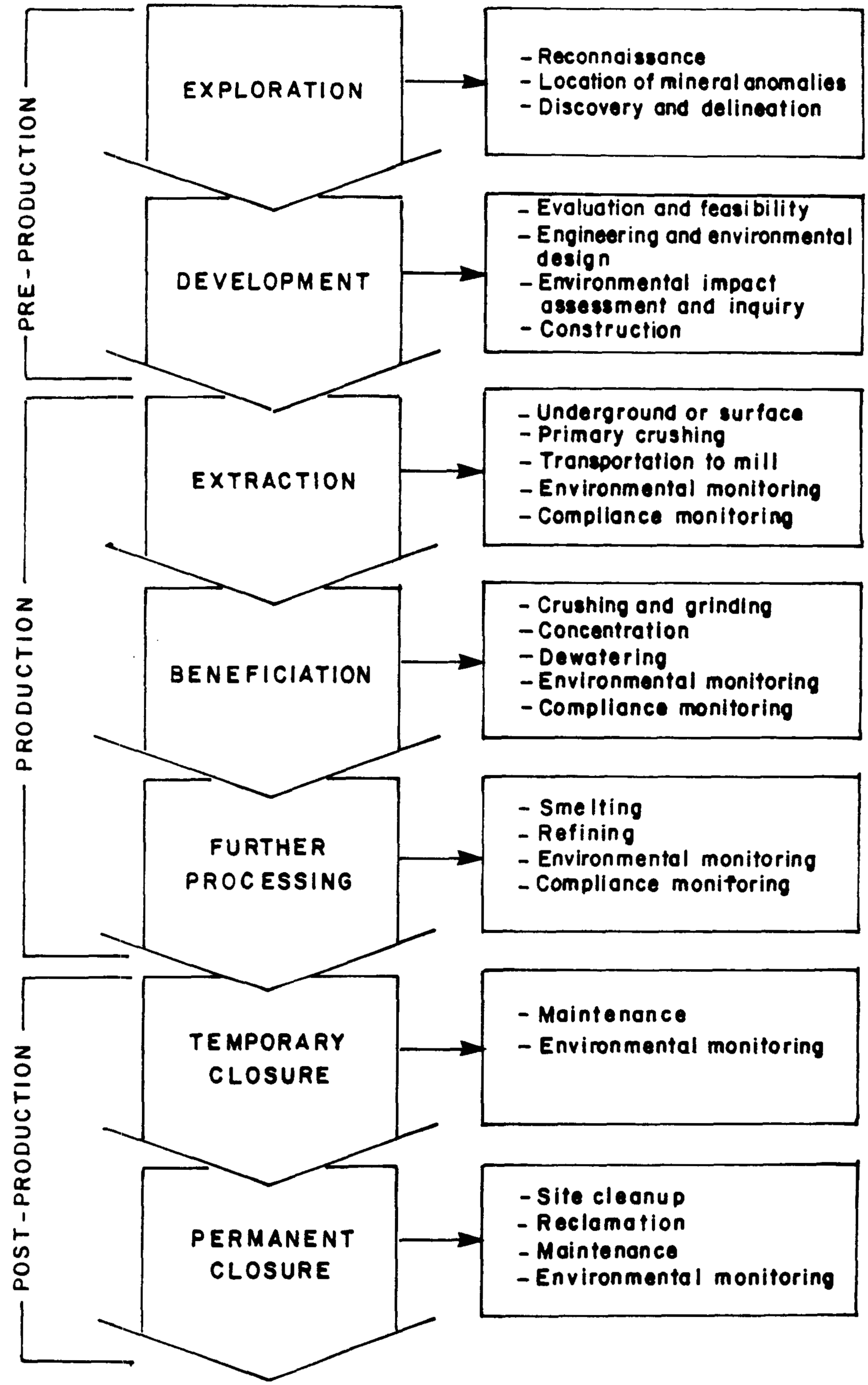


FIGURE 3.2 MAJOR STAGES IN THE MINING PROCESS
(Adapted from Marshall, 1982)

TABLE 3.1 CLASSIFICATION AND CHARACTERISTICS OF MINERAL WASTES (Marshall, 1982)

	TYPE		
	OVERBURDEN	GANGUE OR WASTE ROCK	MINE AND MILL TAILINGS
DESCRIPTION	Material that must be removed to expose the bedrock or ore body. Usually consists of soil, sand, clay, shale, gravel, boulders, etc. Usually excavated by dragline, scraper, bulldozer or other earth moving equipment, transported and dumped, usually in ridges, cones or long slopes.	Coarse graded material other than overburden of no present value that must be broken and removed during metal and non-metallic operations to obtain the ore. Often removed together with overburden and disposed of in waste dumps. Usually fairly homogeneous for each mine operation but can be quite different from one mine to another, even when the same type of ore is mined.	Tailings are finally sized particles that are discarded following the concentration and recovery of the desired mineral values from metallic and non-metallic ores. Normally handled as a water slurry which is transported by pipeline or flume and deposited by natural settling into artificial ponds created by damming or into a natural water body or a combination of the two. Effluent is decanted, treated and may be recycled into the mill.
CHARACTERISTICS	Heterogeneous and unconsolidated. Consists of two components: 1) Pedogenic topsoil that has undergone oxidation and weathering, forming a layered-profile structure, with vegetation growing on it. 2) Surficial (subsoil) unaltered material not presently undergoing weathering or oxidation (soil forming factors). Little or no organic matter; dosen't support plant life. Surface cover removed in coal strip mines; sand and gravel pits; tar sands extraction, etc.	Variable in size, due to variation in ore formations and different mining techniques. Size ranges are from boulders down to gravel. In general, all sources of waste rock can be reduced to a desired gradation by normal crushing and sizing methods. Some waste rock may still have a low grade metal content which may be considered as a potential resource in future.	Mineralogical composition generally corresponds to that of the parent rock from which the ore was derived. Difficult to generalize on characteristics due to wide range of source rock types and processing techniques. Most tailings are composed of hard, angular siliceous particle with a high percentage of fines. (40-90% passing a 200 mesh or .074 mm sieve). Usually more than 90% of the original ore remains as tailings after the milling process. Range from sand to slime sizes but are sometimes larger; may include sulphides. Widespread throughout base, ferrous, precious metal mines, and non-metallic mineral operations.

TABLE 3.2 FEDERAL REGULATORY LEVELS FOR PRESCRIBED DELETERIOUS SUBSTANCES IN UNDILUTED MINE EFFLUENTS (Environment Canada, 1977)

SUBSTANCE	MAXIMUM AUTHORIZED MONTHLY ARITHMETIC MEAN CONCENTRATION (mg/L)	MAXIMUM AUTHORIZED CONCENTRATION IN A COMPOSITE SAMPLE (mg/L)	MAXIMUM AUTHORIZED CONCENTRATION IN A GRAB SAMPLE (mg/L)	FREQUENCY OF MEASUREMENT		
				Weekly conc. ≥ (mg/L)	Every 2 weeks conc. ≥ (mg/L)	Monthly conc. ≥ (mg/L)
Arsenic	0.5	0.75	1.0	0.5	0.2	0.1
Copper	0.3	0.45	0.6	0.3	0.1	0.05
Lead	0.2	0.3	0.4	0.2	0.1	0.05
Nickel	0.5	0.75	1.0	0.5	0.2	0.1
Zinc	0.5	0.75	1.0	0.5	0.2	0.1
Total Suspended Matter	25.0	3.75	50.0	25	20	15
$Radium^{226}$ (pCi/L)	100 (minimum)	20 (minimum)	30.0 (minimum)	10	5.0	2.5
pH (pH units)	6.0	5.5	5.0			

Note: All concentrations are total metals, with the exception of $Radium^{226}$

The Provincial government regulates all aspects of mine development and operation, including environmental control. Provincial requirements for mining effluent discharges are site-specific and are included in the terms of the discharge permit issued to the company under the provincial Waste Management Act. Guidance in setting effluent quality requirements for each permit is obtained from a set of "Pollution Control Objectives for the Mining, Smelting, and Related Industries of British Columbia" (Pollution Control Board, 1979). These Objectives provide for a wide range of possible discharge concentrations which take into account the needs of a particular receiving environment (Table 3.3). In addition, water quality objectives have also been developed (Table 3.4).

Both federal and provincial agencies are concerned with heavy metals, suspended solids, toxicity and pH. The major difference between the two is the measurement of metals. While the federal government regulates on the basis of total metals, provincial guidelines and permits set levels for dissolved metals. The provincial Waste Management Branch has discretion, however, in requesting total metal monitoring as well as dissolved to reflect the amount immediately available biologically.

Levels of suspended solids in mine tailings discharges have not been limited to those described in Tables 3.2 and 3.3 but are rather dealt with by the design and placement of outfalls.

The amount of tailings discharged to the marine environment is difficult to calculate on a province-wide basis due to the limited records of early mines, and the vagaries of international market demands which result in variable mine operating schedules. Based on the average discharge flow rates and total suspended solids measurement for each mine, the approximate tonnages of tailings which have been discharged daily by each mine is given in Table 3.5. This table also provides details of the mining operations and tailing characteristics.

3.2 Physical Impacts of Mine Tailings

Eight coastal mines have discharged tailings to the marine environment in British Columbia either by direct deposition on the intertidal

TABLE 3.3 PROVINCIAL OBJECTIVES FOR THE DISCHARGE OF MINE FINAL EFFLUENTS TO MARINE AND FRESH WATERS

PARAMETER (5) (mg/l dissolved in effluent unless otherwise stated)	RANGE		PARAMETER (5) (mg/l dissolved in effluent unless otherwise stated)	RANGE	
Total suspended solids (1) (2)	25	25	Radioactivity (6):		
Total dissolved solids	2500	2500	Gross Alpha pCi/L	10	100
Toxicity (96-hour LC_{50} static bioassay) (3)	100%	80%	$Radium^{226}$ pCi/L (dissolved in effluent passing through a 3 um filter)	< 10	< 10
pH (pH units)	6.5-8.5	6.5-8.5			
SPECIFIC ELEMENTS AND COMPOUNDS					
Aluminum (Al)	0.5	1.0	Manganese (Mn)	0.1	1.0
Ammonia (as N)	1.0	10.0	Mercury (Total) (Hg) (4)	Nil	0.005
Antimony (Sb)	0.25	1.0	Molybdenum (Mo)	0.5	5.0
Arsenic (as trivalent As)	0.05	0.25	Nickel (Ni)	0.2	1.0
Arsenic (total dissolved)	0.10	1.0	Nitrite/Nitrate (as N)	10.0	25.0
Cadmium (Cd)	0.01	0.1	Phosphate (Total P biologically available in effluent)	2.0	10.0
Chromium (Cr)	0.05	0.3			
Cobalt (Co)	0.5	1.0	Selenium (Se)	0.05	0.5
Copper (Cu)	0.05	0.3	Silver (Ag)	0.05	0.5
Cyanide (as CN)	0.1	0.5	Uranyl (UO_2)	2.0	5.0
Fluoride (F)	2.5	10.0	Zinc (Zn)	0.2	1.0
Iron (Fe)	0.3	1.0	Oil and Grease (Total)	10.0	15.0
Lead (Pb)	0.05	0.2			

(1) Not applicable to approved direct discharge of tailing solids.
(2) Variances may be allowed during periods of excess runoff.
(3) Bioassay on salmonids species.
(4) Natural background concentration will be assessed.
(5) Analysis for total elements in tailings may be required prior to and during operations and the Director would give consideration to this information when issuing a permit.
(6) To apply to operations where the objective is not the mining of radioactive ores.

(Pollution Control Board, 1979)

TABLE 3.4 PROVINCIAL OBJECTIVES FOR MINE WASTE RECEIVING WATERS (1)

PARAMETER	LEVEL
Dissolved Oxygen	Not less than 90 percent of the seasonal natural value.
Temperature	To be within 1°C of the natural level.
Turbidity	Not more than 5 JTU above the natural value.
Floatable solids	None
pH	No change
Toxicity (96 hr static bioassay)	Below detectable limit
Colour	No change
Aesthetics	No decrease
Alkalinity (2)	Not less than 20% natural value
Chloride (2)	Not more than 25 mg/L
Fecal coliforms (3)	Not to exceed Ministry of Health standards.

(1) Applicable outside the initial dilution zone.
(2) Not applicable to marine discharge.
(3) Applicable only when sanitary discharge is mixed with effluent.

(Pollution Control Board, 1979)

TABLE 3.5 B.C. MINING OPERATIONS INVOLVING MARINE DISPOSAL OF MILL TAILINGS

MINE DATA		MILL TAILINGS DESCRIPTION			
		SOLIDS COMPONENT		LIQUID COMPONENT	
1. MINING CO. 2. TYPE OF OPERATION 3. MINERAL CONCENTRATES PRODUCED 4. MINE LOCATION 5. OPERATIONAL PERIOD 6. TAILINGS DISCHARGED TO 7. WMB PERMIT NO.	1. DAILY TONNAGE - DRY SOLIDS (tonnes/day) 2. SLURRY % SOLIDS BY WT. 3. PERMIT LEVEL TS ($mg.L^{-1}$) 4. TSS DAILY DISCHARGE ($mg.L^{-1}$) 5. PERMIT LEVEL TSS ($mg.L^{-1}$) 6. TAILINGS DISCHARGE FLOW RATE ($m^3.day^{-1}$) 7. PERMIT LEVEL FLOW ($m^3.day^{-1}$)	Major Minerals	Total Heavy Metal (ppm)	pH	Dissolved Heavy Metals (measured) ($mg.L^{-1}$)
A) 1. Island Copper Mine 2. Open pit 3. Copper, molybdenum 4. Rupert Inlet 5. 1971 - present 6. 50 m depth, Rupert Inlet 7. PE-379	1. 38,000 - 43,000 2. 40 3. - 4. 506,000 - 552,000 [a] 5. 500,000 6. 67,727 - 72,727 [a] 7. 82,000 [a] annual average: 1978-1983 prior to seawater dilution 1:1	quartz feldspar pyrite	Cd 0.2 Co 0.25 Pb 20 Mn 21 Hg 68 Cu 525 Mo 30	10.1	Cu .015 Mo .122 Cd < .001 Cr .035 Co .004 Fe .035 Pb .006 Mn .001 Ni .005 Zn .0053 As .039 CN .049 Hg .0001
B) 1. Amax of Canada 2. Open pit 3. Molybdenum 4. Kitsault, B.C. Canada 5. 1967 - 1972; 1981 - 1982 6. 1967 - 1972: Lime Creek 1981 - 1983: 50 m depth, Alice Arm 7. PE-4335	1. 1967 - 1972: 5440 1981 - 1983: 8120 2. 34 (1981 - 83) 3. - 4. 480,500 - 525,000 (1981-83) 5. 400,000 (1981-83) 6. 14,135-15,382 (1981-83) 7. 27,500 prior to seawater dilution of 2:1 to 6:1	quartz - diorite quartz - monzonite	Mo 95 Pb 52 Zn 314 Cd 16 CN 28	10.0	Cu < .007 Mo 1.6 Cd < .002 Fe .08 Pb < .003 Mn .088 Ni < .005 As < .004 Hg .001
C) 1. Wesfrob Mine 2. Open pit (1907 - 1976) Underground (1976 - 1983) 3. Iron, Copper 4. Tasu, Queen Charlotte Islands 5. 1907 - 1983 6. pre-1977 surface discharge post-1977 12 m depth Tasu Sound 7. PE-1288	1. 7000 2. 30 3. 260,000 4. 203,000 - 223,800 5. 260,000 6. 4,054 - 6,129 7. 6,100 no seawater dilution prior to discharge			7.6	Cu < .05 Cd < .02 Pb < .02 Zn .1 Fe < .1 As < .005 total Hg < .05

CONTINUED...

TABLE 3.5 (Continued)

MINE DATA		MILL TAILINGS DESCRIPTION			
		SOLIDS COMPONENT		LIQUID COMPONENT	
1. MINING CO. 2. TYPE OF OPERATION 3. MINERAL CONCENTRATES PRODUCED 4. MINE LOCATION 5. OPERATIONAL PERIOD 6. TAILINGS DISCHARGED TO 7. WMB PERMIT NO.	1. DAILY TONNAGE - DRY SOLIDS (tonnes/day) 2. SLURRY % SOLIDS BY WT. 3. PERMIT LEVEL TS ($mg.L^{-1}$) 4. TSS DAILY DISCHARGE ($mg.L^{-1}$) 5. PERMIT LEVEL TSS ($mg.L^{-1}$) 6. TAILINGS DISCHARGE FLOW RATE ($m^3.day^{-1}$) 7. PERMIT LEVEL FLOW ($m^3.day^{-1}$)	Major Minerals	Heavy Metal Contents (ppm)	pH	Dissolved Heavy Metals (measured) ($mg.L^{-1}$)
D) 1. Britannia Mine 2. Underground 3. Copper, zinc 4. Brittania Beach, Howe Sound 5. 1899 - 1974 6. surface and submerged (50 m) into Howe Sound 7. no permit issued	1. 3000 2. - 3. - 4. - 5. - 6. 10,000 7. -	silicate minerals	Cu .2% Zn .125% Fe 5.5%		
E) 1. Jordan River 2. Underground 3. Copper 4. Jordan River 5. 1960 - 1974 6. 13 m into JuandeFuca Strait 7. 427P (provisional)	1. 1000 - 1500 2. - 3. 250,000 4. 127,100 5. 250,000 6. 3,600 7. 4,545				Cu < .11 Pb < .2 Zn < .08 Cd < .02 Cr < .15 CN < .01
F) 1. Texada Mine 2. Open pit till 1964 then U/G 3. Iron, copper 4. Texada Island 5. 1952 - 1976 6. At high tide into Georgia Strait 7. none issued	1. 4100 2. - 3. 7.39% (permit application) 4. 101400 5. 7.39% (permit application) 6. 11,000 7. 9,770 (permit application)				Cu .017 Mo .18

Notes: 1. Table adapted from Ellis and Poling (1982).
2. Measured levels in liquid component of tailings derived from company and government records.

zone or by submerged outfall, with or without prior mixing with seawater. For some, environmental conditions have been monitored (Table 3.6) and reviewed by Ellis and Poling (1982). Martin (1985) and Dorcey (1985) have analysed the use of science in environmental management decision-making as applied to two of these. The following discussion of physical impacts focuses on the three coastal mines which have been active during the last decade: the Island Copper Mine at Rupert Inlet, the Wesfrob Mine at Tasu Sound, and the Kitsault Mine at Alice Arm. The physical impacts are commonly determined by measuring the effect of suspended tailings on light transmittance (using a transmissometer) or light scatter (using a nephelometer). Deposition rates of mine tailings on the sea floor are also determined by chemical and other means.

3.2.1 **Island Copper Mine.** Impacts of the Island Copper Mine have been reported in Goyette and Nelson (1977) and others, and reviewed in Waldichuk and Buchanan (1981). The environmental assessment process and agency interaction has been reviewed by Martin (1985).

The Island Copper Mine tailings discharged into Rupert Inlet were predicted to generally remain below 100 metres and flow as a density current down the sloping bed of the inlet to settle in the deeper portions. It was also predicted that high current velocities in the area would remain above 60 metres and not resuspend tailings deposits on the floor of the inlet. To assess the validity of these predictions, the company initiated an extensive monitoring program. Elements of the "physical effects" portion of the program are divided into two segments: assessment of the vertical, spatial distribution of suspended material in the water column, and deposition rates of mine-derived materials on the sea floor (Utah Mines, 1984). The program, which began in 1971, includes monthly water column sampling at seven stations in Rupert Inlet, Holberg Inlet and Quatsino Sound. Water samples are collected at 1, 5, and 30 m depths and at a designated above-bottom depth for temperature, salinity and turbidity determinations. Turbidity is also measured quarterly at all standard sampling depths at three stations; and during a detailed survey conducted each September, temperature, salinity and turbidity are measured at all seven stations and all standard sampling

TABLE 3.6 SUMMARY OF COMPANY RECEIVING WATER MONITORING PROGRAMS AT B.C. COASTAL MINES (Ellis and Poling, 1982)

MINE	FREQUENCY	COMPONENTS (See Key)
Island Copper	Regular, variable periods	All listed components
Kitsault	Regular, variable periods	All listed components
Wesfrob	Irregular	a, d, f, h, j, m, n
Britannia	--	none during operation
Jordan River	Regular	a, b, d, f, h, j, m, n
Texada	Irregular	no information available
Toquart Bay	Irregular after closure	f, m
Yreka	None	None

KEY TO RECEIVING AREA MONITORING COMPONENTS

a. Tailings discharge rates and chemical analyses
b. Acute Bioassays (LD_{50}s, etc.)
c. Other bioassays (long term in situ, etc.)
d. Turbidity (suspended solids, etc.) - ambient levels
e. Density Current (tailings plume)
f. Tailing deposition (coring, bathymetry, chemical, mechanical, etc.)
g. Physical oceanography (current measures, stratification, etc.)
h. Chemical oceanography (trace metals, dissolved oxygen, nutrients, etc.)
i. Biological oceanography (primary production, phytoplankton, chlorophyll, zooplankton, ichthyoplankton, etc.)
j. Benthos (stocks and dynamics)
k. Shellfish (stocks and dynamics)
l. Fish and wildlife (stocks and dynamics)
m. Shoreline (stocks and dynamics)
n. Trace metal bioaccumulation and biomagnification

depths. During the detailed survey, gravimetric determinations of suspended sediments are also taken (Ibid, 1984).

The bottom sediment monitoring program includes direct measurement of sediment deposition and mapping of the tailings distribution on the bottom using visual (sediment cores), chemical (annual heavy metal distributions) and sonic (biannual echo sounder) techniques. In situ sediment sampling was initiated in 1976 in shallow waters (i.e. less than 20 m) to measure the ratio of sediment accumulation at various localities in the Rupert-Holberg-Quatsino system.

During the first two years of mine operation, some surface turbidity was observed immediately offshore from the waste rock dump in Rupert Inlet. This was attributed to the effects of wave action along the shorelines of the waste dump and to direct dumping of waste rock material into the inlet.

Studies conducted between 1973 and 1976 by the Environmental Protection Service (Goyette and Nelson, 1977) using aerial photography concluded that surface turbidity patterns were not consistent with the predictions of tailings behaviour made by the company. Photographs taken during the latter part of a flood tide confirmed surface turbidity throughout Rupert Inlet and Quatsino Narrows and in portions of Holberg Inlet and Quatsino Sound extending to the western tip of Drake Island, some 17 km from the mine site. The area around Hankin Point, the mouth of Rupert Inlet and the northern entrance to Quatsino Narrows were the most affected, with the intensity of surface turbidity declining towards the mine site, except for waters immediately adjacent to the waste rock dump. This trend continued through 1977, when satellite images by EPS showed the same distribution of surface turbidity, with the highest density near the mine site and inside the sill at Quatsino Narrows. Subsurface turbidity, as measured using transmissometer profiles (an instrument that measures light attenuation due to turbidity), had developed throughout most of Rupert Inlet by 1973, with transmittance sharply lowered below a depth of 40 metres. Transmittance at four stations in Rupert Inlet at depths greater than 50 m was consistently lower than the corresponding depths at a site in Holberg Inlet. Analysis of particles size collected in water samples during the transmissometry profiles suggested that silt and clay fractions similar to those found in the Island Copper Mill effluent would remain suspended by very slight (< 1.98 $cm.sec^{-1}$) current velocities.

Goyette and Nelson (ibid) concluded that "turbidity clouds" appearing at the mouth of Rupert Inlet resulted from resuspension of benthic tailings deposits near Hankin Point, due to tidal currents from Quatsino Narrows. This observation was strengthened by noting that surface turbidity at the mouth of Rupert Inlet did not occur until benthic deposits had reached the area off Hankin Point.

The distribution of mine sediments on the bottom was investigated by Goyette and Nelson (ibid) between 1971 and 1974 based on visual observations of Ponar grab samples. The data shows that tailings had extended past Thorp Point in Holberg Inlet, approximately 11 km from the mine site but had not entered Quatsino Sound. Figures 3.3-3.6 show the progression of tailings distribution during 1971-1974. During these same studies, SCUBA diving observations noted that the total area of mine sediment deposition extended well beyond that shown by the Ponar grab sampling and paralleled the surface turbidity noted in the aerial photographs. The authors concluded that the total area of mine sediment deposition represented approximately 3846 hectares, with the thickness of mine sediment deposits ranging from "light to heavy".

In March of 1978, following concerns about the sea disposal of mine tailings raised at the British Columbia Pollution Control Board Inquiry into the Mining, Mine Milling and Smelting Industries of British Columbia, a federal-provincial review of the Island Copper mine operation was initiated. The review was to deal with (a) the disposal pattern of tailings from Utah Mines into Rupert Inlet and (b) the environmental change which was taking place, and its significance. The report was published in 1980 (Waldichuk and Buchanan, 1980).

The review concluded that the obliterative effects of the discharge on the bottom of the Rupert-Holberg Inlet system was occuring as originally anticipated, and would eventually result in approximately 10% of the volume of the system being filled in during the life of the mine. However, the resuspension of tailings by tidal turbulence and upwelling at the junction of Rupert and Holberg inlets was not anticipated during the planning process for

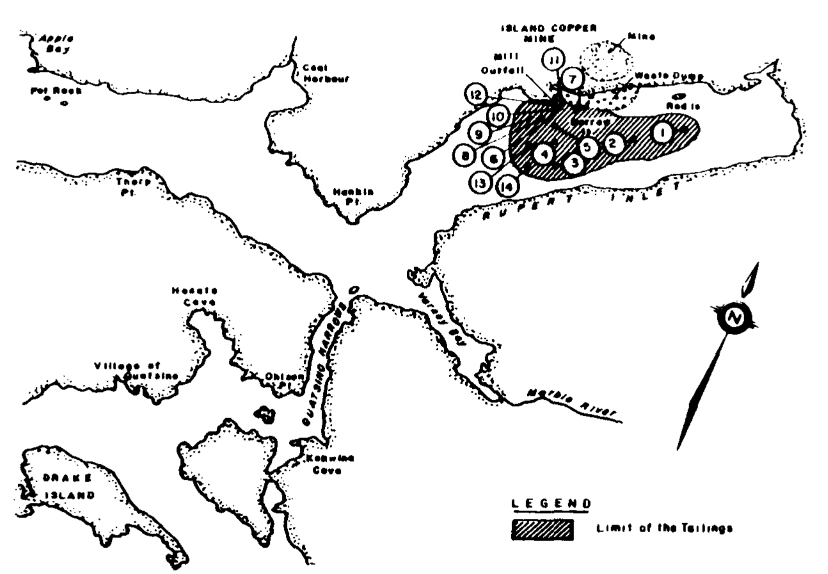


FIGURE 3.3 TAILINGS DISTRIBUTION AS DEFINED BY GRAB SAMPLES - NOVEMBER 3, 1971

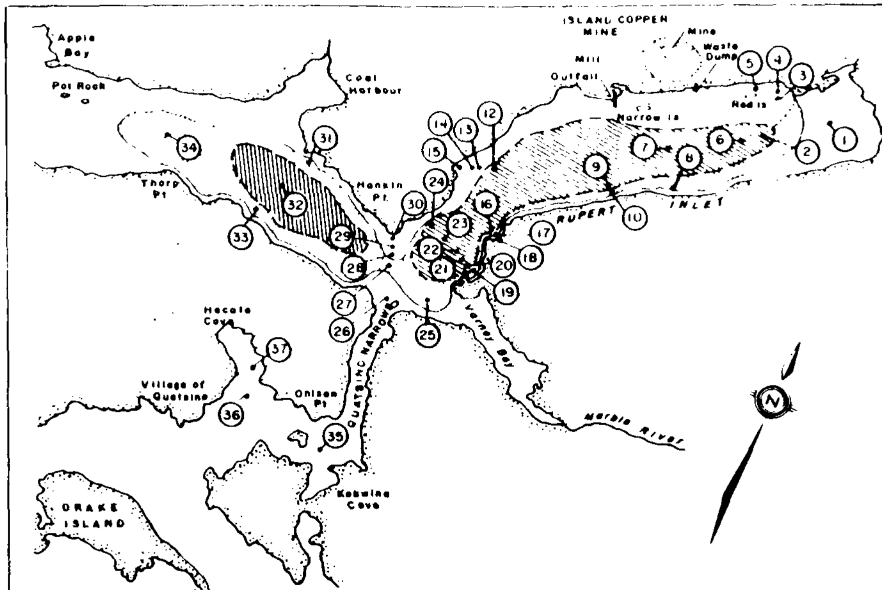


FIGURE 3.4 TAILINGS DISTRIBUTION AS DEFINED BY GRAB SAMPLES - OCTOBER 6, 1973

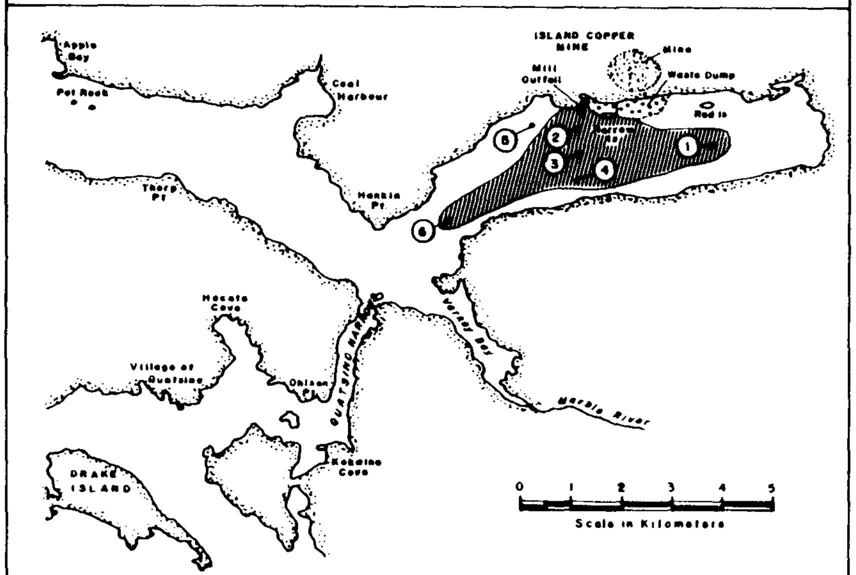


FIGURE 3.5 TAILINGS DISTRIBUTION AS DEFINED BY GRAB SAMPLES - MARCH 7, 1972

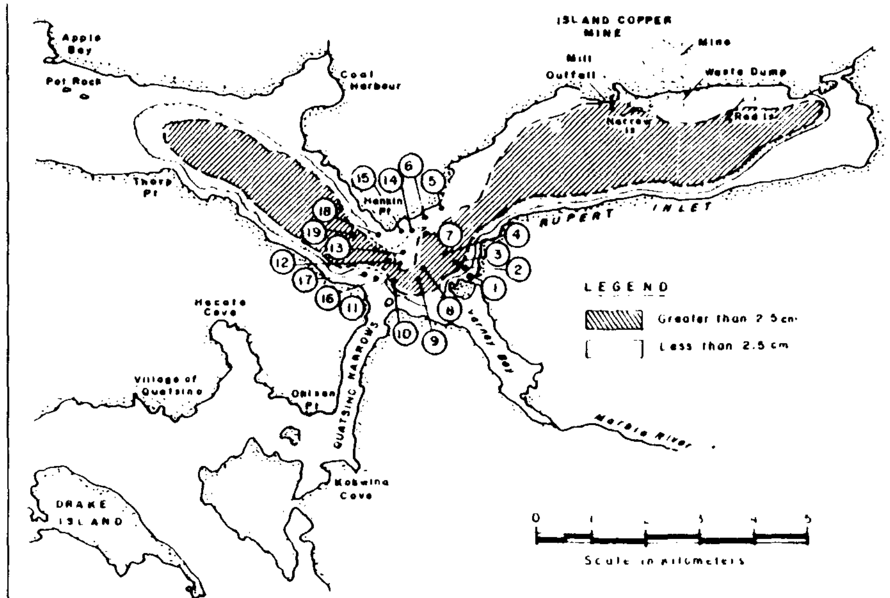


FIGURE 3.6 TAILINGS DISTRIBUTION AS DEFINED BY GRAB SAMPLES - MAY-JUNE 1974 (Guyette and Nelson, 1977)

the tailings disposal system. The mechanism of the mine tailing disposal and the evolution of submarine channel systems in the Rupert Inlet mine tailing deposit has been studied by Hay (1982) and has provided some insight into the unanticipated turbidity problems. The formation of submarine channels reduces the lateral divergence of the tailings thereby maintaining the velocity and excess density of the continuous flow to greater distances and depths. Material can be carried to even greater distances along the floor of the inlet by "surge-type turbidity currents". These arise when the channel levees, which are unstable, slump or fail. This in turn reduces the areal extent of deposition in the near-outfall area. However, the presence of a channel in Rupert Inlet means higher rates of transport to the Hankin Point area, where the material can then be resuspended and brought to the surface by the intense turbulence generated by the tidal jet during annual replacement of deep water. The intensity of surface turbidity in the Hankin Point - Quatsino Narrows area undergoes seasonal cycles, related in part to tidal range and in part to density of resident water relative to inflowing seawater (Waldichuk and Buchanan, 1980).

Year-to-year fluctuations in surface and subsurface turbidity have also been observed during the mine operation to date. The 1983 monitoring program report (Utah Mines Ltd., 1984) summarized suspended solids, turbidity and transmittance data for Rupert Inlet, Holberg Inlet and Quatsino Sound for 1971-1983. Quatsino Sound had the lowest levels of fixed suspended solids followed by Holberg Inlet and Rupert Inlet. By comparing annual mean levels of fixed suspended solids from all stations, the report concluded that the loadings in Rupert Inlet had remained "more or less consistent" since 1978. Annual mean turbidity, as measured by nephelometer (an instrument that measures light reflected from particles in the water), in the three inlets during 1983 remained similar to those levels observed in the previous six years, with turbidities at 5 m being highest in Rupert Inlet followed by Quatsino Sound and Holberg Inlet. At the 30 m depth, turbidity levels have generally paralleled the fixed suspended solids data since the beginning of the mine operation. Transmittance data indicates the presence of the tailings cloud at approximately 50 m depth off the outfall. Studies conducted by EPS in 1981 (summarized by Harding, 1983) showed a well mixed water column with slight to moderate turbidity from surface to 40-55 meters and moderate to heavy turbidity from 40-55 meters to the bottom.

The fluctuation in surface turbidity is also reflected in the sedimentation rates measured by the company at Hankin Point. The greatest rate of sedimentation occurs during summer months and has increased slowly between 1979 and 1982, as demonstrated in Figure 3.7. The decrease observed in 1983 was presumed to be due to oceanographic processes. Very little information is available on the depth of tailings deposits in the intertidal area at Hankin Point, although Waldichuk and Buchanan (1980) reported deposits as much as 25 cm deep in July 1978 on a rather coarse natural substrate. Sedimentation rates at three other stations were substantially lower (< 3%) than the rates recorded at Hankin Point.

By 1981 tailings had moved well into Quatsino Sound, Holberg Inlet and Neroutsos Inlet, based on copper content of sediment, (Utah Mines Limited, 1984) as shown in Figure 3.8. The distribution of mine-derived sediment, as determined by visual observation of the cores, was unchanged from 1982 (Utah Mines Ltd., 1984). The 1983 echo sounder survey provided strong evidence that a major slump of deposited tailings occurred in the region of the outfall and resulted in the transport of a very large quantity of material down the axis of Rupert Inlet, coming to rest in the Hankin Point region. The depth of tailings in Rupert Inlet has been estimated by comparing pre-operational bathymetry data with new information collected by the Canadian Hydrographic Service in 1982. With the exception of the waste rock area, the greatest accumulations were observed in the Hankin Point area, with maximum depths of 30-35 m. The mean tailings accumulation rate in the trough of Rupert Inlet is estimated to be 0.15 m per month, which would result in a final depth of tailings of 46 m, assuming present production rates (ibid, 1984). Between 1971 and 1985, 185 million tonnes of tailings have been discharged by the mine (D. Goyette, pers. comm.).

Intertidal sediments are not collected by the mine for metal analysis. Goyette and Nelson (1977) found high (689 $ug.g^{-1}$) copper levels in Hankin Point intertidal sediments relative to Thorp Point in Holberg Inlet (62 $ug \cdot g^{-1}$) during a 1975 study, confirming the resuspension and redeposition of tailings along the foreshore.

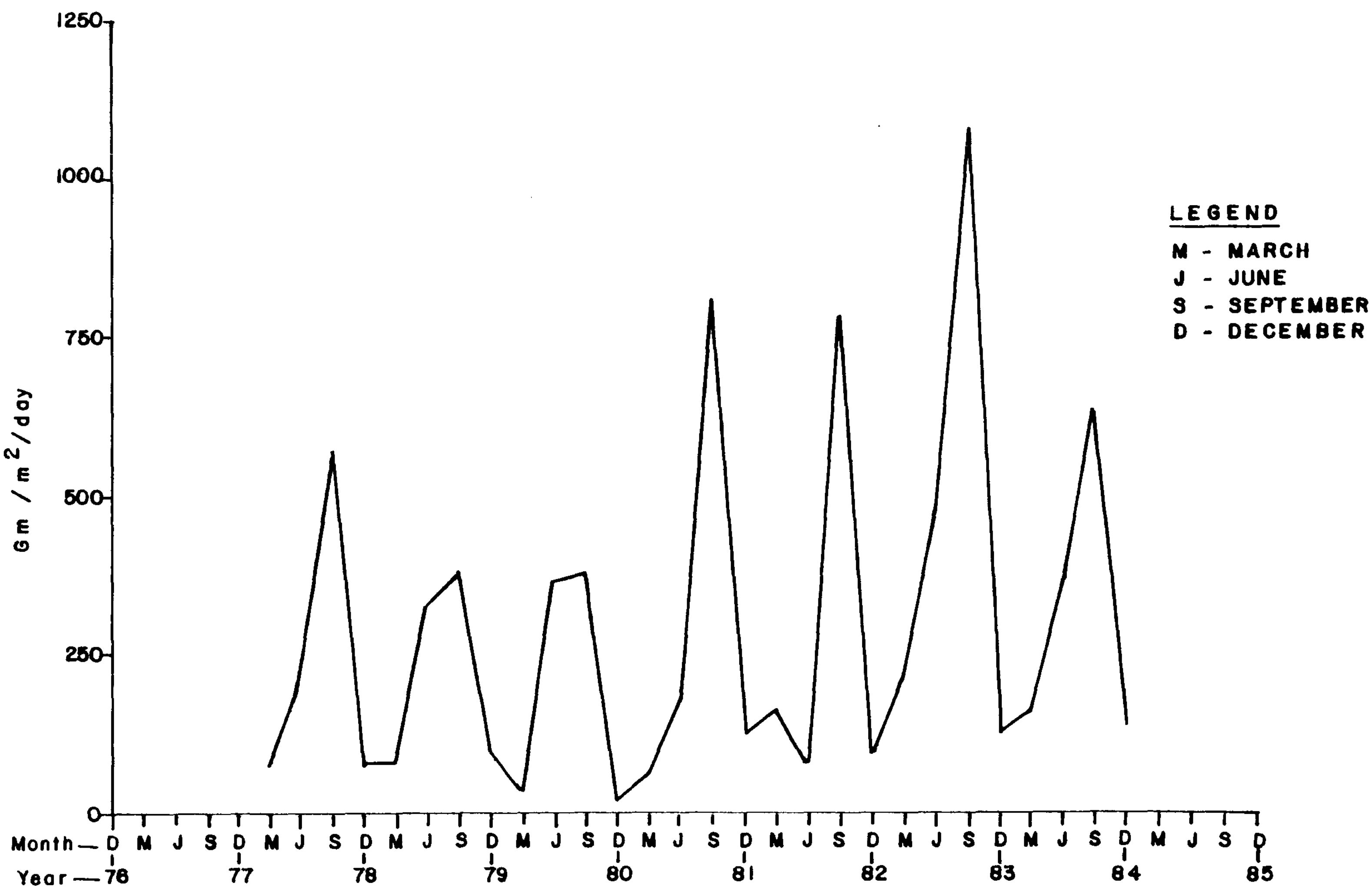


FIGURE 3.7 IN SITU SEDIMENTATION AT HANKIN POINT - 1977 - 1983 (Utah Mines, 1984)

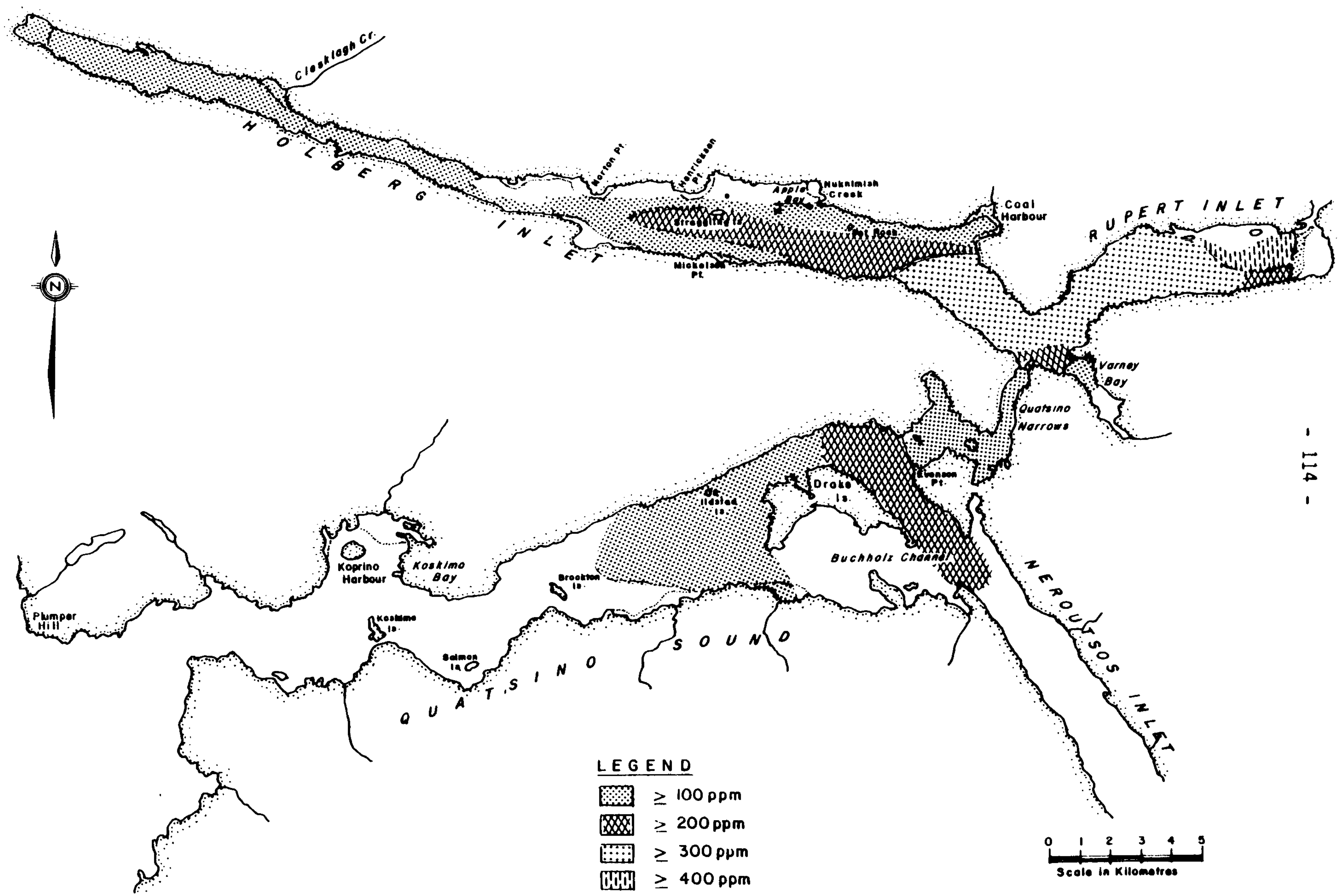


FIGURE 3.8 DISTRIBUTION OF COPPER IN BENTHIC SURFACE SEDIMENTS, 1984
(Adapted from Island Copper Mine, 1984)

3.2.2 **Wesfrob Mine.** The Wesfrob mine discharged tailings into Tasu Sound, located on the west coast of Moresby Island, the southernmost of the two main Islands of the Queen Charlotte group. Prior to 1977, the mine discharged tailings across the foreshore from two mill circuits (pellet and sinter). In January 1977 the sinter circuit was terminated and the pellet circuit tailings were diverted to a new submarine outfall.

Between 1970 and 1974 the mine undertook a voluntary environmental assessment program. During this period, the embayment between Horne Island and Gowing Island, which received the surface-discharged tailings, showed various effects, including smothered intertidal populations, impoverishment of settling larval populations and detectable changes in some water quality parameters. Tailings were shown to be present around the edge of the discharge embayment, with some dispersion outside the embayment as indicated by sediment cores (Ellis, 1975).

During June 1977, EPS assessed the environmental effects of the new discharge (Brothers, 1978). Transmittance profiles detected turbidity approximately 500 m from the outfall at 25-35 m depth, and visually at the surface over a somewhat greater (1.5 km) radius. Based on observations from local residents, the area affected by visual turbidity reportedly increased since the installation of the outfall. It was postulated this effect was due to the entrainment of air in the tailings effluent and resultant buoyant effect on the plume. Figure 3.9 depicts the visual evidence of the discharge.

Harding (1983) has summarized the results of a 1982 EPS study which concluded the turbidity pattern remained similar, with very clear water at all stations except for high surface turbidity very near (0.5 km) the mill. Tailings distribution in the sediments was not clearly delineated by Brothers (1978) although elevated copper levels (approx. 3.5 times background) were detected 2.3 km from the foreshore discharge. Sedimentary zinc and iron concentrations followed a similar distribution pattern as for copper, but on a reduced scale. In 1982 (Harding, 1983) the tailings distribution was clarified to extend to the far end of a deep basin up the main inlet, but not up the two side inlets with shallower sills. The seaward extent of the tailings was not determined. Figure 3.10 shows the tailings distribution prior to closure of the mine in 1983.

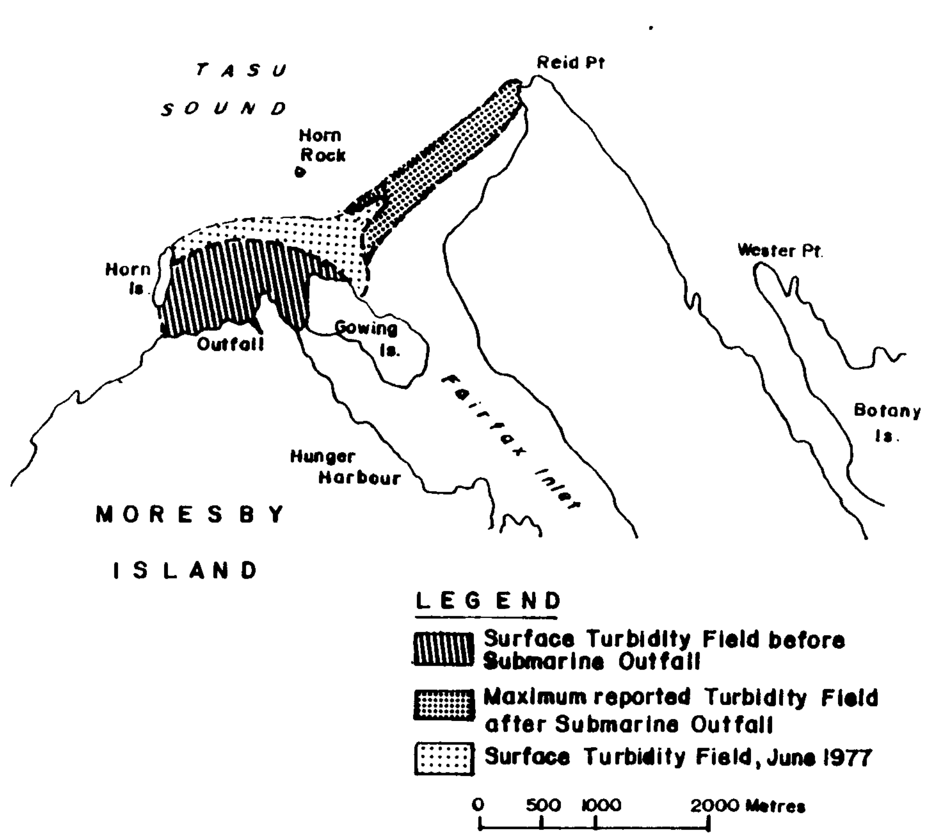


FIGURE 3.9 SURFACE TURBIDITY IN TASU SOUND (Brothers, 1978)

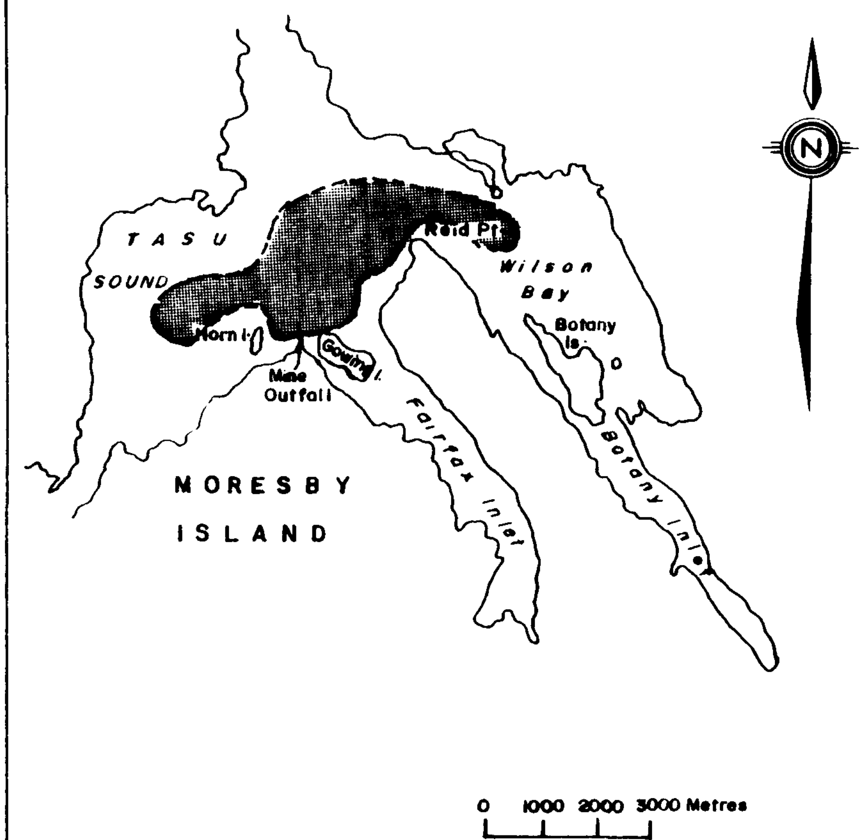


FIGURE 3.10 TASU SOUND - DISTRIBUTION OF TAILINGS IN SEDIMENT (Harding, 1983)

3.2.3 **Kitsault Mine.** Alice Arm has been the subject of a number of studies both prior to and during the operation of the Kitsault Mine. A complete list of environmental studies associated with this mine is provided elsewhere (Kay et al., 1986).

Considerable collection of pre-discharge background data has been carried out for the Climax Molybdenum Corporation (Littlepage, 1978) and by EPS (Sullivan and Brothers, 1979; Goyette and Christie, 1982a) to assess existing conditions due to the heavy mineralization of the area and the impact from two abandoned mines in Alice and Hastings Arms. Between 1914 and 1936 a copper mine and smelter operated at Anyox, near the junction of Alice Arm and Hastings Arm. Slag from the smelter was deposited on the shoreline of Granby Bay while tailings appear to have been impounded inland in a small tailing pond located behind the smelter adjacent to Hidden Creek (Goyette and Christie, 1982a). In 1967 the community at Kitsault was built to serve the new British Columbia Molybdenum Limited Mine near the mouth of Lime Creek, Alice Arm (see Figure 3.11). Tailings from this mill, which were discharged directly into Lime Creek, have been estimated at about 12 million tons during the life of the mine (Goyette and Christie, 1982a). After the mine ceased production in 1972, the property was acquired by Climax Molybdenum Corporation of British Columbia Limited, (Littlepage, 1978) now Amax of Canada Ltd. The Kitsault mine began operation in April 1981 and continued until October, 1982 when it closed due to declining markets. Between 1972 and 1981, no ore was mined in Alice Arm. The studies described in the following discussion were undertaken during this period.

Natural surface turbidity (generally the upper 10 m) in the Alice Arm and Hastings Arm regions is due to glacial flow washdown by the Kitsault, Dak, Illiance, Kshwan and Nass Rivers from the glacial fields above the inlets. During periods of heavy runoff, river water is heavily laden with ultra-fine particles which remain suspended in the brackish water surface layer. This gives the surface water a milky appearance and greatly reduces light transmission. Transmissometry profiles showed greatly reduced (< 11%) transmittance in the upper 2-5 m of the water column. Water below 10 m often exceeded 50% transmittance while water deeper than 50 m occasionally exceeded 90% of instrument light transmission. Turbidity was present in Observatory

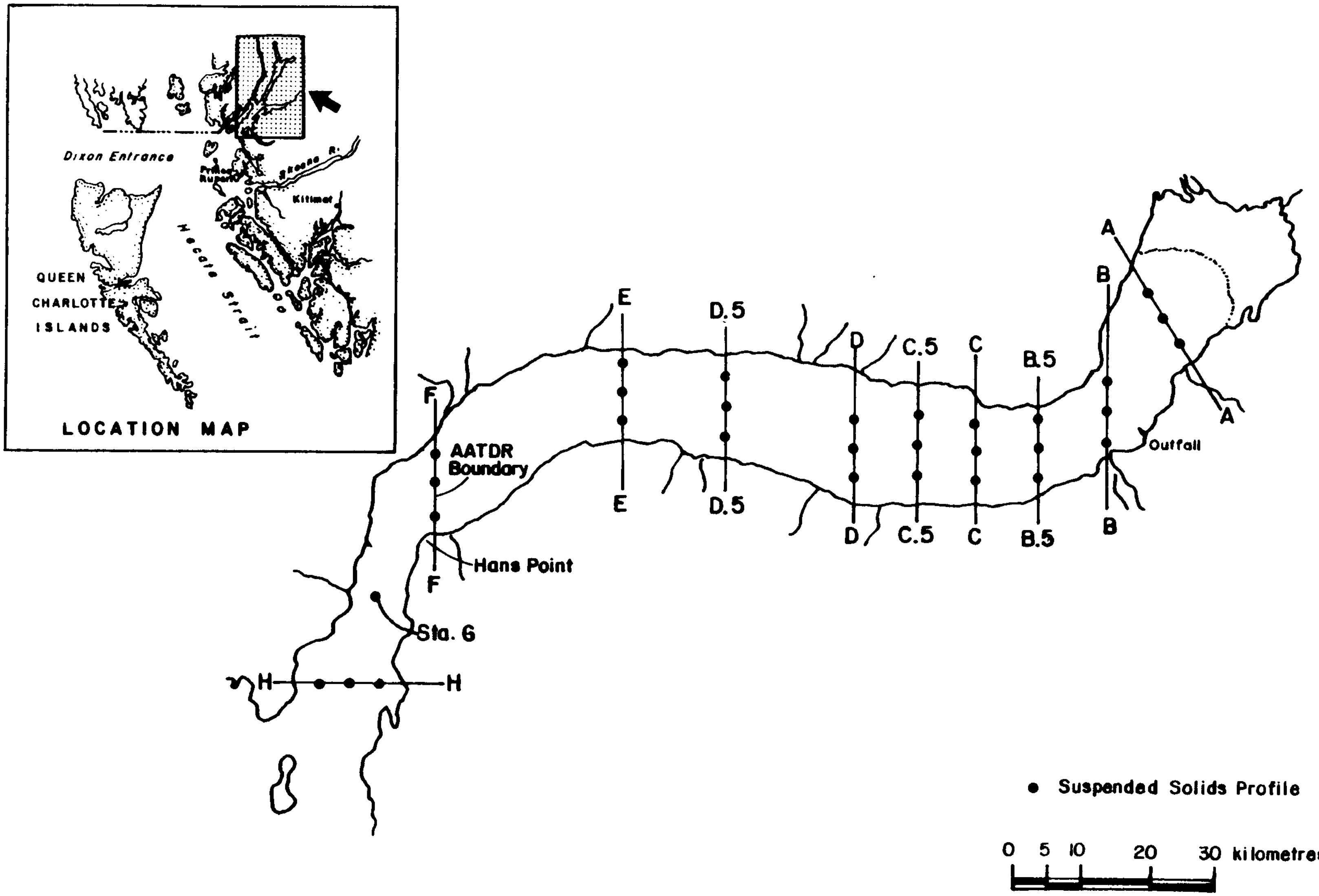


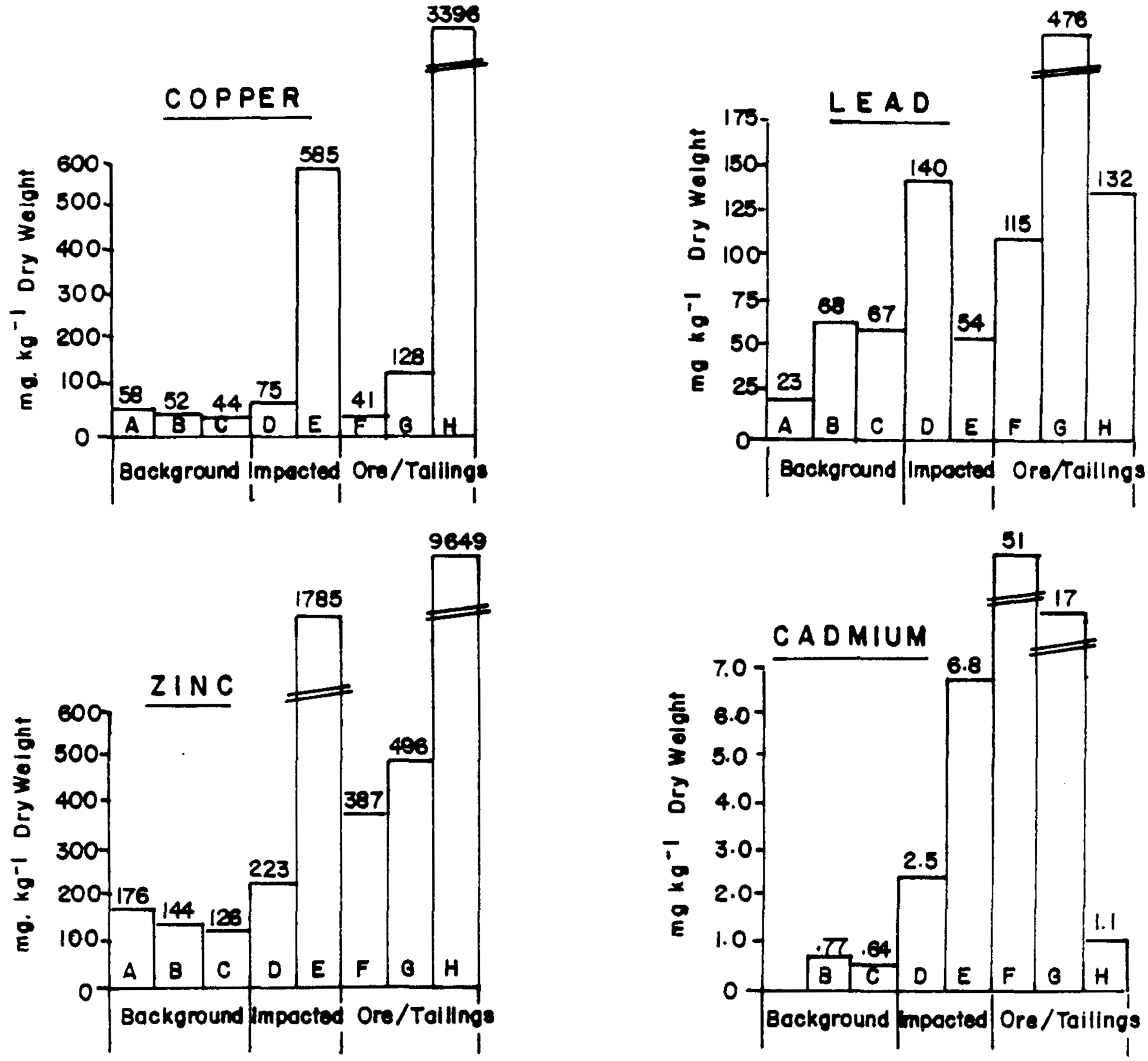
FIGURE 3.11 LOCATION MAP AND SUSPENDED SOLIDS SAMPLING STATIONS, ALICE ARM
(Amax of Canada Ltd., 1982)

Inlet where a surface light transmission of 20% was recorded off Brooke Island (Littlepage, 1978). Similar results were obtained by Sullivan and Brothers (1979) who noted generally very clear water below 5 m at sites in Alice Arm and Hastings Arm.

Sediment metal levels were determined by EPS (Goyette and Christie, 1982a) during studies in 1978 and 1980 of both surface (Smith- McIntyre grab) and depth (box corer) sediment samples. These techniques permitted an evaluation of the metal levels resulting from the previous mining operations (core samples) and existing natural levels (surface samples). They concluded that the newer, naturally-deposited Alice Arm sediments, although lower in metal concentrations than the deeper older sediments, had not completely covered the sediments originating from the B.C. Molybdenum operation. On the other hand, levels in the surface sediment near Anyox remained relatively high 42 years after abandonment, due to the continual supply of slag from shore deposits. Metals may also be contributed from acid mine drainage, as it continues to be released from the Anyox mine site (K. Ferguson, pers. comm.). Copper, lead, zinc, cadmium, silver and molybdenum showed the greatest increase in Alice Arm sediments while copper, zinc and iron concentrations near Anyox were several orders of magnitude above those in Alice Arm. Based on 1980 surface sediment metal concentrations, tailings from the B.C. Molybdenum operation were estimated to extend approximately 10 km seaward along the central trough of Alice Arm. Figure 3.12 shows the mean sediment levels of various metals from impacted and unimpacted areas as compared to levels measured in the ore/tailings.

Studies conducted for Climax Molybdenum at 40 sampling sites showed zinc entering Alice Arm in high concentrations from Lime Creek and Anyox. Alice Arm sediments reached background levels 13 to 16 km from the Kitsault River delta and then began to rise as the other point source, Anyox, was approached. Molybdenum was found to have only one source, originating from the Lime Creek tailings disposal, and background levels were reached 13-15 km from the delta. Intertidal distribution of zinc and molybdenum from more than 50 intertidal sites indicated the tailings from the B.C. Molybdenum operation had extended seaward in surface waters to a maximum of about 11 km (Littlepage, 1978).

In April 1981 the Amax Kitsault mine began discharging approximately 15,000 $m^3.day^{-1}$ of tailings through a nearshore submerged



LEGEND

A - Alice Arm Basin (1978)
B - Kitsault River Estuary (1980)
C - Unimpacted Area - Alice Arm (1980)
D - Impacted Area - Alice Arm (1980)
E - Impacted Area - Anyox (1980)
F - Kitsault Ore (1978)
G - B.C. Moly Tailings (1976)
H - Anyox Slag (1976)

FIGURE 3.12 COMPARISON OF NATURAL SEDIMENTS TRACE METAL CONTENT WITH THE KITSAULT AND ANYOX TAILINGS AND MARINE SEDIMENT (Adapted from Goyette and Christie, 1982) outfall at a depth of 50 metres. The tailings were mixed with seawater prior to discharge to facilitate rapid settling and prevent the plume from surfacing. The tailings effluent from the Kitsault mine comes under special Federal regulations (Alice Arm Tailings Disposal Regulations - AATDR) which were promulgated in April, 1979. These regulations require that:

- the solid portion of the tailings do not extend down Alice Arm beyond Hans Point and are not deposited on the estuaries of the Illiance or Kitsault Rivers or at a depth of less than 100 m except at the discharge point, where they must remain below 50 m deep.
- solid tailings particles do not remain in suspension in the waters of Alice Arm above a depth of 100 m, except at the discharge point, where they must remain below 50 m.
- dissolved metal concentrations for arsenic, copper, lead, nickel, zinc radium^{226} and cadmium do not exceed prescribed levels.
- the 96-hr LC_{50} = 100%.

To ensure that the requirements of the regulations were being met, both the federal government and the company conducted extensive monitoring programs.

The behaviour of the tailings plume in Alice Arm was monitored by the mill through monthly profiling of stations shown in Figure 3.11 and as described in their annual monitoring reports (Amax of Canada, 1981; Amax of Canada, 1982). The instrument used in the program, a nepholometer, was calibrated to measure suspended solids as $mg.L^{-1}$. In addition, EPS conducted extensive transmissometer profiling (Goyette et al., 1985) following the opening of the mine. Both the company and government data has been reviewed by an independent panel of experts reporting to the Minister of Fisheries and Oceans. Their technical assessment has been prepared in two volumes (Burling et al., 1981; Burling et al., 1983) and will be considered herein as representing the knowledge and understanding of the tailing behaviour and effects during the mine operation.

Soon after the commencement of the tailings discharge, a cloud of suspended material began to appear between depths of 65 and 125 m near line BB (Figure 3.11). Suspended sediment concentrations were approximately 15 $mg.L^{-1}$ in the cloud, decreasing to about 2 $mg.L^{-1}$ or less within 2.5 to 5 km down inlet and descending to below 100 m depth in about the same distance. Burling et al. (ibid) estimated that about 2 to 8% of each day's tailings entered this mid-depth cloud while the remaining 92 to 98% fell towards the bottom near the outlet or travelled down the inlet close to the bottom. The panel concluded the tailings could be detected in three more or less discrete components:

- the uppermost layer as a low density (< 5 $mg.L^{-1}$) mid-depth cloud in the vicinity of the outfall with a ceiling which slopes from 65 m depth to more than 100 m within a distance of 2.5 km down inlet.
- as a dense (sometimes > 100 $mg.L^{-1}$) plume ("nepheloid layer") near the bottom but sometimes separated down inlet from the bottom by a narrow zone of higher transmittance.
- as a turbidity current which carries most of the tailings solids down the central trench toward the deepest part of the inlet, 9 to 10 km west of the outfall.

The extent of the tailings deposits was examined by EPS during the seven months following start-up (Goyette and Christie, 1982b) through the measurement of trace metal levels in core samples. Samples were collected at seven sites in Alice Arm, two sites in Hastings Arm and two sites near Anyox. Core samples taken from upper Alice Arm near the Kitsault mine showed two main peaks in copper, lead, zinc, cadmium and molybdenum concentrations. The upper peak, occuring between 0 and 30 cm, represented fresh deposits from the Kitsault mine while the lower peak, occurring between 30 and 40 cm, represented historical levels from the previous B.C. Molybdenum mine operation. Cadmium showed the most significant change, with maximum values approximately 5.5 km from the mine site, and tapering to background outside the sill near Hans Point. A similar pattern was observed for molybdenum, with above background levels being noted at a station approximately 9 km from the mine site.

Sediment trace metal data collected by the company, and summarized in their 1983 Annual Report (Amax of Canada, 1984) showed that the tailings deposits were largely confined to the deep central trough, extending down the centre of the inlet as far as transect EE. The current extent of tailings deposition in Alice Arm is shown in Figure 3.13 (Burling et al., 1983). The Panel concluded that with the exception of some excursions of the tailings plume above the depth set out in the AATDR, the plume behaviour and tailings deposition substantially met the requirements of the AATDR. Notwithstanding this observation, the extent of physical impact of the tailings is large, approximately 10 km down-inlet, and for some distance eastward towards the estuary. This latter impact reflects the presence of both old and recent tailings.

3.2.4 Abandoned Mines. Environmental monitoring studies at most now-abandoned mine sites were not extensive for a number of reasons including the age of the mine, lack of environmental legislation at the beginning of mining operations and a general lack of environmental awareness. One exception was the Jordan River Mine operation located at Jordan River on Vancouver Island, which operated between 1960 and 1974. In 1971, an effluent permit was issued to the mine requiring the installation of an emergency spill basin and submerged outfall. The permit also included a requirement for a monitoring and surveillance program both pre- and post-outfall installation.

During the first year (February 1972 to July 1973) of monitoring, transmissometer profiles showed the turbidity field to be highly variable. Maximum offshore distance of the turbidity occurred at the outfall site, where the 20% transmittance limit was between 800 and 900 metres from the high tide mark. The effluent field extended along the shoreline 2700 metres east and west of the outfall and turbidity vertical profiles showed uniform turbidity from surface to bottom at points near the oufall. Sediment trace metal levels during the first year showed variable and inconclusive results for copper, zinc and chromium (Ellis and Littlepage, 1973).

Subsequent transmissometer studies showed similar variable tailings dispersal patterns. Trace metals in intertidal sediments showed elevated

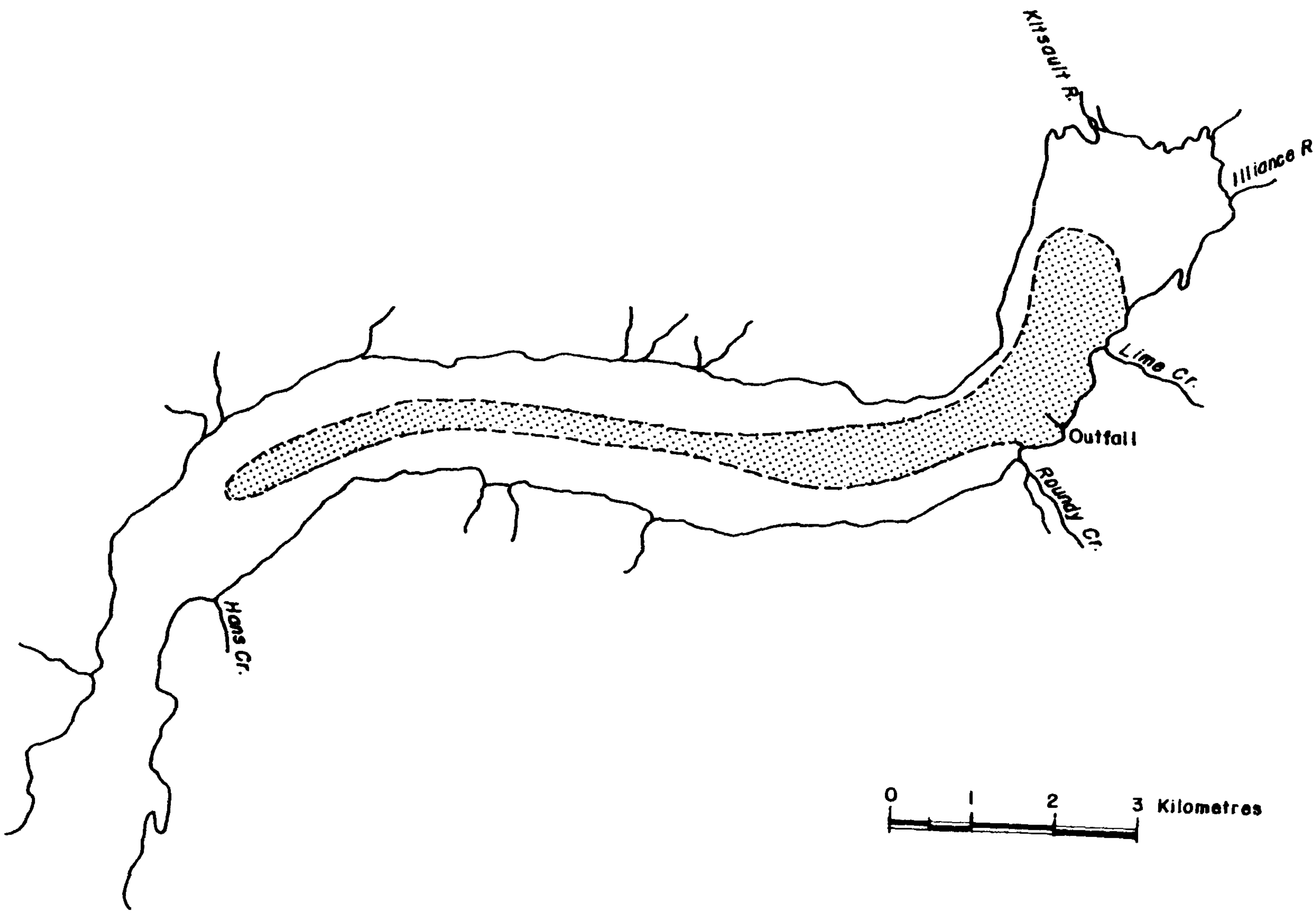


FIGURE 3.13 EXTENT OF TAILINGS DEPOSITION IN ALICE ARM (Adapted from Burling et al, 1983)

copper and zinc levels during the monitoring program in late 1973 with copper levels being approximately 30 times higher than control sites (Sooke Harbour). Intertidal tailings were visible at the outfall site. At a subtidal sediment station located at the outfall terminus, copper, zinc and chromium levels were similar or lower than Sooke Harbour control sites (Dobrocky Seatech, 1974). The monitoring program was discontinued when the mine closed in 1974, however it is apparent from the limited data available that the major physical impact was in the intertidal area, caused by surfacing tailings effluent and subsequent re-deposition.

The distribution of tailings from the Texada Mine, located on Texada Island in Georgia Strait, was examined in 1975 by means of sediment analysis for copper and zinc (Thompson et al., 1979). The study followed the closure of the mine and cessation of the shoreline tailings disposal. Copper concentrations of up to 1600 $ug.g^{-1}$ (dry weight) of sediment were found in nearshore stations within 1.8 km of the outfall and rapidly decreased with background levels being observed at 9-18 km distance. Zinc showed no trends with distance and its presence was not considered a function of the tailings discharge.

The extent of physical perturbation resulting from the Britannia Copper Mine shoreline tailings discharge to Howe Sound were studied qualitatively in 1973 by means of underwater visual observation (Levings and McDaniels, 1973), and in 1976 by EPS using the Pisces IV submersible (Petrie and Holman, 1983). The 1973 study detected turbidity 1.8 km from the disposal sites and visibility in surface waters was less than 1 metre. Visibility increased rapidly below 10 metres but then dropped quickly again at 250 metres, becoming less than 30 cm at the bottom (270 m). It was postulated that the turbidity cloud resulted from tailing deposition on the steep fjord walls of Howe Sound. Sediment copper levels were found to decrease with increasing distance from the mine site during studies of sediment metal levels by Thompson and McComas (1974) and Goyette (1975). Two areas of high copper to zinc ratios were noted. The first was directly off the mine site, extending approximately 1.5 km west of Britannia Creek, likely the result of the intertidal discharge, and copper levels in the creek, resulting from acid leaching. A second tongue was found running north-south in the central basin, and was thought to be the result of redistribution by currents. Copper levels were still high as much as 2 km or more from the mine site.

3.3 Biological Impacts of Mine Wastes

The biological impacts of mine tailings disposal, other than the obvious obliterative effects resulting from deposition, are less easy to define. Concerns include bioaccumulation and biomagnification of heavy metals in the food webs, acute and sublethal toxicity of tailings, changes in spawning patterns and populations of commercially viable fisheries due to habitat loss and decreased primary productivity resulting from decreased light penetration. Although bioaccumulation in animal tissues exposed to mine tailings has occurred, biomagnification (progressive increase through successive trophic levels) has not yet been documented. A variety of studies have been conducted at coastal mine sites by government and industry investigations to assess the biological effects of mine tailings disposal.

3.3.1 Primary Productivity. Between 1974 and 1976, the Environmental Protection Service conducted a series of surveys in Rupert and Holberg Inlets to evaluate the effects on phytoplankton productivity of the Island Copper Mine tailings and waste rock disposal (Sullivan, 1979). Determinations of primary productivity, chlorophyll a, phytoplankton standing crop and seston were made as were chemical and physical measurements for dissolved oxygen, salinity, temperature, inorganic carbon, pH, nutrients, temperature and light. The three year study concluded that the surface turbidity had a limited impact on phytoplankton productivity. The turbidity field originating from the waste rock disposal area was determined to be considerably more significant than the tailings disposal turbidity field near the mouth of Rupert Inlet in terms of effects on phytoplankton productivity because of its more persistent nature.

Island Copper Mine (Utah Mines Ltd., 1984) has measured chlorophyll a as an estimate of phytoplankton standing crop in Rupert and Holberg Inlets and Quatsino Sound since 1971. Levels in each inlet have varied over time but no consistent temporal changes have been reported. Quatsino Sound has consistently had the lowest chlorophyll a concentrations.

The highest annual mean concentrations have been equally distributed between Rupert and Holberg Inlets. Waldichuk and Buchanan (1980) have suggested the concentration of tailings particles present in most parts of the Quatsino Sound-Rupert-Holberg system are more likely to scatter light than attenuate it effectively in the euphotic zone.

Phytoplankton productivity was measured at two sites in Tasu Sound during a 1977 EPS assessment (Brothers, 1978) of the Wesfrob Mine. Although the chemical and physical parameters affecting productivity were similar at both test and control sites, phytoplankton productivity at the test site at Horn Island was approximately 1/10 that of the control site, approximately 3.5 km from the discharge point.

Littlepage (1978) reported primary production in Alice Arm occured within the upper 10 to 20 metres during studies in 1974 and 1975. Chlorophyll concentrations were detected up to 30 metres deep. The measurement of primary productivity was not incorporated into the environmental monitoring program for the Amax (Kitsault) mine since the tailings disposal outfall system was designed to keep the turbidity cloud at depth, beneath the euphotic zone.

3.3.2 Toxicity. During the development of federal regulations and guidelines for metal mining liquid effluents, 28 mines in British Columbia were surveyed to assess their effluent chemistry and acute toxicity (Hoos and Holman, 1973). The 96 hour LT_{50} (time to death of 50 percent of the organisms) results for the coastal mines are given in Table 3.7. None of the raw tailings samples created acute toxicity patterns when tested at neutral pH despite the high concentration of total heavy metals. The survey determined that, at the four inland mines having toxic effluents, the toxicity was attributable in whole or in part to the effects of dissolved copper, zinc and/or lead.

Monthly bioassays of Island Copper Mine tailings effluent show it to be substantially within federal and provincial requirements, with the majority of samples being non-toxic (i.e. 96 hour $LC_{50} > 100\%$). Similar results have been observed with the Amax (Kitsault) effluent. It is evident therefore that neutralized mine tailings discharges of these mines are not normally acutely toxic to standard test species. This is undoubtedly due to the geochemical properties of these mines which retain potentially toxic trace metals in mineral lattices, not readily dissociable, particularly in highly buffered seawater (McGreer et al., 1980). This is in contrast to mines located elsewhere in the world where high levels of dissolved metals that may be toxic can be found in marine systems (McGreer, ibid).

TABLE 3.7 **96 HOUR LT_{50} BIOASSAY RESULTS FOR MINE TAILINGS (Hoos and Holman, 1973)**

MINE	SAMPLING POINT	INITIAL SAMPLING pH	% SURVIVAL (96 hr)	LT_{50}
Britannia	discharge from mill	8.2	100	> 96 hr
	discharge from scavenger flotation	7.8*	100	> 96 hr
	discharge from precipitation plant[1]	4.2	0	7.0-9.4 hr
Jordan River	raw tailings	7.0*	100	> 96 hr
Texada Mine	raw tailings	7.8	100	96 hr
Wesfrob Mine	raw tailings	7.9*	100	96 hr
Utah Mine	raw tailings	10.2	0	24 hr
		7.5	60	96 hr

* sample neutralized prior to bioassay
[1] treated acid mine drainage

3.3.3 **Trace Metals.** The bioaccumulation and subsequent biomagnification of contaminants in the food chain are early warnings of potential ecological damage and human health concerns. Although there is evidence of bioaccumulation of certain trace metals from mine tailings in certain species, there is no evidence of biomagnification in local food webs. On a world-wide scale evidence of general biomagnification in the environment has been shown with mercury in a relatively short food chain (Bryan, 1980).

The availability of metals to biota depends upon numerous physical and biological factors. Generally, metals in the solid phase are thought to be stable and not biologically available; that is, they are not in the dissolved form. According to Poling (1982) the maintenance of slightly basic pH conditions in seawater generally enhances the long-term stability of heavy metal solids in the sediments. However, under suitable conditions, which are not always completely understood, metals are returned to the overlying water following remobilization and upward diffusion. As a result, contaminated sediments may persist as sources of metals, particularly to bottom feeders and pelagic fish. Many monitoring programs and experimental studies have therefore been designed to measure metal content in sediments and resident biota. Other programs also include the measurement of dissolved metals in the water column.

One method of determining the biological availability of tailings - derived dissolved metals to examine the leaching of such metals in seawater. Goyette and Christie (1982b) have reported virtually no leaching of metals with seawater from short term tests conducted on Kitsault tailings. Waldichuk and Buchanan (1980) have reported that leaching experiments on Island Copper Mine tailings have not shown increases in iron, copper or molybdenum in supernatant seawater. However, manganese levels did show a 15-fold increase. Chemical and/or bacterial leaching of Anyox slag is postulated due to toxicity to test fish (100% mortality in 24-48 hours) in a static freshwater bioassay (D. Goyette, pers. comm.).

There is little published information on metal concentrations in the interstitial water of tailings deposits or the water immediately overlying sediments. Island Copper Mine has measured copper, molybdenum and manganese at seven water sampling stations (1, 5, 30 m and bottom) monthly since 1971. Mercury is also analysed yearly. The company also collects seawater from four zooplankton sampling stations from 15 m, 30 m and a designated bottom depth for dissolved and particulate copper, manganese, zinc and arsenic analysis. The results from the company's 1983 monitoring program summary (Utah Mines Ltd., 1984) show dissolved metal levels generally well below those recognized to be potentially hazardous to marine life (Table 3.8). Rupert and Holberg Inlets have higher annual mean dissolved copper and manganese concentrations than Quatsino Sound, while dissolved molybdenum concentrations have generally been highest in Quatsino Sound. The company concludes that long-term consistent changes are not developing.

TABLE 3.8 DISSOLVED METAL LEVELS IN HOLBERG INLET, RUPERT INLET AND QUATSINO SOUND, 1971-1983 (Utah Mines Ltd., 1984)

METAL ($ug.L^{-1}$)	HOLBERG INLET	QUATSINO SOUND	RUPERT INLET	MINIMAL RISK*
Copper	0.5 - 5.6	0.3 - 3.9	0.6 - 8.4	< 10
Manganese	0.5 - 24.6	0.1 - 18.4	0.1 - 26.0	< 20
Molybdenum	4.5 - 13.1	4.2 - 12.0	1.9 - 13.0	--
Zinc	0.4 - 12.0	0.1 - 10.8	0.3 - 13.5	< 20
Arsenic (total)	0.3 - 8.1	0.3 - 5.3	0.2 - 6.9	< 10

*Level considered to present minimal risk to marine life (Clark, 1980)

Analysis of trace metal levels in seawater has not been a routine monitoring parameter at other coastal mines. The Wesfrob mine measured dissolved and total copper and iron at three sites in Tasu Sound. The highest dissolved copper values were noted at the discharge point, with a mean value of 0.15 $mg.L^{-1}$ (British Columbia Waste Management Branch, 1984). Dissolved iron levels had a mean of 4.98 $mg.L^{-1}$ (British Columbia Waste Management Branch, 1984). Mean levels of dissolved copper and iron at the control site were 0.15 $mg.L^{-1}$ and 1.78 $mg.L^{-1}$ respectively. Both the discharge point and control site metal levels exceeded those considered to constitute a hazard to marine life ($Cu \geq 0.05$ $mg.L^{-1}$; $Fe \geq 0.3$ $mg.L^{-1}$; Clarke, 1980). However, the accuracy of the data was not verified and is questionable, since the measured seawater mean concentrations exceed the mean values measured in the tailings effluent (Cu = 0.025; Fe = 0.11; British Columbia Waste Management Branch, 1984).

During the brief monitoring program conducted for the Jordan River Mine between 1972 and 1974, seawater samples were collected at a site over the outfall and a control station. Analysis for dissolved copper, zinc, chromium, cadmium and lead showed no detectable levels at either station during the three year program. Detection limits were as follows: Cu .05 $mg.L^{-1}$; Zn .02 $mg.L^{-1}$; Cr .1 $mg.L^{-1}$; Cd .02 $mg.L^{-1}$; Pb .2 $mg.L^{-1}$.

In a study of arsenic levels in marine sediments and interstitial waters around the Island Copper and Kitsault mine sites, Reimer et al. (1985) found that bound arsenic levels were within the range expected for natural sediments. However, there was no relationship between bound and dissolved arsenic levels at either location. Based on their observations, tailings from the Kitsault mine were particularly susceptible to leaching of arsenic, especially with increasing sediment depths, and the authors suggest that interstitial arsenic should be more biologically available than bound arsenic.

The measurement of trace metal concentrations in marine plants, vertebrates and invertebrates is the main tool used by mining companies and government agencies in assessing the biological impact of mine tailings. Due to the extensive nature of many of these programs, it is impossible to discuss them in detail here. The general trends are reviewed, however, and mean trace metal concentrations for representative metals and species are summarized in Figure 3.14 for the various mines (Goyette and Christie (1982b); Utah Mines (1984); Brothers (1978)).

The Island Copper Mine samples a variety of intertidal, pelagic and benthic species for copper, molybdenum, lead, cadmium, zinc, arsenic and mercury (Utah Mines Ltd., 1984). The program has been altered over the years with the addition of some new species. The present program is summarized in Table 3.9. The 1983 Annual Environmental Assessment report for Island Copper Mine (Utah Mines Ltd., 1984) has summarized the results of the tissue metal monitoring programs since they began. Significant increases in copper, lead, zinc and to a lesser extent, cadmium have been observed in Fucus tissue, with copper, lead and zinc concentrations being notably higher at stations having visible influence of tailings. Mercury levels have shown a marked decrease over time while there is not a consistent trend to the arsenic data. Metal levels may not represent the true tissue concentrations since mineral particles have been observed to adhere to the exterior mucus sheath of the specimens. Eelgrass tissue concentrations have not shown any long-term trends of change. Light tailings impact and reference stations had the statistically lowest levels of copper, lead and zinc. The only metals showing a consistent inter-group pattern since 1978 were cadmium and zinc. Both were highest at moderately influenced stations, followed by heavy, light and reference groups respectively. Zooplankton has not exhibited any persisting trends in tissue metal levels at any station although a weak increasing trend in copper, mercury and zinc concentrations in euphausids is suggested. Shrimp tissue has been analyzed since 1980 and no consistent

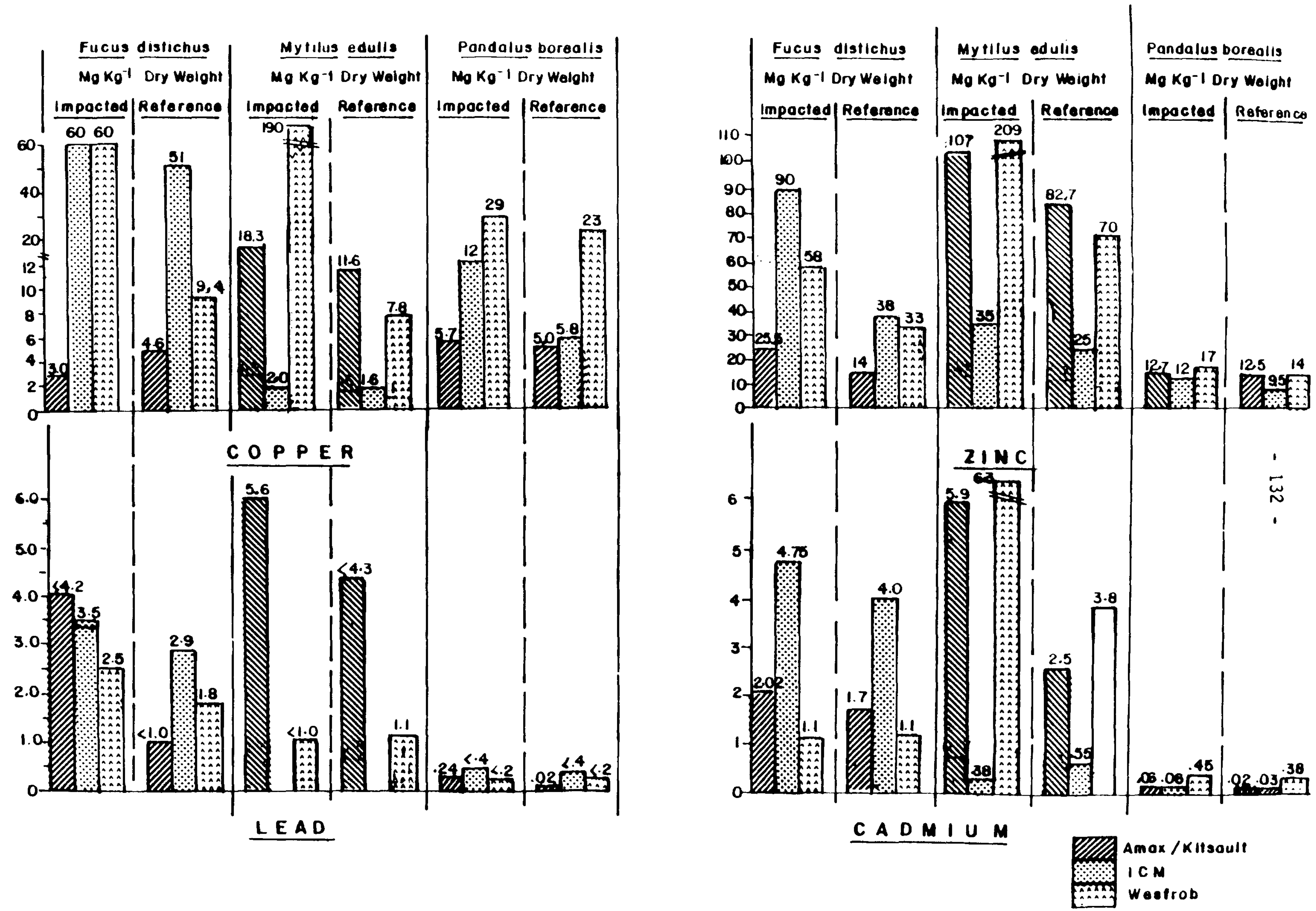


FIGURE 3.14 MEAN TRACE METAL CONCENTRATIONS IN A SEAWEED, MUSSEL AND SHRIMP AT COASTAL MINE SITES ($\mu g.g^{-1}$)

inter-inlet tissue level patterns exist for any for the metals analyzed. Cadmium and molybdenum have shown a steady decline in Rupert Inlet samples since the program began while zinc levels have been significantly higher than Holberg Inlet and Quatsino Sound. Metal bioaccumulation rates in Dungeness crab have not shown any significant trends based on Duncan's multiple range test. Tissue arsenic levels consistently are the highest in Quatsino Sound. The bivalve tissue metal data demonstrates large year to year variability, with no consistent temporal patterns of change in the tissue levels of arsenic, cadmium, copper, mercury or molybdenum. Copper and lead tissue levels were the highest at the Utah concentrate loading dock. Tissue arsenic levels in the bivalve Humilaria kennerleyi were higher at Hankin Point, where upwelling of tailings has occurred, than in Quatsino Sound, however the small data set necessitates a more cautious assessment of these results.

Between 1971 and 1974, EPS collected intertidal bivalves in Rupert Inlet at Red Island and a station located west of the mine site and in Holberg Inlet at Apple Bay. Macoma iris collected from Red Island showed considerably higher concentrations (mean = 305 $ug.g^{-1}$ dry wt.) than those from Holberg Inlet (mean 70 $ug.g^{-1}$ dry wt.) and stations west of the mine site (mean = 66 $ug.g^{-1}$ dry wt.). Mussels (Mytilus edulis) collected from Hankin Point on a single occasion showed higher copper concentrations (82-150 $ug.g^{-1}$ dry wt.) than all other stations (5.87 $ug.g^{-1}$ dry wt.) (Goyette and Nelson, 1977).

During September 1981, EPS conducted four trawls in areas of light tailing deposition in Holberg Inlet, Rupert Inlet and Quatsino Sound; one in Holberg Inlet beyond the area of tailings deposition and one, a reference area, at the mouth of Quatsino Sound. A trawl in the area of heavy tailings deposition did not produce sufficient animals for a representative series of samples of any species. Two species of shrimp were collected in sufficient numbers and distribution to be representative. No significant differences were noted in any metals between areas affected by tailings and areas not affected, except for arsenic. Arsenic was significantly higher in both species of shrimp sampled in the reference area than in the area of tailing deposition. Flatfish were also collected in the trawls but not in sufficient numbers for statistical comparison. However, the levels observed in all

TABLE 3.9 TISSUE METAL MONITORING PROGRAM - ISLAND COPPER MINE

SPECIES	NUMBER OF SAMPLING STATIONS	FREQUENCY	METALS ANALYZED FOR
Rockweed (*Fucus distichus*)	16	quarterly	Cu, Mo, Pb, Cd, Zn, As, Hg
Eelgrass (*Zostera* sp.)	16	"	"
Zooplankton	4	"	"
Shrimp	3	"	"
Dungeness crab (*Cancer magister*)	6	"	"
Softshelled clam (*Mya arenaria*)	9	yearly	"
Littleneck clam (*Protothaca staminea*)			
Butter clam (*Saxidomus giganteus*)			
Macoma (*Macoma iris*)			
Mussels (*Mytilus edulis*)	3	quarterly	"
Deepwater clam (*Humilaria kennereyi*)	varied	occasional	"

(Utah Mines Ltd., 1984)

species, both in tailings and reference areas, were consistent with those from unpolluted areas of the northern coast of British Columbia (Harding, 1983).

The data collected by the company and by EPS reinforce the conclusions made by Waldichuk and Buchanan (1980) during their technical review of the Island Copper Mine. The authors concluded that there was little short-term bioaccumulation of metals by the biota from the tailings deposited in the inlet system under normal conditions. However, they cautioned that nothing can be said about the long-term changes in availability of metals in the sediments through the process of diagenesis[1], with the addition and decomposition of organic material, creation of anoxic conditions, possible solubilization of metals in the sediments and release into the overlying waters. Pedersen (1985) has shown that reactions in the tailings on the inlet floor are supporting fluxes of both dissolved copper and molybdenum to the overlying water. The copper flux was shown to be similar to that from natural sediments in upper Holberg Inlet while the molybdenum flux was shown to be unique to the tailings, although not to the extent of having a measureable effect on Mo concentration in the overlying seawater.

The tissue trace metal sampling program undertaken by the Kitsault mine in accordance with regulatory requirements consisted of monitoring the basket cockle (Clinocardium nuttalli), the yellowfin sole (Limanda aspera), the bay mussel (Mytilus edulis), the pink shrimp (Pandalus borealis) and a deposit-feeding clam (Yoldia sp.). Each species was examined for arsenic, cadmium, copper, lead, molybdenum and zinc concentrations in whole body tissue. Bivalves were depurated in clean seawater for 24 hours prior to analysis. Notable observations include the low (below detection limits) concentrations of cadmium, lead and molybdenum in yellowfin sole, higher cadmium and lead levels in mussels collected near the mine site, increases in arsenic, cadmium, copper and zinc levels in pink shrimp between 1982 and 1983 (suggested by the company to be due to natural variability and/or inter-laboratory bias), and increases in zinc, lead, copper and cadmium levels in Yoldia sp. at stations nearest the mine site (Amax of Canada Ltd., 1984).

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[1] "the sum total of processes that bring about changes in a sediment or sedimentary rock subsequent to deposition in water" (Berner, 1980).

EPS studies conducted during the first seven months of operation concluded that tissue trace metal concentations in most species sampled had not changed significantly from data collected prior to start-up. One exception was Yoldia thraciaeformis from Alice Arm, which exhibited a pronounced increase over previous levels for copper, lead, zinc and cadmium. Other tissues analyzed included algae (Fucus distichus), mussels (Mytilus edulis), pink shrimp (Pandalus borealis), Brown king crab (Lithodes aequispina), shrimp (Crangon communis) and mixed species of sole (Goyette and Christie, 1982). Between 1981 and 1982, significant increases (Figure 3.15) in lead and molybdenum were observed in Yoldia spp. following startup of the Kitsault mine (Goyette et al., 1985). Accumulation of lead in Yoldia spp. continued to increase through 1983, and appeared to be levelling off or decreasing in 1985 although further analysis is required (EPS unpublished data). As well, some metals (copper, lead and cadmium) have increased significantly in mussels and at least one crab species (EPS unpublished).

During 1981 and 1982, the Department of Fisheries and Oceans determined the metal content of Nass River eulachons (Thaleichthys pacificus) and small numbers of king crab (Paralithodes kamtschatica) and Tanner crab (Chionoecetes bairdi) from Alice Arm. The study was in response to native Indian concerns with respect to the potential for metal contamination of certain food fish and invertebrates as a result of the tailings disposal. Arsenic, cadmium, lead, molybdenum, nickel, and mercury concentrations in eulachon whole body tissue were generally below detection limits and did not exceed 5 $mg.kg^{-1}$ dry weight with the exception of one eulachon in which a concentration of 7.0 mg/kg^{-1} lead (dry weight) was measured. Chromium, copper and manganese exceeded detectable limits but were consistently less than 5 $mg.kg^{-1}$ (dry weight) while zinc ranged from 17.9 to 61.2 $mg.kg^{-1}$ (dry weight). Lead, molybdenum and nickel in the King and Tanner crabs leg muscle tissue were below detection limits and other metals were typically similar to values reported for B.C. locations and elsewhere in the world. The study concluded that the metal levels recorded and available information on the life history of the eulachon suggest metal uptake and accumulation as a result of the tailings discharge is unlikely (Futer and Nassichuk, 1983).

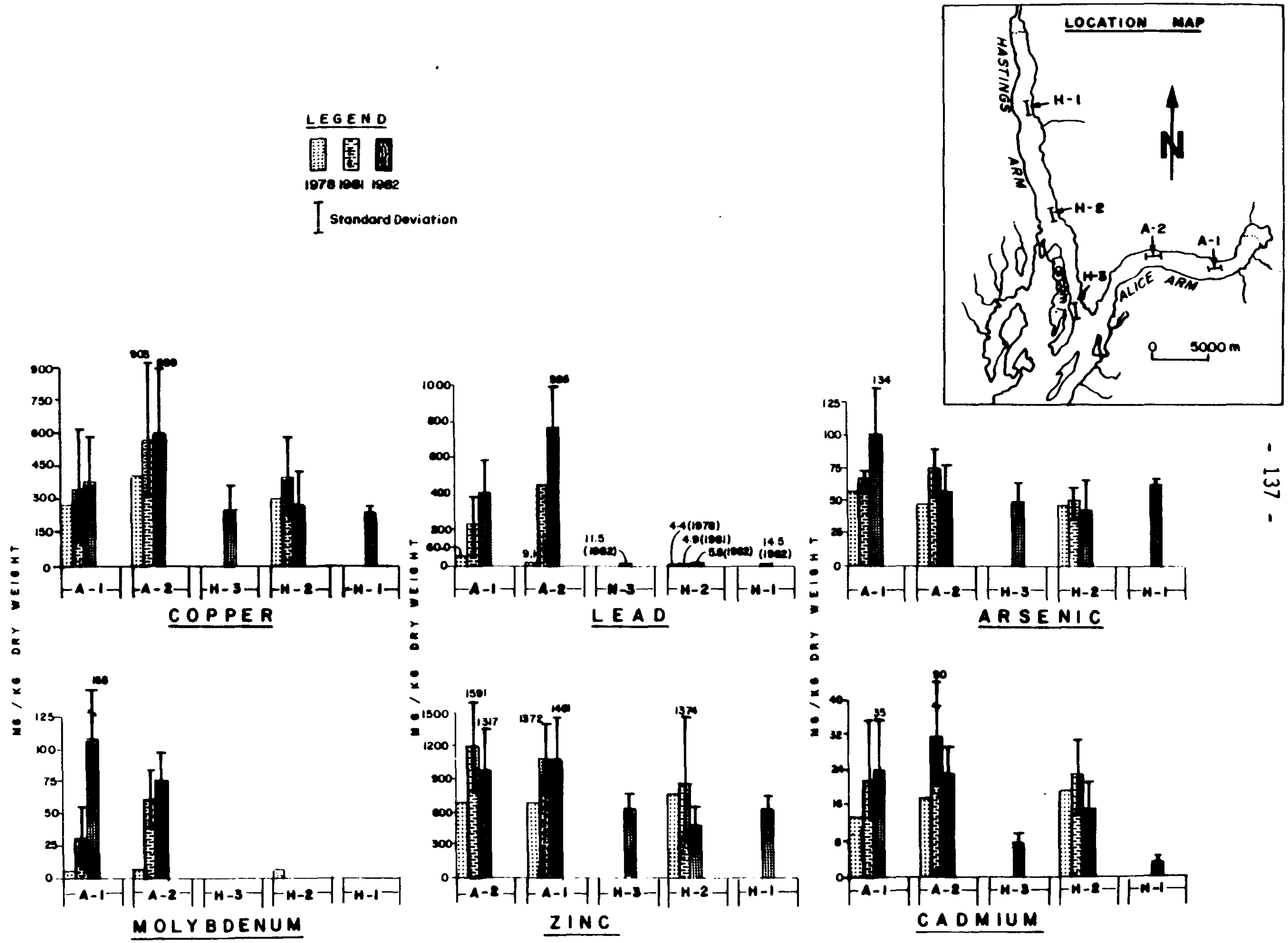

FIGURE 3.15 LEVELS OF TRACE METALS IN YOLDIA spp. FROM ALICE ARM 1978 - 1982 (Goyette et al, 1985)

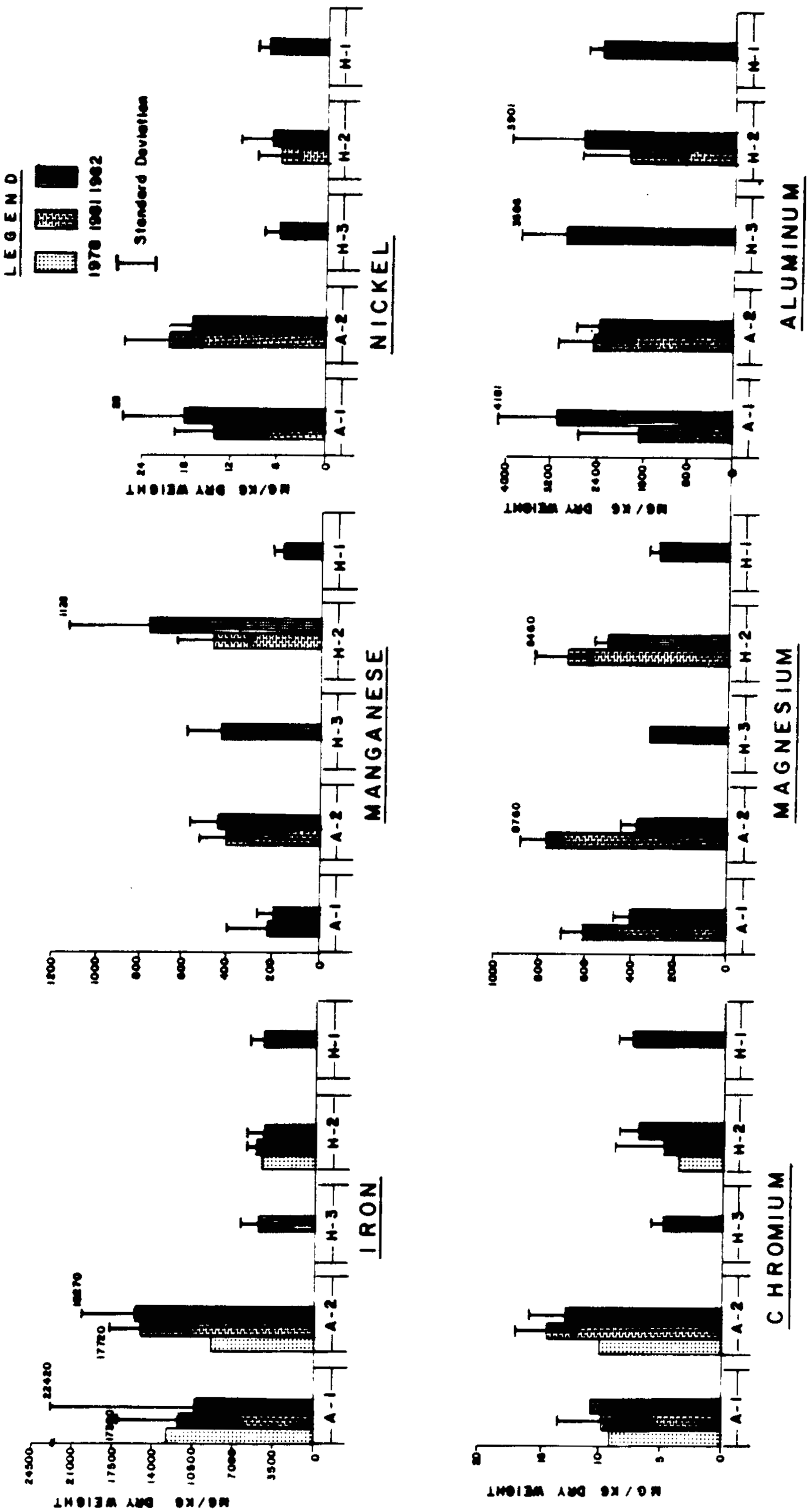

FIGURE 3.15 (continued)

Two separate laboratory studies have been conducted to examine the bioaccumulation of trace metals by two marine bivalves exposed to Kitsault mine tailings. McLeay et al. (1984) exposed Mytilus edulis and Yoldia limulata to Alice Arm sediment contaminated with Kitsault tailings for variable periods of 2 to 90 days. The extent to which metals accumulated in whole-body tissues of each bivalve species was as follows: Pb > Mo > Cd > Zn > Cu. No bioaccumulation of copper in mussels was observed. The elevated tissue metal concentrations in mussels were attributed to dissolved metal released from Alice Arm sediments whereas those in Yoldia sp. were thought to reflect direct uptake from the sediment ingested as well as that from dissolved metals. No bioaccumulation was observed in bivalves exposed to sediment from a reference site in Satellite Channel. Maximum concentration factors (during a 90 day exposure period) as compared with the reference site were as follows.

Mytilus edulis Cd - 2.1; Cu - 1.2; Pb - 24.2; Mo - 4.8; Zn - 1.5
Yoldia sp Cd - 8.7; Cu - 1.5; Pb - 43.7; Mo - 15.7; Zn - 3.3

This study concluded that, due to the observed bioaccumulation of metals of health concern, notably cadmium and lead, continued monitoring of these metals in bivalves and other edible marine life within Alice Arm should be undertaken.

Very similar results were found in a long term (100 day) bioaccumulation test by EPS using deposit feeding (Macoma spp.) and filter-feeding (Mya arenaria and Venerupis japonica) clams, and the worm, Cirratulus spectabilis (Guthrie, 1985). All clam species accumulated lead, molybdenum, zinc, iron and vanadium, while the worm accumulated only molybdenum and lead from the tailings.

Thompson et al. (1986) have shown that gill tissues of Golden King Crabs from Alice Arm have elevated levels of molybdenum and lead as compared to Hastings Arm. They postulate the source of these elements may be deposited tailings on the floor of the inlet. The same study found statistically significant higher copper and zinc burdens in hepatopancreas from reference (Hastings Arm) animals which suggested 1) another source, such as the abandoned Anyox smelter or 2) these elements in mine tailings in Alice Arm were less biologically available to the species than they are in natural sediments. No difference in metal-binding protein concentrations in hepatopancreatic tissues was observed regardless of the sample site.

Studies conducted at the Wesfrob mine site by EPS in 1977 (Brothers, 1978) showed elevated levels of copper, zinc, iron and cadmium in mussels at a sampling site at the mine as compared with control sites located approximately 7 km distant. No difference was noted in levels of copper, zinc, lead, cadmium and mercury in flatfish and shrimp collected in trawls in Tasu Sound and Wilson Bay. Higher iron concentrations were recorded in shrimp collected at the trawl nearest to the discharge. Additional EPS sampling in 1982 (Harding, 1983) found copper and iron concentration in mussels within 1 km of the discharge to be double that of mussels collected at more distant locations but no trends were noted for cadmium, lead or zinc. The only animals collected in sufficient numbers for statistical comparison was abalone (Haliotis kamschatkana), a commercially harvested species in the Queen Charlotte Islands. Copper and iron concentrations followed the same trends in abalone as they did in mussels.

The pattern of elevated metal levels in bivalves near mine discharge sites was repeated at the Jordan River mine, where copper levels in littleneck clams near the discharge point were higher than control sites. Zinc and chromium levels did not show differences between test and control sites. Copper concentrations in Dungeness crabs did not increase relative to pre-discharge levels (Ellis, 1974).

Collections of fish and invertebrates for trace metal analysis were made at Britannia Beach in Howe Sound by EPS in 1975, 1976, 1979 and 1982 (Goyette and Ferguson, 1986). They found very high levels of copper in mussels (up to 380 $ug \cdot g^{-1}$) and oysters (2100 to 2500 $ug \cdot g^{-1}$) near the mine, compared to those further away in Howe Sound, but noted that the levels seemed to have decreased at some stations between 1975 and 1979. These levels were also higher than in the same species in a number of other industrial and reference sites. In addition, copper levels in one species of shrimp (sidestripe) were approximately double (average 45.5 $ug \cdot g^{-1}$) that found in reference sites (16.9 to 23.1 $ug \cdot g^{-1}$). The probable source was given as dissolved copper in mine water being discharged to a creek on the Britannia Beach property.

3.3.4 **Smothering and Habitat Alteration.** The obliterative effects of tailings deposition in benthic and intertidal areas, and the resultant loss of habitat, are obvious and well known impacts of mine tailings disposal. However, the longer term impacts on the ecosystem, such as changes in species diversity and abundance and removal of commercially important species from the system, are less predictable. In an attempt to assess trends in such biological changes, company and government studies have included qualitative (submersible observations), semi-quantitative (species diversity/abundance in trawls) and quantitative (periphyton settling) tests.

The Island Copper mine benthos monitoring program includes measuring the effect of shallow water deposition on periphyton (attached algae) growth at 16 stations, annual benthic infauna sampling at 24 stations and collection of Dungeness crabs quarterly at six stations (Utah Mines Ltd., 1984). Rupert Inlet was found to have the highest levels of total solids and organic (volatile) solids growth since monitoring began, followed by Holberg Inlet and Quatsino Sound. The large amount of inorganic deposition has reportedly resulted in a corresponding increase in organic deposition, although the ecological significance of this is not known. The benthic infauna have been the most heavily impacted by the mine operations due to the direct effect of rapid sediment accumulation and tailings deposit instability. Observations from the review of infaunal data showed low numbers and depressed diversities where tailings movement occurred frequently.

Benthos diversity at some stations with tailings substrate were similar or greater than stations having no visible evidence of tailings. Waldichuk and Buchanan (1980) conclude that although recolonization of the tailings-covered bottom by many species should occur within five years following cessation of tailings discharge, it may be decades before the system stabilizes ecologically.

The choice of Dungeness crabs as a parameter in the monitoring program reflects the importance of the fishery, both as a food source and as a commercial operation. Due to intensive fishing (up to 500 traps in Rupert and Holberg Inlets at any one time) the data are subject to a large unquantified variability. The crab catches have shown a fairly consistent decreasing trend between 1975 and 1982, which, according to the company, coincides with an apparently natural reduction in crab populations along the western seaboard from California to Alaska. A trend towards reduced crab weights and carapace widths has been noted in Rupert and Holberg Inlets and Quatsino Sound since 1975.

Scuba observations of the impacts on intertidal and shallow subtidal benthos by EPS (Goyette and Nelson, 1978) have noted partial or complete burial of many sessile invertebrates at Hankin Point. The presence of numerous fish and invertebrates in Quatsino Sound showing preference for rocky or hard coarse substrates prompted concern by the authors that this habitat may become smothered with a resultant negative impact on the ecosystem. Elimination of epibenthic fauna over large areas of Rupert Inlet was confirmed by consistently poor or empty trawl catches (Harding, 1983; Goyette, pers. comm.).

Submersible observations (DeMill, 1983) in Alice Arm and Hastings Arm between 1980 and 1982 confirm the expected elimination of epibenthic and infaunal communities in fresh tailing deposition areas, although motile organisms occurred in this area. This effect resulted from the 4 million tons of tailings deposited during the initial 19 months of operation. A detailed benthos survey in October 1982 (Kathman et al., 1983) found stations up to 8 kilometres west of the outfall were lower in both numbers (an order of magnitude) and species diversity than control sites in Hastings Arm. Cross inlet transects indicate the greatest changes in the deep natural trench. Flatfish abundance has decreased, likely due to the reduction of benthic food sources through smothering (Byers et al., 1984). Under experimental conditions, Reid and Baumann (1984) showed that burial of up to 30 cm with Kitsault tailings did not affect clam survival, but burial by more than 20 cm did reduce survival of a polychaete worm. This may have been due to physical or chemical impacts, or synergistic effects of both.

Benthic populations in the vicinity of the Britannia Mine were studied in 1973 at three sites (McDaniel, 1973). A vertical transect, perpendicular to the shore, from the surface to a depth of 33.5 m (110 feet) directly between two main docks at the townsite showed the bottom to be thickly covered with tailings deposits. Over the length of the transect, no flora or epifauna were observed. Stations located approximately 1.6 km (1 mile) north and south of the mine also had rather impoverished faunas compared to stations located across the inlet near Woodfibre. A recent submersible observation in November 1984 off the Britannia mine site revealed an almost total absence of invertebrates and fish between 200 metres and 140 metres (Goyette and Ferguson, 1986). However, it is difficult to isolate the impact of the tailings from the natural periodic oxygen depression, which has been recorded as low as 0.1 to 0.5 $mg.L^{-1}$ (McDaniel et al., 1978), or from effects of acid mine drainage from the abandoned mine site.

3.4 Mining Summary

Clearly the most important impact of mine tailings on environmental quality is the smothering of benthic habitats. In Rupert Inlet, smothering has occurred widely throughout the system, extending from Rupert Inlet into Holberg Inlet, Neroutsos Inlet and Quatsino Sound. Areas affected include deep trough, shallow subtidal and intertidal habitats up to about 18 kilometres from the mine's outfall. At Alice Arm the area effected includes the deep trough to about 7 kilometres from the mine, while at Tasu Sound, the deep trough and shallow subtidal habitats have been covered to 3-4 kilometres on either side of the tailings discharge. These differences in areal impact reflect differences in production rates and operating periods, as well as physical/oceanographic difference in the receiving waters. The tailings deposition patterns have not always followed pre-discharge predictions, and underscore the complexities of oceanographic processes.

Smothering of benthic habitats implies change to the marine ecosystem, but not necessarily damage in terms of resource abundance. Some animals, such as attached invertebrates, cannot live in mine tailings, during deposition or in continuous, heavy deposition of any kind of sediment, and these must decline or vanish in affected areas. Others, including some marine worms, can and do thrive in recent deposits of mine tailings, and others recolonize rapidly once the discharge ceases. Therefore, the physical effects of mine tailings in British Columbia have been initial reduction (or virtual elimination) of benthic communities, followed by a change in community structure. The ecological significance of long term changes remains to be assessed.

Other measured effects of mine tailings have been minor by comparison to physical impacts. Trace metals have been studied intensively, and while they have accumulated in some marine species at all B.C. coastal mines, they have neither bioaccumulated to levels toxic to individuals, nor biomagnified in successive trophic levels. Turbidity has apparently not reduced primary productivity by attenuation of light in Rupert Inlet, and has not significantly affected zooplankton in Alice Arm (although some minor changes were noted). No toxic effects have been observed, and no increase in toxicants affecting suitability for human consumption have been measured. Despite the lack of obvious damage, however, the existence of processes which could conceivably lead to such effects -- such as the postulated increased biological availability of interstitial arsenic in tailings -- suggests a cautious approach to regulatory control, and continued monitoring.

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APPENDIX I

QUALITY ASSURANCE ON EPS DATA

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The comparison of year to year data, and establishment of certain trends in data depends on both proper sampling techniques and regimes and consistent analytical methodology. During the early 1970's, results of EPS quality assurance/quality control (QA/QC) tests were not routinely recorded. QA/QC data are available from 1975 to 1978. Some new analytical instruments were introduced and in 1979 a laboratory manual standardized methods which had been in place prior to that time. The following summarizes the QA/QC program and results during the period 1975-1985:

> An overall laboratory quality assurance program was applied to metals and organics analyses performed on the tissue and sediment samples. Analytical methodology was applied according to the 1979 Laboratory Manual.[1] Calibration standards were referenced to primary materials. All batches of samples were analyzed with applicable digestion or extraction blanks, a number of samples equivalent to at least the square root of the batch size were analyzed in duplicate, and a minimum of two reference materials or control standards, where available, were analyzed with each sample batch. Typical reference materials were NBS BCSS-1 and MESS-1 marine sediments, the NBS 1566 Oyster tissue and NBS 1577 Bovine liver for marine tissue samples. Reference materials for organic analysis were generally not available, but samples were spiked with known quantities of analytes to check recovery.
>
> The laboratory participated in many related interlaboratory studies over the period in question. Sponsoring agencies included the International Atomic Energy Agency, the U.S. Geological Survey, the Geological Survey of Canada and Environment Canada. Recovery of transition elements (e.g. Cu, Cd, Pb and Zn) in internal QC and interlaboratory studies was quantitative. Recovery of refractory and silica-bound elements (eg. Al, Ca, Fe, Mo) was incomplete due to the use of an acid-extraction, rather than total, digestion. Long term metal analysis precision was in the 5-10% standard deviation range. Recovery of spiked organics ranged from 70% to 130% with a precision of 20-40% standard deviation. Analytical methodologies evolved during the period (e.g. replacement of atomic absorption with plasma emission spectrometry, changes in digestion and extraction procedures) but significant recovery trends were not noted.
>
> This program provides a good basis for data comparison since 1978. Caution should be used in comparing data sets between years prior to 1978. The Bioassay Laboratory has used consistent techniques since the early - 70's.

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[1] Swingle, R.B. and J.W. Davidson, 1979. Environmental Laboratory Manual, January 1979. Departments of Environment and Fisheries and Oceans.