3369

Skeena
Environmental Effects Monitoring (EEM)
Pre-Design Reference Document

Prepared for:

SKEENA CELLULOSE INC.
P.O. Box 1000
Prince Rupert, B.C.
V8J 3S2

Submitted by:

HATFIELD CONSULTANTS LTD.
201-1571 Bellevue Avenue
West Vancouver, B.C.
V7V 3R6

August 1994

Dr. L.W. Dwernychuk, R.P. Bio.
Director
EEM Programs

Dr. D. Levy, R.P. Bio.
Coordinator
EEM Programs

T. Boivin, M.Sc., R.P. Bio.
Project Manager
Skeena EEM Pre-Design

TABLE OF CONTENTS

ACKNOWLEDGEMENTS

The Local Monitoring Committee (LMC) for Skeena Cellulose Inc. consists of representatives from the federal and provincial governments, environmental managers from Skeena Cellulose Inc. and Hatfield Consultants Ltd. (HCL). The LMC meetings provided a valuable forum for reviewing sections of the pre-design document while in early draft stages, thus ensuring that content and direction of the document conformed to expectations. The authors would like to acknowledge members of the LMC for their assistance:

- Mr. Al Colodey - Environment Canada;
- Mr. Alan Redenbach - Environment Canada;
- Mr. Uriah Orr - Department of Fisheries and Oceans;
- Mr. Phil Ross - Ministry of Environment, Lands and Parks;
- Mr. Murray Webster - Skeena Cellulose Inc.; and
- Mr. Ted Cant - Skeena Cellulose Inc.

The following personnel contributed to the production of this report:

- Mr. Martin Davies (Plume Delineation);
- Mr. Alex Sartori (Habitat Inventory and Classification);
- Mr. Bob Gregory (Resource Inventory);
- Ms. Leslie Young (Historical Receiving Environment Data);
- Mr. Tom Boivin/Mr. Ted Cant (Mill History, Current Operations, and Effluent Quality);
- Ms. Krista Jakobsen (Colour Graphics); and
- Ms. Stefanie Stevenson (Production).

Ms. Karen Munro provided technical editorial services.

Dr. L.W. Dwernychuk was the overall Project Director for EEM programs at HCL; Dr. D. Levy was EEM Coordinator, and Mr. Tom Boivin was Project Manager.

EXECUTIVE SUMMARY

This Pre-Design document fulfills two primary objectives:

1) to summarize the existing state of the environment in the vicinity of Prince Rupert through review of historical monitoring programs; and

2) to provide a basis for the design phase of an environmental effects monitoring program (EEM) for the Skeena Cellulose Inc. pulpmill located near Prince Rupert.

HISTORICAL OVERVIEW, ENVIRONMENTAL CONCERNS

Skeena Cellulose Inc. pulpmill is located on Watson Island, within a channel system separating the British Columbia mainland from Kaien Island, on which Prince Rupert is situated. The original mill was a 200 t/d sulphite pulpmill which commenced operation in 1951. Currently, two kraft mills produce a total of 350,000 ADt/yr (1992). Since 1989, primary and secondary treatment facilities have been installed to reduce effluent and atmospheric emissions.

PLUME DELINEATION

Near-field dispersion of effluent is dominated by strong tidal mixing of the water column in Porpoise Harbour immediately or soon after discharge. Effluents are diluted to less than one percent of release concentrations within 250 m of the diffuser to the south on an ebb tide (Hodgins and Knoll 1990). A similar rapid mixing of effluent is expected to also occur during flood tides, when effluent is carried to the north through Zanardi Rapids, given similarly strong and turbulent tidal flows. During slack tides, effluent dilution in the water column is restricted to the zone near the diffusers, although effluent probably does not accumulate to a great extent due to residual currents. Therefore, the near-field effluent concentration field has been defined as a circle of 500 m radius from the diffuser, sufficient to accommodate the maximum potential extent of effluent of one percent or greater concentration. For First Cycle EEM purposes, a near-field study area has been defined which includes the area of 1% effluent and surrounding waters in Porpoise Harbour and Wainwright Basin (Figure 2.20). Effluent concentrations of 1% or greater do not occur in Wainwright Basin; it has been included in the near-field study area because of relatively high concentrations of organochlorines in biota and sediments noted there, perhaps resulting from chronic exposure to dilute effluent under current operations and historical discharges.

Strong tidal currents disperse effluent widely throughout the Kaien Island area. Far-field dispersion occurs as far southwest as Agnew Bank, and north along Ridley Island to Digby Island on ebb tides. On flood tides, effluent disperses northward through Wainwright Basin and passages beyond. Although effluent mixes quickly with the tides, its further dissipation is physically limited in relatively still Wainwright and Morse Basins. As a result, effluent likely moves slowly through the entire passage system, flushing back and forth with the tides. Organochlorine monitoring suggests that effluent also reaches into Denise Inlet off Morse Basin. Beyond Fern Passage, dioxins and furans in crab hepatopancreas have been recorded as far north in Prince Rupert Harbour as Osborn Cove, and through Venn Passage as far as the northwest shore of Digby Island (Figure 2.20). Far-field dispersion does not represent a specific concentration of effluent in the water column, but rather corresponds to the maximum measurable extent of effluent dispersion as suggested by the dye study and by dioxin and furan monitoring data.

HABITAT INVENTORY AND CLASSIFICATION

Physical and biological habitat inventories in the vicinity of Skeena Cellulose Inc. are mapped, including the near-field effluent zone and areas in the vicinity of the pulpmill. The inventory focuses on Porpoise Harbour (six shore units) and Wainwright Basin (ten units). Each shore unit is divided into subtidal, intertidal and backshore zones and descriptions are accompanied by four figures. Fetch and wave exposure were calculated for Shore Unit #4 in each waterbody, which indicated that these areas are "protected".

A potential reference site has been selected in Kitkatla Inlet, Porcher Island (Figure 3.5). Physical and biological habitat mapping will be completed for the reference site during Cycle 1.

FISHERIES HABITAT AND RESOURCES

The marine, estuarine, and freshwaters in the vicinity of the Skeena Cellulose pulpmill near Prince Rupert are important habitats for many fish and invertebrate resource species. Groundfish, salmon, herring, shrimp, prawn, crab, octopus, sea urchin, sea cucumber, geoduck, and intertidal clams are found throughout the area and several are common in many locations. Chatham Sound represents an important migration corridor for both juvenile and adult salmon of many stocks from the Skeena River watershed and local coastal streams. The Skeena River dominates fisheries of the local area and the river's estuary is ecologically sensitive, supporting the juvenile stages of many fish species (especially, salmon). Herring spawn in large numbers in several areas throughout Chatham Sound, especially the Tsimpsean Peninsula and northern Porcher Island.

Commercially, the Prince Rupert area is a large producer of finfish resources, including pink and sockeye salmon of the Skeena River drainage and groundfish species. Commercial invertebrate harvesting of geoduck clam, shrimp, prawn, sea urchin and sea cucumber are significant locally.

First Nations harvesting primarily targets sockeye salmon in and around the Skeena River, although other salmonids are also fished. Historically, herring, halibut and eulachon were also taken.

Sport fishing is becoming increasingly important, targeting coho and chinook salmon. Other fish harvested include lingcod, rockfish and Pacific halibut. Dungeness crab and prawn are also harvested recreationally.

Urbanization and industry have affected abundance and accessibility of some of these resources in recent years. Closures and advisories are in effect in many areas (Porpoise Harbour, Wainwright

Basin, Morse Basin, Prince Rupert Harbour) due to the presence of domestic and municipal waste, and the presence of chlorinated dioxins and furans. Resources primarily affected by various closures and advisories include crab and shrimp.

HISTORICAL RECEIVING ENVIRONMENT DATA

A large quantity of data has been collected from the marine environment in the vicinity of Skeena Cellulose Inc. in relation to:

- water quality parameters;
- sediment quality;
- intertidal and benthic communities; and
- mill effluent compounds that have accumulated in shellfish, crab and groundfish tissues.

Water Quality

Prior to 1978 and operation of the diffuser, mill effluents influenced temperature, pH, salinity (to some extent) and dissolved oxygen in Wainwright Basin and upper Porpoise Harbour. Temperature was approximately 1.5°C higher near the Wainwright Basin discharge station, pH was lower (6.01), and salinity was reduced most likely due to both mill effluent and Wolf Creek runoff. Dissolved oxygen levels were particularly affected by sulphite liquor discharges which had a high oxygen demand. Oxygen levels below the detection limit (0.5 mg/L) were recorded in 1961 and until 1978, especially during the summer months. Piping of the red liquor effluent to Chatham Sound was not always effective in improving local water quality - breaks in the piping occasionally occurred, which lowered dissolved oxygen levels and resulted in fish kills.

After 1978, water quality gradually improved in Wainwright Basin and upper Porpoise Harbour until virtually no effect was recorded by mill effluents for temperature, dissolved oxygen, pH and salinity. However, true colour and tannin/lignin concentrations did exhibit some influence by effluents released through the diffuser into Porpoise Harbour. True colour (maximum 90 APHA units) and tannin/lignin levels (maximum 6.4 mg/L) appeared to decline during the 1980's. Turbidity was occasionally elevated near the pulpmill, but the major source was Skeena River runoff during freshet. Natural runoff may also have contributed to decreased secchi depth (transparency) in Wainwright Basin and Porpoise Harbour in recent years.

Resin acids, AOX, and chloroform were detected in water samples collected in the vicinity of Skeena. Resin acids at all stations were generally well below sublethal levels for fish during testing in 1983 to 1987. In 1990/1991, AOX and chloroform concentrations were highest at Stations 2 and 6, and indicated that well-mixed effluent was entering Wainwright Basin as well as flowing into Chatham Sound.

Sediment Quality

The extent and depth of fibre deposition has not specifically been studied. Fibre deposition was high in Wainwright Basin until 1976, and large mats of fibre frequently appeared on the surface. Fibre accumulations still occur in "pockets" in the basin. Since 1978, fibre deposits have also been identified in Porpoise Harbour. Visual observations of sediment samples in 1993 indicated fibre and small wood pieces were present to a distance of 750 m north of the diffuser. The substrate to 1 km in both directions from the diffuser was identified as black and anoxic, often with a hydrogen sulphide gas odour. Fibre deposition should no longer be occurring with operation of the clarifier.

Particle size in Skeena sediments indicated a composition of predominantly sand or silt/clay. Volatile residue values were highest in Wainwright Basin and in the northern end of Porpoise Harbour, probably due to fibre deposition. Trace metal sampling in 1987 recorded elevated levels of mercury and cadmium in the north end of Porpoise Harbour; however, no clear effluent effect could be determined.

Resin acid levels in sediments appeared to reflect mill effluent effects, with highest values occurring near the diffuser in Porpoise Harbour and near the old discharge location in Wainwright Basin. Organochlorine concentrations have decreased since 1989 in the Skeena area. In 1991, catechols and phenols were below detection limits; guaiacols were found at levels less than 5 ng/g. Dioxins and furans have also declined in recent years, with concentrations slightly higher in Morse Basin than those recorded adjacent to the diffuser. This difference between locations may be partly due to tidal action and flushing rates, which direct effluent north into the calmer basins where these compounds may accumulate. Low furan concentrations were measured at two stations in Prince Rupert Harbour in 1992, indicating the extent of effluent dispersion.

Intertidal and Benthic Communities

The intertidal community has been characterized annually by the macroalgae community, and occasionally with invertebrate studies. An improvement in the algal community over time near the old discharge in Wainwright Basin has been recorded; no impact by mill effluents released by the Porpoise Harbour diffuser has been noted. Macroalgae have been the most stressed at Station 6 (on Ridley Island opposite the diffuser) which is likely due to sedimentation caused by log boom activities.

Subtidal benthic macroinvertebrates do not presently appear to be impacted by mill effluents. Generally, densities and number of taxa have increased since 1979. Densities of *Capitella capitata*, used to indicate organic pollution, were greatest near the diffuser in 1981, but numbers have since dropped. There is no evidence of organic loading which would support pollution tolerant taxa. Nematodes have at times dominated subtidal communities, but their presence may be influenced by habitat (particle size) rather than stress induced by mill effluents.

Biological Tissues

In 1990, chlorinated phenolic concentrations, predominantly guaiacols, were detected in trace amounts in shrimp tissues. Chloroguaiacols were detected in crab tissues from samples collected throughout the area in 1990 and 1991; however, monitoring of these compounds in crabs and other biological tissues was discontinued in 1992.

Shrimp tissues currently indicate trace or non-detectable concentrations of dioxins, and furan levels appear to be declining. Mussels and groundfish have not been monitored for dioxins and furans since 1990 and 1991, respectively. Dioxin and furan levels in Dungeness crab hepatopancreas tissues have generally declined since 1989. Levels are highest in Wainwright Basin crabs, and measurable concentrations were detected at several stations on Digby Island. With the decrease in dioxin and furan concentrations in these tissues, Total-TEQ values for crab hepatopancreas have also declined since 1991. TEQs have been recorded at highest levels near the diffuser, but decrease with increasing distance from Skeena Cellulose Inc.

EFFLUENT QUALITY

The volume of effluent currently discharged from Skeena Cellulose Inc. is approximately 150 m^3/ADt production. Marked declines in BOD_5 has occurred since April 1991; present levels are less than 10 t/d. Suspended solid levels have remained basically the same since 1988, ranging between 10 and 20 t/d. AOX values in final effluent have declined from an average of 5 kg/ADt (1990) to approximately 2.5 kg/ADt (1993). Concentrations of dioxins and furans have decreased markedly since 1992; levels in 1993 were less than 10 ppq dioxin and 50 ppq furan except in January. Since February 1993, all CEPA TEQs have been below the target of 20 ppq for pulpmill effluent. Acute toxicity tests have shown 100% survival of rainbow trout since February 1992.

1.0 INTRODUCTION

This document provides a basis for the design phase of an environmental effects monitoring program (EEM) for Repap's pulp and paper mill, Skeena Cellulose Inc., located near Prince Rupert, British Columbia. Guidelines for the EEM program were developed by the federal government, environmental consultants, and pulp and paper industry representatives over the past six years, and were incorporated into the Pulp and Paper Effluent Regulations during 1992. The EEM program encompasses two primary objectives:

- to assess the overall adequacy of effluent regulations by monitoring for environmental effects at each receiving water site; and
- to achieve national uniformity in industrial site monitoring of effects.

The contents and scope of this pre-design document follow guidelines specified in the Technical Guidance Document (Anon., 1993) and refined during discussions with Local Monitoring Committee (LMC) members. Skeena Cellulose Inc. LMC members include representatives from Environment Canada, Department of Fisheries and Oceans, British Columbia Ministry of Environment, Lands and Parks, environmental managers from Skeena Cellulose Inc., and personnel from Hatfield Consultants Ltd. (see Acknowledgements for list of LMC members).

The pre-design document is essentially a "State of the Environment" report which will be used to characterize the receiving environment, and assist in the identification of sampling areas. It will assist LMC members in making critical decisions during the first cycle study design stage (e.g., choice of sentinel fish species) and provide a foundation for designing each of the components for the first cycle program.

The report has been organized into the following nine sections:

Section 1.0	Introduction;
Section 2.0	Plume Delineation;
Section 3.0	Habitat Inventory and Classification;
Section 4.0	Resource Inventory;
Section 5.0	Historical Receiving Environment Data;
Section 6.0	Mill History, Current Operations, and Effluent Quality;
Section 7.0	Implications for Environmental Effects Monitoring;
Section 8.0	References; and
Section 9.0	Glossary.

The report has been organized in a format to enable the reader to find specific information within the large data set presented. Tables, figures, and appendices are separated from the report to facilitate their location when referenced throughout the document.

2.0 PLUME DELINEATION

2.1 INTRODUCTION

The pre-design phase of the federal environmental effects monitoring (EEM) program requires a determination of the zone of effluent mixing in the receiving environments of Canadian pulpmills, in order to facilitate proper design and targeting of future monitoring efforts. Delineation of the extent of an effluent plume may be carried out directly, through the use of injected dye tracers, or indirectly, by relying on studies which accurately characterize effluent movement in the receiving environment.

In the case of the Skeena Cellulose Inc. pulpmill near Prince Rupert, a previous dye dispersion study has been conducted, and monitoring of pulpmill contaminants has been undertaken throughout the surrounding receiving environment. This section of the pre-design report summarizes known physical oceanographic features of the area, reports results of the previous dye dispersion study and of contaminant monitoring studies that aid in delineating the zone of effluent mixing.

2.2 LOCAL PHYSICAL OCEANOGRAPHY

2.2.1 Physiography

The Skeena Cellulose Inc. pulpmill is located on Watson Island, within a channel system separating the British Columbia mainland from Kaien Island, on which Prince Rupert is situated (Figure 2.1). Effluent is discharged to Porpoise Harbour, which opens to Chatham Sound to the south, and connects to Wainwright Basin to the north via Zanardi Rapids. Wainwright Basin, in turn, is connected to Morse Basin via Galloway Rapids, then to Fern Passage via Butze Rapids. Fern Passage opens to Prince Rupert Harbour. These passages are typically shallow, with rocky substrates. Shallow topography and large tidal amplitudes in the area result in significant amounts of shoreline being exposed at low tide.

2.2.2 Tides and Currents

Tides in the Prince Rupert area are some of the largest along the British Columbia coast, with spring tides reaching 7.5 m in amplitude (Waldichuk, 1966). Tidal currents in the region are in turn very strong, especially through the various rapid systems; the Canadian Hydrographic Service's *Sailing Directions* handbook describes tidal currents through Zanardi Rapids as "violent" (CHS, 1977). Tidal currents in Porpoise Harbour, in the vicinity of the Skeena Cellulose Inc. diffuser, achieve speeds of 60 to 70 cm/sec on flood tides, and 50 to 60 cm/sec on the ebb (H.A. Simons, 1977 *cited in* Hodgins and Knoll, 1990).

Tides display a mixed diurnal/semi-diurnal pattern, and at various points around Kaien Island are not in phase; tides in Morse Basin are typically one to two hours later than those at Prince Rupert, and high tides in Morse Basin are 1.5 to 2 m lower than at Prince Rupert (Waldichuk, 1962). Water moves through the passages separating Kaien Island from the mainland "almost continuously" because of continually unequal tidal levels through these passages. These flows do not show any apparent diurnal rhythm, but rather display periodic and rapid changes in water movement and current speed. Surface drogue current data collected by Waldichuk (1962) suggested that, at least at the surface, waters in the passages have a net southward flow from Fern Passage to Porpoise Harbour.

Although currents through these rapids are very strong and turbulent, Waldichuk (1962) observed that water in Wainwright and Morse Basins "remains relatively still", and as a result, flushing processes in these basins occur "much slower...than might be expected." With respect to tidal flushing of this area, Hoos (1975) states:

"Although the tidal action is very effective in flushing Chatham Sound and most of the waters along the Skeena River estuary, some of the more confined basins such as Wainwright and Morse ... are poorly flushed by tidal action because of the constrictions in the passages connecting them with the open sea."

Recent drogue studies in Wainwright Basin by Dayton & Knight Ltd. (1990) indicated that a strong current from Zanardi to Galloway Rapids does occur along the southern portion of Wainwright Basin during flood tides, and that a counter-clockwise gyre occurs in the northwestern bay of Wainwright Basin through all phases of the tidal cycle, only reversing briefly near low ebb tide. This study also indicated that residual currents flow from Porpoise Harbour through Wainwright and Morse Basins and through Fern Passage to Prince Rupert Harbour. AESL (1977 *cited in* Dayton & Knight Ltd., 1990) noted that about 21% of waters flowed through Galloway Rapids and 79% flowed through Fern Passage during a tidal cycle in Morse Basin. The results of these studies is consistent with previous residual current observations by Waldichuk (1962).

Outside of the Porpoise Harbour to Fern Passage basin system, currents are still primarily tidally driven. Stucchi and Orr (1993) determined that tidal forces accounted for 80% of the variance in currents observed in Prince Rupert Harbour.

2.2.3 Freshwater Input and Vertical Structure

The Skeena River introduces large amounts of fresh water to the Kaien Island area, especially during spring and summer when river flows are highest (Figure 2.2). However, strong tidal currents cause rapid vertical mixing to occur, resulting in well-mixed waters in the river estuary (Figure 2.3); vertical stratification is not pronounced at any time of the year (Hoos, 1975). There is only a small amount of freshwater runoff in the vicinity of the pulpmill, the largest single source being Wolf Creek (Waldichuk, 1962). Water flow through Wolf Creek is not precisely known, but averages in the range of 75,000 m^3/day (T. Cant, Skeena Cellulose Inc., *pers. comm.*). This system empties into Wainwright Basin through Lagoon #2, a former process effluent discharge location, discontinued in 1978.

Waters are somewhat stratified in the open waters of Chatham Sound, with lower salinity waters from the mouth of the Skeena River overlying more saline ocean waters. In early April 1990, Hodgins and Knoll (1990) observed a weak halocline near approximately 15 m depth in Chatham Sound, outside Porpoise Harbour, with warmer, less saline waters resulting from Skeena River discharges overlying colder, more saline waters. In late July 1992, Stucchi and Orr (1993) observed a deeper and more pronounced halocline between 20 and 30 m in Prince Rupert Harbour; the greater depth of the halocline in this study is consistent with greater freshwater discharge from the Skeena River during this time (Figure 2.2).

Turbulent tidal flows result in a well-mixed vertical structure in the water column in areas surrounding the pulpmill, particularly near Zanardi, Butze and Galloway Rapids along the inside passage east of Kaien Island (Waldichuk, 1968). Figure 2.4 shows the effect of this vertical mixing on various chemical oceanographic parameters. The distinct values for these parameters at site P15 (high temperature/low salinity), near the western outlet of Wainwright Basin, may indicate the presence of pulpmill effluent, as spent sulphite effluent was discharged to this part of the Basin during the 1961 survey. The water column is vertically well-mixed through Porpoise Harbour (P9 to P14) and into Chatham Sound (P7 to P8); any vertical stratification in the Wainwright Basin is weak below the top 2 or 3 m of the water column.

2.3 MIXING AND DISPERSION OF EFFLUENT

2.3.1 Outfall Diffusers: Construction and Location

The outfall diffuser from Skeena Cellulose Inc. extends from the mill site on Watson Island approximately 450 m along the bottom into Porpoise Harbour (Figure 2.5). Effluent is discharged through eighteen ports along the final 75 m of the diffuser, into water approximately 20 m deep. Effluent has been discharged here since 1978; previous to this, effluent from the sulphite mills and first kraft mill at the mill site were discharged through a surface outfall into Wainwright Basin (Figure 2.1). Red liquor from the sulphite mill was discharged directly to Chatham Sound until 1976.

Previous to 1993, Lagoon #1, which discharges to Lagoon #2 then Wainwright Basin, received process wastewater flows when power outages or other events prevented their discharge through the Porpoise Harbour diffuser. This practice has been discontinued; since mid-1993, this lagoon has received only non-process flows, including storm sewer flows, filter backwash and raw water overflows from the water treatment plant (Section 6.1).

2.3.2 Vertical Mixing of Effluent

The dispersion and mixing of effluent discharged to Porpoise Harbour was observed by Hodgins and Knoll (1990) using a rhodamine dye tracer in March/April 1990. This dye was injected to the effluent previous to its release; its dissipation was monitored in the receiving environment. Dye-labelled effluent was discharged to the harbour at the onset of a large ebb tide and observed over the following complete tidal cycle (Figure 2.6). For technical details of this study, see Hodgins and Knoll (1990).

The strong tidal turbulence in Porpoise Harbour quickly mixed effluent vertically through the water column after its discharge. Hodgins and Knoll (1990) observed three distinct trapping layers of effluent in the upper 10 m of the water column, immediately above the diffuser (Figure 2.7); these trapping layers had broken down within 80 m of the diffuser as effluent had mixed through the upper 10 m by this point (Figure 2.8). Within 250 m of the diffuser, effluent had completely mixed through the water column (Figure 2.9).

Dwernychuk *et al.* (1992a) documented further evidence of rapid and complete vertical mixing in June 1990 and January 1991. To the north through Zanardi Rapids in Wainwright Basin, water-borne organochlorines (AOX) were observed to be well-mixed through the water column (Figure 2.9). This would be expected given the intense tidal mixing which occurs through Zanardi Rapids.

2.3.3 Effluent Dispersion South into Chatham Sound

Hodgins and Knoll (1990) observed dye-labelled effluent dispersing south through Porpoise Harbour into Chatham Sound with the ebb tide. Dispersion of effluent to the north was recorded to occur only within 300 m of the diffuser.

Effluent dispersed rapidly to the south through Porpoise Harbour during the dye study (Figure 2.11). The dilution of effluent immediately above the diffusers ranged from 49:1 (2.02% of release) to 84:1 (1.18% of release). Within 80 m of the diffuser, the minimum observed effluent dilution was approximately 1.1% of release; approximately 250 m south of the diffuser, effluent had been diluted to 0.75% of its initial concentration (see Figures 2.8, 2.9, and 2.11). Net transport velocity of effluent was greater than 30 cm/sec.

On exiting Porpoise Harbour, effluent dispersed out along the northwest edge of Flora Bank and across Agnew Bank (Figure 2.12). The topography of the mouth of Porpoise Channel deflected effluent northward along the shore of Ridley Island (Figure 2.1). Figure 2.13 illustrates the dissipation of effluent along this pathway as recorded by Hodgins and Knoll (1990); the maximum effluent concentration contour in this diagram corresponds to an effective dilution ratio of 7220:1, (0.014%). In Chatham Sound, effluent became more discretely distributed vertically through the water column, above approximately 8 m in depth, in the slightly less saline waters resulting from Skeena River outflow (Figure 2.14).

Further effluent dispersion in surface waters of Chatham Sound will be influenced by winds, which blow to the northwest and west over nearly the entire year, and by general current circulation patterns north along Hecate Strait and through Dixon Entrance (CHS, 1977). Winds in the region blow predominantly from the south and southeast throughout the year, expect from April to August, when winds are more variable but blow more often from the west; average wind speeds from 1961 to 1971 ranged from 6.8 knots (3.5 m/s) in July to 10.6 knots (5.5 m/s) in October (CHS, 1977). These winds and currents, combined with the effects of Skeena River discharges in summer, will tend to disperse dilute effluent to the northwest along Hecate Strait. Strong tidal currents and narrow channels likely greatly outweigh any effects of wind on effluent dispersion in the Porpoise Channel-Wainwright Basin system. Stucchi and Orr (1993) observed that tidal forces accounted for 80% of current variances in Prince Rupert Harbour, suggesting that the effects of wind on current movement are minimal.

2.3.4 Effluent Dispersion North into Wainwright Basin

Effluent dispersion to the north of the diffuser through Zanardi Rapids into Wainwright and Morse Basins was not observed by Hodgins and Knoll (1990), as their study began on an ebb tide. Historical water quality data collected in these basins and in the connecting passages further north, indicate that effluent does disperse through this area (Dwernychuk, 1988; Dwernychuk *et al.*, 1992a).

Flood tides through Porpoise Channel are of even greater velocity than ebb tides (see Section 2.2.2); therefore it is expected that, near the diffuser, effluent will disperse vertically at least as rapidly to the north as to the south. Given the narrow constriction of the channel at Zanardi Rapids, effluent will likely completely mix through the water column through these rapids. Dwernychuk *et al.* (1992a) monitored adsorbable organic halide (AOX) concentrations in the water column in the vicinity of the Skeena Cellulose mill in June 1990, August 1990 and January 1991. Maximum concentrations of AOX observed at Site W2 in Wainwright Basin corresponded to effective dilution ratios of 0.08% to 0.31%; effluent was vertically well-mixed through the water column (Figure 2.10).

To check the validity of these estimates, a general approximation of pulpmill concentration through Zanardi Rapids was determined through a volumetric analysis of effluent flow versus water flow through Zanardi Rapids during a flood tide. Assumptions made in this calculation are detailed below.

- The Canadian Hydrographic Service does not report current flows through Zanardi Rapids; in the volumetric analysis, a 5 knot (2.58 m/s) flood current was assumed, which is the flood current reported through Galloway Rapids reported by CHS (1977, 1991). This estimate is very conservative, as tidal flows through Zanardi Rapids are known to be much more rapid and turbulent than those through Galloway Rapids.

- At low tide, the dimensions of the narrowest point of Zanardi Rapids were determined from hydrographic charts (CHS, 1991) and personal observation. Average depth assumed to be 2 m;

width across the channel was assumed to be 100 m. These estimates are also conservative for low tide conditions.

- Effluent flow was assumed to be 160,580 m^3/day (1.86 m^3/s), the average effluent flow to Porpoise Harbour in 1993. At flood tide conditions, all effluent was assumed to be entrained in water flowing through Zanardi Rapids, in order to simulate potential worst-case conditions.

- Effluent was assumed to mix completely into the turbulent water flows either previous to or upon entering the Rapids. This assumption is well supported by historical water chemistry and effluent monitoring data (Section 2.3.2; Waldichuk, 1962, 1968).

Based on these assumptions, the volume of water moving through Zanardi Rapids may be conservatively estimated:

$$\text{Flow Volume } (m^3/s) = 2.575 \text{ m/s (current velocity)} \times 2 \text{ m (channel depth)} \times 100 \text{ m (channel width)}$$

$$= 515 \text{ m}^3/\text{s};$$

and effluent concentration in the water column entering Wainwright Basin may estimated:

$$\text{Effluent Concentration (\% of release)} = \frac{1.86 \text{ m}^3/\text{s (effluent volume)}}{515 \text{ m}^3/\text{s (receiving water volume)}} \times 100\%$$

$$= 0.36 \text{ \% of release (277:1 dilution).}$$

Using a more reasonable tidal flow of 7 knots yields an estimated effluent concentration of 0.26% (388:1 dilution). These conservative estimates indicate that effluent concentrations in the water column are well below 1% of release upon entering Wainwright Basin during a flood tide.

Waldichuk (1966) and Waldichuk *et al.* (1968) observed the dispersion of effluent from the pulpmill during the time when sulphite effluent was discharged to Wainwright Basin through a surface outfall (Figure 2.15). These data clearly cannot be used to infer concentrations or specific patterns of effluent dispersion from the mill today because of changes in mill processes and discharge location. They do, however, illustrate that effluent in Wainwright Basin is carried both southwest into Porpoise Harbour (lower figure) and northeast into Morse Basin (upper figure). Drinnan (1974 *cited in* Hoos, 1975) observed that subtidal benthic communities near the southwest end of Morse Basin were adversely affected by sulphite mill effluent, also indicating the transfer of effluent through the Galloway Rapids. Figure 2.16 illustrates water exchange mechanisms in the passages as suggested by Waldichuk *et al.* (1968).

Hatfield Consultants Ltd. has monitored the receiving environment in the vicinity of Skeena Cellulose since 1985, including comprehensive studies of biological community structure, and monitoring of organochlorine concentrations in waters, sediments, and biota (Dwernychuk, 1986, 1987, 1988, 1989a,b; Dwernychuk *et al.*, 1992a,b, 1993a,b; Dwernychuk and Boivin, 1993). These studies suggest that Wainwright Basin and Porpoise Harbour areas near the diffuser may be similarly impacted by pulpmill effluent, as concentrations of organochlorines measured in sediments were similar between all sampling locations in these areas (such as tetrachloroguaiacol: Figure 2.17).

Organochlorine concentrations in Dungeness crab tissues have been monitored in the vicinity of Skeena Cellulose Inc. since 1989 (Dwernychuk, 1989b; Dwernychuk *et al.*, 1992a,b, 1993a,b; Dwernychuk and Boivin, 1993). These data suggest that effluent disperses throughout the entire passage system, from Wainwright Basin to Prince Rupert Harbour (Figure 2.18). In the 1993 dioxin monitoring program, Dwernychuk *et al.* (1993b) recorded measurable concentrations of chlorinated dioxins and furans in crab hepatopancreas sampled throughout the study area, including samples collected along the northern shore of Digby Island. Higher concentrations were found in samples from Porpoise Harbour and Wainwright and Morse Basins than in the Chatham Sound area. When using these crab data to determine presence of effluent in certain areas, the mobility of crabs must be kept in mind, as it is possible that organochlorines may be accumulating in areas other than the ultimate capture site.

It is important to note that Wainwright Basin was subject to over 20 years of direct effluent discharges from the original sulphite mill and the first kraft mill (see Sections 5.0 and 6.0). Given the relatively slow breakdown of organochlorines and the long-term nature of previous effluent inputs, sediment data in Wainwright Basin may partly reflect historical discharges to the basin, and may not solely be due to current operations.

2.3.5 Seabed and Shoreline Contact Areas

Figure 2.19 indicates the seabed and shoreline areas expected by Hodgins and Knoll (1990) to be contacted by effluent dissipating on an ebb tide. Dispersion to the north through the passages is more difficult to precisely delineate. Given effluent becomes completely mixed into basin waters through turbulent mixing in the various rapids systems, and current flows likely disperse effluent throughout the passage system to Prince Rupert Harbour, most seabed and shoreline areas from Wainwright Basin to Fern Passage are contacted by dilute effluent. However, intertidal and subtidal community surveys conducted by Dwernychuk (1988) and Dwernychuk *et al.* (1992a) suggest that measurable effects of pulpmill effluent on these communities are limited to Wainwright Basin to the north.

2.3.6 Seasonal Changes

Given the extremely strong tidal mixing and flushing occurring in the vicinity of the mill and given that effluent dispersion from the mill appears to be nearly entirely tidally-driven, seasonal changes in effluent dispersion patterns are expected to be minimal. Hodgins and Knoll (1990) suggest that far-field dispersion of effluent may change slightly with increased Skeena River outflow in summer; the ultimate flushing of dilute effluent to Dixon Entrance may occur further to the south through Brown and Eyre Passes as opposed to Dundas Pass, which they suggest occurs during non-freshet conditions. Dispersion and dissipation of effluent through Porpoise Harbour and the passages behind Kaien Island likely remain similar year-round for reasons stated above.

2.4 CONCLUSIONS

2.4.1 Near-Field Dispersion of Effluent

Strong tidal mixing of effluent through the water column in Porpoise Harbour results in rapid vertical mixing of effluent immediately or soon after discharge. Hodgins and Knoll (1990) observed effluent concentrations of less than one percent of release within 250 m of the effluent diffuser to the south on an ebb tide. This rapid mixing of effluent is expected to also occur during flood tides, when effluent is carried to the north through Zanardi Rapids, given similarly strong and turbulent tidal flows.

While rapid effluent dilution is expected to occur within a few hundred metres of the diffuser during ebb and flood tides, the possible effect of effluent accumulation near the diffuser during slack tides must be considered, as effluent dilution in the water column would likely occur more slowly near the diffusers during slack tides. Slack tides in this area are of short duration, lasting 30 min after flood tides and 90 min after ebb tides (CHS, 1977; Figure 2.6); diffuser performance studies in 1978 (Skeena Cellulose Inc., *unpubl. data*) indicated that effluent did not concentrate in waters in the immediate vicinity of the diffuser at any time. Besides tidal flows, residual currents move continually through the basin and passage system (Waldichuk, 1966; AESL, 1977), also consistent with no effluent accumulation near the diffuser on slack tides. However, in the delineation of an effluent concentration field corresponding to the maximum expected extent of 1% effluent, this possibility has be considered. The effluent concentration field has been conservatively defined as a circle of 500 m radius from the diffuser (Figure 2.20). This area is expected to be sufficient to accommodate the maximum potential extent of effluent of 1% or greater concentration.

While effluent is rapidly diluted by turbulent mixing to below 1% concentrations within a few hundred metres of the diffuser, concern has been expressed about the relatively high concentrations of organochlorines and other contaminants observed in Wainwright Basin compared to Porpoise Harbour. These data may partly reflect historical discharges to Wainwright Basin, or may be a result of chronic effluent exposure under current pulpmill operations. While Porpoise Harbour is flushed by uncontaminated waters from Chatham Sound on each flood tide, Wainwright Basin and the other basins and passages are continually exposed to effluent, which flushes back and forth on the tides as it is carried by residual currents toward Fern Passage. Given the relatively high organochlorine concentrations found in biota and sediments in Wainwright Basin, and the chronic exposure of Wainwright Basin to dilute effluent from Skeena Cellulose Inc., a near-field study area has been defined for First Cycle EEM purposes which encompasses the area of 1% effluent concentration and the surrounding waters of Porpoise Harbour and Wainwright Basin, including contiguous Lagoon #2 (Figure 2.20).

2.4.2 Far-Field Dispersion of Effluent

While effluent is quickly diluted in Porpoise Harbour by strong tidal mixing, these strong tidal currents also disperse effluent widely throughout the Kaien Island area. To the south, Hodgins and Knoll (1990) indicate that effluent disperses as far southwest as Agnew Bank, then north along

Ridley Island. This dye study and historical organochlorine monitoring studies (Dwernychuk, 1989b; Dwernychuk *et al.*, 1992a,b, 1993a,b; Dwernychuk and Boivin, 1993) suggest that effluent exiting Porpoise Channel disperses at least as far north as Digby Island. Dilute effluent entering Chatham Sound becomes vertically stratified in the upper 10 m of the water column; further effluent dispersion in surface waters of Chatham Sound will be influenced by winds, which blow to the northwest and west over nearly the entire year, and by general current circulation patterns north along Hecate Strait and through Dixon Entrance (CHS, 1977).

On flood tides, effluent disperses northward through Wainwright Basin and the passages beyond. Historical water quality monitoring data and general modelling of effluent transport through Zanardi Rapids indicates that effluent is rapidly diluted by tidal flows and that effluent concentrations above 1% of release will not occur in Wainwright Basin (Section 2.3.4). Further dissipation of dilute effluent beyond Zanardi Rapids is physically limited by the relatively still waters of Wainwright and Morse Basins. As a result, effluent likely moves slowly through the entire passage system, flushing back and forth with the tides. Organochlorine monitoring suggests that effluent also reaches into Denise Inlet off Morse Basin. Dioxins and furans in crab hepatopancreas have been recorded beyond Fern Passage as far as Osborn Cove in Prince Rupert Harbour, and through Venn Passage as far as the northwest shore of Digby Island (Figure 2.18).

The expected far-field dispersion of effluent from the Skeena Cellulose Inc. pulpmill is illustrated in Figure 2.20. The dotted line illustrating far-field dispersion does not represent a specific concentration of effluent in the water column, but rather corresponds to the maximum measurable extent of effluent dispersion as suggested by the dye study (Hodgins and Knoll, 1990) and by dioxin and furan monitoring data (Dwernychuk, 1989b; Dwernychuk *et al.*, 1992a,b, 1993a,b; Dwernychuk and Boivin, 1993).

3.0 HABITAT INVENTORY AND CLASSIFICATION

The Habitat Inventory and Classification section of the pre-design document maps and discusses the physical and biological characteristics of the shorezone surrounding each pulp and paper mill. The shorezone is defined by the landward limit of wave action or the top of a coastal cliff and the seaward limit to the 20 m depth contour. The inventory and classification system is a comprehensive, standardized approach for describing habitats. Habitat information will be used to identify reference areas and select appropriate sampling species for the first cycle of the EEM program.

The boundaries for the mapped area were defined by:

- the immediate area of impact affected by the 1% dilution zone;
- important physical characteristics near the pulp and paper mills; and
- a practical scale to easily view the information on a single map.

The affected area to be mapped was chosen prior to a field reconnaissance program in early September, 1993. Photographic and video documentation were combined with habitat information available on the Prince Rupert area to produce four maps (Figures 3.1, 3.2, 3.3, and 3.4). A reference site has been selected in Kitkatla Inlet, Porcher Island (Figure 3.5). Complete physical and biological habitat mapping will be completed for the reference site during Cycle 1.

3.1 CLASSIFICATION SYSTEM USED FOR MAPPING

The classification system used for generating the required map sets is based on Department of Fisheries and Oceans (DFO) Coastal/Estuarine Fish Habitat Description and Assessment Manual (DFO, 1993) which DFO adopted for the characterization of coastal habitat areas. The mapping system was developed by Hatfield Consultants Ltd. using AutoCAD Release 12c (Autodesk Inc.) and combines information collected using techniques in Howes and Harper (1984), and the Assessment Manual (DFO, 1993). The mapping system attempts to present a large amount of information in a logical and comprehensible manner.

3.1.1 Overview of Coastal/Estuarine Fish Habitat Assessment Technique

The fish habitat assessment technique incorporates the following coastal classification systems:

- Ministry of Environment, Lands and Parks physical shorezone classification (Howes and Owens, 1980);
- Environment Canada coastal resource folios (Lands Directorate, 1984); and

- U.S. Fish and Wildlife Service wetlands and deep water habitats classification (Cowardin *et al.*, 1979).

The following modifications were made to simplify mapping:

- combining shallow subtidal and deep subtidal zones into one subtidal zone;
- combining all anthropogenic materials (e.g., concrete, metal, rubble) into one anthropogenic category;
- separate maps for physical habitat components and biological components; and
- processes (i.e., wind, wave, tides) were not mapped, due to the similarity of the processes throughout the mapped area.

The area encompassed by the maps (Porpoise Harbour and Wainwright Basin) is relatively small and protected by several islands. Processes, such as tides, wind, and waves, are quite similar throughout the area and do not provide significant variation to distinguish between shore units. Discussions of various processes are located in Section 2.2.2 - tides and currents, Section 2.3.3 - winds in Chatham Sound, and Section 3.3.1 - wave exposure.

The classification system divides habitat into four levels (ecosystem, shore unit, zone and component), according to the following table (DFO, 1993):

CLASSIFICATION LEVELS AND CATEGORIES FOR THE DFO MARINE/ESTUARINE FISH HABITAT DESCRIPTION PROCEDURE

Level	Category
I. Ecosystem	1. Marine 2. Estuarine
II. Shore Unit	1. Cliff to -20 m
III. Zone	1. Backshore 2. Intertidal 3. Subtidal - shallow - deep
IV. Components	1. Physical 2. Biological 3. Resource Use

The ecosystem level of classification consists of two categories: marine and estuarine. The marine ecosystem is described in DFO (1993, page 20) as: *"influenced by oceanic waters and have high salinity (e.g., 18 to 35 ppt), are directly affected by oceanographic processes (e.g., waves, currents* *and tides) and have typical marine biota."* The estuarine ecosystem is described as: *"characteristically a semi-enclosed body of water which has direct access to the sea but is diluted by freshwater input. It has a wide salinity range (0.5 to 18 ppt), is influenced by oceanic processes but generally tends to be sheltered and experiences lower energy regimes, and is much more influenced by terrestrial inputs than marine ecosystems."*

The shore-unit level of classification extends from the top of the coastal cliff or landward limit of marine processes seaward to the -20 m isobath. This category is subdivided into continuous alongshore units which are composed of homogenous across and along shore components with respect to morphology, sediment type and geomorphic processes (Howes and Harper, 1984).

The zone level of classification consists of the following three categories that are based on spring tide elevations: backshore, intertidal and subtidal (both shallow and deep). The backshore zone consists of land above high tide. The intertidal zone consists of the area between high and low tides; subtidal zones are segmented into shallow subtidal (0 to 10 m) and deep subtidal (10 to 20 m).

The component level of classification describes the physical, biological and resource categories. The following tables describe the different components based on Howes and Harper (1984) and DFO (1993).

FORM COMPONENTS	
Anthropogenic	Man-made or man-modified features.
Beach	An accumulation of unconsolidated material formed by waves and wave-induced currents in the zone that extends landward from the lower low water line for large tides to the place where there is a marked change in material or physiographic form, usually the effective limit of storm waves.
Cliff	A sloping face steeper than 20 degrees.
Delta	An accumulation of sand, silt and gravel deposited at the mouth of a stream where it discharges into the sea.
Dune	A mound or ridge formed by the transportation and deposition of wind blown material.
Platform	A relatively level or inclined surface with a slope of 20 degrees or less formed by erosional processes.
Tidal Flat	A level or gently sloping (less than 5 degrees) constructional surface exposed at low tide, resulting from tidal processes.

MATERIAL COMPONENTS	
Anthropogenic	metal concrete rubble logs structural wood
Unconsolidated	boulder cobble pebble sand mud
Bedrock	
Woodwaste	

BIOLOGICAL COMPONENTS	
CATEGORY	**DESCRIPTION**
Backshore	
Tree	Woody vegetation more than 5m in height.
Shrub	Woody vegetation less than 5m in height.
Grass	All non-woody vegetation including grasses and herbs growing above the high tide level.
Marsh	Composed of emergent vegetation that is infrequently inundated by high tides.
Intertidal	
Marsh	Similar to above except that the periods of inundation are more frequent.
Macroalgae	Non-vascular vegetation.
Seagrass	Vascular marine plants.
Barnacles	Colonizing crustaceans on hard surfaces.
Mussels	Colonizing bivalves on hard surfaces.
Clams	Bivalves living in finer sediments.
Subtidal	
Seagrass	Vascular marine plants.
Macroalgae	Non-vascular plants.

Cover is expressed as a percentage, based on the Braun-Blanquet vegetation cover abundance scale (DFO, 1993).

% COVER	
Sparse	less than 25 %
Moderately Sparse	26 - 50 %
Moderately Dense	51 - 75 %
Dense	76 - 100 %

Other conventions used in the mapping include species codes for salmon and trout that inhabit the local streams:

- Co - coho salmon;
- Cm - chum salmon;
- Pk - pink salmon;
- Dv - Dolly Varden char;
- St - steelhead;
- Rb - rainbow trout; and
- Ct - cutthroat trout.

3.2 HABITAT DESCRIPTIONS IN THE VICINITY OF PRINCE RUPERT - SKEENA CELLULOSE INC.

Visual assessments of substrate composition and floral and faunal foreshore community were made on September 1 and 2, 1993, during low tide. In Porpoise Harbour, seven shore units were identified. Wainwright Basin was divided into ten shore units. Each shore unit is individually as it pertains to the Figure 3.1 to 3.4.

3.2.1 Porpoise Harbour

- Figure 3.1 Physical Habitat Components: Porpoise Harbour
- Figure 3.2 Biological Habitat Components: Porpoise Harbour

Shore Unit # 1

Shore Unit #1 begins at the entrance of Porpoise Channel and continues for 1.2 km to a section of rip rap before Gay Island. The intertidal zone consists of a series of bedrock outcrops and small pocket beach formations consisting of gravel or cobble. The backshore zone consists mainly of bedrock either as a whole or in a fissured form. Some of the bedrock is covered with logs and driftwood. The subtidal zone was determined with a ponar dredge and it consists primarily of mud. Vegetation along the backshore zone is a dense stand of coniferous trees consisting mainly of cedar. In the intertidal zone, rockweed (*Fucus* spp.) is the dominant vegetation on bedrock and beach formations. There are also significant patches of kelp *(Nereocystis)* which extend from the deep intertidal to the subtidal zone.

Shore Unit # 2

Shore Unit #2 consists of a small 200 m section of man-made shoreline to the east of Gay Island. This unit consists primarily of large angular rip rap, both in the backshore and intertidal zones. The subtidal zone, again, consists of mud. Intertidal vegetation in this section is dominated by rockweed (*Fucus* spp.) with patches of sea lettuce (*Ulva*). The backshore contains little or no vegetation.

Shore Unit #3

Unit #3 encompasses a large portion of the west side of Porpoise Harbour from Gay Island to the log booming grounds approximately 2.0 km to the north. The substrate composition is similar to Shore Unit #1 where a series of bedrock cliff outcrops and small pebble beaches dominate. The subtidal zone consists primarily of mud with some sand. The backshore is made up of bedrock and small patches of large angular rip rap. Backshore vegetation is classified as trees; cedars are the dominant species. In the intertidal zone, rockweed is the dominant species with a dense covering along the bedrock and a moderately dense covering along the beach formations. There are sections of the backshore zone which have significant volumes of large logs and driftwood.

Shore Unit #4

Shore Unit #4 begins at the log booming grounds on the western shores of Porpoise Harbour and ends at the entrance to Zanardi rapids. This section (approximately 3.7 km) encompasses the complete northern shore of the harbour. The backshore in this unit is comprised of mainly anthropogenic materials (i.e., rip rap, asphalt or concrete). There are sections of bedrock along the northwestern portion of the harbour. The intertidal zone also consists primarily of anthropogenic materials, but has some areas of bedrock cliffs and intertidal beaches made up of mud and/or cobble. The subtidal zone was examined using a ponar dredge and it mainly consists of mud throughout the unit. There are areas in which large log debris are found buried in the mud and numerous old log pilings, mostly in the vicinity of the log booming grounds. Patches of smaller driftwood are present throughout the intertidal zone along the western and northern sides of the unit. The vegetation in the backshore consists primarily of a sparse covering of shrubs intermixed with small amounts of trees. There is a moderately sparse to moderately dense stand of trees along the western shore near the log booming grounds. Intertidal vegetation consists of macroalgae, dominated by rockweed (*Fucus* spp.) and some sea lettuce (*Ulva*). One discharge enters Porpoise Harbour from this shore zone (D1). Discharge D1 consists of collected leachate from a landfill directly adjacent to the access road to the grain terminal.

Shore Unit #5

Shore Unit #5 begins at the southern shore entrance to Zanardi Rapids and continues along the eastern shore to the tidal flats at the southern end of the harbour. This section (approximately 3.5 km) encompasses Skeena Cellulose's foreshore property and the town of Port Edward. The backshore in this unit is comprised entirely of anthropogenic materials (i.e., rip rap, asphalt or concrete). The intertidal zone also consists primarily of anthropogenic materials, but has some areas of bedrock cliffs and intertidal beaches made up of mud and/or cobble. The subtidal zone was examined using a ponar dredge and it mainly consists of mud/fines throughout the unit. The eastern shoreline contains small patches of driftwood debris along its length. The vegetation in the backshore consists of very small isolated patches of shrubs or grass. Intertidal vegetation consists of macroalgae, dominated by rockweed (*Fucus* spp.) and some sea lettuce (*Ulva*). There are also intertidal sparse coverings of barnacles in the vicinity of the mill. This unit encounters the majority of shipping traffic in the harbour and is susceptible to effects from it. There are also three discharge points within this shore unit. They are (Williams, 1991):

Site	Permit #	Description	Daily Maximum Allowable Discharge (m^3/day)
D2	PE-01157	Skeena Cellulose Inc.- final effluent discharge	200,000.00
D3	PE-04557	Village of Port Edward - municipal discharge	
D4	PE-07866	Aero Trading Company Ltd.- process discharge	110.00

Shore Unit #6

This shore unit consists of a shallow tidal flat channel which lies between Tsimpsean Peninsula and Lelu Island. Only a small portion of this channel was surveyed as it continues beyond Stapeldon Island. This 350 m unit is primarily made up of mud and fines in the intertidal zone which are exposed during low tide. There are sections of bedrock cliffs on the eastern and western sides. The backshore zone consists of bedrock on the western side and a mud/sand beach on the eastern end. Biological features include a moderately sparse covering of macroalgae, dominated by rockweed, in the intertidal zone. The backshore zone is dominated by moderately dense to dense stands of coniferous trees. There are also piles of driftwood debris throughout the intertidal and backshore zones.

Shore Unit #7

Shore Unit #7 encompasses the entire south side of Porpoise Channel. Its physical and biological make up is very similar to Shore Unit #1. The substrate material in the intertidal zone consists of a series of bedrock cliff outcrops and pebble/cobble beaches. The backshore zone is a series of bedrock cliffs and pebble cobbled/beaches. The subtidal zone was tested with a ponar dredge and it consists of mud. The vegetation in the backshore zone is comprised of dense stands of coniferous trees, dominated by cedars. The intertidal zone consists of a dense covering of macroalgae on the bedrock cliffs and a moderately dense covering on the beach formations. There are also moderately sparse patches of kelp in the subtidal zone.

3.2.2 Wainwright Basin

- Figure 3.3 Physical Habitat Components: Wainwright Basin
- Figure 3.4 Biological Habitat Components: Wainwright Basin

Shore Unit #8

Shore Unit #8 begins at the northeastern corner of the basin and encompasses Zanardi Rapids and beyond to the small tidal flat adjacent to the mill's #2 lagoon. The backshore substrate in this unit consists of fissured bedrock in a cliff form. The intertidal area is mainly mud in a beach or tidal flat formation, with areas of intertidal bedrock. The subtidal zone in this unit was not completely surveyed due to high currents in the area of Zanardi Rapids at the time of survey. The vegetation in the intertidal zone is primarily comprised of a moderately sparse to moderately dense covering of macroalgae, dominated by rockweed and intermixed with barnacles. The backshore vegetation consists primarily of coniferous trees in a moderately sparse to moderately dense covering. This area is exposed to very high currents which run through Zanardi Rapids.

Shore Unit #9

Shore Unit #9 is an area adjacent to the mill's #2 lagoon. The material in the intertidal and backshore zones is primarily of anthropogenic origin. Large angular rip rap line the intertidal and backshore zones. The subtidal zone is composed of mud in a tidal flat formation. The biological components in this unit consist of a sparse covering of macroalgae in the deep intertidal area and a moderately sparse covering of barnacles in the shallow subtidal zone along the riprap and scattered log debris. The backshore zone consists of some sparsely planted shrubs on the western side and a moderately sparse covering of trees on the eastern side of the shore unit. There is a significant amount of large log and driftwood debris which lies in the deep and shallow intertidal zones. Discharge from Lagoon #2 consists of natural flows form Wolf Cr. and a number of sources which flow from Lagoon #1, these inputs into lagoon #1 include:

- storm sewers;
- filter backwash;
- cooling water from TGS; and
- and raw water weir overflow.

Shore Unit #10

Shore Unit #10 begins where the anthropogenic material of Shore Unit #9 ends and continues for approximately 700 m to a log booming area. The substrate in this unit is comprised mainly of bedrock cliff formations in both the intertidal and backshore zones. The subtidal zone consists of mud with various proportions of woody debris intermixed as the test sampling with the ponar dredge came closer to the booming area. The vegetation in this unit is comprised of a moderately dense stand of coniferous trees in the backshore. The intertidal zone consists of dense growths of rockweed all along the rock face. Along with rockweed there is a significant growth of barnacles in the shallow intertidal zone. Shore Unit #10 is bordered on the south side by a major roadway which runs between Port Edward and Prince Rupert.

Shore Unit #11

This shore unit is approximately 750 m in length and is comprised mainly of the log booming area and adjacent beaches. It is bordered by a major roadway to the south and anthropogenic materials to the east. The backshore material is mainly cobble and cobble-sized fissured bedrock. The intertidal zones material is comprised of mud in a tidal flat formation at the head of the bay and a mud and cobble beach formation at the eastern end. The vegetation in this shore unit consists mainly of grass with trees in the backshore zone. The intertidal zone vegetation is a sparse covering of macroalgae except on the cobble beach where the macroalgae covering increases to moderately dense. The subtidal substrate was tested with a ponar dredge and it contains significant quantities of woody debris even out to the 20 m isobath. The backshore, intertidal and subtidal zones are constantly exposed to log booming activities in this shore unit.

Shore Unit #12

Shore Unit #12 is approximately 550 m in length and contains mainly anthropogenic rip rap materials. The backshore and shallow intertidal zones are made up of large angular rip rap, while the deep intertidal area consists of a mud beach. The subtidal area mainly consists of mud and fines. Vegetation in the backshore zone consists of a sparse covering of shrubs. The intertidal zone vegetation consists of a sparse to moderately sparse covering of macroalgae dominated by rockweed and sea lettuce. The backshore is directly adjacent to a major highway connecting Port Edward to Prince Rupert.

Shore Unit #13

Shore Unit #13 encompasses the eastern end of Wainwright Basin including Galloway Rapids and the highway bridge crossing. The backshore and shallow intertidal zones substrate on the southern side of Shore Unit #6 consists mainly of bedrock outcrops in a cliff formation, with the deep intertidal zone made up primarily of a mud/sand tidal flat. There is also a small pocket beach with a pebble substrate. The northern side of Shore Unit #13 has a bedrock cliff backshore, shallow intertidal zones and a deep intertidal zone comprised of mud in a beach formation. The southern portion of this unit has a moderately sparse covering of trees while the northern end has a moderately sparse covering of shrubs. Vegetation in the intertidal zone is primarily rockweed and varies in percent coverage from a sparse covering to a moderately dense covering. This shore unit also contains a large dense patch of eelgrass in the intertidal and subtidal zones. This shore unit is susceptible to fast flowing currents due to Galloway Rapids. In this area, large schools of stickleback were observed at the time of the survey.

Shore Unit #14

This 350 m shore unit runs parallel to the highway and is comprised of anthropogenic material in both the backshore and shallow intertidal zones. The deep intertidal zone is comprised of a mud tidal flat which encircles a moderately sized island vegetated with trees. There are small bedrock outcrops on all sides of the island which are moderately densely vegetated with macroalgae. The vegetation in the deep intertidal zone consists of a sparse covering of macroalgae. The shallow intertidal area along the rip rap material has a sparse covering of barnacles and some macroalgae. The backshore vegetation is comprised of a moderately sparse covering of shrubs.

Shore Unit #15

This shore unit, located at the northeastern end of Wainwright Basin, has an unnamed creek which empties into it. There is little information on this creek, but it is known to support cutthroat trout. The substrate in the backshore consists primarily of pebble sized rocks with fines intermixed. The intertidal zone consists of a large mud tidal flat vegetated sparsely with macroalgae and scattered throughout with empty clam shells. There is also a large patch of eelgrass on the fringe of the intertidal and subtidal zones. The backshore zone is vegetated with a moderately dense stand of coniferous trees. The subtidal zone was sampled with a ponar dredge and it consists of mud and fines.

Shore Unit #16

Shore Unit #16 encompasses the north central portion of Wainwright Basin. Its backshore zone is a series of bedrock cliffs and cobble beaches. The intertidal zone is primarily made up of a mud tidal flat formation with areas of fissured bedrock cliffs and a small mud beach. The subtidal zone consists of mud and fines. The vegetation in the backshore zone consists of moderately sparse to moderately dense stands of coniferous trees. The intertidal zone has a sparse to dense covering of macroalgae, depending upon the substrate on which it is growing. There was also evidence of clams in this shore unit, with empty shells scattered sparsely throughout.

Shore Unit #17

This shore unit, located at the northwestern end of Wainwright Basin, has four unnamed creeks which empty into it. There is little information on these creeks, but it is known that cutthroat trout inhabit all four. The substrate in the backshore zone is comprised mainly of cobble sized rock or bedrock with fines intermixed. The intertidal zone is a large mud tidal flat which extends up to 600 m from shore. The vegetation in the backshore consists primarily of a moderately sparse covering of grass with trees and shrubs intermixed and behind the grass layer. The intertidal vegetation consists of a moderately sparse covering of macroalgae. There are three significantly large patches of eelgrass with many smaller patches throughout the area. The intertidal zone substrate contains a small amount of woody debris which was evident in patches. The backshore contains significant quantities of large log and driftwood debris.

3.3 PHYSICAL OCEANOGRAPHIC FACTORS INFLUENCING HABITAT FEATURES IN THE VICINITY OF SKEENA CELLULOSE INC.

The productive capacity of floral and faunal communities in coastal habitat are influenced by oceanographic forces such as tides, wind, waves, and sediment transport (DFO, 1993). Oceanographic conditions in the Porpoise Harbour and Wainwright Basin areas are discussed in the following subsections, or in Section 2.2.2 - tides and currents.

3.3.1 Effective Fetch, Maximum Fetch and Wave Exposure Index

Shoreline communities can be influenced by wind and wave action (DFO, 1993). Effective fetch and wave exposure index calculations were made at the center of Shore Unit #11 in Wainwright Basin and from the most northerly point in Porpoise Harbour at Shore Unit #4. The effective fetch for a specific location is the measured fetch distances of a line perpendicular to shore (i.e., shore normal), and lines 45 degrees to the left and right of shore normal. Maximum fetch is the distance (in km) that is exposed to wind driven waves. Compass bearing is often determined as a component of fetch (DFO, 1993). The effective fetch formula is:

$$\text{Effective fetch} = \frac{\Sigma(\cos\alpha)F_i}{\Sigma(\cos\alpha)} = \frac{(\cos\alpha_1)F_1 + (\cos\alpha_2)F_2 ... (\cos\alpha)F_i}{\cos\alpha_1 + \cos\alpha_2 + ... \cos\alpha_i}$$

where F = measured fetch distance and,

α = angles between normal (i.e., 90°) and transects (i.e., 45°).

WAVE EXPOSURE INDEX				
	EFFECTIVE FETCH (km)			
MAXIMUM FETCH (km)	<10	10 - 49	50 - 499	>500
<1	very protected	n/a	n/a	n/a
1 - 9	protected	n/a	n/a	n/a
10 - 49	semi-protected	semi-protected	n/a	n/a
50 - 499	semi-exposed	semi-exposed	semi-exposed	n/a
>500	n/a	semi-exposed	exposed	exposed

Source: Howes *et al.*, 1993.

The wave exposure index is determined by measuring the maximum wave fetch and effective fetch, and using these values to find the corresponding index in the above table.

Fetch calculations for Porpoise Harbour indicate:

- Effective fetch - 2.2 km
- Maximum fetch - 4.1 km
- Wave exposure index - protected

Fetch calculations for Wainwright Basin indicate:

- Effective fetch - 1.5 km
- Maximum fetch - 2.1 km
- Wave exposure index - protected

3.3.2 Sediment Characteristics

Sediment physical characteristics and quality near the pulpmill are described in Section 5.2. That section presents information on fibre beds, particle size, sediment volatile residue, trace metals and organochlorines associated with sampling programs.

4.0 RESOURCE INVENTORY

4.1 INTRODUCTION

The fish resources of northern British Columbia coastal waters are both diverse and economically important. This Resource Inventory documents the abundance of all fish species which may, at some point of their life-cycle, come into contact with effluent from the Skeena Cellulose Inc. pulpmill at Prince Rupert, British Columbia. Information for this inventory includes published material from Department of Fisheries and Oceans (DFO) and B.C. Ministry of Environment, Lands and Parks (MELP) sources updated with current information from personal communications with DFO and MELP personnel. Hoos (1975), Ketchen *et al.* (1983), and the Coast Salish Fisheries Working Group document (CSFWG, 1993) provide reviews relevant to British Columbia coastal fisheries and were used extensively.

This Resource Inventory is divided into four sections and a synopsis:

- Regional Resource Inventory, which deals with the finfish and shellfish species contributing to the commercial, native, and sport fisheries as well as limited information on currently non-harvested fish of the north coast of British Columbia[1];

- Local Resource Inventory, which provides detailed coverage of these resources in the Prince Rupert area, within an approximately 30 km radius of the Skeena Cellulose pulpmill, at Prince Rupert. Although the majority of the coverage is marine, freshwater drainages are also included in the inventory (the most notable of these being the Skeena River);

- Fish Community Studies, which summarizes recent reports on fish communities in aquatic habitats (freshwater, marine, and estuarine) in the vicinity of Prince Rupert; and

- Candidate Sentinel Species, which discusses the biology and ecology of local species which could be considered for use as sentinel species as defined by the Technical Guidance Document (Anon., 1993b).

4.2 REGIONAL RESOURCE INVENTORY

The Regional Resource Inventory was prepared as a summary overview of the fish resources of northern British Columbia coastal waters. Many species occurring in local waters are harvested as part of larger nearby stocks (e.g., walleye pollock in Hecate Strait). This overlap of local and

---

[1] There is currently a general lack of information on most species which have no historical commercial, sport or native fisheries value. However, such information has been included here when it was available.

regional resources, in the vicinity of Prince Rupert, and the lack of information on regionally distributed fish stocks, necessitated this broader approach. The Regional Resource Inventory provides information on basic biology, distribution, and harvests (commercial, First Nations, and recreational) allowing an overall assessment of the relative importance of resources, which may come into contact with the Skeena Cellulose pulpmill. Local information on regional finfish and invertebrate stocks will be highlighted within this context.

4.2.1 North Coast and Hecate Strait

4.2.1.1 Geomorphology and Oceanography

A detailed description of the geomorphology and oceanography of Hecate Strait and northern coastal waters may be found in Thompson (1981), and is summarized below.

Hecate Strait is the shallowest of the major channels that make up the Hecate Depression; the other two channels being Dixon Entrance and Queen Charlotte Sound (Figure 4.1). This depression forms a segment of a continuous, low-lying area which extends from Puget Sound to Alaska. The long axis of Hecate Strait is a narrow 220 km long submarine valley with depths that diminish from approximately 300 m in the south to 50 m in the north. The bathymetry is fairly regular compared with other British Columbia coastal waters.

Tides in Hecate Strait are semidiurnal and co-oscillate with those in the North Pacific Ocean. The constricting waters of the strait cause the tidal range to increase from about 2.0 in the ocean waters to about 3.7 m in the vicinity of Prince Rupert. In the absence of strong winds and freshwater inputs, the surface currents within Hecate Strait are relatively simple; floods are directed to the north and ebbs flow southward at maximum rates of about 50 cm/s. Wind and runoff both have strong seasonal effects on surface currents.

The coastline of the Hecate Lowland consists of discontinuous sand, gravel, and boulder beaches between low rocky headlands. The Skeena River enters these lowlands approximately 20 km south of Prince Rupert, and forms a delta extending 30 km into Chatham Sound. The Skeena River delta is the second largest in the province. Although the delta exhibits no extensive tidal flats, sediment from the river has been deposited between the area islands. The currents at the mouth of the river may exceed 1.5 m/s and have formed extensive bars.

4.2.1.2 Fisheries Statistical Areas

Hecate Strait and the waters in the immediate vicinity of Prince Rupert are located within the North Coast "area", for management purposes by DFO. Hecate Strait is located in Statistical Area 5C and 5D. Prince Rupert is located within Management Area 4. Productive fisheries occur throughout the area for a wide variety of finfish and invertebrate resources. Catches for many of these species have been recorded since the first quarter of this century; herring records date back to 1877 (Haist and Schweigert, 1992). Use of the area's resources by First Nations extends back many millennia.

4.2.2 Finfish

Commercial fishing employs a significant number of people in the Prince Rupert area (42% in 1970 - Hoos, 1975). Of the various fisheries in the area, salmon represents the single largest source of income. However, a number of other species contribute significantly to the sport, commercial, and native fisheries in the area. These species are listed in Table 4.1. Although information on harvested stocks is the most readily available, there are also numerous unharvested finfish species in Hecate Strait and the Prince Rupert area. Limited information on these unharvested species may be found in Hart's (1973) "Pacific Fishes of Canada", which describes over 300 species of finfish from British Columbia waters.

Hoos (1975) has reviewed the resources of the Skeena River estuary and surrounding fisheries. Although now dated, his report provides an historical review and useful background information. The present Regional Resource Inventory updates Hoos' review with current information, and presents stock, and area specific information in more detail.

4.2.2.1 Salmon

Significant salmon runs pass through Hecate Strait both as adults returning to spawn and as immature forms in the first years of marine life. The Skeena River produces large numbers of salmon, and is second only to the Fraser River among British Columbia rivers in total salmon output. Sockeye and pink salmon are the most abundant, although coho, chum, chinook salmon, and steelhead trout also contribute to the recreational and commercial harvest (Hoos, 1975). In addition to the Skeena River stocks, many other rivers emptying into the inlets and estuaries of Hecate Strait exhibit sizable populations of salmon. The total British Columbia commercial harvest of salmon had an annual wholesale value of $540 million between 1987 to 1989 (Henderson, 1991). The economic value of the tidal and freshwater sport and native fisheries for these species has not been similarly quantified, but they are without doubt considerable. The commercial sectors of the salmon fishery include gillnet, seine, and troll fisheries.

The migration patterns of salmon within Hecate Strait and the pattern of commercial, sport, and native fishing complicates the assignment of the various catches to specific areas. Much of the commercial fishery operates as an intercept fishery far from the stream of origin. Except for terminal fisheries at the mouths of creeks and rivers (most notably the Skeena River), individual fish caught in the strait could be from almost any spawning stream. Therefore, management of the salmon fishery within British Columbia coastal waters is conducted on the basis of stream escapement. The spawning escapements of the appropriate salmon bearing watersheds in the vicinity of Prince Rupert are described below in the Local Resource Inventory (Section 4.3.6).

Sockeye

Sockeye are the most economically significant salmon species in the commercial catch from Hecate Strait. Catches of this species within the tidal waters of Management Area 4 (Prince Rupert) are shown in Figure 4.3. Sockeye salmon tend to exhibit cyclic dominance within individual spawning stocks, and may have relatively high spawning escapements every four years. Although sockeye from the area are from a number of spawning populations (and therefore often exhibit asynchronous cycles), the dominant Babine stocks of the Skeena River watershed profoundly influence the landings in any given year. As a consequence, the landings are normally quite variable between years. Over the past ten years, these landings have ranged between 1,000 and 6,000 tonnes annually. On their return spawning migration, sockeye adults appear in numbers in the Prince Rupert area from early July until September. Within this period, specific stocks may be observed over a much shorter duration (often a few weeks).

The biology of sockeye salmon has been summarized in detail by Burgner (1991). Sockeye salmon are either of the anadromous (migratory) or non-anadromous (non-migratory) form. Anadromous sockeye spend up to three years in freshwater before migrating to sea as smolt and up to four years at sea. The majority of spawning stocks of the Skeena River spend one full year in freshwater and two or three full years in the north Pacific Ocean, returning to their natal stream to spawn in their fourth or fifth year. Average fecundity is between 2,000 to 5,000 eggs per female, depending on fish size. Spawning may take place in inlet streams to nursery lakes or in the lakes themselves. Following their freshwater residency, yearling sockeye smolt migrate seaward in April to June.

After reaching the Skeena River estuary during their downstream migration, some sockeye smolt move along the mainland and westward islands, but the majority remain in the vicinity of the river mouth for about one month (Hoos, 1975). Upon entering Hecate Strait, Skeena River sockeye smolt disperse northward along the mainland coast then west through Dixon Entrance to the Pacific Ocean.

Pink

Pink are the second most abundant salmon species in the commercial catch from Management Area 4. Most of these fish are likely of Skeena River origin. Catches of this species within the tidal waters are shown in Figure 4.3. Both odd and even year runs of pink salmon are important in the Prince Rupert/Skeena River area. This is in contrast to many southern areas, where only one type of run predominates (Heard, 1991). Over the past ten years, pink salmon landings have ranged between 1,000 and 3,700 tonnes. Numbers of inshore migrating pink salmon peak between late July and early September.

The biology of pink salmon has been summarized in detail by Heard (1991). Pink salmon spend only a short period of time in freshwater, migrating seaward immediately upon emergence from spawning gravels. Individuals spend over a year at sea and return to their natal stream to spawn in their second year. Average fecundity is between 1,100 and 2,200 eggs per female, depending on fish size. Spawning generally takes place in coastal streams, although a few Skeena River populations occur far upstream. Most pink salmon smolt migrate seaward in April to June in the Skeena River and disperse widely (>50 km) from their natal stream in a few days. Pink salmon from the Skeena River, may spend up to one month near the banks offshore of the Skeena River before entering open ocean. Unlike sockeye smolt, they do not reside at the mouth of the Skeena River itself (Hoos, 1975).

Chum

Chum are the third most abundant salmon species in the commercial catch from the marine waters in the vicinity of Prince Rupert. Catches of this species within tidal waters are shown in Figure 4.3. Over the past ten years, annual landings have ranged up to 1,200 tonnes. Over the past several decades, chum salmon in Management Area 4 have been heavily harvested; exploitation rates have rarely been lower than 60% and occasionally may exceed 80% of the returning biomass (Beacham, 1984). However, the local stocks appear to be able to withstand such high exploitation rates. The numbers of chum salmon peak in October as they return to their natal streams to spawn.

The biology of chum salmon has been summarized in detail by Salo (1991). Individuals migrate seaward shortly after emergence and may spend two to four years at sea before returning to their natal stream to spawn. Chum salmon spawn in over 800 coastal streams in British Columbia making it the most ubiquitous among the salmon species. Chum are relatively large; up to a meter in length and 20 kg in weight. Average fecundity is between 2,000 and 4,000 eggs per female, depending on fish size and egg diameter. Spawning generally takes place in coastal streams or for short distances up larger rivers (generally not above obstructions). Most chum salmon smolt migrate seaward in April in the Skeena River. Individual chum are dependent on estuaries for several weeks in May and Skeena River chum salmon may not migrate to sea until late summer (Hoos, 1975). Upon entry into salt water, underyearling chum tend to remain in shallow water, utilizing intertidal waters at high tide before they move to deeper waters (20 to 40 m deep). Migration to open ocean is believed to occur shortly afterward.

Chinook

Chinook are of modest significance as a commercial species and harvest has been decreasing due to management regulations and reduced stock abundance. Commercial catches of this species within the tidal waters of Management Area 4 are shown in Figure 4.3. Over the past ten years, these landings have ranged between 100 and 225 tonnes, and they have been steadily declining. Chinook are also an important sport fish species. Within this period, specific stocks are observed over a much shorter duration.

The biology of chinook salmon is reviewed by Healey (1991). Adults of this species are easily distinguished from other Pacific salmon by its size; adults may attain 45 kg. Chinook salmon exhibit a wide range of life history strategies, but there are two general forms. "Stream-type" stocks remain in freshwater for one or two years, while "ocean-type" individuals (mostly from coastal systems) migrate seaward as underyearlings. Both forms remain in the marine environment for one to five years (on average, "stream-type" individuals are one year older at maturity). Spawning populations are generally small, and weakly correlated with river discharge. Average fecundity is between 4,000 and 10,000 eggs per female, depending on fish size (and possibly latitude). Following their freshwater residency, underyearling smolt of "ocean-type" forms migrate seaward in May to June in the Skeena River, taking up residence in estuarine habitats in the lower river. Chinook fry tend to take up residence in estuarine habitats at the mouth of the Skeena River from May to August (Higgins and Schouwenburg, 1973). Yearling "stream-type" individuals migrate seaward later than the "ocean-type" form and generally exhibit a short estuarine residency period (or none at all). Healey (1980) found that the older "stream-type" chinook were resident in nearshore waters in the Strait of Georgia from late May to August, while the underyearling "ocean-type" chinook may remain in near-surface waters throughout their first year in the marine environment.

Coho

Coho salmon are currently of modest importance as a commercial species, but extremely important as a sport fish species. Historically, coho salmon commercial harvests were quite high, with approximately 100,000 fish being taken annually in the Prince Rupert area from 1951 to 1963 (Hoos, 1975). Commercial catches of this species within tidal waters of Management Area 4 are shown in Figure 4.3. Over the past ten years, these landings have ranged between 200 and 550 tonnes. Spawning migrations occur in Fall. Coho exhibit a protracted spawning migration compared to other salmon; possibly three months or more in many stocks (Sandercock, 1991).

The biology of coho salmon has been summarized by Sandercock (1991). For north coast British Columbia populations, the majority of coho (approx. 95%) return to spawn as three year olds after 16 months at sea, but younger male individuals ("jacks") may spawn after only four to six months in the marine environment. Average size and weight of the three year olds is about 50 cm and 3.2 kg. Average fecundity is about 2,000 to 3,000 eggs per female, depending on fish size (and latitude). Following their one year freshwater residency, yearling smolt migrate seaward in April to July and exhibit an estuarine residency period of up to two months at the mouth of the Skeena River.

Steelhead

Steelhead trout, the anadromous form of rainbow trout, are highly prized game fish which can grow to an excess of 1.0 m and 19 kg; a 19.5 kg individual was caught off Port Simpson, near Prince Rupert (Hart, 1973). Most young fish spend two or three years in freshwater. Although, steelhead are known to use the estuaries as rearing habitat in some systems during their first year (e.g., Macdonald *et al.*, 1987), this does not appear to be the case in the Skeena River (Hoos, 1975). Steelhead return to spawn after one to four years at sea. Unlike the salmon species above, steelhead may spawn more than once and return to the sea after each spawning event. They may spawn two or three times over their lives.

There are concerns about the long term implications of commercial fishing pressure for other salmonid species on much smaller steelhead stocks, which are caught as a by-catch. These concerns are coast-wide but are especially relevant to the Prince Rupert area as the Skeena River supports the largest steelhead run of any river in the province. Commercial steelhead landings in Management Area 4 have been less than 120 tonnes fish annually over the past decade and are declining (Figure 4.3).

4.2.2.2 Groundfish

Various groundfish species (cod, pollock, flatfish, lingcod, and rockfish) support important fisheries within the waters of Hecate Strait and the Prince Rupert area. These resources are assessed annually by DFO, and management quotas are assigned where appropriate to protect commercially important stocks. The most recently published stock assessments may be found in Leaman (1992a), which summarizes catches up to 1991 for many of the groundfish stocks of the British Columbia coast. Hart (1973) provides additional biological information on groundfish life-histories.

Pacific cod

The Pacific cod is a true cod (i.e., a member of the Cod Family - Hart, 1973). Pacific cod exhibit a high rate of growth and can reach about one meter in length. Females are very fecund producing several million eggs each and can reach sexual maturity in three years; males mature in two years. Few individuals survive past age 7. The species spawns in aggregations during winter, but remains dispersed for much of the remainder of the year. Pacific cod consume a wide variety of invertebrates and fish, including worms, crabs, molluscs, shrimp, herring, sand lance, walleye pollock, and flatfish species.

Pacific cod is a major component of the fishery for trawl-caught demersal fish species in British Columbia (Tyler and Hand, 1992). Currently, the cod catches in the Prince Rupert area appear to be stable within normal population variances. However, landings can be quite variable depending on the relative sizes of a few dominant year-classes (e.g., from 1982 to 1992 landings fluctuated between 530 and 3,000 tonnes annually - Figure 4.4).

Walleye pollock

Like Pacific cod, the walleye pollock is a member of the cod family and attains lengths of 80 cm (Hart, 1973), although they rarely exceed 60 cm in the commercial catch (Saunders, 1992b). Spawning occurs in deeper waters. They are common throughout British Columbia coastal waters and appear to overlap spatially with Pacific hake (Saunders, 1992b).

In the commercial fishery, walleye pollock are marketed as "bigeye cod" and are used as a substitute for Pacific cod when landings of the latter are low (Saunders, 1992b). Currently, there is a low intensity fishery for walleye pollock on the British Columbia coast. Landings in Prince Rupert have occasionally represented over 25% of the British Columbia commercial harvest (Figure 4.5).

Sablefish

Sablefish (or black cod), is not a member of the cod family but is anatomically similar to cod species. The sablefish is an important commercial species from western Vancouver Island and offshore waters (Saunders and McFarlane, 1992), and has been commercially exploited since the late nineteenth century. Foreign vessels increased the exploitation of the species in the 1960's and 1970's (Figure 4.6); unrestricted foreign fishing ceased with the establishment of the 200 mile limit in 1977. Landings in Hecate Strait in general, and the Prince Rupert Area specifically, represent only a minor component of the sablefish harvest (Figure 4.6). Over the past ten years, sablefish landings in Prince Rupert have not exceeded 45 tonnes annually.

Sablefish grow to 1 meter long and can be over 57 kg (Hart, 1973). They grow at a moderate rate; at 51 cm fish grow about 450 g annually and reach approximately 57 to 60 cm in five years (off the Oregon coast). occur in the Strait of Georgia as immature individuals (Hart, 1973), but the importance of the Strait to their life-cycle has not been established. Pelagic eggs are spawned in January and February. Schooling juveniles are known to occasionally enter inshore harbours. Sablefish appear to be opportunistic feeders, consuming crustaceans, worms, and small fish (Hart, 1973).

Lingcod

The lingcod is also not a true cod, but is a member of the Greenling Family. The following summary of the biology and economic significance of lingcod in British Columbia has been synthesized from a recent review by Cass *et al.* (1990). Lingcod are present throughout British Columbia coastal waters (Figure 4.7), and are considered non-migratory. Adult lingcod spawn in rocky, current swept areas (rocky crevices) between December and March. Eggs are deposited in a single mass in these nests with older females laying as many as 500,000 eggs (Hart, 1973). Male lingcod remain close to the nests and protect the eggs from predators (e.g., kelp greenlings, striped seaperch, rockfish, cabezon, and starfish) while they develop. While nest-guarding, the adult male lingcod are vulnerable to predation by seals and sealions as well as exploitation by divers. Following hatching and a brief pelagic larval period, the juveniles settle to the bottom and assume an epibenthic existence, first residing in shallow water adjacent to kelp and eelgrass beds. Lingcod exhibit a high degree of site fidelity, and rarely stray more than 10 km from where they were hatched. Lingcod growth is rapid during the first several years, with average body sizes of 21, 33, and 45 cm achieved by the end of the first, second, and third years of life, respectively. Males may live for 14 years and females 20. The largest lingcod on record was 1.5 m long and weighed 32 kg. As they grow, individuals tend to occupy deeper habitat. Lingcod are vulnerable to fishing at age 2, and are fully recruited to the fishery at age 6. Adults are voracious predators of both fish and invertebrates, consuming herring, hake, sand lance, flatfish, rockfish, dogfish, young lingcod, salmon, crab, shrimp, squid, and octopus.

The British Columbia commercial lingcod fishery developed during the late 19th century. By the 1940's, approximately 200 handline vessels fished within Georgia Strait, with peak landings of 3,300 tonnes per year in 1944 (Richards and Yamanaka, 1992). The catch in southern British Columbia waters has declined steadily since the 1960's but appears stable in the Prince Rupert area (Figure 4.8). The annual commercial catch in northern British Columbia waters is relatively modest (e.g., less than 160 tonnes in Management Area 4). In recent years, lingcod have also been harvested by recreational anglers and scuba divers.

Flatfish

There are 21 species of flatfishes in British Columbia waters (Hart, 1973). Most of these are halibut, soles, or flounder; the remaining two are sanddabs. Flatfish begin life as a planktonic larva then go through an elaborate metamorphosis in which the body flattens laterally and one eye "migrates" to the other side of the head (e.g., sanddabs are said to be "left-eyed", while other British Columbia flatfish are "right-eyed"). Following this change in body morphology, the animal settles to the bottom to assume an epibenthic existence. Many species utilize near-shore and estuarine waters as larvae and juveniles before moving to deeper waters as they grow. This pattern is well established for the starry flounder.

Other than Pacific halibut, which is managed under the auspices of the International Pacific Halibut Commission (Leaman, 1992b), flatfish assessments are restricted to petrale sole, Dover sole, rock sole, and English sole (Fargo, 1992). The main commercial fishing areas for these species include the west coast of Vancouver Island, Queen Charlotte Sound, and Hecate Strait (Fargo, 1992). All four of these species are landed in Prince Rupert as part of the commercial catch, and their aggregated landings have been stable between 600 and 1,700 tonnes annually (Figure 4.9 and Figure 4.10). Halibut landings of between 150 and 200 tonnes are also landed in Prince Rupert (approximately 15 to 25% of the British Columbia total - Figure 4.11). Turbot, or arrowtooth flounder, is also harvested locally at levels up to 750 tonnes annually (Figure 4.10). Other flounder species are also harvested in modest amounts (Figure 4.10).

Two flatfish species have been considered as candidate sentinel species for EEM (Forsyth, 1993). These are English sole and starry flounder (see Section 4.4).

Rockfish

Rockfish include a species complex within the family Scorpaenidae (Scorpionfishes) that are represented in British Columbia waters by 35 species of the genus *Sebastes* and two species of the genus *Sebastolobus* (Hart, 1973). They are a "reef fish", tending to be found in rocky areas of varying depths (Figure 4.12). Rockfish females produce as many as a million eggs. The species fertilizes internally and young are born live. Some species grow as large as 90 cm although most species rarely exceed 60 cm. Age determination is difficult for rockfish, but individuals of some species may live 70 years or more (Richards and Yamanaka, 1992).

For management purposes, rockfish are divided into slope rockfish, shelf rockfish, and inshore rockfish (Leaman, 1992a). Common species in the Hecate Strait harvest include silvergray rockfish, yellowtail rockfish, and canary rockfish - among the "shelf" species - as well as numerous species from inshore waters. The relative importance of individual rockfish species to the inshore fishery of the north coast is not generally known although yelloweye rockfish (red snapper) appear to be the dominant species (Richards and Yamanaka, 1992). Most of the commercial vessels use handline/troll or longline gear. The commercial fishery expanded rapidly in the mid-1970's (Figure 4.13) in response to increasing demand for live rockfish to supply the restaurant trade, primarily in Vancouver's Chinatown. Inshore rockfish are also exploited as a sport fish.

4.2.2.3 Herring

Herring are an important component of the British Columbia commercial fishery with catch records dating from 1877. The historical development of the commercial herring fishery in British Columbia is described by Ketchen *et al.* (1983). In the early part of the century, herring were dry-salted and exported to markets in the Orient. Between 1935 and 1967, a purse-seine fishery operated in the fall and winter months, with most of the catch being reduced to meal and oil. The early 1960's witnessed a catastrophic decline which was attributed to poor recruitment, over-exploitation, and ineffective management (Ketchen *et al.*, 1983). Catches recovered somewhat in the 1970's as part of a "roe fishery", which currently supplies the Japanese market. The roe fishery takes place in March, just prior to spawning. Current landings in the Prince Rupert area represent 12 to 25% of the British Columbia harvest (Figure 4.14 and Figure 4.15).

Herring may reach sexual maturity in their second, third, or fourth year and may live in excess of eight years (Hart, 1973). Herring spawn in schools, depositing their eggs in seagrasses and various marine algae such as rockweed, kelp, and red and green algae. They may also spawn on rocks in subtidal areas. Part of the "herring" harvest consists of roe on kelp, which has seen stable to increasing harvests over the past decade (Figure 4.15). The strength of an individual cohort (and stock size in subsequent years - Figure 4.14) is determined by the survival of larvae and juveniles in their first summer.

4.2.2.4 Dogfish

The spiny dogfish is a small shark found commonly throughout British Columbia coastal waters. The species can attain lengths up to 1.3 m and weights in excess of 9 kg (Hart, 1973). Females mature at lengths over 80 cm and have slow growth, low fecundities, long gestation period (eggs are fertilized and brooded internally for 23 months), and are noted for their longevity. They require at least 20 years to reach maturity and many individuals live in excess of 70 years (Ketchen *et al.*, 1983). They feed on almost anything smaller than themselves, although diet changes predominantly to fish prey as they grow.

The exploitation of dogfish since the late 1800's has tracked market trends, alternately being ignored and rigorously exploited by various fisheries (Ketchen *et al.*, 1983). The most common commercial use for the species has been for fishmeal and oil. However, dogfish have often been harvested simply for "pest control". Catches reached a maximum of 15,000 tonnes during the 1940's. Current assessments (Thomson *et al.*, 1992) describe the Hecate Strait catch as up to 400 tonnes annually, during the 1980's (Figure 4.16).

4.2.2.5 Other Finfish

Hart (1973) provides detailed descriptions of the anatomy, biology, and ecology of a total of 325 marine fish species which are found in British Columbia waters. Several of these species deserve attention either because of their potential to become important fishery resources in the future, or their potential utility as EEM sentinel species.

Pacific hake are common along the entire British Columbia coast. The Pacific hake can grow to about 90 cm and females exhibit high fecundities (approx. 500,000 eggs at 70 cm - Hart, 1973). A description of spawning behavior may be found in Mason *et al.* (1984). Pacific hake are harvested mainly in Strait of Georgia waters. The absence of particular parasites known to infect offshore Pacific hake, and the potential for a roe harvest from large spawning aggregations has made this an increasingly important fishery in that area in recent years (Saunders, 1992a). They are generally not harvested in north coast waters; although modest landings of 34 tonnes have been reported in preliminary catch statistics for 1993, from Prince Rupert (DFO, Data Management Unit).

Recently, an experimental trap fishery for Pacific hagfish was started off the west coast of Vancouver Island for export to Asian markets (Neville and Beamish, 1992). At present there is no quota assigned. Recorded landings from Statistical Area 23 (southwest Vancouver Island) totaled 227 tonnes in 1989. Although not currently fished elsewhere, hagfish are known to occur throughout British Columbia waters and other locations may supply an expanded fishery in the future.

The Pacific staghorn sculpin is common throughout British Columbia coastal waters in subtidal and intertidal zone habitats and penetrates into lower portions of coastal streams (Hart, 1973). The species has been considered as a potential sentinel species because it remains in areas exposed to effluent, is an obligate benthivore, is reasonably abundant, exhibits site-specific spawning behavior, has moderate fecundity and longevity, and rapid growth (Hart, 1973; Forsyth, 1993). However, the species may be too tolerant of effluent to be of use as a sentinel species (Forsyth, 1993).

Cabezon is a large member of the sculpin family and may achieve sizes up to 75 cm in length and 11 to 14 kg (Hart, 1973). It is known to be abundant at moderate depths (Hart, 1973), but its exposure to effluent is not known (Forsyth, 1993). It has the same general description as the sculpin, but is much longer-lived.

The threespine stickleback is an abundant anadromous species in British Columbia waters (Hart, 1973). It has been considered to be a potential sentinel species because of its exposure to effluent, site-specific spawning and rearing characteristics, its abundance, short longevity (one to two years), and rapid growth (Hart, 1973; Forsyth, 1993). Its lack of sensitivity to effluent has made its use as a sentinel species questionable (Forsyth, 1993).

Three members of the surfperch family are relatively common in British Columbia coastal waters. These include the shiner perch, the striped seaperch, and the pile perch. They are relatively shallow water species of medium size (growing to 15, 38, and 44 cm in length, respectively), low fecundity (they bear less than 100 live-young), benthic food habits, short longevity (maximum two years - Hart, 1973), and fast growth rate. Of the three species, the pile perch is the only one harvested commercially and is of some importance in California. Although they have not been commercially harvested in British Columbia waters, pile perch are taken occasionally by angling from docks (Hart, 1973) and shiner perch are harvested recreationally by some ethnic groups in the Prince Rupert area (P. Ross, MELP Smithers, *pers. comm.*). As candidate sentinel species, the three taxa are considered to be worthy of consideration as alternatives to other species. However, detailed information on their biology and ecology is scarce (Forsyth, 1993).

The ratfish is a near-relative of the sharks, having cartilage instead of bone (Hart, 1973). The species is relatively common in British Columbia coastal waters and occurs at about 90 to 270 m depth in the Strait of Georgia (Hart, 1973). Fecundity is very low (two eggs per spawning event). They are bottom feeders, consuming clams, shrimp, crabs and, occasionally, fish. It has been considered as a candidate sentinel species (Forsyth, 1993). However, the ecology and population dynamics of the species are poorly understood.

Two species of the gunnel family, the penpoint gunnel and the crescent gunnel, have been considered as candidate sentinel species (Forsyth, 1993). They are both elongated, laterally-compressed, "eel-like" fish (Hart, 1973). They are abundant and are found from the low intertidal zone, to 55 m in depth in subtidal waters (Hart, 1973). They are found in cobble habitats where they live under rocks and consume benthic crustaceans. They exhibit low to moderate fecundity and rapid growth in the first few years of a five to seven year life-span (Hart, 1973; Forsyth, 1993). Information on basic biology and ecology is scarce.

Several smelt species occur in the Prince Rupert area. The surf smelt (*Hypomesus pretiosus*) is a small fish which matures between 80 and 145 mm in total length (Hart, 1973). They spawning in summer in the upper high-tide zone on sandy beaches. Females produce 1,300 to 30,000 eggs and may live for at least three years. The species is well known in populated areas such as Vancouver, where it is harvested recreationally using gillnets (Levy, 1985). The highest recorded catches (49 tonnes - Hart, 1973) were from the 1960's. The three other smelt species exhibit the same general biological characteristics. Eulachon (*Thaleichthys pacificus*) are generally under 23 cm long (Hart, 1973). They are anadromous, spawning between mid-March and mid-May, for short distances upstream. The species is known from the Skeena River, although only in small numbers (Hoos, 1975). Capelin (*Mallotus villosus*) spawn on area beaches in enclosed bays and coves during Fall (Hoos, 1975). Longfin smelt (*Spirinchus thaleichthys*) is known to occur in the Skeena River estuary and its young may exhibit a considerable residency in local waters (Hoos, 1975).

4.2.3 Shellfish

Marine invertebrates total about 3,800 species in British Columbia waters, representing approximately 3.5% of the world's taxa (Tunnicliffe, in press). Surprisingly little is known about the vast majority of these species. New taxa are continually being discovered or introduced. The present inventory discusses only those invertebrate resources which have been or are currently being harvested in Strait of Georgia waters. A complete list of all the commercially exploited invertebrates in British Columbia waters is shown in Table 4.2.

Between 1981 and 1990, shellfish and other invertebrate resources of British Columbia were harvested at a rate of 6,000 to 20,000 tonnes annually (Table 4.3), with a landed wholesale value of \$9.6 to 42.2 million per year (Table 4.4). Approximately 70% of that value currently comes from the crab, shrimp/prawn and geoduck fisheries (Thomas, 1992).

4.2.3.1 Dungeness Crab

The crab harvest in northern British Columbia consists of three main species: king crab, tanner crab, and Dungeness crab. Dungeness crab are the most commonly harvested and occur throughout British Columbia coastal waters in tidal and shallow subtidal habitats, primarily on firm sandy bottom. Fertilized eggs are retained by female crabs; these hatch and pass through six pelagic planktonic stages before descending to the bottom. Maturity is achieved at three years of age; size ranges up to 20 cm carapace width. Although Dungeness crab do not swim, they are capable of considerable movement. Studies in Strait of Georgia (Archibald and Bocking, 1983) and California (Gotshall, 1978) have suggested that individuals may move up to 4 or 5 km in less than a month, although most do not move more than 2 km in a two year period (Gotshall, 1978). This crab species is generally found in shallow sandy bottoms and burrows. Dungeness crab feed largely on small clams (Kozloff, 1983).

The Dungeness crab fishery is regulated through a minimum size limit. Recent commercial production assessment statistics for the species were compiled by Joyce (1992) and are shown in (Figure 4.17). Landings in the north and central coast represent a minor portion of the total British Columbia landings. However, these landings are significant locally (50 to 408 tonnes annually) and harvests have been increasing since the late 1980's (Figure 4.17). Crabs are also harvested recreationally.

4.2.3.2 Shrimp/Prawn

There are six species of shrimp and prawn exploited within British Columbia waters: smooth pink shrimp, spot prawn, pink shrimp, sidestripe shrimp, humpback shrimp, and coonstripe shrimp. Most shrimp are captured in trawl fisheries or traps. Females carry fertilized eggs for several months prior to their release as free-swimming larvae. Most species mature first as males for one or two seasons, and then transform into females.

Shrimps and prawn support a modest commercial fishery in the Prince Rupert area. Total shrimp and prawn landings since 1982, generally have not exceeded 100 tonnes annually (Figure 4.18). Prawn populations are also exploited by the recreational "trap" fishery.

4.2.3.3 Bivalves

Out of the 800 species of molluscs in British Columbia, only relatively few serve directly as food for humans. These include several species of bivalve such as clams, oysters, and mussels. While the life-cycle varies between species and geographic location, the following description, synthesized from Quayle and Bourne (1972), will serve as a brief general review of bivalve biology.

Growth rate depends on geographic location and local oceanographic conditions. Sexual maturity is a function of size rather than age. In most bivalve molluscs, the sexes are separate, although some individuals are hermaphrodites (i.e., produce both eggs and sperm). In some species (e.g., Pacific oyster), an individual may change sex from year to year, depending on environmental conditions. When food supply (plankton) is good, there is a tendency for males to transform to females. When food supply is poor, the reverse is true.

Spawning in most species of molluscs occurs once per year via the discharge of eggs and sperm via the siphon. Synchronous mass spawning occurs to ensure successful fertilization. The duration of the "free-swimming" larval stage depends on temperature and food concentration, and generally lasts about 3 weeks. During this time a larva metamorphoses through several intermediate stages (in turn: trochophore, veliger, and umbone stages) before finally settling onto the bottom substrate and attaching itself by means of fine byssal threads (mussels retain these byssal threads into the adult stage). The settled larvae (or "spat") then change anatomically to resemble smaller versions of adult clams or oysters about 5 mm long. In clams, the spat burrows by means of a foot. Once settled to the bottom, individuals are essentially sessile; subsequent horizontal movements are negligible. Survival at the larval stage is critical to the future success of a given year class of molluscs. While still in the free-swimming larval stage, molluscs may disperse over large distances. For example, oyster larvae can disperse over 50 km away from the breeding site depending upon local currents and, therefore, may "seed" other beach areas.

Most molluscs feed and extract oxygen by drawing water over their large, well developed internal gills by means of the coordinated beating of tiny hair-like cilia attached to the gills. Because food particles (mostly phytoplankton, detritus, and bacteria) are essentially "filtered out" of the water, molluscs are often highly susceptible to waterborne contaminants from industrial, municipal, and domestic sources. These pollutants may become concentrated in their tissues. For the same reason, they are prone to paralytic shellfish poisoning (PSP) due to the concentration of toxins from planktonic dinoflagellates. Although PSP is harmless to the mollusc itself, it is often fatal to humans. As a result of warm water conditions, in which toxic dinoflagellates thrive, shellfish beds can be closed to harvesting during summer. Most populations from north coast beaches are not monitored for PSP contamination and are, therefore, not open to commercial harvesting (Quayle and Bourne, 1972).

Age at sexual maturity varies by species, location, density, and other ecological factors influencing growth rate, but is generally several years. Growth is most rapid during spring and summer when food is plentiful and water temperatures are high, but decreases and virtually stops during the winter, resulting in annual winter growth checks (i.e., growth rings) which are visible on the shells of most adults. Predators of bivalves are numerous and include starfish, snails, crabs, worms, fish, and ducks.

Species which are commercially exploited in British Columbia include the butter clam, two littleneck clams (the native littleneck and the introduced Manila clam), razor clam, and geoduck clams. Other species that are utilized commercially to a lesser degree include the cockle, two horse clam species, as well as two species of mussels. Additionally, the soft-shell clam, an important Atlantic coast species, was accidentally introduced and is now abundant in certain coastal areas and estuaries, but is not presently exploited. Management regulations to control mollusc harvesting generally rely on some form of minimum size limit which is set above "the size at first reproduction" to protect pre-recruits from exploitation. The production in a given year reflects the growth of successive year-classes that were protected from exploitation during previous years, in intensively harvested populations.. However, repeated "diggings" may be deleterious to survival due to mechanical disruption. Because of their mode of dispersal as larvae, populations are considered to be "open", with recruitment to any particular beach originating from adjacent beach sites.

Intertidal clams

In the north coast of British Columbia, the commercial intertidal fishery is only significant in the northern portions of the Queen Charlotte Islands (Dickson, 1992). A modest sized razor clam fishery has developed there. In the Prince Rupert area, the intertidal fishery has generally been closed during the past three decades because of the lack of PSP monitoring. When open, intertidal clam landings have been less than 1,000 kg annually (Dickson, 1992).

Historically, the butter clam was the most important commercial clam species in British Columbia. It is a relatively large species, reaching approximately 12 cm in length. These clams prefer soft substrates and occur most frequently in the lower third of the intertidal zone. Small butter clams are situated immediately below the surface of the beach, while large adults can be as deep as 30 cm beneath the surface. Butter clams are recruited to the fishery at 6.25 cm shell length. Spawning occurs once the clams surpass about 4 cm in length.

The native littleneck clam is a medium sized clam that reaches 6 to 6.5 cm in length. This species extends between the lower third and the middle of the intertidal zone (often overlapping with butter clams), in a gravely, relatively firm substrate. Clams entering the fishery at 4 cm in length are 3.5 to 4 years old, while those of 6 to 6.5 cm are about ten years in age.

The Manila clam (also called Japanese littleneck clam) was accidentally introduced into British Columbia with imports of Japanese oyster seed in the Strait of Georgia in 1936. The Manila clam is currently the most important commercially harvested intertidal clam species in British Columbia, comprising 90% of the intertidal landings (Dickson, 1992). Cool water temperatures effectively prevent their expansion in a northward direction. They are not found in the Prince Rupert area.

Cockles are widely distributed in British Columbia in sand-mud substrates, and also occur in eel grass beds. They possess relatively short siphons, and are present just beneath, or slightly exposed within surface substrates. Individuals are hermaphroditic and reach sexual maturity after two years.

Razor clams are exploited almost exclusively in the northern Queen Charlotte Islands, and are not commercially harvested elsewhere in British Columbia (Dickson, 1992). Approximately 85 tonnes are harvested annually in this area (>100 tonnes annually between 1986 and 1990). It is only found on surf swept sand beaches close to the low tide mark (Quayle and Bourne, 1972).

Geoduck

A description of the commercial geoduck fishery in British Columbia is provided by Harbo *et al.* (1992). The geoduck is a large subtidal clam - average commercially harvested geoducks in British Columbia weigh 1.2 kg, with the largest individual recorded at 4.5 kg. Geoducks occur in water as deep as 60 m in sand-mud, gravel, and broken shell substrates, into which they bury as deep as 1.3 m. Unlike many other clams, geoducks cannot fully withdraw their siphon into their shell. Geoducks grow rapidly during their first eight to ten years, reaching a weight of 0.7 kg. These clams can be very long-lived, for example, geoducks adjacent to Ladysmith had an average age of 50 years, and a maximum age of 140 years.

Commercial harvesting of geoducks is undertaken by divers using hand-held high pressure water jets. The commercial fishery for geoducks in British Columbia began in south coast waters in 1976. The British Columbia catch increased to annual landings in excess of 2,000 tonnes by 1979, levels at which the harvest presently continues (Harbo *et al.*, 1992). Over the period from its inception, the fishery has increasingly relied on catches from northern waters. Catches from the prince Rupert area are now approximately 150 tonnes annually (Figure 4.19); harvesting is currently regulated on a three year rotation. Annual quotas have been set at 1% of the stock biomass, a harvest level felt to be sustainable in the long-term (Harbo *et al.*, 1992).

Horse clams

Two species of horse clams are relatively large animals, reaching 12 to 15 cm in length. The habitats of the two species differ - *Tresus nuttalli* occurs in pure sand bottoms, while *T. capax* overlaps with butter and littleneck clams in gravel-shell substrates. These clams are generally discarded by commercial clam diggers, due to very muscular neck skin which must be removed or minced. The total British Columbia harvest has averaged 133 tonnes annually (Harbo, 1992). This species is not currently harvested in the Prince Rupert area (DFO Fisheries Data Management Unit, Harbo, 1992).

4.2.3.4 Abalone

Of the 94 species of abalone found worldwide, the northern abalone is the only species found in British Columbia. A review of abalone biology and fisheries management is provided by Federenko and Sprout (1982). The animals are distributed in shallow water (zero tide to 5 m depth), and are frequently associated with kelp beds. In good habitat, northern abalone reach the minimum legal size limit of 10 cm in six to eight years.

Abalone supports a valuable fishery ($1.3 million in 1990 - Thomas, 1992). This shellfish is harvested by divers in shallow subtidal waters. The species is prized for its edible muscular foot, which comprises approximately 40% of its body weight, and is sold to buyers on world markets.

Due to explosive growth of the commercial abalone fishery and subsequent decline in southern British Columbia stocks in the late-1970's, fishing effort until the early 1990's was centered in the North Coast and the Queen Charlotte Islands (as much as 98%). However, commercial landings declined during the 1980's in the Prince Rupert area. Harvest levels were beyond sustainable harvest levels (Federenko and Sprout, 1982), and the fishery has been closed for the last several years (DFO Prince Rupert, *pers. comm.*). The recreational dive fishery is also closed.

4.2.3.5 Sea Urchins

There are three shallow water sea urchin species in British Columbia, of which the red sea urchin is the largest and most important in the fishery, although green sea urchins are also taken. Sea urchins are primarily located in fast flowing waters, on hard substrates, frequently in association with kelp. Sea urchin gonads (i.e., "roe") are processed largely for the Japanese export market. The total British Columbia harvest is in excess of $2 million annually (Thomas, 1992). Commercial harvesting of sea urchins in Georgia Strait expanded rapidly in the late-1970's, with most production obtained in Statistical Area 17. Recruitment of juveniles has been estimated at only 5.5% of the total population (Adkins *et al.*, 1981), suggesting that the population can sustain only low harvest rates. The sea urchin harvest in the Prince Rupert area was 1,085 tonnes in 1991 (Figure 4.20).

4.2.4 Other Invertebrates

4.2.4.1 Octopus

The largest known octopus species, the giant Pacific octopus is found throughout the northern Pacific and in the Strait of Georgia. Newly hatched octopi are planktonic for several weeks; adults are solitary, except for breeding seasons, and consume bivalves and crabs. There do not appear to be any quantitative assessments of octopus in British Columbia, although annual catch statistics have been reported for catches in the 1980's, and harvest sustainability is in doubt (Heizer, 1992a). Annual landings in the Prince Rupert area have averaged less than 8 tonnes annually in the 1980's.

4.2.4.2 Squid

There are seventeen or more species of squid found in British Columbia (Bernard, 1980), of which the red squid is the most prevalent in northern British Columbia. The animals migrate vertically in the water column, spending daytime periods in water depths between 20 to 50 m, and migrating into shallow water at night, frequently congregating near lighted areas. Their are two major periods of squid spawning activity, in March and again in July (Bernard, 1980). The squid harvest is negligible in the Prince Rupert area, but Heizer (1992b) reports that squid appear to be underutilized in British Columbia, and they are present in nearby waters.

4.2.4.3 Sea Cucumber

The giant sea cucumber is the most conspicuous sea cucumber along the British Columbia coast, and can reach 50 cm in length. A modest but growing commercial fishery exists for this species; frozen muscle strips are currently shipped to markets in Singapore and Hong Kong. Between 1986 and 1989, the British Columbia catch has ranged between 790 to 1,920 tonnes annually (Heizer and Thomas, 1992); up to 74 tonnes have been harvested annually in the Prince Rupert area (Figure 4.20). Biological and stock abundance information for this species are limited, although a basic description was provided by McDaniel (1982).

4.2.4.4 Amphipods

Amphipods are not harvested, but have been considered as candidate sentinel species (Forsyth, 1993). Many species of amphipod are found in British Columbia waters. They are generally abundant, epibenthic, omnivorous animals, with short life-spans, making them suitable as sentinel species. Their limited mobility also suggests that they would be found within a given area (e.g., effluent plume) throughout their entire lives. Their small size appears to make them unsuitable for the necessary dissection work that will be required in future cycles of EEM.

4.2.5 Rare/Endangered/Threatened Species

Accounts of rare, endangered, or threatened species in the marine waters of British Columbia have not been produced by DFO or MELP personnel. Several species are overexploited by harvesting, but cannot be considered endangered or threatened within British Columbia waters from an ecological perspective. Species receiving the most attention regarding exploitation levels include the stocks of chinook and coho salmon, lingcod, and rockfish. Steelhead trout stocks are currently at very depressed levels in many British Columbia rivers (including the Skeena River). Although these problems are less acute than in south coast areas, the declining abundance of steelhead in Prince Rupert area streams has generated concern among locals and fisheries biologists. Salmon stocks in streams which have been reduced to low annual escapements (<100 fish/year) are susceptible to reduced genetic diversity (Nehlson *et al.*, 1991), which may be a concern in some watersheds.

4.2.6 Commercial Fishery

The commercial fisheries for finfish and invertebrates have been described in the individual species accounts previously documented in this section. Most commercial fisheries are managed by DFO on either a stock or an area basis. Most of these fisheries are regulated seasonally on an area, fleet sector, or individually based quota system or by in-season regulations (e.g., salmon). Only a few fisheries (e.g., hagfish) are not regulated in some way. The previously documented species accounts by necessity include many commercially relevant details (including economic significance). Recent stock assessments of commercially important species may be found in the following sources:

- Thomas (1992) - shellfish and other invertebrates;
- Leaman (1992a) - groundfish; and
- Haist and Schweigert (1992) - herring.

4.2.7 Native Fishery

Most native bands in the Prince Rupert area have territories either at the mouths of rivers (such as the Skeena River) or near important fishing areas. As a result, salmon are of great economic, cultural, and consumptive value. Hoos (1975) reported that the average Skeena River salmon and steelhead catch by First Nations peoples totaled 500 tonnes annually from 1960 to 1973.

Many natives involved in the salmon fishery also participate in the various commercial fisheries for other finfish species. Native fishermen not only utilize all the resources available to contemporary fishery techniques, their use of the local marine and freshwater resources using traditional methods has occurred for thousands of years. Historically, lingcod, rockfish, halibut, and herring were also fished by natives. Based on archaeological excavations and biological assessments, Stewart (1975) determined the following seasonal finfish resource use among Tsimshian peoples:

- herring January to February;
- eulachon March to May;
- salmon June to September; and
- halibut November to December.

Molluscan shellfish have been an important staple item for First Nations peoples of British Columbia for thousands of years. Frequent occurrences of shellfish remains, particularly clam shells, from excavated middens have been documented. Cockles are one of the preferred species of clam used by natives. In addition to use as food, some mollusc species were used for tools, jewelry, and money. In Morse Basin and Wainwright Basin, mussels, shrimp, prawn, crab, gooseneck barnacles, and clams have historically been harvested by Tsimpsean peoples (P. Ross, MELP Smithers, *pers. comm.*).

Native fishery resource concerns particular to southern British Columbia have been summarized by the Coast Salish Fisheries Working Group (CSFWG, 1992, 1993a,b) and apply generally to First Nations throughout British Columbia. In the Prince Rupert area, prominent territories of the Tsimpsean First Nation include lands at the mouth of the Skeena River, Dolphin Island (Kitkatla Inlet), northern DeHorsey Island, eastern Smith Island, Inverness Passage across from Lelu Island, south shore of Denise Inlet, both sides of Morse Basin at Prince Rupert, Tugwell Island, and the largest area includes the northern end of Digby Island and lands to its north along Chatham Sound on the Tsimpsean Peninsula.

Department of Fisheries and Oceans management priorities for salmon resources are ordered as follows:

1. maintenance of sufficient spawning escapements to ensure the productivity of individual salmon stocks;

2. ensuring that the ceremonial and consumptive requirements of native peoples are met; and,

3. supplying the needs of the commercial and recreational harvest.

Due to salmon migratory habits, the management sequence is reversed and generally follows:

1. commercial and recreational harvest;

2. native harvest; and, lastly,
3. spawning escapement.

In view of recent legal judgements, it is likely that participation of First Nations in fisheries management will increase in the near future CSFWG (1992). At this time, it is unclear what form this involvement will take. However, most First Nations are generally interested in the following objectives:

1. increased access to fisheries resources within traditional territories; and

2. assumption of managerial responsibility for fisheries resources within these territories.

4.2.8 Sport Fishery

Recreational fishing is a significant activity in the Prince Rupert area, but has a relatively modest impact on local stocks compared to activity in southern British Columbia. Many shellfish and finfish species are taken recreationally. Among finfish, salmon, Pacific halibut, rockfish, and lingcod are utilized. The invertebrate recreational harvest consists principally of prawn and crab.

4.2.8.1 Finfish

As with the commercial fishery, salmon represent the most highly prized species recreationally. Coho and chinook dominate the sport catch, whereas sockeye and pink salmon form the bulk of the commercial landings (Figure 4.3). In the 1970's, Hoos (1975) estimated that 19% of the Prince Rupert population derived a direct benefit from the sport fishery. The sport fishery in the local area appears to be increasing (E. Fast, DFO Prince Rupert, *pers. comm.*), and presently supports 35 to 40 charter operations in Chatham Sound. The sport fishery in the Skeena River is not currently enumerated (E. Fast, DFO Prince Rupert, *pers. comm.*).

Among marine fish species, lingcod are taken both by "hook and line" and dive fisheries. Currently, there are size restrictions on the recreational harvest for this species (Richards and Yamanaka, 1992). Rockfish are also commonly harvested in the recreational fishery.

There are no detailed accounts of the sport fishery in northern British Columbia, such as are periodically performed in the Strait of Georgia (e.g., Collicutt and Shardlow, 1992).

4.2.8.2 Invertebrates

Landings statistics are not currently available for recreational harvests of crab, intertidal clams, prawn, or other invertebrates.

4.2.9 Aquaculture

In 1991, aquaculture generated over $110 million in British Columbia, of which the largest component (≈90%) was from salmon culture. Production levels in the aquaculture industry are predicted to reach $150 million annually by 1995 (Anon., 1992). Salmon farming (primarily for Atlantic and chinook salmon) has experienced rapid growth since 1985. There are currently 105 farms operating on the coast (Anon., 1993a). Early development of the industry centered on the Sunshine Coast, but the industry has shifted to the Campbell River region, and the west and north coasts of Vancouver Island.

In the Prince Rupert area, aquaculture has not been extensive. Currently, no aquaculture operations are active (B. Carswell, B.C. Ministry of Agriculture, Fisheries and Food, Victoria, *pers. comm.*). A salmon farm which operated in Morse Basin (near Wolf Creek) ceased operation in 1989. The closest salmon farm currently in operation is located in Grenville Channel, well below Porcher Island.

No invertebrates are cultured in Management Area 4. Oyster culture was attempted in the area but was unsuccessful (Hoos, 1975). Low temperatures restrict growth to such an extent that the industry is uneconomical in northern waters (Quayle, 1988).

4.2.10 Non-exploited Species

Given that the available information on many of the harvested species of fish and invertebrates is incomplete, it is perhaps not surprising that information on unexploited forms is virtually non-existent. Most of the available information on the over 300 species of marine finfish may be found in Hart (1973). Similarly thorough accounts of the approximately 3,800 marine invertebrate taxa in British Columbia (Tunnicliffe, *in press*) are currently non-existent.

4.3 LOCAL RESOURCE INVENTORY

This inventory describes the finfish and shellfish resources in the vicinity of Prince Rupert and the Skeena Cellulose Inc. pulpmill on Watson Island. The inventory area lies within Department of Fisheries and Oceans Management Area 4 (Figure 4.21). This area (Figure 4.22a) encompasses the marine waters of Chatham Sound (from the north end of Dundas Island to the southern end of Kennedy Island). From the coast, the area extends westward to Stephens Island and Brown Passage. The marine resources of Kitkatla Inlet, the proposed reference area for first cycle EEM studies, are shown in Figure 4.22b. All significant salmon bearing streams in these areas, and their associated marine and intertidal habitats, are discussed (Figure 4.23). Romaine (1984) was used as a basis for describing the marine distribution of major species in the vicinity of Prince Rupert. This source was updated where more current information was available.

Marine finfish are highly mobile. Individuals occurring within the local area are generally part of much more widely ranging populations, and many are highly migratory. The Local Resource Inventory considers species which are known to be present locally, exhibit high degree of site fidelity or spawn in the local area. The most notable of these finfish species include herring, lingcod, rockfish, flatfish, cod, and several salmon stocks.

Most marine invertebrates are planktonic for a variable period after they hatch. While in this planktonic stage, most species passively disperse with the currents and become widely distributed. As adults, many benthic invertebrate species found in marine waters are sessile (e.g., most bivalve molluscs), and many others move only short distances (e.g., crabs). Such invertebrates may be exposed to pulpmill effluent throughout their entire adult lives. Local populations of invertebrates have been summarized herein.

Aquatic habitats within the zone of potential effluent exposure include creeks, rivers, and marine foreshore areas. Fish inventory information for streams is available through the Fish Habitat Inventory Program (FHIIP, 1991). This inventory was compiled by interviews with federal and provincial fisheries staff, local residents, and a variety of published sources, including consultants' reports, and DFO and MELP internal reports and files. Detailed salmon escapement information was obtained from the Salmon Escapement Data System (SEDS) managed by DFO Science Branch (Serbic, 1991).

An inventory of aquatic habitats and resources in the Prince Rupert/Watson Island/Chatham Sound area is shown in Table 4.6 and Table 4.7. Stream inventory information for the rivers and creeks within the area described by this local inventory was found by examining the stream summaries for Statistical Area 4A - Skeena River (Figure 4.21; FHIIP, 1991). The area streams in the local inventory produce all salmon species although pink salmon, and to a lesser extent coho salmon, dominate the smaller streams. Sockeye salmon are present in several systems; along with pink salmon, they dominate the fisheries of the Skeena River. Chinook and chum salmon are significant but less so than the other species. Steelhead trout are also present in a number of watersheds - the largest steelhead run in British Columbia returns to the Skeena River. Chinook and coho salmon are significant target species in a growing sport fishery. Sockeye salmon, especially returning to the Skeena River, dominate the harvests of First Nations peoples.

4.3.1 Chatham Sound

Chatham Sound features commercial, native, and recreational fisheries for a variety of marine and anadromous finfish and invertebrate resources. The majority of the commercial harvests described in the Regional Resource Inventory (Section 4.2) in Management Area 4 originate either from Chatham Sound or in the northeastern portions of Hecate Strait. In addition, salmon returning to the Skeena River and other coastal watersheds throughout the sound are harvested in either interception or terminal fisheries. Recreational fishing has assumed increasing importance in the area, both in freshwater, and in marine waters.

4.3.1.1 Marine Resources

Most of the commercial fisheries for groundfish, salmon, herring, and invertebrate fish resources in the Prince Rupert area occur in Chatham Sound. Native and recreational fishing for finfish species takes place throughout the sound.

Commercial groundfish harvests are taken throughout the sound, with prominent areas including the northern portions to the east of Dundas Island, and those to the west of Stephens Island (near Butterworth Rocks). Pacific halibut are harvested to the east and southeast of Dundas Island (Figure 4.22). One of the most important sole harvesting areas in British Columbia coastal waters is located in the vicinity of Butterworth Rocks (especially for lemon sole, rock sole, and petrale sole).

The commercial salmon harvest is extensive throughout the sound (Figure 4.22). Seine and gillnet fisheries predominate the near-coast and northern areas, while Brown Passage (between Dundas Island and Stephens Island) is the main site of a much smaller troll fishery (approximately 20% of the commercial salmon harvest). Native salmon harvests occur throughout the sound, especially in the southern areas near the mouth of the Skeena River.

Much of the Chatham Sound area represents important rearing habitat for juvenile fish, including salmonids and other species. The near-shore waters of many of the area islands are important rearing habitats for pink salmon.

In the early 1960's, the herring harvest in the Prince Rupert area amounted to approximately 25% of the British Columbia total; the area's contribution is about 15% currently (Figure 4.14). The intertidal and subtidal areas along the Tsimpsean Peninsula are important herring spawning areas (Figure 4.22). These areas support a significant portion of the north coast spawning activity (Hay *et al.*, 1989), estimated at about 60% by Knapp and Cairns (1978). Herring rearing occurs throughout many of the inlets of the sound.

Harvests of most invertebrate species in Chatham Sound are not large in comparison with many other areas of the British Columbia coast. However, there are several notable exceptions. The sea urchin harvest has become increasingly northern based in the last decade - approximately 10 to 20% of the north and central coast harvest originates from Area 4, including Chatham Sound. Sea cucumber harvests are of similar significance. Geoduck harvests are also increasing in importance in northern waters, and the majority of the Area 4 harvest is based in the sound. Shrimp trawling is a significant commercial activity within the sound (especially southern portions - Figure 4.22). The harvest of shrimp in Chatham Sound, which dates back to early in the century (Hoos, 1975), is modest by southern British Columbia standards, but represents the majority of the harvest of the north and central coast. Scallops are also known from the area, but not in commercial quantities.

Intertidal clams are not harvested in any great quantity in Chatham Sound, due to both the low productivity of the beds (due to low water temperature) and to the periodic occurrence of paralytic shellfish poisoning (and a lack of PSP monitoring). Areas which are occasionally harvested for intertidal clams (butterclam and littleneck clams) include the southern end of Dundas Island, and the eastern portions of both Baron Island and Dunira Island.

Dungeness crab are found near Ridley Island and Lelu Island, and have been harvested there in past years. Tanner and king crab are both taken in the sound in low numbers.

Recreational fisheries are conducted throughout Chatham Sound and are increasingly popular both among locals and tourists (E. Fast,. DFO Prince Rupert, *pers. comm.*). Approximately 35 to 40 charter boats operate out of Prince Rupert and smaller communities in the Chatham Sound area. The primary target species, and the corresponding 1993 approximate catches (E. Fast, DFO Prince Rupert, *pers. comm.*), include coho salmon (several thousand), chinook salmon (1,200 to 1,500), Pacific halibut (350 to 400), lingcod (200 to 300), and rockfish (400 to 500). Unknown numbers of Dungeness crab are also taken throughout the sound.

4.3.1.2 Freshwater Resources

In addition to the Skeena River, Chatham Sound has many coastal watersheds which are productive spawning streams for anadromous freshwater resources. Most of these anadromous freshwater resources are discussed in other subsections of this Local Resource Inventory, which focus on more specific areas. One of these streams, La Hou Creek, falls beyond these specific areas, and is described below.

La Hou Creek

La Hou Creek is a respectable producer of salmon, flowing into Chatham Sound approximately 22 km north of Prince Rupert. Although the creek is susceptible to low water conditions, it has good gravel bars for spawning. Logging in the upper reaches has affected water levels.

La Hou Creek supports populations of coho and pink salmon. Pink salmon escapements are generally a few thousand, and often exceed 10,000 annually (Figure 4.24); the highest recorded escapement was 70,000 in 1989. Pink salmon spawning occurs from September to early November in the estuary, and lower 3.0 km of the creek. Coho salmon have only been irregularly observed spawning in the creek, up to 4.0 km from the mouth during autumn. Steelhead have also been reported in low numbers.

4.3.2 Digby Island

Digby Island forms the western boundary of Prince Rupert Harbour. The marine waters of Chatham Sound, off its western shore, support gillnet fishing for salmon (mainly pink and sockeye). A recreational salmon fishery continues to be supported in Metlakatla Passage (Hoos, 1975; E. Fast, DFO Prince Rupert, *pers. comm.*). Herring spawning on the Chatham Sound side of the island is significant; although, little fishing for herring occurs in this area.

Littleneck clam and butterclam, as well as Dungeness crab, have been harvested in the Metlakatla Bay and Venn Passage area (Hoos, 1975). The marine resources on the Prince Rupert Harbour side of Digby Island have been described elsewhere (Section 4.3.3)

There is one unnamed creek, located on the southwestern side of the island in the vicinity of the airport, which flows into Chatham Sound. The stream appears to support a small degree of coho salmon spawning activity; coho fry have been observed in a small lake within the watershed.

4.3.3 Prince Rupert Harbour

4.3.3.1 Marine Resources

The marine and anadromous resources of Prince Rupert Harbour are significant. Several coastal streams flow into the harbour, or in adjacent inlets, and some pink salmon rearing will likely occur in marine nearshore habitats as a result of production from these systems (Hoos, 1975). Prince Rupert Harbour may have supported herring rearing in the past (Knapp and Cairns, 1978).

Although domestic pollution and red tide have closed much of the shellfish harvest of the area (Hoos, 1975), prawn continue to be harvested by trapping in the harbour and in Tuck Inlet. A fisheries recreational and native consumption advisory and commercial fishery closure was recently implemented by the Government of Canada (1993) in August, 1993, closing Prince Rupert Harbour to commercial crab harvesting due to the presence of dioxins (see Section 4.3.8).

4.3.3.2 Freshwater Resources

The creeks flowing into Prince Rupert Harbour and Tuck Inlet support several thousand pink salmon and lesser numbers of coho salmon spawners annually in many years. These streams also support small numbers of chum salmon, Dolly Varden char, and cutthroat trout. There is an active sport fishery for salmon in the harbour area and surrounding waters (Hoos, 1975; E. Fast, DFO Prince Rupert, *pers. comm.*).

In addition to the creeks described in detail below, Morse Creek (at the western end of the city of Prince Rupert) supports a small population of cutthroat trout and Dolly Varden char.

McNichol Creek

McNichol Creek flows into Prince Rupert Harbour on its north shore. The creek has a fair supply of spawning gravel, and is accessible to spawning anadromous salmonids for the lower 6.5 km of its length. Silting was noted in the creek in most years from 1971 to 1980; it is unknown whether this is presently the case.

McNichol Creek supports a modest spawning escapement of pink salmon. Annual escapements have attained numbers as high as 13,000 (in 1986), but between 500 and 1,000 is more usual

(Figure 4.25). Pink migration and spawning occurs from late August to October. Coho salmon have also been observed spawning in the creek in some years during October.

Silver Creek

Silver Creek flows into the head of Prince Rupert Harbour. The creek is accessible to anadromous salmonids for 2.0 km upstream of the mouth.

Silver Creek supports a modest pink salmon run, with spawning escapements ranging up to 9,000 individuals (in 1986), although numbers of spawners is generally less than 2,000 (Figure 4.25). Pink salmon migration and spawning occur from August to October.

In addition to its pink salmon run, Silver Creek also supports some coho and chum salmon spawning during some years. Dolly Varden char and cutthroat trout are also present in unknown numbers.

Hays Creek

Hays Creek is located on Kaien Island and flows northward into Prince Rupert Harbour, through the city of Prince Rupert. As a consequence of its location, the creek is subject to urban development and related water quality problems (FHIIP, 1991). The creek is accessible to spawning salmon up to 3.5 km from its mouth, and in one tributary (Oldfield Creek).

Hays Creek supports a small number of spawning coho salmon, generally less than 100 fish annually (Figure 4.25). The creek also supports small numbers of pink salmon, as well as cutthroat trout and Dolly Varden char. A small hatchery has operated on one of its tributaries, Oldfield Creek, since 1986, producing coho salmon.

4.3.4 Morse Basin/Watson Island

The presence of the Skeena Cellulose Inc. pulpmill on Watson Island has generated several investigations of fish and invertebrate fauna in Porpoise Harbour, Wainwright Basin, and Morse Basin. The fisheries resources of these waterbodies are not large compared with similar areas elsewhere within this Local Resource Inventory.

4.3.4.1 Marine Resources

Prawn, crab, and herring occur in all three waterbodies. Shrimp and prawn fisheries were supported in these three areas before 1960, and local fisheries for these species were among the largest in British Columbia (Knapp and Cairns, 1978). Crabs were harvested by local residents in Porpoise Harbour until recent closures (Government of Canada, 1993; see Section 4.3.8). First Nationals peoples historically harvested mussels, clams, barnacles, shrimp, prawn, and crab in Morse Basin and Wainwright Basin (P. Ross, MELP Smithers, *pers. comm.*). Crab movements within this area are not known, but studies elsewhere (see Section 4.2.3.1) suggest that movements of several kilometers are not uncommon.

In 1987, Hatfield Consultants Ltd. performed a beach seine study of littoral fish in Morse Basin, Wainwright Basin, Porpoise Harbour, and Inverness Passage (Dwernychuk, 1988). Sockeye, pink, chum, chinook, and coho salmon, Dolly Varden char, Pacific herring, and smelt were identified among the weekly catches of the three month survey. Among the salmonids, underyearling and yearling individuals dominated the catch. Individuals of all salmon species were captured from all sites during their survey, and no obvious patterns to the species spatial distribution was evident. The largest herring catches were made in Porpoise Harbour sites. In Lagoon #2 (part of Wainwright Basin), anecdotal reports indicate salmon and herring may be present on occasion. Also pink salmon pass through this lagoon during migrations to and from Wolf Creek (see below).

The intertidal biota of Ridley Island were described by Hoos (1975) as sparse, but that this did not appear to be related to the presence of effluent. These observations have been supported by more recent observations (1984 to 1992) of the intertidal and subtidal flora and fauna of Porpoise Harbour made by Hatfield Consultants Ltd. (see Section 5.3).

4.3.4.2 Freshwater Resources

There are several coastal streams in Wainwright Basin and Morse Basin which have significant anadromous salmonid resources. These have been discussed below. Smaller streams in the area also support small numbers of salmonids, and include several creeks which flow into Wainwright Basin. A small coho salmon sport fishery operated near the mouth of the Kloiya River; however, runs to this system have been low in recent years (see below).

An unnamed creek, located on Kaien Island and flowing into Wainwright Basin, supports a population of cutthroat trout and is monitored periodically by DFO. Four other creeks on the south side of the island (flowing into Wainwright Basin) also support cutthroat trout populations (FHIIP, 1991).

Wolf Creek

Wolf Creek flows north into Wainwright Basin via Lagoon No. 2. It supports a small run of pink salmon; pink have been observed at 1.2 km upstream of the mouth (Knapton, 1987). Coho have been present historically.

A minnow trap survey was conducted August 10 and 11, 1994, by the Department of Fisheries and Oceans and Skeena Cellulose Inc. (*unpubl. data*) to ddetermine the present status of fish species in Wolf Creek. All three sites were located upstream of Lagoon No. 2 in the vicinity óf the highway. The following fish were collected in three G-traps set over a 24-hr period:

- 2 coho salmon (65 mm and 100 mm);
- 8 cutthroat trout; and

- 52 sculpins.

Given the short duration of the survey, these data suggest that Wolf Creek presently supports a significant fish community. An extensive fisheries habitat assessment and inventory of Wolf Creek will be conducted during Cycle 1.

Wolf Creek is the former site of a salmon farm that operated between 1986 and 1989 (B. Carswell, B.C. Ministry of Agriculture, Fisheries and Food, Victoria, *pers. comm.*). The private hatchery at this site, which produced coho and chinook salmon, is currently closed (P. Ross, MELP Smithers, *pers. comm.*).

Shawatlan River

The Shawatlan River flows westward into Fern Passage at the head of Morse Basin. A BC Hydro dam is located 6.8 km upstream of the mouth and generates power for the City of Prince Rupert. The supply of spawning gravel is good, and no water quality problems have been reported.

Shawatlan River is a modest sockeye and coho salmon producing stream, and pink, chum, and chinook salmon, and steelhead are also present. Sockeye salmon escapements to the watershed number in the low thousands annually, with the highest recorded escapement of 6,000 individuals occurring in 1982 (Figure 4.26). Spawning sockeye salmon enter the river in early September. Coho salmon escapements have generally numbered in the low hundreds, with a recorded high of 3,500 fish (Figure 4.26); maturing fish enter the river in September and October, and spawning lasts until November. Small numbers of spawning pink and chinook salmon are found in the river July to October and August to October, respectively.

Denise Creek

Denise Creek flows into the head of Denise Inlet, which links to the southeastern end of Morse Basin. The creek has good gravel beds for spawning in the lower 2.3 km. Small runs of coho, pink, and chum salmon and cutthroat trout are supported by the creek. Pink and coho salmon escapements are generally not in excess of 100 fish annually (Figure 4.27); although the 1986 pink salmon spawning escapement was 600 individuals.

Kloiya River

Kloiya River flows into Kloiya Bay, which links with the southeastern end of Morse Basin. The lakes of this watershed have provided water for the pulpmills at Port Edward since 1960. The river is dammed 2.0 km upstream of the mouth, and a fishway was constructed to allow anadromous fish passage.

The Kloiya River watershed supports resident populations of rainbow trout, cutthroat trout, and Dolly Varden char, as well as anadromous populations of sockeye, pink, chinook and coho salmon, and steelhead trout. Chum salmon have been observed in the river in the past (prior to 1979), but none have been observed in recent years.

Sockeye salmon escapements (Figure 4.28) in the two decades prior to 1989 were generally in the low thousands, but numbers were generally between 4,000 and 7,000 in the 1950's and 1960's. (maximum 10,000 in 1958). Sockeye upstream migration and spawning occurs from August to October. Pink salmon escapements increased through the 1980's and are currently in the low thousands (Figure 4.28); 4,000 in 1991 (G. Serbic, DFO Nanaimo, *pers. comm.*). Pink spawning occurs in the lower 2.0 km of Kloiya River, below the dam, between August and October. Chinook salmon enter and spawn in the Kloiya River between July and October. Chinook escapements are generally in the low to mid-hundreds annually (Figure 4.28), but have been recorded as high as 1,500 (1963). At the base of the dam 2.0 km upstream of the mouth, an incubation box and rearing trough program was begun in 1981, targeting on chinook, coho, and steelhead enhancement. Coho salmon escapements to Kloiya River have steadily declined since the 1960's and are currently represented by less than 100 fish annually (Figure 4.28).

4.3.5 Flora Bank

Flora Bank is an important part of the local area from an ecological perspective. Development plans for port development in the Flora Bank and Kitson Island area during the 1970's were shelved because of the importance of this location for fisheries resources (Hoos, 1975). The bank is highly productive, supporting approximately 50 to 60% of the total eelgrass of the Skeena River estuary (Hoos, 1975). Large numbers of salmonids utilize this area during their early estuarine residency, including both the majority of sockeye juveniles and a large number of pink juveniles originating from the Skeena River watershed (Knapp and Cairns, 1978).

Commercial gill and seine fisheries occur to the south of the bank (Figure 4.22). Dungeness crabs are common near Kitson Island (Hoos, 1975).

4.3.6 Porcher Island

The marine waters and coastal streams of Porcher Island support significant fisheries, especially for finfish resources. The resources of approximately the northern-most half of the island and Kitkatla Inlet (First Cycle EEM reference area) are included in this Local Resource Inventory.

4.3.6.1 Marine Resources

Porcher Island supports significant commercial and recreational salmon fishing. Gillnet fisheries operate throughout the marine waters of the northern end (Figure 4.22a) and southern end (Figure 4.22b) of the island. The recreational harvest for salmon resources is also significant in these waters (E. Fast, DFO Prince Rupert, *pers. comm.*), especially in Hunts Inlet (Knapp and Cairns, 1978). The nearshore waters of the island support salmon rearing, from stocks originating both on the island itself (primarily coho and pink salmon) and from the Skeena River (all species).

The northern end of Porcher Island is also an important herring spawning area, although relatively less so than the Tsimpsean Peninsula locations (Figure 4.22a). A herring roe fishery is supported in the southwest of the island (Figure 4.22b). Kitkatla Inlet supports sole species and eulachons. The area may be an important salmon rearing area.

Commercial fishing for Pacific halibut is significant to the immediate west of the island in offshore waters in Hecate Strait.

Intertidal butterclams have been harvested on beaches in Prescott Passage, north of Eyde Passage, and in Kitkatla Inlet (Figure 4.22b). Sea cucumber appear to have attracted some interest as a commercial/native fishery in Kitkatla Inlet, but information is sparse (P. Ross, MELP Smithers, *pers. comm.*). Commercial fisheries for coonstripe and humpback shrimp, Dungeness crab, and octopus also occur in this inlet (E. Brooke, commercial fisherman Prince Rupert, *pers. comm.*).

4.3.6.2 Freshwater Resources

Significant anadromous salmonid resources originate from several streams of Porcher Island. Escapements to these watersheds consist mainly of pink salmon, which have often numbered in the tens of thousands. Coho salmon returns to northern Porcher Island creeks are modest when present. Other salmon species are not common in these creeks, if present at all.

Humpback Creek

Humpback Creek is located in the northeastern portion of Porcher Island and flows into Chatham Sound. The watershed was logged in 1966 and the creek has since been subject to the input of related debris; the creek has also been subject to scouring, erosion, and silting since. Water levels fluctuate and low water is a problem between rains. The lower 1.6 km is brackish-water marsh habitat.

Humpback Creek supports a respectable spawning escapement of up to 18,000 adult pink salmon annually; although numbers closer to 5,000 are more usual (Figure 4.29). Adult pink salmon are present in the creek from August to October up to 700 m upstream of the mouth. Coho salmon have been observed in the creek; although, escapements are low and irregular. Spawning activity has been observed in October and early November, 1.0 km upstream from the mouth.

Chismore Creek

Chismore Creek is located in the northeastern portion of Porcher Island and flows into Chismore Passage. Pink salmon spawn in the creek up to about 1.2 km upstream of its mouth in modest numbers; escapements ranged from the low hundreds to several thousand (Figure 4.29). No information is available on run timing.

Spiller Creek

Spiller Creek is located in the northeastern portion of Porcher Island and flows into Chismore Passage. The creek supports a modest annual escapement of 3,000 (average) adult pink salmon (Figure 4.29), which spawn in the lower 1.8 km and in the estuary. Coho salmon were observed in significant numbers (up to 1,500) in the lower 1.8 km of the creek during the late 1960's, but none have been observed since 1969.

Oona River

Oona River is located in the eastern portion of Porcher Island and flows into Ogden Channel south of Kennedy Island. The river is considered a good pink and coho salmon spawning stream. The river is prone to debris and log jams, which are kept open by habitat improvement projects.

Pink salmon escapements have ranged up to 35,000 annually (in 1989); although they have generally been around 10,000 (Figure 4.30). Adult migrants and spawners are present in the river from late August to late October. The river also supports a modest spawning escapement of coho salmon, which are present in the river from September to October (Figure 4.30). A hatchery, located near the mouth of the river, has produced modest numbers of coho since 1982 (FHIIP, 1991). Two relatively larger escapements of coho salmon in 1990 and 1991 may have partially resulted from enhancement efforts, although the recent trend toward increasing run size has only been observed for a short period (Figure 4.30).

Little Useless Creek

Little Useless Creek is located in the northwestern portion of Porcher Island and flows into Edye Passage. The creek is subject to flash flooding but provides salmon habitat in its lower reaches. Pink salmon spawn mainly in the lower end, but have been observed as far upstream as 1.0 km, from August to October. Spawning escapements of pink salmon range up to 9,500 (in 1986), but are generally around 1,000 annually (Figure 4.31). Coho salmon have been reported in the creek, but have not been observed spawning since 1957.

Useless Creek

Useless Creek is located in the northwestern portion of Porcher Island and flows into Edye Passage. This stream has good quantities of spawning gravel, but low discharge rates make upstream migrations difficult for spawning fish in some years. Low flows have been associated with prespawning mortality in some years. During freshets, the creek is subject to flash floods.

Useless Creek is a respectable producer of pink salmon, supporting an escapement of several thousand fish annually; the maximum escapement on record was 35,000 in 1962 (Figure 4.31). Pink spawning occurs mainly in the lower end and estuary but has been observed up to 8.5 km from the mouth; adult pink salmon have been observed in the creek from August to early October. Coho salmon have been observed spawning in the creek on only five occasions since 1953; the most recent of these was 1984 when 100 spawners were enumerated. When present, coho adults spawn up to 9.0 km from the creek mouth during October and November.

Hunt Inlet Creek

Hunt Inlet Creek is located in the northern portion of Porcher Island and flows into Chatham Sound via Hunt Inlet. The creek supports a modest spawning escapement of up to a few thousand pink salmon, mainly in even-numbered years (Figure 4.31). Coho have been observed in the creek but their escapements have not been enumerated.

4.3.7 Skeena River

The Skeena River is the second largest salmon producer in British Columbia, after the Fraser River. Escapements of sockeye and pink salmon are often in the millions of fish annually. This production supports substantial commercial, First Nations, and recreational fisheries in Chatham Sound and throughout nearby waters (Porcher Island and the Skeena River estuary). The majority of the salmon harvest in the Prince Rupert area by First Nations peoples occurs within the Skeena River and estuary (U. Orr, DFO Prince Rupert, *pers. comm.*).

In addition to these resources, the river and estuary support many other resident, anadromous, and catadromous fish species.

4.3.7.1 Skeena River Estuary

The Skeena River estuary consists of an extensive network of tidal channels separated by islands and shoals. Freshwater from the Skeena River flows mainly through Inverness Channel, Marcus Passage, and Telegraph Passage. The extent of freshwater influence varies seasonally with river discharge (range 85 to 4,100 $m^3 \cdot s^{-1}$, annual mean = 923 $m^3 \cdot s^{-1}$) but generally extends throughout Chatham Sound. Like the Fraser and Squamish rivers, the estuary of the Skeena River is very turbid, due to the presence of suspended sediments from glacial scour within the watershed or from resuspension of sediments during spring freshet (May to July).

The estuary is a productive fish habitat supporting estuarine stages of many marine and anadromous fish species (Higgins and Schouwenburg, 1973). Its numerous channels and shoals provide abundant food and cover for fish (Hoos, 1975). Hoos (1975) identified 46 fish species as living within the estuarine waters of the Skeena River or migrating through it during various stages of their life-cycle.

Several species of importance for human consumption utilize the estuary year-round or seasonally (often for breeding). The most prominent of these species include flatfishes (especially starry flounder), Pacific herring, and smelts (i.e., eulachon, surf smelt, capelin, and long-fin smelt).

Additional species found in freshwater and estuarine influenced waters are listed in Table 4.7.

Skeena River

The Skeena River is the second most important producer of salmon in British Columbia, after the Fraser River. Over 180 tributary streams contribute to the total salmon spawning habitat to the Skeena River watershed. Pink and sockeye salmon continue to be the most numerically important commercial fish species in the Skeena River. Average escapements over the past ten years (1983 to 1992) were 1.24 million sockeye, 2.30 million pink, 22,000 chum, 52,000 chinook, and 38,000 coho salmon annually (Figure 4.33), and lesser but significant numbers of steelhead trout.

Sockeye salmon escapements have been increasing since the 1950's, when numbers of spawners averaged approximately 0.5 million. These escapements have more than doubled since then. Current escapements (1983 to 1992) range between 709,000 to 2,171,000 annually, depending on the cycle-year. Most of these fish return to the Babine watershed. Returning sockeye spawners are present in the river and tributaries from June to October.

Like sockeye salmon, pink salmon escapements in the Skeena River have been increasing over the past several decades. Escapements recorded from the 1950's were approximately 200,000 to 1,300,000; currently (1983 to 1992) these numbers range between 760,000 and 4,200,000 (Figure 4.33). Pink salmon spawn mainly in the lower tributaries of the Skeena watershed, but some fish spawn in the Babine watershed as well (Hoos, 1975). Pink salmon migration and spawning generally occur between late July to the end of October.

Chum salmon are of modest significance to the salmon fishery, relative to pink and sockeye salmon. Escapements of this species have ranged from under a thousand to over 100,000 since 1953; the highest recorded escapement was 110,370 fish in 1988. Chum spawners are generally in the Skeena River mainstem from late July to early September. Although the spawning escapements have been relatively low for this species, chum stocks in the Skeena River appear to be quite productive and may be able to withstand high fishing pressures relative to other British Columbia stocks (Beacham, 1984).

Chinook salmon are currently (since the early 1980's) the third most numerous of the salmon species in the Skeena River. Escapements of this species have ranged from 12,980 to 108,900 spawners annually (Figure 4.34); the maximum escapement was recorded in 1958. Numbers ranging between 20,000 to 60,000 are the norm. Adult migrating and spawning chinook salmon are generally present in the Skeena watershed from late June to early October.

Coho salmon escapements to the Skeena River watershed have ranged from about 11,000 to 161,000 annually (Figure 4.34). Numbers of spawners have fluctuated between 11,000 and 69,000 in the past ten years, but appear to have ceased a long-term decline which began in the mid-1960's. Adult coho salmon are generally present in the river and tributaries from August to November.

Steelhead trout are taken incidentally in fisheries for other salmon species. Escapements of steelhead to the Skeena River are not currently kept. However, given the decline in catch over the last decade (Figure 4.3), it is likely that escapements to this river have exhibited considerable decline.

Among the non-commercial salmonid species, the Skeena River supports anadromous populations of Dolly Varden char, cutthroat trout, as well as resident rainbow trout and mountain whitefish.

Ecstall River

Ecstall River is the first major tributary of the Skeena River watershed upstream of the mouth. The lower reaches of this river are tidally influenced. A small dam operates on one of the tributaries of the river, and there has been recent logging activity in the lower portions of the watershed (1990 - FHIIP, 1991). Although it is subject to seasonal fluctuations, the water supply in the river is relatively good compared to other coastal rivers; extreme changes in water level are associated with heavy rains. The river has elevated suspended sediment loads up to 43.5 km from the mouth. Ecstall River supports all of the major salmonid species present in the Skeena River; although sockeye salmon are far less significant in this tributary than other streams. Mountain whitefish, Dolly Varden char, rainbow and steelhead trout, and cutthroat trout are present. Eulachon and other estuarine forms are present in the lower portions of the river (Hoos, 1975).

Sockeye salmon spawning escapements to Ecstall River have been modest in size and irregular since 1953 (Figure 4.34). Sockeye salmon have only been observed in six years over the past four decades, however, they were recorded in several consecutive years in the late 1980's.

Pink salmon escapements in Ecstall River have been as high as 35,000 (in 1987) during the past four decades (Figure 4.34); currently (1984 to 1992) escapements range between 5,000 and 35,000. Their numbers have markedly increased since the early 1980's, when escapements of only a few hundred were average.

The chum salmon escapement to Ecstall River regularly represents over half of the Skeena River total (Figure 4.33 and 4.34). The maximum recorded annual escapement was 75,000 in 1988, with numbers of adult spawners in excess of 10,000 individuals occurring on ten occasions since 1953.

Ecstall River exhibits a modest chinook salmon escapement of up to 3,800 individuals annually (Figure 4.34); numbers are generally in excess of 1,000 spawners.

Coho salmon exhibit a modest spawning population; although, numbers appear to have been increasing over the past decade (Figure 4.34). Current escapements (1983 to 1992) have ranged between 500 and 10,000 spawners.

Moore Cove Creek

Moore Cove Creek is located approximately 15 km south of the mouth of the Skeena River and flows into Telegraph Passage via Moore Cove. The creek is accessible to anadromous fish up to 6.7 km during high water (2.4 km otherwise). The upper watershed was logged in 1988 (FHIIP, 1991).

Moore Cove Creek is a productive pink salmon spawning stream, supporting escapements of up to 130,000 spawners annually (Figure 4.35). Annual escapements have averaged over 35,000 during the past forty years. Coho salmon have historically utilized this stream; the highest recorded escapement was 7,500 adults in 1966 (Figure 4.35). Coho have not been recorded in respectable numbers since 1974. Coho and pink salmon have been observed spawning up to 4.0 km upstream of the mouth, from late September to November and from late August to October, respectively.

4.3.7.2 DeHorsey Bank

Located at the mouth of the Skeena River, DeHorsey Bank supports salmon rearing, especially for pink salmon juveniles during their brief, one-month estuarine residence before they migrate seaward.

4.3.7.3 Smith Island

Smith Island supports commercial salmon fishing activity (gill and seine net - entire island) and sport fishing activity (in Tsum Tsadai Inlet - Knapp and Cairns, 1978). Commercial crab fishing occurs within Tsum Tsadai Inlet and in nearshore waters at the southern end of the island (Figure 4.22).

Bremmer Lake Creek, flowing into the Skeena River estuary near DeHorsey Bank, supports a small amount of coho spawning and rearing (FHIIP, 1991). The nearshore waters of Smith Island support salmon rearing, primarily in the Inverness Passage area (Hoos, 1975; Knapp and Cairns, 1978; Dwernychuk, 1988).

4.3.7.4 Kennedy Island

Salmon gillnet fisheries operate throughout the Skeena River estuary, including the waters around Kennedy Island. Like other areas of the Skeena estuary, the island provides rearing habitat for the juvenile salmon prior to, and at the beginning of, their seaward migration. Dungeness crab are also commercially harvested in the northwestern and southern ends of the Island.

4.3.8 Local Area Fisheries Advisories

Closures and advisories pertaining to fisheries resources in the Prince Rupert - Skeena area have been issued in past years due to the presence of domestic sewage, industrial effluent, and naturally occurring toxicants. These closures and advisories have mainly related to shellfish resources.

Harvesting closures and consumption advisories for crab and prawn in the vicinity of Kaien Island and Ridley Island, due to the presence of dioxins and furans, are currently in effect (Government of Canada, 1993). The crab fishery in Wainwright Basin and Porpoise Harbour were closed to all harvesting in May, 1988, in Wainwright Basin and Porpoise Harbour; these areas currently remain closed. As additional results of dioxin sampling programs became available (see Section 5.0), closures and consumption advisories were revised to include aspects of crab and shrimp fishing in adjacent areas.

The current closure/advisories are shown in Figure 4.36. Commercial crab fishing is closed in Porpoise Harbour, Wainwright Basin, Morse Basin, much of Prince Rupert Harbour, and southwestern waters off Ridley Island. The commercial shrimp fishery is closed in Porpoise Harbour and the waters to the southwest of Ridley Island.

All recreational and native crab harvesting is closed in Porpoise Harbour, Wainwright Basin, and the southwestern waters of Ridley Island. For crab taken in the recreational and native harvest in Morse Basin and much of Prince Rupert Harbour, a consumption advisory issued by the Government of Canada (1993) suggests that the consumption of crab hepatopancreas tissue be limited to 70 grams weekly.

Intertidal clam harvesting closures are also in effect in Prince Rupert Harbour due to contamination from domestic and industrial sources and to Paralytic Shellfish Poisoning (PSP).

There are no harvesting closures currently in effect for finfish resources due to dioxins and furans or other compounds. However, there is currently a general advisory recommending against the consumption of bottomfish livers in the vicinity of all coastal pulpmills in British Columbia.

Additional closures of various fisheries may be issued due to management reasons. These are generally seasonal and are associated with the maintenance of fish stocks.

4.3.9 Fish Community Assessments

Assessments of the fish community in Management Area 4 are limited. However, substantial implicit information can be obtained by examining the numerous investigations which have been conducted to facilitate the management of significant commercial and recreational species (e.g., Leaman, 1992a; Thomas, 1992). Often, such stock assessments are performed annually.

Studies, which have either investigated many species simultaneously (true community assessments) or have attempted to integrate existing knowledge on many species into a composite picture, are rare in British Columbia waters. Several that come the closest to being true assessments of fish communities are listed, along with their principal findings and conclusions, in Table 4.8. The study of the Skeena River estuary by Hoos (1975) provides background fish and invertebrate community information from the river and estuary, and also from the nearby coastal waters as well. The resources of Management Area 4 have also been described by Knapp and Cairns (1978).

Several unpublished studies have also been conducted (see Williams, 1991).

4.3.10 Fish Contaminant Reports

The accounts of the available fish contaminant information have been discussed in Section 5.4. A summary of these studies, and their principal findings and conclusions, are presented in Table 5.5.

4.4 CANDIDATE SENTINEL SPECIES

Several species of marine finfish and invertebrates were considered as candidate sentinel species at a recent "*Ad-hoc* meeting on marine sentinel species" held at the Pacific Biological Station, Nanaimo on June 2, 1993 (Forsyth, 1993). Of a total of sixty-two finfish species initially examined, eleven were given detailed consideration. These have been listed in Table 4.9. The basic biology and importance to humans as resource species have been discussed in the various subsections of the Regional Resource Inventory. The finfish species considered most favourably (≥5 on a scale of 10) as marine sentinel species include English sole, stickleback, starry flounder, staghorn sculpin, and surf perch in descending order of rank.

Among the unspecified number of invertebrate species initially examined, seven were given detailed consideration (Table 4.9). Similar to the criterion for finfish, the invertebrate species considered most favourably as candidate marine sentinel species include oysters, geoducks, horseclams, mussels, and crabs in descending order of rank.

All of the above species occur within the area considered in the Local Resource Inventory. Therefore their use as candidate sentinel species appears appropriate based on their distribution with respect to the Skeena Cellulose Inc. pulpmill near Prince Rupert. Although the ideal ranking of fish and invertebrate species may be taken as listed above, local patterns of abundance or catchability may make certain selections problematic. For example, although crab are most appropriate (due to abundance and biology) in the vicinity of Prince Rupert, female crab are very scarce making the collection of 20 males and 20 females more difficult than might first seem apparent. Therefore, the final selection of sentinel species should be flexible within the above priority lists and made on the basis of obtainability. Concerns may remain about the use of locally harvested species within impacted sites and potential reference sites, given the effects of harvest on the productivity of populations. Tentative selection of sentinel species and capture techniques has been detailed in the Skeena Cellulose First Cycle EEM Design document (Hatfield Consultants Ltd., *in prep.*).

4.5 SYNOPSIS

The marine, estuarine, and freshwaters in the vicinity of the Skeena Cellulose pulpmill near Prince Rupert (Management Area 4) are important habitats for many fish and invertebrate resource species. Groundfish, salmon, herring, shrimp, prawn, crab, octopus, sea urchin, sea cucumber, geoduck, and intertidal clams are found throughout the area, and several are common in many locations. Chatham Sound represents an important migration corridor for both juvenile and adult salmon of many stocks from the Skeena River watershed and local coastal streams. The Skeena River dominates fisheries of the local area, and the river's estuary is ecologically sensitive, supporting the juvenile stages of many fish species (especially, salmon). Herring spawn in large numbers in several areas throughout Chatham Sound, especially the Tsimpsean Peninsula and northern Porcher Island.

Commercially, Management Area 4 is a large producer of finfish resources (principally salmon). These include several pink and sockeye salmon stocks of the Skeena River drainage, and groundfish species. Invertebrates are generally harvested only in relatively low quantities. However, geoduck clam, shrimp, prawn, sea urchin, sea cucumber are significant commercial species locally. Most of the salmon harvest originates from the terminal fisheries near the Skeena River or as intercept fisheries throughout Chatham Sound. Commercial invertebrate fisheries are of modest significance compared to the rest of British Columbia. Aquaculture activity in the Prince Rupert area is currently non-existent.

The use of the local fisheries resources by First Nations is important, specifically in and around the Skeena River. Sockeye salmon are the principal target species, but all other salmon species are harvested. Historically, herring, halibut, and eulachon were also taken.

The Skeena River/Chatham Sound area is becoming increasingly important as a sport fishing area, both among local residents and locals. Charter operations have grown in number through the past decade. Primarily, the target species have been coho and chinook salmon. However, significant numbers of lingcod, rockfish, and Pacific halibut are also taken. Dungeness crab and prawn are also harvested recreationally.

In addition to the effects of pulpmill effluent from Skeena Cellulose, domestic sewage has been a cause for concern in recent decades. The resources of the Porpoise Harbour, Wainwright Basin, Morse Basin, and Prince Rupert Harbour, as well as Ridley Island, have been the most susceptible. These areas are at some distance from the principal fisheries resource areas. Fisheries closures and advisories for crab and prawn harvesting, due to the presence of dioxins and furans, are currently limited to the above mentioned areas.

5.0 HISTORICAL RECEIVING ENVIRONMENT DATA

The purpose of this section of the pre-design document is to discuss data provided during historical and present environmental monitoring performed in the Prince Rupert area. Monitoring data may identify environmental effects and aid in selection of study and reference areas for the Environmental Effects Monitoring (EEM) program.

Repap's Skeena Cellulose Inc. pulp and paper mill (Skeena) is situated on Watson Island approximately 10 km south of Prince Rupert, British Columbia (Figure 5.1). A dissolving sulphite pulpmill commenced operation in 1951. In 1966, a bleached kraft pulpmill was built on this site. In January 1976, the sulphite mill was closed and a second bleached kraft pulpmill was constructed, which commenced operation in 1978.

Initially, discharge from the sulphite operation was directed into Wainwright Basin. In 1966, effluent was piped under Porpoise Harbour, across Ridley Island and into Chatham Sound at "Discharge Cove". The original kraft mill continued to discharge into Wainwright Basin. However, with completion of the second kraft operation in September 1978, all discharges were directed into Porpoise Harbour through a diffuser located at a depth of approximately 18 m. See Section 6.0 for further mill history.

Major commercial fisheries of salmon, herring, crab and shrimp exist in the Prince Rupert area (Section 4.0). Fish processing plants are located approximately 1.5 km south of the diffuser at Port Edward. The Skeena River estuary is of great importance given the sockeye salmon runs (Hoos, 1975). In November 1989, the Department of Fisheries and Oceans issued a directive for fishing closures in the vicinity of Skeena after the identification of dioxins/furans in edible biological tissues. All crab fisheries were closed in Wainwright Basin; the shrimp fishery was closed along most shores of Ridley Island. Concurrently, commercial crab fishery closures and health advisories for the consumption of crab hepatopancreas were delineated; these were revised in August 1993 to include Morse Basin, the west coast of Ridley Island, and Prince Rupert Harbour east of Digby Island.

The Skeena pulpmill has been monitored by environmental experts since the 1970's. Table 5.1 lists studies of the receiving environment conducted in this area. Hatfield Consultants Ltd. have been conducting organochlorine (including dioxin and furan) monitoring studies of the receiving environment since 1987. Between 1985 and 1990, Hatfield Consultants Ltd. also conducted water quality and biological monitoring. Beak Consultants Ltd. (later IEC Beak Consultants Ltd.) conducted water quality, intertidal and subtidal monitoring on an annual basis under Permit PE-1157, B.C. Ministry of Environment, between 1978 and 1984. Governmental agencies have conducted occasional marine surveillance programs in the Prince Rupert area since 1953.

This section of the pre-design document discusses the historical monitoring data from the vicinity of Skeena, and includes:

- water quality parameters;
- sediment quality;
- intertidal (macroalgae and invertebrate) and subtidal (invertebrate) communities; and
- biological tissues of shellfish, crab and groundfish.

5.1 RECEIVING WATER QUALITY

Physiography, tides and currents in the Prince Rupert area are discussed in Section 2.2 of this document. Freshwater influences of the Skeena River and Wolf Creek (Wainwright Basin) are presented in Section 2.2.3.

Since 1978, water quality monitoring in the vicinity of Skeena pulpmill has been conducted by Hatfield Consultants Ltd., IEC Beak Consultants Ltd., and Beak Consultants Ltd. (Table 5.1). Water quality monitoring stations used between 1981 and 1991 include (Figure 5.1):

- Stations 1, 2 and 3 - Wainwright Basin;
- Stations 4, 5, 6 and 7 - Porpoise Harbour;
- Stations 8 and 9 - Porpoise Channel; and
- Stations 10 and 11 (both added in 1990) - Chatham Sound.

The initial monitoring program in 1978 to 1979 included most of these stations with an additional one located in Morse Basin. Station locations in 1980 were the same as Stations 1 to 8 in 1981. Water quality parameters included temperature, dissolved oxygen, pH, salinity, true colour, tannins/lignins, turbidity and Secchi depth. Between 1983 and 1987, resin acid concentrations were monitored. In 1990/1991, water samples were also analyzed for chloroform and adsorbable organic halides (AOX).

5.1.1 Temperature

Water temperatures in the Prince Rupert waterbodies respond to seasonal conditions, with a thermocline being formed usually in June, July, and August. Temperatures are somewhat higher in July in the more isolated Porpoise Harbour, Wainwright Basin and Morse Basin (Hoos, 1975).

Surface temperature in Wainwright Basin near the mill appeared to be elevated in 1961 (Figure 2.3). Waldichuk (1961) reported temperatures of 13.7°C at the discharge station compared to 12.3°C and 12.7°C at other stations in the basin. In 1978, when effluent was still discharged into Wainwright Basin, surface temperatures at Station 2 were as much as 3.5°C greater than bottom temperatures - a greater increase in temperature than noted at any other station (Beak Consultants Ltd., 1980). However, since 1979, temperature measurements in Wainwright Basin have reflected a well-mixed, small body of water that was subject to a slightly greater range of seasonal temperatures and influenced by freshwater inflow (Figure 5.2, Station 2). Pulpmill effluent in 1990 did not appear to have any influence in this basin (Dwernychuk *et al.*, 1992a).

Since 1978, temperatures in Porpoise Harbour near the diffuser have not indicated an effect by mill effluents. In 1980, a slight increase of 0.2 to 0.3°C at the 2 to 15 m depth at Stations 5 and 6 was noted; this was possibly due to effluent, but the influence was minimal (Beak Consultants Ltd., 1981). In 1985, warmer temperatures in the upper 10 m of the water column at stations in Porpoise Channel and Harbour were probably due to Skeena River flows introducing warmer surface waters into the region (Dwernychuk, 1986). The volume of mill effluent discharged into Porpoise Harbour did not appear to influence the thermal regime of Porpoise Harbour. In June 1990, a possible exception was noted in the temperature profile at Station 6, in which the water column temperature was elevated between the depths of 3 and 10 m, perhaps indicating the presence of the effluent plume (Figure 5.2; Dwernychuk *et al.*, 1992a).

5.1.2 Dissolved Oxygen

The water quality parameter most affected by sulphite mill effluent (red liquor) is dissolved oxygen. Sulphite effluent contains many organic compounds, including sugars. Decomposition of these compounds exerts a high biochemical oxygen demand (BOD), which results in the depletion or complete loss of dissolved oxygen in receiving waters (Hoos, 1975).

Dissolved oxygen concentrations in Chatham Sound ranged between 8 and 9 mg/L (Stokes, 1953; Waldichuk, 1961). However, in 1961, dissolved oxygen concentrations were recorded at less than 0.5 mg/L in Porpoise Harbour and Wainwright Basin (Figure 5.3; Waldichuk, 1961). Prior to 1978, maximum levels of dissolved oxygen in both water bodies were rarely observed above 5.0 mg/L (Stokes, 1953; Waldichuk, 1961; Goyette *et al.*, 1970), the level necessary to maintain normal life processes. Deeper waters in these areas were somewhat oxygenated due to relatively regular flushing action by tides (Waldichuk, 1961).

In 1968, "numerous breaks ... occurred in the red liquor line releasing liquor to Porpoise Harbour with the result that fish kills occurred" (Kussat, 1968, *cited in* Packman, 1979). Dissolved oxygen levels ranged between 0 and 6.1 mg/L in Porpoise Harbour, Wainwright Basin and Morse Basin following the break in the pipeline in September 1968.

Low dissolved oxygen levels in Wainwright Basin continued until the 1980's even though the discharge of sulphite mill effluent into Wainwright Basin ended in 1966 (Figure 5.4). This was probably due to residual mill wastes or wastes associated with log handling with a high oxygen demand, which were carried from the abandoned settling lagoons into Wainwright Basin by freshwater runoff from Wolf Creek. In 1978, dissolved oxygen values at the surface were 0.8 mg/L and 0.0 mg/L in June and July, respectively (Beak Consultants Ltd., 1980). In May 1981, the lowest dissolved oxygen level at Station 2 was 4.5 mg/L (Beak Consultants Ltd., 1982). Since 1983, dissolved oxygen concentrations have improved at Station 2, and levels have fallen within the measured range of values at all other stations.

In 1982, it was speculated that dissolved oxygen levels were correlated to tannin/lignin concentrations (IEC Beak Consultants, 1983). However, this was not statistically verified in following years; tests confirmed the lack of relationship between effluent presence (i.e., tannins/lignins) and dissolved oxygen concentrations (Dwernychuk, 1986). Rather, differences in dissolved oxygen values may be related to the intrusion of freshwater during high Skeena River flows during May, June and July, with perhaps residual effects extending into August and September. Since 1983, dissolved oxygen concentrations usually have ranged between 8.0 and 10.0 mg/L at most stations in the Prince Rupert area. In 1990/1991, dissolved oxygen concentrations generally were lower in the water columns at Stations 2 and 6 (averaging approximately 8 mg/L, Figure 5.2) than at other stations (average 10 mg/L), suggesting that mill effluents and/or log handling activities in Porpoise Harbour may have influenced water quality (Dwernychuk *et al.*, 1992a).

5.1.3 pH

Seawater is strongly buffered at approximately pH 8.0 by the carbonate/bicarbonate cycle. Values of pH in Chatham Sound average 8.0 (Hoos, 1975). In 1961, water samples from Porpoise Harbour had lower pH values (7.1 to 7.5) than did those taken in Chatham Sound. Bottom samples usually were higher in pH than those obtained from the top 15 m of the water column (Figure 5.3; Waldichuk, 1961). In Wainwright Basin, pH values were lower than normal sea water, ranging from 6.9 to 7.2, except at the station closest to the mill (6.0, Figure 5.3). Sulphite effluent has influenced pH of receiving waters at the discharge point.

Since 1978, pH has shown minimally decreased values due to mill effluents. The usual range of pH was 7.2 to 7.8 near Skeena pulpmill in surface waters (Figure 5.4). In October, a slight decrease of pH at 10 m compared to 20 m depth at Stations 5 and 6 may have been due to mill effluent; however, these decreases of 0.3 to 0.4 units of pH have not occurred consistently with other indicators of mill effluent (i.e., tannins/lignins; 1984 (Dwernychuk, 1985). The 1990/1991 monitoring program found that mill effluent discharge had no significant effect on the pH profile collected at Station 6 (Dwernychuk *et al.*, 1992a) although a slight decrease was noted (Figure 5.2). No change in pH was noted between 3 and 10 m at Station 2.

5.1.4 Salinity

Surface salinities in the Prince Rupert area usually vary between 26 and 28 ppt. Salinity concentrations below approximately 20 m depth remain constant at 30 to 32 ppt. During the September 1961 monitoring program, surface salinities varied between 26.77 and 27.67 ppt in Porpoise Harbour (Figure 2.3; Waldichuk, 1961). However, salinity levels in Wainwright Basin were generally lower, ranging between 11.99 ppt near the mill and 26.71 ppt near the center of the basin during that same study. The low value near the mill was influenced most likely by the sulphite mill effluent which entered the basin near this station and by freshwater runoff from Wolf Creek (Waldichuk, 1961).

Since 1978, decreases in salinity were influenced mostly by freshwater sources rather than mill effluents in both Wainwright Basin and Porpoise Harbour. The freshwater source near Station 2 reduced surface salinities to 13.8 ppt in August 1978 (Beak Consultants Ltd., 1980), but to only 20.60 ppt in June 1982 (IEC Beak Consultants Ltd., 1983). In Porpoise Harbour and Channel, surface salinities have been reduced to 16.9 ppt (May 1981, Beak Consultants Ltd., 1982). This was due mostly to Skeena River inflow by tidal action during freshet. A slight decrease due to effluent was possibly noticed in 1983; however, the influence of the Skeena River was more significant (IEC Beak Consultants Ltd., 1984).

In 1990/1991, salinity profiles recorded at Skeena pulpmill stations were relatively constant at all depths except during freshet when freshwater inputs were noted near the surface (Station 6; Figure 5.2). Stations 9, 10 and 11 also reflected profiles typical of a freshwater overly from the Skeena River during the June and August sampling events. Mill effluent discharge had no discernible impact on salinity profiles at any of the sampling stations (Dwernychuk *et al.*, 1992a). Surface salinities in both waterbodies at times other than freshet usually ranged between 26 and 30 ppt since 1978.

5.1.5 True Colour

True colour (APHA units) is a measure of the amount of dissolved substances in water. It is often used as an indicator of pulpmill effluent.

Between 1978 and 1983, the highest colour values were reported at Station 2 in Wainwright Basin (Figure 5.4). True colour (maximum 220 units, March 1978, Beak Consultants Ltd., 1980) decreased considerably between 1980 and 1983 (maximum 90 units). Since 1984, colour at Station 2 has seldom been recorded higher than 25 units.

Since 1981, elevated colour levels have been measured in Porpoise Harbour (Figure 5.4). In November 1981, Station 6 surface colour concentration was 90 units (Beak Consultants Ltd., 1982); in January 1984, surface levels were 40 units (Dwernychuk, 1985). Station 5, north of the diffuser, recorded 60 colour units at 10 m depth in October 1984. In 1987, the highest colour concentration (65 units) was recorded at Station 6, while the range of colour at all other stations was 10 to 35 units (Dwernychuk, 1988). Sufficient data exist that would indicate pulpmill effluent in Porpoise Harbour is probably the factor responsible for elevations in colour content near the diffuser (Dwernychuk, 1985).

5.1.6 Tannins/Lignins

Tannins and lignins are largely uncharacterized polyphenols that provide mechanical strength to wood by binding cellulose fibres. Elevated tannin/lignin concentrations are often correlated with true colour levels, and may indicate mill effluent.

The highest levels of tannin/lignin have been found at Stations 2, 5 and 6 (Figure 5.5). In 1978, Station 2 levels averaged 16.5 mg/L since kraft mill effluent was discharged into Wainwright Basin until September. Levels continued to be elevated at this station, most likely due to freshwater runoff through Lagoon #2 into Wainwright Basin (Beak Consultants Ltd., 1983). In Porpoise Harbour, a maximum level of tannin/lignin (6.4 mg/L) was recorded November 1981 at Station 6 (Beak Consultants Ltd., 1982). In 1985 (Dwernychuk, 1986), concentrations of tannin/lignin were 1.40 mg/L at the surface in February, and values at Stations 5 and 6 in November ranged between 0.70 and 0.90 mg/L. Tannin/lignin concentrations were less than 0.4 mg/L at all stations monitored in 1988 (Dwernychuk, 1989). Concentrations appeared to be declining during the 1980's (Figure 5.5).

5.1.7 Turbidity

Turbidity measures the presence of suspended solids in receiving waters. Turbidity levels in Porpoise Harbour may be influenced by either mill effluent or freshwater encroachment from the Skeena River during freshet. Monitoring programs have usually recorded turbidity levels less than 2.0 FTU (Figure 5.5). Occasional higher turbidity levels (4.0 to 5.2 FTU) have been recorded (Beak Consultants Ltd., 1980, 1982). Elevated turbidity may be correlated to colour or tannin/lignin concentrations, and consequently, to mill effluents. This was evident in 1978 when turbidity averaged 8.7 FTU at Station 2, correlating with high tannins/lignins and colour when effluent was still being discharged into Wainwright Basin (Figure 5.5). However, high turbidity values have occurred when the other parameters were low, which would indicate natural levels due to freshet. The following table gives an example of each:

	Station	Date	Turbidity	Colour	Tannin/Lignin
Mill	#2, surface	Nov. 1978	9.4 FTU	175 units	15.0 mg/L
Other	#9, surface	Nov. 1987	2.9 FTU	25 units	0.42 mg/L

Since 1978, mill effluents have had less influence on turbidity than natural sources, since Station 9 was most likely affected by Skeena River inflow (Figure 5.5; Dwernychuk, 1988).

Turbidity levels in Wainwright Basin have fallen to within the levels recorded in Porpoise Harbour. Higher values in recent years (i.e., 4.7 FTU, Station 2, June 1983) have been associated with runoff during freshet rather than pulpmill effluent (IEC Beak Consultants Ltd., 1984).

5.1.8 Secchi Depth

Secchi depth (or transparency) may be an indicator of the presence of pulpmill effluent in receiving waters. During the 1980's, low secchi depths were usually found in Wainwright Basin at Station 2 (0 to 2.5 m). These depths were often associated with high colour and tannin/lignin concentrations at that station (IEC Beak Consultants, 1983). In Porpoise Harbour, secchi depth varied between

1.0 to 3.5 m during most monitoring programs, and depths at stations near the diffuser have not shown evidence of effluent influence (Dwernychuk, 1986).

5.1.9 Resin Acids

Resin acids are produced during the kraft processing of pulp and are toxic to fish at concentrations between 1.0 mg/L and 5.0 mg/L (McKee and Wolf, 1963, *cited in* Dwernychuk, 1988). Sublethal conditions may be expected at resin acid concentrations of 0.050 to 0.250 mg/L. Resin acids were monitored at three stations (Stations 2, 6 and 9) near Skeena pulpmill between 1983 and 1987.

Total resin acid concentrations mostly have been below 0.010 mg/L or the detection limit (0.001 mg/L). Station 6 has, on two dates, slightly exceeded the lower sublethal value (0.055 mg/L surface, 1983; 0.068 mid-depth, 1987). Mean water columkn concentrations are shown on Figure 5.5. The probability of significant, long-term sublethal response patterns, due to resin acids, is considered low given the mobility of fish and the lack of consistently high concentrations over extended periods of time in ambient waters (Dwernychuk, 1988). Variability in resin acid concentrations may be due to very small sample size, inherent tidal influences and possible channelling of effluent.

5.1.10 Organochlorine Compounds

In the late 1980's, the presence of chlorinated organic compounds in receiving environments near bleached kraft mills became a public concern. In 1990/1991, Hatfield Consultants Ltd. was engaged to conduct a comprehensive survey of the physical, chemical and biological components of intertidal and subtidal systems at Prince Rupert, which included testing of receiving waters for chloroform and adsorbable organic halides.

Adsorbable organic halide (AOX) has become a standard for measuring the total amount of chlorinated constituents of kraft mill effluents in receiving waters. AOX concentrations were elevated in the vicinity of Watson Island (Stations 2 and 6, Figure 2.10) compared to concentrations detected at other stations (Dwernychuk *et al.*, 1992a). Highest concentrations at Station 6 were found in January 1991 (125 µg/L, surface) and at Station 2 in June 1990 (113 µg/L, bottom). Concentrations did not vary consistently with depth, suggesting that the effluent plume was well mixed at the two monitoring stations. At Station 9, AOX concentrations were below or close to detection limit (30 µg/L) at all depths and for all three sampling events. However, individual samples analyzed at the more distant stations (Stations 10 and 11) were found to contain higher levels of AOX. For example, water collected from 10 m depth at Station 10 contained 69 µg/L AOX. These differences may have been a result of the strong tides and currents in the area (Section 2.2.2).

Chloroform is a byproduct of chlorine bleaching. Chronic toxicity (27-day LC50) to aquatic life occurs at concentrations of 1,240 µg/L in freshwater (EPA, 1986). During the 1990/1991 monitoring program, chloroform concentrations were highest at Station 6, near the effluent diffuser in Porpoise Harbour, and at Station 2, Wainwright Basin (Figure 5.6; Dwernychuk *et al.*, 1992a). Traces of chloroform were detected at Station 9 during the first two sampling events; however, none were detected in January 1991. Chloroform concentrations in samples collected at Stations 10 and 11 were below the detection limit at all depths sampled. Chloroform, when present, was well dispersed in the water column and levels were unlikely to pose a threat to marine biota (Dwernychuk *et al.*, 1992a).

5.1.11 Water Quality Synopsis

Prior to September 1978 and operation of the diffuser, mill effluents influenced temperature, pH, salinity (to some extent) and dissolved oxygen in Wainwright Basin and upper Porpoise Harbour. Temperature was approximately 1.5°C higher near the Wainwright Basin discharge station, pH was lower (6.0), and salinity was reduced due to mill effluent and Wolf Creek runoff. Dissolved oxygen levels were particularly affected by sulphite liquor discharges, which had a high oxygen demand. Oxygen levels below the detection limit (0.5 mg/L) were recorded between 1961 and 1978, especially during summer months. The piping of red liquor effluent to Chatham Sound was not always effective in improving local water quality; breaks in the piping occasionally occurred, which lowered dissolved oxygen levels and resulted in fish kills. In Wainwright Basin, true colour, tannins/lignins, and turbidity levels were affected by kraft pulpmill effluents.

Since 1978, water quality gradually improved in Wainwright Basin and upper Porpoise Harbour until virtually no effect by mill effluents was recorded for temperature, dissolved oxygen, pH and salinity. However, true colour and tannin/lignins did exhibit some influence by effluents released through the diffuser into Porpoise Harbour. True colour (maximum 90 APHA units) and tannins/lignins (maximum 6.4 mg/L) were recorded in the 1980's and levels appear to be declining. Turbidity is occasionally elevated near the pulpmill, but the major source is Skeena River runoff during freshet. Natural runoff also has contributed to decreased secchi depth (transparency) in Wainwright Basin and Porpoise Harbour in recent years.

Resin acids, AOX and chloroform were detected in water samples collected near Watson Island. Resin acids were variable and generally well below sublethal levels for fish. AOX and chloroform concentrations were highest at Stations 2 and 6, indicating that well-mixed effluent was entering Wainwright Basin, as well as flowing through Porpoise Harbour.

5.2 SEDIMENT QUALITY

Sediments were monitored to assess particle size, volatile residue and heavy metal content during federal monitoring programs between 1979 and 1981 (Figure 5.7; Pomeroy, 1983a). Between 1983 and 1987, resin acid concentrations in sediments were monitored by environmental consultants. Since 1989, Hatfield Consultants Ltd. monitored organochlorine compounds in sediments, including dioxins and furans, primarily at two locations (Figure 5.8). A list of studies of sediment quality are provided in Table 5.1.

5.2.1 Fibre Bed

Suspended solids discharged into the marine environment with mill effluents are considered the primary source of fibre deposition adjacent to pulpmill outfalls (Pomeroy, 1983b). These solids settle out of suspension as a fibre bed, covering the habitat with wood fibres and smothering benthic organisms (Colodey *et al.*, 1990). The fibre beds often form jelly-like mats which can be several centimetres deep (Pomeroy, 1983b). The wood fibre slowly decomposes to become a black, anaerobic deposit and may release hydrogen sulphide gas, resin acids, trace metals, and organic contaminants. The biological oxygen demand created by decomposing fibre often results in lower dissolved oxygen concentrations near the beds. As a consequence, these fibre beds may become a serious threat to the receiving environment.

Effluent data indicated that about 67.88 t/d suspended solids (>90% volatile) were discharged into the receiving waters of Wainwright Basin in 1975 (Pomeroy, 1983b). By 1966, large intertidal and subtidal fibre deposits had formed in the basin. Large mats of fibre frequently appeared on the surface, raised by hydrogen sulphide gas accumulation (Pomeroy, 1983b).

During 1979 to 1981, a federal monitoring program examined sediments collected in Porpoise Harbour, Porpoise Channel and Chatham Sound. In 1979, visual examination of grab samples in the field indicated the existence of black reducing sediments containing fibre material extending from the entrance to Porpoise Harbour up to the northern end. Pomeroy (1983b) identified a fibre deposit forming in the vicinity of the diffuser in response to an average daily discharge of about 22 t/d total suspended solids. The pattern of deposition appeared to be concentrating fibre in the deeper parts of the harbour. In comparison, the bottom substrate in Porpoise Channel consisted of shale, rocks and some fine mud.

By 1987, total suspended solids in effluent had been reduced to 12 t/d (Colodey *et al.*, 1990). In that year, it was noted that northern sites in Porpoise Harbour did tend to indicate some form of accumulation effect relative to more southern sites; responsibility for this effect is unknown, but may be related to bottom contours (Dwernychuk, 1988). Zanardi Rapids may affect tidal shifts, resulting in a higher amount of material settling out towards the northern region of the harbour. In 1987 in Wainwright Basin (Station S2, Figure 5.8), "pockets" of wood/fibre were scattered throughout bottom sediments, indicating that fibre still remained in the basin (Dwernychuk, 1988).

A thorough study of the depth and extent of fibre deposits in Wainwright Basin and Porpoise Harbour has not been undertaken. Given that suspended solid discharge has greatly reduced since the clarifier was installed, fibre deposition should no longer be occurring.

5.2.2 Particle Size

Particle size has been measured since the late 1970's in an effort to relate sediments characteristics with mill activities. In 1979, sediments collected during the federal monitoring program consisted mostly of sand or silt/clay. In 1980 and 1981, the percentage of large particles (greater than

500 µm) increased at two stations in northern Porpoise Harbour. Fibre and wood debris were predominant in these samples in that size classification (Pomeroy, 1983a).

IEC Beak Consultants and Hatfield Consultants Ltd. (Figure 5.9) monitored sediment particle size in 1983 to 1987. At Station S6 in Porpoise Harbour, sediments were predominantly silt/clay (<62.5 µm) except in 1987 when the highest proportion of sediments was fine sand (62.5 to 250 µm). At Station S9 (Porpoise Channel), fine sand found in 1983 and 1984 gradually shifted to medium sand (250 to 500 µm) in 1987 (60.0%). At Station S2 in Wainwright Basin, particle size was predominantly greater than 500 µm until 1987, when a higher proportion of medium sand was found. These shifts in particle size were related most likely to specific sample locations, particularly at Station S2, where pockets of fibre/wood existed which influenced quantities of material being retained at various sieve fractions (Dwernychuk, 1988).

Between 1990 and 1993 (Dwernychuk *et al.*, 1992a,b, 1993a,b), Stations S2, S6 and S9 were again monitored for particle size, but in the four size categories of gravel (>2 mm), sand (2 mm to 63 µm), silt (63 µm to 4 µm) and clay (<4 µm). In 1990, sediments at Station S2 were predominantly silt, with equal amounts of clay and sand (Figure 5.9). The same was true at Station S6. Station S9 sediments, however, were predominantly sand, followed by silt. Since 1989, Stations SS1 and SS3 (Figures 5.8 and 5.9) were monitored. Morse Basin sediments (SS1) were predominantly clay and silt; Porpoise Harbour sediments (SS3) consisted mostly of silt with equal amounts of clay and sand (Dwernychuk *et al.*, 1993a). Large fibre and wood particles (>500 µm) do not appear to be accumulating in recent years.

5.2.3 Sediment Volatile Residue

Volatile residue is an approximate measure of total organic material in sediment by weight and can serve as an indicator of fibre deposition. The top 2 cm of sediment cores was used to determine volatile residue.

Volatile residue (percent organic content) of subtidal surface sediments at stations up to 750 m from the diffuser increased following startup of effluent discharge in Porpoise Harbour in 1978 (Pomeroy, 1983a). Prior to operation of the diffuser, volatile residue ranged between 1.3 and 3.9%. A slight increase in volatile residue was noted within 750 m of the diffuser in 1979 and 1980; however, 1981 values were considerably higher, particularly to the north of the diffuser. In 1981, maximum volatile residue was 21.0% at 750 m north of the diffuser; 750 m south of the diffuser, volatile residue was 6.0% (Pomeroy, 1983a).

Sediment monitoring between 1983 and 1991 indicated values for volatile residue similar to previous years in Porpoise Harbour (Figure 5.10). Volatile residue at Station S6 (Figure 5.4) ranged from 5.8 to 8.1% during the 1980's. Station S9 (Porpoise Channel) residues were lower (3.0 to 5.3%) than at Station S6 and reflected control values. It appeared that volatile residue (and therefore fibre deposition) at these two stations has remained fairly constant.

Station S2 in Wainwright Basin was also monitored during 1983 to 1991 for volatile residue. Values dropped from a high of 88.9% in 1985 to 13.4% in 1990/1991 (Dwernychuk, 1986; Dwernychuk *et al.*, 1992a). There appears to be a decline in values in Wainwright Basin; however, the deposition of fibre on the bottom substrate has been described above as occurring in "pockets", and differences in volatile residue may be due to either sample location or sediment quality.

Volatile residue monitoring between 1990 and 1993 (Dwernychuk *et al.*, 1992a,b, 1993a,b) has been conducted at Stations SS1 (Morse Basin) and SS3 (Porpoise Harbour). Station SS1 values (11.4 to 15.4%) have been higher than those at SS3 (6.2 to 9.3%).

5.2.4 Trace Metals

From 1979 to 1981, the Environmental Protection Service monitored trace metals in sediments in Porpoise Harbour (Pomeroy, 1983a). The following metals were included: cadmium, copper, iron, manganese, nickel, mercury, lead and zinc. Environment Canada also collected sediments from transects across Porpoise Harbour in 1987 and analyzed the samples for metal content. Figure 5.7a shows the sampling locations, and Table 5.2 lists the range of values measured near Skeena pulpmill.

Between 1979 and 1981, concentrations of trace metals measured in the subtidal surface sediments of Porpoise Harbour varied slightly, but there was no clear indication of a pulpmill effluent effect (Pomeroy, 1983a). In 1987, the majority of trace elements in sediments from the six transects (and sites therein) located in Porpoise Harbour proper were quite similar to the highest value recorded in sediments from the Porpoise Channel reference site - Transect 7 (Figure 5.7b). Sites located at the northern sector of Porpoise Harbour exhibited levels of certain metals (i.e., example, mercury, calcium, chromium, copper, and cadmium) which were slightly in excess of those detected in more southern regions of the harbour. The most significant increases relative to reference Station 7 were for mercury (four fold difference) and cadmium (six fold difference) at Transect 1 (Table 5.2).

Data from 1987, when reviewed in conjunction with sediment information from Pomeroy (1983a), suggested that no significant differences emerged between 1981 and 1987. However, sampling stations were not identical, and direct comparisons were not possible. The 1987 data suggested no clear, direct mill effluent effect (Dwernychuk, 1988).

To assess the 1987 metal levels in sediments, the highest concentration measured in Porpoise Harbour (Table 5.2) were compared to BAET levels. BAET (Benthic Apparent Effects Threshold) was developed in Puget Sound, Washington, to define the sediment concentration level at which a detrimental effect on organisms is expected 100% of the time (Tetra Tech Inc., 1986).

SKEENA AND BAET METAL CONCENTRATIONS[1]		
Metal	Skeena 1987 Level (mg/kg dry weight)	BAET (mg/kg dry weight)
Cadmium	1.8	5.8
Copper	56.3	310
Lead	24	300
Mercury	0.28	0.88
Zinc	127	260

[1] BAET = Benthic Apparent Effects Threshold.

All 1987 metal concentrations in Skeena sediments were well below BAET concentrations.

5.2.5 Resin Acids

Sediments in coastal waters near pulpmills have contained trace levels of resin acids and organochlorines of mill origin. Resin acids were monitored between 1983 and 1987 at Skeena.

Resin acid concentrations have fluctuated considerably during the five years of monitoring (Dwernychuk, 1988). An extremely high value (6,828.0 µg/g, dry weight) at Station S2 in 1985 probably represents a sample collected in a "pocket" of fibrous substrate (Dwernychuk, 1988). The lowest value (2.31 µg/g) at that same station was recorded the following year. Resin acid concentrations at Station S6 were also quite variable (<0.05 µg/g, 1985; 45.04 µg/g, 1986), but generally indicated that sediments received mill effluent compounds. Resin acid levels at Station S9 in Porpoise Channel ranged between less than 0.05 µg/g and 3.87 µg/g.

5.2.6 Organochlorine Compounds

Organochlorine compounds are created during the pulp processing (particularly the bleached kraft process). Compounds monitored since 1987 include chlorinated phenolics; dioxins and furans have been monitored since 1989. The following discussion of organochlorines in sediments is based upon these reports as summarized in Table 5.3.

In January 1977, a transformer at the pulpmill malfunctioned and spilled approximately 800 L of PCB fluid into the storm sewer system which drains into the marine waters of Porpoise Harbour near the loading dock. Sediments and biota were sampled between 1977 and 1982 to determine the environmental contamination and the effectiveness of spill containment (Garrett, 1983). Concentrations of up to 75,000 ppm/dry weight were detected in sediments immediately off the storm sewer outfall in the mill booming grounds in June 1977 (Figure 5.11). Concentrations decreased with increasing distance and time from the spill. By 1982, sediments contained very low or non-detectable levels of PCBs. The only site where PCB levels remained elevated was adjacent to the workboat mooring float between Woodrooms 2 and 3, and is comparable to levels found in several industrialized areas of British Columbia (Garrett, 1983).

In 1987, Environment Canada tested for chlorinated organic compounds in sediments across transects in Porpoise Harbour (Table 5.3, Figure 5.7b). All chlorinated phenolics, except PCB/Aroclor 1260, were below detection levels at all stations. PCB was found in concentrations of 0.02 to 0.03 μg/g in the north basin (Transects 1, 2 and 3) and at 0.01 μg/g at the reference station (Transect 7). The PCB level at the station in Wainwright Basin was 0.26 μg/g. All these concentrations were below the level (0.48 to 1.4 μg/g) that may elicit overt biological effects (Dwernychuk, 1988).

In 1990, concentrations of chlorinated phenolics were highest in Wainwright Basin (Stations S1 and S2) compared to all other stations. Phenols were as high as 10 ng/g at Station S2, and <5.0 ng/g at all toher stations. Guaiacol concentrations in Wainwright Basin ranged from 25 to 28 ng/g, and catechol levels were between 30 and 94 ng/g. At Station S6, guaiacols ranged from 2.7 to 16 ng/g; catechols ranged from 6.3 to 11 ng/g (Dwernychuk *et al.*, 1992a).

Since 1989, chlorinated phenolic compounds (phenols, catechols and guaiacols) in sediments were monitored annually near Skeena pulpmill at two stations (SS1 in Morse Basin, SS3 near the diffuser, Figure 5.8). Chlorophenols were not usually detected, except in low concentrations at Station SS3 (i.e., pentachlorophenol, 3.6 ng/g, 1991). Chlorinated catechol concentrations declined between 1989 and 1992 from a high of 41 ng/g tetrachlorocatechol (SS3, 1989) to below detection limits in 1992. Chlorinated guaiacols generally appear to be increasing (Figure 5.12). In Morse Basin (Station SS1), levels increased from 4.0 ng/g to 11.5 ng/g trichloroguaiacol (TCG) and 4.0 ng/g to 5.6 ng/g tetrachloroguaiacol (TeCG) between 1989 and 1993. At Station SS3, TCG and TeCG concentrations were highest (mean 30.8 ng/g and 30.8 ng/g, respectively) in 1992; however levels were lower in 1993 (17.4 ng/g and 5.9 ng/g, respectively).

Dioxin (2,3,7,8-tetrachlorodibenzo-para-dioxin) and furan (2,3,7,8-tetrachlorodibenzofuran) concentrations in sediments show a decreasing trend since 1991. Both dioxin and furan concentrations (Figure 5.12) at Station SS1 have been slightly higher than at the diffuser (Station SS3) since 1989. The 1993 dioxin levels were 5.7 pg/g (SS1), and 2.6 pg/g (SS3); furan concentrations were 180 pg/g (SS1) and 65 pg/g (SS3), respectively.

In March 1992, Skeena Cellulose sampled two additional sediment sites (Stations SS13 and SS14) in Prince Rupert Harbour (Figure 5.8; Dwernychuk and Boivin, 1993). No chlorinated guaiacols, catechols or phenols were detected. Dioxins were not detected (<0.4 pg/g), and furans were low (1.8 pg/g, SS13; 5.8 pg/g, SS14). Furan concentrations may indicate that mill effluents may be transported in tidal waters through Prince Rupert Harbour (Section 2.3.4).

5.2.7 Sediment Quality Synopsis

The extent and depth of fibre deposition have not been studied specifically. Fibre deposition was high in Wainwright Basin until 1976, and large mats of fibre frequently appeared on the surface. Fibre accumulations still occur in "pockets" in the basin. Since 1978, fibre deposits were also identified in Porpoise Harbour. Visual observations of sediment samples indicated fibre and small wood pieces were present to a distance of 750 m north of the diffuser. The substrate to 1 km in both directions from the diffuser was identified as black and anoxic, often with a hydrogen sulphide gas odour. Fibre deposition should no longer be occurring with operation of the clarifier.

Particle size in Skeena sediments indicated a composition of predominantly sand or silt/clay. Volatile residue values were highest in Wainwright Basin and in the northern end of Porpoise Harbour, probably due to fibre deposition. Trace metal sampling in 1987 recorded elevated levels of mercury and cadmium in the north end of Porpoise Harbour; however, no clear effluent effect could be determined.

Resin acid levels appeared to reflect mill effluent effects, with highest values occurring near the diffuser in Porpoise Harbour and near the old discharge location in Wainwright Basin. Containment of a PCB spill in 1977 resulted in very low or non-detectable concentrations in sediments five years after the event. In 1987, PCB concentrations were 0.03 μg/g in Porpoise Harbour and 0.26 μg/g in Wainwright Basin.

Organochlorine concentrations mostly have decreased since 1989 in the vicinity of Skeena. In 1991, catechols and phenols were below detection limits; guaiacols were found at levels less than 5 ng/g. Guaiacol concentrations, however, were higher in 1992 than previously. Dioxins and furans have declined in recent years, with concentrations slightly higher in Morse Basin than those recorded adjacent to the diffuser. This difference between locations may be partly due to tidal action and flushing rates, which direct effluent north into the calmer basins where these compounds may accumulate. Low furan concentrations were measured at two stations in Prince Rupert Harbour in 1992, indicating the extent of effluent dispersion.

5.3 INTERTIDAL AND SUBTIDAL COMMUNITIES

Intertidal and subtidal communities may reflect stress due to human or natural sources. In the vicinity of Skeena, human sources include pulp mills, log boom activities, fish processing plants and subsequent discharges. Natural sources include freshwater runoff and suspended sediment deposition from the Skeena River, Wolf Creek and other streams.

5.3.1 Intertidal Community - Macroalgae and Invertebrates

Intertidal monitoring surveys at Skeena pulpmill have been conducted by observation, photographic documentation and sampling by transect since 1974 (Table 5.1). Species lists and photographs have been presented in each annual report; a review of the temporal changes in dominant algae since 1985 was conducted in 1991 (Dwernychuk *et al.*, 1992a) and 1992 (Dwernychuk, 1992). Intertidal surveys have concentrated on the macroalgae community to represent the ecology of the area, and occasionally sampled invertebrates. Figure 5.13 shows the historic sampling stations used in the annual monitoring programs.

5.3.1.1 Macroalgae

In general, small red algae (i.e., *Gigartina*, *Odonthalia*, and *Rhodomela*) appeared to be the most pollution sensitive group of the algal community (Drinnan, 1974, 1977). Stressed communities were comprised primarily of green algae (i.e., ulvoids - *Ulva* and *Enteromorpha*). Brown algae (i.e., *Fucus*) and diatoms were also found, and appeared to be somewhat sensitive to stress.

From intertidal macroalgae studies conducted in 1974 and 1975, Drinnan (1974, 1977) reported that Wainwright Basin (particularly near the effluent outfall), the most northerly areas of Porpoise Harbour and the red liquor Discharge Cove (northwest corner of Ridley Island),were severely affected by mill discharges with relatively few algae species being present. Up to 1978, a general decline in the number of algal taxa was noted from Morse Basin through to eastern Wainwright Basin. This phenomenon was probably related to effluent still being discharged into Wainwright Basin. Subsequent to the redirection of effluents into Porpoise Harbour, there appeared to be an increase in the number of species collected at all Wainwright Basin stations within one year (Beak Consultants Ltd., 1980).

Algae data from 1981 indicated that as a progression was made from Porpoise Channel up Porpoise Harbour to Station 6, the percent composition of sensitive red algae decreased and the percent composition of green algae increased. These data could indicate that flushing action decreased as one moved up Porpoise Harbour, and organic loading from fish processing plants possibly was contributing to the change in algal communitites (Beak Consultants Ltd., 1982). However, since Station 1 (upper Wainwright Basin) supported green algae at a comparable percentage to Station 5 (Porpoise Harbour), the negative influence of fish processing plants in Porpoise Harbour was considered less significant in determining species composition. Algal communities at the old discharge site in Wainwright Basin (Station 2) continued to improve.

In 1982, the relative proportion of red and green algae as comparable to that in 1980 and 1981 (IEC Beak Consultants Ltd., 1983). Stations 5 and 6 generally supported fewer taxa with some fluctuation over the years. The limited growth at these stations was assumed to be related to the high sediment load in evidence at these sites in Porpoise Harbour and not to mill activity (IEC Beak Consultants Ltd., 1983). Cluster analyses since 1980 have not identified problem areas where algal growth was influenced by the presence of mill effluent (Dwernychuk, 1988).

During the most recent surveys in 1990 and 1991, healthy *Fucus* communities were the most noticeable component of the intertidal zones at all locations (Dwernychuk *et al.*, 1992a). Differences in areal coverage, species abundance and new growth were related to colonization on new rock, the amount of rainfall prior to the surveys, and fresh water seepage on beaches. Station 6 again had more sediment, which may be affected by log boom activities. In general, intertidal zones in 1990 and 1991 supported healthy growths of macroalgae, with a trend towards increasing coverage and luxuriance of growth among the various algae groups.

In 1992, algal species were observed that had previously been of sporadic occurrence or not present before (Dwernychuk, 1992). *Fucus* appeared more luxuriant than usual at all stations.

5.3.1.2 Invertebrates

Intertidal invertebrates were monitored using quadrat analyses in 1978 (Beak Consultants Ltd., 1979) and 1987 (Dwernychuk, 1988). In 1978, species composition data did not reveal the presence or absence of certain invertebrates as being related to station positioning. In terms of numbers of individuals (including barnacles), Morse and Wainwright Basin stations appeared to support lower numbers of invertebrates relative to Porpoise Harbour and Chatham Sound. However, the majority of Morse and Wainwright Basin locations exhibited a high level of community diversity. In 1987, population densities of intertidal benthic fauna did not appear to change dramatically relative to proximity to the pulpmill discharge. A barnacle species (*Balanus balanus pugettensis*) was most common in quadrat samples. Numbers of taxa were the lowest near the diffuser on Watson Island; however, no other inverse relationship existed with respect to proximity to the mill discharge (Dwernychuk, 1988). In 1992, the dominant invertebrates (i.e., the littorine snails, hemigrapsid crabs and limpets) appeared to be generally as abundant or slightly more abundant than in previous years (Dwernychuk, 1992). It was believed the level of impact of mill discharges on intertidal invertebrates was not considerable.

Beginning in 1984, photographic surveys of the log pond (Lagoon #2) south of Station 2 and east of Watson Island were conducted to assess the state of substrate and intertidal communities. In 1984, the survey concluded that the log pond area had remained intact and the intertidal cap had not been disturbed (Dwernychuk, 1985). Diverse fauna were present near the outlet channel with no overt display of stress as a result of drainage through the channel from Lagoon #2 into Wainwright Basin (Dwernychuk, 1986). This area has continued to be undisturbed (Dwernychuk *et al.*, 1992a).

5.3.2 Subtidal Community - Benthic Macroinvertebrates

Subtidal benthic invertebrates have been monitored near Skeena pulpmill since 1978 (Table 5.1, Figure 5.14). Grab (ponar dredge) samples were collected at each stations and sieved through a screen consisting of 0.5 mm openings. A number of parameters have been used to characterize the benthic community: density, number of taxa, number and proportion of nematodes and *Capitella capitata*, richness, equitability, dominance, and diversity indices. Table 5.4 gives summary data of some of these indices at each station. The Keefe-Bergersen diversity index (TU) provides a measure of community complexity using the number of organisms and taxa. The index, based on the statistical theory of runs (Keefe and Bergersen, 1977), was selected because it readily allows sample intercomparison with confidence intervals (Beak Consultants Ltd., 1980). An important characteristic of diversity is that several parameters which affect the structure of a community are incorporated into this single term. The primary components of diversity are equitability (i.e., the evenness with which individuals are distributed among sampled genera) and richness (i.e., the number of different genera).

Benthic stations within the study area supported densities of fauna ranging from 119 organisms/m^2 (Station 6, 1983) to 314,251 organisms/m^2 (Station 5, 1987). Densities have varied considerably from year to year, but appeared to have increased during 1986 to 1990 compared to 1979 to 1983 (Table 5.4). Generally, Station 2 in Wainwright Basin has supported the lowest number of organisms since 1979. Densities at stations near the diffuser in Porpoise Harbour (Stations 5 and 6) do not appear to be affected by mill effluents.

Since 1986, stations to the north of the diffuser and in Wainwright Basin have supported fewer taxa (13 to 49) than those to the south (52 to 102). This may be due to sediment quality, such as higher fibre deposition, coarser sediments, or mill effluent. Nematodes were the most common fauna collected, and their relative proportion of the community was as high as 98% at Stations 1, 5, 8 and 9 in July 1987 (Table 5.4). The distribution of nematodes appears to have no direct correlation to the pulpmill discharge. Other macro/micro habitat factors (fine sediments) probably were instrumental in effecting the colonization and persistence of these subtidal fauna (Dwernychuk, 1988).

The relationship between the polychaete *Capitella capitata* and increased levels of organic enrichment has been documented (Pearson and Rosenberg, 1978). The percentage of the sampled community that consisted of *C. capitata* at Skeena pulpmill stations are given in Table 5.4. This taxa was collected in greatest densities from stations situated in Porpoise Harbour during both 1980 and 1981 (Beak Consultants Ltd., 1982). In June/July 1981, *C. capitata* densities of 6,802 organisms/m^2, 9,610 organisms/m^2 and 2,981 organisms/m^2 were found at Stations 5, 6 and 8, respectively, and constituted 26%, 18% and 25%, respectively, of the total benthic invertebrate populations (Dwernychuk, 1988). Similar high densities were also found during federal monitoring in 1981 (Pomeroy, 1983). The federal monitoring stations were located adjacent to the pulpmill diffuser and 1.5 km south near fish processing plants at Port Edward. The higher proportion of *C. capitata,* in the case of Porpoise Harbour, reflected a combined pulpmill and fishing industry impact. Numbers of that invertebrate decreased substantially towards the north and south ends of Porpoise Harbour where direct organic input was reduced (Pomeroy, 1983a).

Between 1982 and 1991, densities of *C. capitata* consisted of 6% or less of the total population at any station. This suggested that continued organic loading into Porpoise Harbour has been low and has not been translated into increased densities of these organisms (Dwernychuk *et al.*, 1992a).

Diversity (TU values) were generally high near Skeena pulpmill. The lowest values were due primarily to the relatively high dominance of one group of taxa (i.e., nematodes) which was not necessarily influenced by mill effluents. It is evident that community complexity and responses to external environmental stresses/stimuli, as described by the TU index, may provide a biased assessment of the "state of the environment". For this reason, it is deemed critical that in the analysis of benthic macroinvertebrate samples collected during studies of this nature, a variety of assessment parameters/approaches be applied to the database in order to facilitate a reliable and realistic appraisal of the biological system (Dwernychuk *et al.*, 1992a).

5.3.3 Intertidal and Subtidal Communities Synopsis

The intertidal community has been characterized annually by the macroalgae community, and occasionally with invertebrate studies. An improvement in the algal community over time near the old discharge in Wainwright Basin has been recorded; no impact by mill effluents released by the Porpoise Harbour diffuser has been noted. Macroalgae have been the most stressed at Station 6 (on Ridley Island opposite the diffuser) which is likely due to sedimentation caused by log boom activities.

Subtidal benthic macroinvertebrates do not presently appear to be impacted by mill effluents. Generally, densities and number of taxa have increased since 1979. Densities of *Capitella capitata*, used to indicate organic pollution, were greatest near the diffuser in 1981, but numbers have since dropped. There is no evidence of organic loading which would support pollution tolerant taxa. Nematodes have at times dominated subtidal communities, but their presence may be influenced by habitat (particle size) rather than stress induced by mill effluents. The TU diversity index is greatly influenced by large populations of one taxa, and may not in itself provide a useful indicator of environmental health.

5.4 BIOLOGICAL TISSUE STUDIES

The Prince Rupert area is frequented by five species of Pacific salmon (chum, coho, chinook, pink and sockeye), Dolly Varden char, steelhead trout and cutthroat trout. Several species of sole, as well as herring and smelt, are caught in the area. Dungeness crab, several species of shrimp and mussels are found in the various waterbodies entering Chatham Sound (see Section 4.0).

Trace metal monitoring in mussels was conducted in 1984 (Maclean, 1986). As a result of the PCB spill, concentrations of PCBs were monitored in biota between 1977 and 1981 (Garrett, 1983). Organochlorine monitoring in biota tissues has been conducted by Hatfield Consultants Ltd. since 1989. The following discussion of organochlorines is based upon these reports as summarized in Table 5.5.

The presence of dioxins and furans in the vicinity of Skeena pulpmill has resulted in the closure of crab and shrimp fisheries since November 1989 (Section 4.0). In August 1993, the Department of Fisheries and Oceans issued a directive for revised fishing closures in the vicinity of the mill, as a result of unacceptable levels of dioxins/furans found in edible biological tissues. Since 1989, all crab fisheries have been closed in Wainwright Basin and the shrimp fishery was closed almost entirely around Ridley Island. The commercial crab fishery and health advisory for the consumption of crab hepatopancreas were issued and then revised in 1993 to include Morse Basin, the west coast of Ridley Island, and Prince Rupert Harbour east of Digby Island.

5.4.1 Shellfish

5.4.1.1 Trace Metals

In 1984, a study of trace metal levels in mussels (*Mytilus edulis*) from Porpoise Harbour indicated that aluminum and iron were bioaccumulating at an accelerated rate at a site near Zanardi Rapids (north of the diffuser) and decreased along a gradient to the south towards Porpoise Channel (Maclean, 1986). The following values were measured (see Figure 5.13 for sampling locations):

Station	Aluminum	Iron
Zanardi Rapids	472 µg/g dry	1500 µg/g dry
Near intertidal Station 7	216 µg/g dry	734 µg/g dry
1 km south of Station 7	170 µg/g dry	509 µg/g dry

Other trace metal concentrations showed no likely influence by mill effluents. For example, mercury was not detected in muscle tissues (<0.05 µg/g wet weight) in 1984 (Maclean, 1986).

5.4.1.2 Organochlorine Compounds

Shoreline biota were monitored for PCB contamination following the spill into Porpoise Harbour in January 1977. Very high concentrations were recorded in mussels (17,000 ppb), isopods (14,000 ppb), algae (83,000 ppb) and spider crabs (72,900 ppb) within 10 m of the spill (Garrett, 1983). PCB concentrations were confined to biota collected in Porpoise Harbour, and levels at other stations did not exceed 1,300 ppb. In areas removed from Porpoise Harbour, such as Chatham Sound, PCB concentrations were at or below the detection level of 5 ppb.

Since 1989, several species of shrimp have been collected from trawls in the Skeena pulpmill area (Figure 5.15). Mussels were also collected in 1989 from Stations SC3 and SC5 (same as crab stations, Figure 5.16).

Organochlorine compounds were not detected in pink shrimp muscle in 1989; however, coonstripe shrimp captured in Porpoise Harbour contained low levels (14 ng/g) of trichloroguaiacol (TCG). In 1990, pink shrimp from Porpoise Harbour contained low concentrations of chlorinated guaiacols: 2.7 ng/g TCG and 1.0 ng/g tetrachloroguaiacol (TeCG). Chlorinated catechols and phenols were below detection limits (<1 ng/g) in shrimp muscle during both years.

During the 1989 monitoring program, dioxin was detected in mussel tissues (7.5 pg/g) near the diffuser (Station SC3) and in shrimp collected in Porpoise Harbour and Chatham Sound (5.7 to 5.9 pg/g, Table 5.5). Furan was measured in mussels (180 pg/g) and shrimp (120 to 130 pg/g) in the same tissues. In 1990, both dioxin and furan concentrations were considerably lower in shrimp (mussels were not tested). These compounds have remained at trace or non-detectable levels from 1990 to 1993 (Table 5.5, Figure 5.15).

5.4.2 Crab

Dungeness crab in Porpoise Harbour were monitored annually between 1977 and 1981 to ensure that PCB tissue concentrations were within acceptable levels following the spill. Health and Welfare Canada recommended PCB levels of 2,000 ppb in fish and shellfish tissues for human consumption (Garrett, 1983). In 1977, concentrations in crab tissues were as high as 2,700 ppb;

however, by 1978, levels had declined to 340 ppb. PCB concentrations in crab tissues did not exceed 50 ppm in 1980 and 1981, and indicated that the spill had been contained (Garrett, 1983).

Receiving environment monitoring programs conducted by Hatfield Consultants Ltd. have analyzed organochlorine compounds in Dungeness crab muscle and hepatopancreas tissues (Table 5.5). In 1989, chlorinated guaiacols were not detected (<5.0 ng/g) in crab muscle or hepatopancreas. In 1990, chlorinated guaiacols were detected in crab hepatopancreas, but not in crab muscle. TCG and TeCG were found in highest concentrations (25 ng/g and 7.5 ng/g, respectively) in crabs captured at Station SC2 in Wainwright Basin. Guaiacols were fairly widespread, with hepatopancreas levels of 7.8 ng/g TCG and 4.7 ng/g TeCG in crabs captured at Station SC5 (Chatham Sound). Chlorinated catechols and phenols were not detected in any crab tissues in 1990, nor in 1991. Guaiacol concentrations in 1991 were slightly lower in crab hepatopancreas (maximum TCG - 16 ng/g, maximum TeCG - 6.8 ng/g). Monitoring for chlorinated phenolics in crab tissues was discontinued in 1992.

Dioxin and furan concentrations were highest in tissues of Dungeness crab collected in 1989 and appeared to be decreasing by 1993 (Table 5.5). Between 1989 and 1991, the highest concentrations were found in hepatopancreas tissues from crabs taken near the diffuser at Station SC3 (140 pg/g dioxin, 1989; 3200 pg/g furan, 1989). In 1992 and 1993, highest concentrations were found at Station SC2 in Wainwright Basin (38 pg/g dioxin, 1993; 810 pg/g furan, 1993). Crab muscle tissue exhibited non-detectable or trace levels of dioxins in 1992 (maximum 3.4 pg/g, SC3); furan concentrations were also low (maximum 49 pg/g, SC3).

Crab captured at stations distant from the diffuser in 1992 and 1993 (SC7, SC9 to SC15, Figure 5.16) exhibited low levels of dioxins (1.4 to 5.4 pg/g) and furans (25 to 260 pg/g) in hepatopancreas tissues. In general, 1993 dioxin and furan levels in crab hepatopancreas were lower than in 1992. Levels of these compounds also appear to be declining at the stations near the mill.

Since 1991, dioxin and furan concentrations have been presented in Total 2,3,7,8-TCDD Equivalent (TEQ) units. Total-TEQ values are used to represent the sum of all dioxin and furan congener values for a sample and to provide a measure of the total toxicity. TEQ's are calculated by multiplying the concentration of each congener with a Toxic Equivalent Factor to normalize the concentration to the level that would be produced by an equivalent amount of 2,3,7,8-TCDD (the most toxic congener). The toxicity equivalents used by Hatfield Consultants Ltd. follow an internationally accepted standard, agreed upon in 1988 (NATO, 1988a,b,c).

Crab hepatopancreas TEQ values for 1991, 1992 and 1993 are shown on Figure 5.16. Average Total-TEQs generally have declined, except at Stations SC1 and SC5. Total-TEQs in 1993 were highest (151.4 pg/g) in crab hepatopancreas tissue sampled at Station SC2 (Wainwright Basin), and generally decrease with increasing distance from the diffuser.

5.4.3 Groundfish

Groundfish, as well as herring and salmonids, were monitored for PCBs in 1977. All concentrations in fish tissue were less than 300 ppb (Garrett, 1983).

Groundfish, including various species of sole, were monitored in 1989 for chlorinated guaiacol concentrations, and in 1990 for all chlorinated phenolics, dioxins and furans (Table 5.5). In 1989, chloroguaiacols were not detected (<5.0 ng/g) in lemon sole muscle. However, livers of sole captured in 1990 did contain low levels of guaiacols. The highest levels (15 ng/g TCG, 2.6 ng/g TeCG) were measured in English sole liver tissues from Porpoise Harbour; a TCG concentration of 9.0 ng/g was found in flathead sole liver from Morse Basin). Chlorinated catechols and phenols were not detected in any sole muscle or liver tissues.

During the 1990 monitoring program, dioxins and furans were tested in muscle and liver tissues of flathead sole (Morse Basin), English sole (Porpoise Harbour), sand sole (Coast Island), and Dover sole (Chatham Sound). Muscle tissue contained non-detectable amounts of dioxins and trace (maximum 5.3 pg/g) concentrations of furans. Dioxins and furans were highest in flathead sole liver tissue (110 pg/g dioxin, 320 pg/g furan) captured in Morse Basin. Concentrations of these compounds in fish liver were also relatively high in Porpoise Harbour. English sole liver contained 30 pg/g dioxin and 120 pg/g furan. Sand and Dover sole liver tissues had lower concentrations (Table 5.5). Dioxin and furan monitoring of groundfish was discontinued in 1991. A 1990 health advisory to not consume liver from bottomfish caught near coastal pulpmills is still in effect.

5.4.4 Biological Tissue Synopsis

Contamination of biological tissues of mussels, crab and fish resulted from the PCB spill into Porpoise Harbour in January 1977. Following containment of the spill in 1978, levels declined rapidly; i.e., crab tissues contained a maximum of 2,700 ppb in 1977, 340 ppb in 1978, and 50 ppb in 1980.

In 1990, chlorinated phenolic concentrations, predominantly guaiacols, were detected in trace amounts in shrimp tissues. Chloroguaiacols were detected in crab tissues from samples collected throughout the area in 1990 and 1991; however, monitoring of these compounds in crabs and other biota tissues was discontinued in 1992.

Shrimp tissues currently indicate trace or non-detectable concentrations of dioxins, and furan levels appear to be declining. Mussels and groundfish have not been monitored for dioxins and furans since 1990 and 1991, respectively. Dioxin and furan levels in Dungeness crab tissues have generally declined since 1989. Levels are highest in Wainwright Basin crabs, and measurable concentrations were detected at several new stations on Digby Island. With the decrease in dioxin and furan concentrations in these tissues, Total-TEQ values for crab hepatopancreas have also declined since 1991. TEQs have been recorded at highest levels near the diffuser, but decrease with increasing distance from Skeena Cellulose Inc.

6.0 MILL HISTORY, CURRENT OPERATIONS, AND EFFLUENT QUALITY

This section presents a description of mill history, current operations, and effluent quality for the Skeena Cellulose pulpmill in Prince Rupert, British Columbia. Additional information on this subject may be obtained from Packman (1979) and Pomeroy (1983a).

6.1 OVERVIEW OF MILL HISTORY AND HISTORICAL DISCHARGES

The original mill located on Watson Island was a 200 t/d sulphite pulpmill which commenced operations in 1951. The main product produced was cellulose acetate grade wood pulp, which is the principal raw material used in the production of textile grade continuous filament acetate yarn and cigarette tow for filters (Packman, 1979). The waste water from this operation was discharged into Lagoon No. 1, a tidal flat, and eventually flowed into Wainwright Basin via Lagoon No. 2 (Figure 6.1). A 1961 B.C. Research Council Study recommended the piping of effluent from the sulphite mill under Porpoise Harbour and across Ridley Island into Chatham Sound. From 1971 until its shutdown in 1976, the red liquor charge from the sulphite mill was discharged into Chatham Sound at a small cove near Bishop Island ("Discharge Cove"). As a result of breaks in the red liquor line, spills to Porpoise Harbour were relatively frequent; this method of effluent disposal proved inefficient and the system required frequent repairs (Kussat, 1968, *cited in* Packman, 1979).

A 750 t/d kraft mill (hereafter referred to as 'A' mill) was started up in 1966 and its waste water was discharged via three sewers (Utility Recovery, Kraft Alkali and Kraft Acid Sewers) into Lagoon No. 2 (Figure 6.1). The second 'kraft' mill, a 500 t/d facility (hereafter referred to as 'B' mill) started up in late 1978. Since September 1978, most combined waste water from both 'A' and 'B' mill is discharged via a foam tower through an effluent diffuser at a depth of 18 m into Porpoise Harbour (Figure 6.2; Packman, 1979). (However, an overflow line from the 48" raw effluent header was still used for emergencies, and discharged into Lagoon No. 1; this line was permanently closed off in the spring of 1993).

In 1971, the Pollution Control Board (the fore-runner to the current Environmental Protection Program [EPP]) introduced effluent regulations for the pulp and paper industry. These regulations required the 'A' mill operation to achieve the 'C' level standards for effluent discharge, while air emissions were required to be 'C' level (recovery boiler TRS) and all other emissions were 'B' level. With the start-up of the converted 'B' mill in 1978, effluent discharge permits for the pulpmill remained at 'C' level standards, and air emission 'A' level standards were applied to new, independent equipment.

In January 1977, a transformer at the pulpmill malfunctioned and spilled approximately 800 L of PCB fluid into the storm sewer system which drains into the marine waters of Porpoise Harbour near woodroom No.3 (Figure 5.11; Garrett, 1983). The transformer was located on the roof of woodroom No. 3, and PCBs leaked down the side of the building to the storm sewer below. Clean-up activities included *in-situ* containment (i.e., capping) of the contaminated area from the rest of Porpoise Harbour to prevent further spread of contamination, and appear to have been effective (Garrett, 1983). The mill submits annual reviews of the PCB spill area (PE-1157) to Environmental Protection.

In the early 1980's, some environmental parameters of the mill operation were not in compliance with permit levels and commitments were made to take corrective action. When the time came to implement these improvements, the economic recession of the early 1980's was under way and all pulp producers were losing millions of dollars. The owner of the mill at that time (B.C. Timber Ltd.) could not afford to implement the committed improvements and requested a deferment for the construction of the needed improvements. The Environmental Appeal Board granted an extension to the timetable for the committed improvements and required the EPP and the company to determine "interim" permit levels. These were agreed upon and have been the permit requirements for the pulpmill since mid-1983.

At the same time, extensive ambient air and marine monitoring programs were established. Since 1983, the marine program involves monthly and annual surveys of the receiving waters and intertidal areas, respectively, located near the pulpmill site. The ambient air monitoring program has been completed in two parts: the first program involved the measurement of TRS gases and dustfall at various locations near the pulpmill site, and the current program includes continuous measurement of H_2S and methyl mercaptan gas levels at monitors located at the village office in Port Edward and at the post office building in Prince Rupert. The monthly marine surveys have consistently shown that the discharged effluent from the mill site has had minimal, if any, impact upon the receiving environment. The air monitors have found that ambient standards for H_2S and methyl mercaptan are occasionally exceeded.

With the completion of the primary and secondary effluent treatment plants in October, 1990 (start-up in April, 1991) at a cost of $60 million, the final commitment of the previous companies was fulfilled and a permit using 'A' level standards for the mill's effluent discharge was in place. Process waters and process waste waters from mill operations were thereafter sent to the effluent treatment system before release from the Porpoise Harbour diffuser. However, during excessive high tides, the wetwell sump pump occasionally overflowed, resulting in spills of effluent into Lagoon No. 1; spills also occurred following power outages (Section 6.3.9 "Spills to the Receiving Environment"). This overflow line from the raw effluent header into Lagoon No. 1 was permanently sealed in mid-1993, and a standby electric generator was installed to reduce the chances of such spills. As of mid-1993, all process waste waters are directed to the Porpoise Harbour diffuser, and Lagoon No. 1 receives only filter backwash, cooling water, and raw water weir overflow (Section 6.3.2).

Prior to completion of the No.3 woodroom settling pond ("Golden Pond") in 1988, wastes from the debarking area and woodrooms were untreated and discharged into Porpoise Harbour (Discharge 'I' in Figure 6.1). Since December 1991, this water is now pumped via the wetwell sump pump to the effluent treatment system.

The conversion of the No. 5 recovery boiler (originally built in 1965 and the major contributor of TRS emissions) to a "low odour" boiler and the installation of new precipitators in 1990 (costing

$35 million) were the significant steps needed for the Watson Island operation to be in full compliance with all the air permit requirements.

The layout of the Skeena Cellulose Inc. mill on Watson Island (as of 1993) is shown in Figure 6.3.

6.2 HISTORY OF POLLUTION CONTROL - WATER

1951 to 1976	Sulphite mill operation discharges were directed to Wainwright Basin via Lagoon No. 1 since 1951. The Kraft Mill operation, known as A-Mill, also discharged its effluent into Wainwright Basin via Lagoons No. 1 and No. 2 beginning in 1966. In 1971, red liquor effluent from the sulphite mill was piped under Porpoise Harbour across Ridley Island and into Chatham Sound. This was a major pollution control project at the time.
1977	Started in-plant control projects in A-Mill and U&R area.
1978	With the completion of the second Kraft Mill (B-Mill) in 1978 and the closure of the sulphite mill in 1976, discharges were diverted to Porpoise Harbour instead of Wainwright Basin in September 1978. A multi-port submarine diffuser, which is located in the middle of Porpoise Harbour, was installed for pollution control. These were considered major pollution control undertakings at the time, i.e., converting the sulphite mill and re-routing sewer flows. Overflow sewers discharged into Lagoon No. 1 only in emergencies.
1977 to 1984	During these years, many smaller projects were implemented. These were mainly in-plant control equipment installations (i.e., sumps and pumps, two reject refiners, dregs filter, etc.)
1986 to 1988	In-plant control installations continued including No. 3 Woodroom effluent settling pond ("Golden Pond").
1989-1991	Primary and secondary treatment plants constructed. Both were in full operation by April, 1991 and have a feedline capacity of 392,500 m^3/day. Process waters and business waste material from mill operations (including Golden Pond) are sent to the effluent treatment system. Organochlorine trend monitoring commenced with objective of determining levels of dioxins and furans in marine sediments and biota in the receiving environment.
1992-1993	Permanent closure of overflow line from raw effluent header into Lagoon No. 1 (mid-1993). Improved monitoring techniques were employed for determining effluent flow rates from the diffuser. Water quality monitoring undertaken at all discharge sites.
1994	Ongoing environmental studies confirm reductions in organochlorine levels in the receiving environment. Monitoring studies continue.

6.3 CURRENT OPERATIONS

The layout of the Skeena Cellulose Inc. mill on Watson Island (as of May 1991) is shown in Figure 6.3. This figure also indicates the locations of the effluent treatment plant and oxygen bioreactor adjacent to Wainwright Basin, and the present layout of storm sewers. An overview of the mill process is provided in Figure 6.4.

Total pulp production for Skeena Cellulose between 1951 and 1992 (for each of the sulphite, kraft "A" and kraft "B" mills) is presented in Figure 6.5. The Skeena Cellulose mill has an annual design capacity of 450,000 tonnes of northern bleached softwood kraft pulp (Repap Enterprises Inc., 1994). In 1993, a new annual productivity record was achieved, as total production increased from 1992 by 30,000 tonnes to 372,000 tonnes.

6.3.1 Process and Non-Process Water Sources

Raw feedwater to the mill comes from Rainbow/Diana Lake watershed system. The water flows via gravity from Taylor Lake through two woodstave pipelines (78" and 48"). The total capacity of the two lines is 72,000 USGPM. The raw water is low in dissolved solids but relatively high in colour. Since the source is a shallow surface supply, the dissolved organic and inorganic salts vary over a fairly wide range (see table below).

Parameter	Range
Calcium as $CaC0_3$	2.0-5.0 ppm
Magnesium as $CaC0_3$	1.0-2.0 ppm
Silica as $Si0_2$	0.9-1.8 ppm
Alkalinity as $CaC0_3$	1.0-8.0 ppm
COD	8.8-18.7 ppm
Colour (Platinum Std Units)	40-90 Units
pH	5.3-6.0

The mill utilizes approximately 20,000 USGPM of raw water for varying purposes such as cooling water, firewater, washwater, steam generation, etc., as well as approximately 10,000 USGPM of treated water. The treated water is conditioned via in-line clarification and filtered through mixed media gravity filters. Chemicals utilized in the clarification process include, alum, caustic, sodium aluminate, poly-aluminum chloride and non-ionic polymer.

6.3.2 Effluent Discharge

Since September 1978, Skeena Cellulose effluent is discharged into Porpoise Harbour via a multi-port submarine diffuser (Figure 2.4). Primary and secondary effluent treatment facilities were installed in October 1990, and were in full operation by April 1991 (Section 6.3.5: Treatment Facilities). As discussed in Section 6.1 above, an overflow line from the 48" raw effluent header discharged into Lagoon No. 1 during emergencies (primarily during power disruptions) until the spring of 1993. Since mid-1993, all effluent is discharged via the diffuser (including discharges when by-pass is opened). The final 75 m of the diffuser has 18 ports, and effluent is discharged into water approximately 20 m deep.

Three main storm sewers are currently located on the property, and discharge into Porpoise Harbour (from the area surrounding woodroom No. 3), Zanardi outfall and Lagoon No. 1 outfall (Figure 6.3). All 3 sewers dispose of storm water. All debarker water goes to a settling pond to remove solids and eventually to the effluent treatment system; however, the storm sewer from woodroom No. 3 also contains sediment, grit and small amounts of bark. The Zanardi outfall receives storm water discharges, lime mud overflow and hog fuel leachate. The Lagoon No. 1 sewer also receives filter backwash, cooling water, and raw water weir overflow. All process water is presently discharged via the diffuser. Details of water chemistry data collected from other discharge points, including Lagoon No. 1 and Zanardi Ditch, are presented in Section 6.3.9.

6.3.3 Description of Furnish

Skeena Cellulose pulp operations utilize approximately 2.0 million m^3 of wood chips annually. The normal breakdown of species utilized in the annual consumption of wood chips is as follows:

- cedar - 3%;
- balsam - 22%;
- spruce - 15%;
- hemlock - 52%; and
- pine - 8%.

6.3.4 Pulping Process

Major steps in the Skeena Cellulose pulping process are presented in Figures 6.6 to Figure 6.18 inclusive, and are described below.

6.3.4.1 Log Handling

Independent contractors harvest the trees in the interior. The limbs are removed and the logs are floated as "log rafts" to the log pond in Porpoise Harbour where they are stored. The logs in these rafts originate mostly from hemlock and balsam trees. Boom boats move the logs around and a log-handling crane (Peco Crane) picks up bundles of logs from the water and places them onto the log decks.

Chain conveyors on the log deck feed the logs into a hydraulic debarker where the bark is removed by high pressure water jets operating at 1,500 to 1,800 PSIG. The bark is sent to the hog fuel pile, while the debarker water goes to a settling pond to remove solids. The supernatant (approximately 1,000 USGPM) is pumped to the effluent treatment system via the chemical preparation sewer.

The debarked logs are sorted by size and logs less than 38" in diameter (the majority) are fed into a "Disc" Chipper where they are reduced to chips approximately 20 mm long and 4 mm thick by high speed rotating blades. Oversize logs (38" to 48") are cut into smaller pieces and fed into a "Block" Chipper. Very large logs (>48") are cut into smaller pieces and are chipped in a "V-drum" Chipper. Conveyors carry all the chips to the chip piles. The log and chip handling sequence is shown in Figure 6.6.

6.3.4.2 Chip Handling

Spruce and pine wood chips are brought in from the interior by rail and truck. A trackmobile is used to move the chip railcars up to the unloading station. Here, a front-end loader unloads the chips (one car at a time) and drops them onto a conveyor that adds them to the chip flow from the woodroom. Full trucks are driven onto a truck unloader, that tips the entire truck up until the load is fully discharged out of the back end. The chips are conveyed and also join with the chip flow from the woodroom.

6.3.4.3 Chip Distribution

From the woodroom, the chips are transferred by a conveyor to the chip piles. High speed endless belts called "flingers" are used to distribute the chips on the pile. The chips fall onto these fast moving belts and are flung onto the piles. The flingers swivel around to distribute the chips. The chip distribution area distributes the chips into four chip piles. The chips remain in the pile until they are required by the mill.

Managing the chip piles is a critical part of the operation. As the chips are exposed to the environment, they begin to deteriorate. A certain amount of deterioration is acceptable, but too much causes a breakdown of fibre and reduces the yield. The chip piles are used in the order they were created to minimize loss of yield.

6.3.4.4 Chip Reclaim

At the bottom of the chip piles are endless drag chain reclaimers. They move the chips to a central area where a conveyor transports them to the scalping screen in the screen building. The reclaimers discharge the chips onto conveyors that carry the chips to the chip screening system. Before the chips enter the screens, a magnet removes any tramp metal that may be carried along in them.

6.3.4.5 Chip Screening

The chip screening system removes stones, knots and chips that are too large or too small for the digesters. The stones and knots are removed to landfill and the small chips, pins and fines, are sent to the hog fuel pile. From the screening building, chips are conveyed through conveyor galleries to the digesters. For the B-Mill batch-type digesters, the chips are fed to a buffer tank (surge bin) that supplies a large chip volume when required for quick filling of the batch digesters.

6.3.4.6 Hog Fuel

Hog fuel is brought in from other mills by truck. A similar system to chip truck unloading is used, with the truck being tipped back and the hog fuel falling out of the back and is then conveyed to the hog fuel pile.

6.3.4.7 Digesters

The digester is where the chemicals in the liquor break down the lignin and release the wood fibres. About 80 to 85% of the lignin is dissolved and removed under the high-temperature and high-pressure conditions of the digester.

6.3.4.8 Continuous Digester

The continuous digester is fed chips continuously and pulp is removed continuously (Figure 6.7). The chips flow slowly down the digester in a solid, continuous plug (cooking as it descends). In the chip bin, the screened chips are preheated with steam to open the wood pores in preparation for cooking. At the bottom of the chip bin, the chip meter feeds measured amounts of chips into the low pressure feeder.

The low pressure feeder takes chips from the low pressure of the chip meter, and feeds them into the higher pressure steaming vessel. While it feeds chips to the steaming vessel, the low pressure feeder prevents steam from escaping from the steaming vessel and entering the chip meter. In the steaming vessel, low pressure steam heats the chips to a higher temperature to further prepare the chips for cooking. A large screw in the vessel moves the chips out of the steaming vessel and into the inlet of the high pressure feeder. The high pressure feeder uses cooking liquor (white liquor) to flush the chips from the feeder into the top of the digester. Cooking liquor is a solution of alkaline chemicals that attack wood lignins, so this pulping process is called "Alkaline Pulping".

At the top of the digester, the top separator separates the chips from the liquor and the liquor returns to the high pressure feeder to flush more chips. The separated chips are pushed down on the top of the other chips and a column builds up in the vessel.

The total height of the digester is approximately 180 ft. At normal rates, it takes about 3.5 to 4 hrs for a wood chip at the top of the digester to become pulp fibre at the bottom. Liquor is continually drawn from the digester, heated via two liquor heaters and returned. The circulation of hot liquor keeps the cook temperature constant at approximately 330°F. When the chips reach the bottom of the digester, they are thoroughly cooked. They retain their chip shape, but are soft and swollen with liquor.

Approximately two-thirds of the way through the digester, the spent cooking liquor is removed to the flash tanks. The pressure drop between the digester and the flash tank causes some water in the spent liquor (black liquor) to "flash" to steam. The steam supplies the chip bin and steaming vessel. The black liquor is cooled and pumped to the Weak Black Liquor (WBL) storage tanks. Cool filtrate is pumped into the bottom of the digester to wash spent chemicals out of the pulp and stop the cook.

Pulp leaves the digester at the bottom through the outlet device. The outlet device and a blow control valve control the rate of pulp removal from the digester. By balancing the chip feed rate and the pulp removal rate, the continuous digester produces a steady supply of pulp fibre from a steady supply of chips and maintains a constant chip level in the digester.

Due to the high pressure in the digester, the cooked chips are actually "blown" out. The quick drop in the pressure causes the chips to "explode" into a mass of separate pulp fibres and they pass into the blow tank. At this point, the pulp is called "brownstock pulp" or just "brownstock". The chemicals in the WBL are recovered and reconstituted to white cooking liquor in the recovery process which is explained later.

6.3.4.9 Batch Digester

The Batch Digesters do not have the complex chip feed system of the continuous digesters (Figure 6.8). Chips are fed into the top of the batch digesters through the open capping valves. This is called "charging" the digester. Steam is injected into the top of the digester with the chips to help pack down the chips and get the maximum amount of chips per "batch". When the digester is full, the capping valves are closed and liquor is added. The liquor is recirculated and heated for the cooking period (approximately 2.5 to 3 hrs).

When the cook is finished, the bottom "blow" valve opens and the chips blow out to the blow tank. As with the continuous digester, the blow creates a mass of separate pulp fibres (brownstock). Heat from the steam which "flashes" off the liquor when the digester blows, is recovered through a series of heat exchangers to provide hot and warm water for the mill process. Brownstock in the blow tank must be cleaned and washed before it can be sent to the bleaching process.

6.3.4.10 Knotters

Brownstock contains some uncooked wood, such as knots and slivers, and also dirt and other impurities. All must be removed because they produce poor quality pulp. Knots are removed from the brownstock by the primary and secondary knotters and hauled away to the hog fuel pile (Figure 6.9). The brownstock is sent to the brownstock washers where filtrate displaces any remaining spent cooking liquor. The liquor is recovered for reuse.

6.3.4.11 Washers

A washer is a large, hollow, screened drum that is partially submerged in a vat. The drum rotates in the vat containing pulp fibre and dilution filtrate. The inside of the washer is under a slight vacuum. As the drum revolves in the vat, the fibre/filtrate mixture is drawn against the surface of the screen by the vacuum inside the drum. Filtrate flows through the screen openings, but the pulp fibres are trapped and held against the screen. As the fibres build-up, they form a "sheet" or a mat on the drum surface.

Filtrate collects in the center of the drum, passes through a vacuum valve and flows down a dropleg to the seal tank. The difference in elevation between the drum and the seal tank, and the rush of filtrate from the drum to seal tank, creates a siphon effect. The vacuum is formed in the drum center by the siphon and is assisted by dedicated vacuum pumps for specific washers in the mills.

As the drum rotation continues, the layer of pulp fibre leaves the vat and sticks to the screen. The pulp mat rotates under a set of showers that spray the surface of the mat across the width of the drum. The shower supply is pulled by vacuum through the pulp fibres on the drum screen and displaces any remaining liquor or filtrate held in the pulp mat. As the drum surface rotates past the showers, remaining filtrate is drawn through the fibres and flows to the seal tank. A thick sheet of pulp remains on the drum.

At approximately the two o'clock position on the drum, a jet of air or water dislodges the pulp sheet and directs it into a horizontal trough. In the trough, a rotating screw called a repulper breaks the fibre stock up and discharges it down a vertical chute, or conveys it to another vat and washer assembly. The low-consistency pulp from the brownstock washers is sent to the brownstock high density storage tank (Figure 6.9).

6.3.4.12 Brownstock Screens

From the brown stock high density storage tank, the pulp is pumped to the brownstock screens. Knot-free brownstock enters a series of screens (primary, secondary and tertiary) where other foreign material is removed such as small slivers of uncooked wood (shives), sand, dirt, etc. This material is hauled away to landfill. Clean brownstock is sent to the brownstock decker where filtrate displaces any remaining impurities and the stock is thickened for storage in the screened, unbleached high density storage tank.

6.3.4.13 Bleaching

Bleaching is the chemical treatment of wood cellulose fibre to increase its brightness. The brown color of brownstock is caused by lignin in the pulp fibres. Bleach chemicals dissolve or color them so the final product has a higher optical quality and therefore a higher market value. Pulp cannot be bleached to full brightness in a single bleaching stage. Too much bleaching breaks down the pulp fibres and reduces the strength of the final product.

At the Skeena Mill a five-stage bleach process is used to produce a strong pulp of high brightness (Figure 6.10). At each stage of bleaching, chemicals are added to dissolve the remaining lignins, sufficient time is provided to allow the dissolving reactions to take place, the pulp is washed to stop the reaction, then the pulp is prepared for the next stage.

The filtrate used in the washers is recovered at each stage and reused at the previous stage. Recycling filtrate to other wash stages is called counter-current washing. Counter-current washing ensures the cleanest filtrate is used on the cleanest pulp and the dirtiest filtrate is used on the dirtiest pulp. It also ensures water consumption in the mill remains at a minimum so pollution is reduced.

6.3.4.14 Chlorination Stage

The first of the five stages is called the chlorination stage or C/D Stage (Figure 6.10) ("C" represents chlorine and "D", dioxide). In the C/D stage, screened brownstock from the high density storage tank is pumped to the brownstock mix tank where filtrate is added to dilute it to the correct consistency. The dilute stock flows to the chlorine dioxide mixer where chlorine gas and a solution of chlorine dioxide are injected directly into the pulp. The use of chlorine dioxide at this part of the process brightens the pulp and preserves pulp strength qualities better than the non-selective chlorine.

Various combinations of chlorine and chlorine dioxide are used for environmental and pulp quality reasons. The amount of chlorine used, expressed as a fraction of the total chemical, is known as the level of chlorine dioxide substitution. The mixture then passes into the chlorination tower where sufficient time is provided for the bleaching chemicals to react with the pulp stock. From the tower, the stock flows to the C/D bleach washer (washer 15) where showers wash the stock. Filtrate is removed to thicken it, then it is repulped in a screw conveyor. A 10% solution of caustic is added to the repulper and the stock is sent to the EO Stage Standpipe. Steam is added to keep the pulp temperature up to improve the reaction.

6.3.4.15 Extraction/Oxygen

In the Extraction/Oxygen (E/O) stage, caustic makes the lignin soluble in the filtrate so it can be removed at the washer. This helps make the pulp bleach more readily in subsequent stages. Pulp from the E/O stage standpipe enters the MC (medium consistency) pump, where oxygen is injected directly into the pulp stream (Figure 6.10). The MC pump also ensures the oxygen is mixed thoroughly with the pulp fibres so it immediately begins to oxidize lignin. The mixture flows out the mixer and into the base of the upflow tower where it slowly moves upwards to the top; giving time for the reaction to take place. From the upflow tower the stock passes into the top of the downflow tower where it slowly descends. At the bottom of the downflow tower, dilution filtrate is added to thin the mixture so it can be pumped to the washer. Showers wash the stock at the EO bleach washer (washer 25). Filtrate is removed to thicken the stock, then it is repulped in a screw conveyor. The stock falls down to a steam mixer/heater and then to the thick stock pump.

6.3.4.16 First Chlorine Dioxide (D1) Stage

The D1 stage is where much of the brightening takes place (Figure 6.10). At this point, most of the lignin has been removed and any further bleach stages mostly raise the brightness of the pulp, though some dissolution of the lignin does take place. Steam-heated pulp from the thick stock pump is injected with chlorine dioxide at a mixer and flows up through the upflow tower which provides retention time for the brightening reaction to take place.

Because the stock and chemical mixture are under pressure in the upflow tower, gassing off of the chlorine is reduced and efficiency increased. Stock leaves the top of the upflow tower and enters the downflow tower which provides additional retention time for the bleaching reaction to continue. Tower level is adjusted to vary the retention time. At the bottom of the tower the stock is diluted and pumped to the D1 stage washer (washer 35). The washer displaces dissolved lignin and residual chemicals, then rethickens the pulp. 10% caustic is added to dissolve more lignins, then the sheet is repulped and conveyed to the second Extraction Stage.

6.3.4.17 Extraction Stage (E2)

In the extraction stage, the added caustic dissolves more lignins in the pulp. From the D2 stage washer, the pulp is heated with steam and pumped to the top of the extraction tower which again provides retention time for the chemical reactions (Figure 6.10). At the tower bottom, dilution filtrate is added and the mixture is pumped to the extraction stage washer (washer 45). The washer displaces dissolved lignin and residual chemicals, then rethickens the pulp.

6.3.4.18 Second Chlorine Dioxide (D2) Stage

The second D2 stage colors and dissolves more lignin to increase the brightness of the pulp. Steam is added in the steam mixer as the stock flows from the extraction washer. Hot stock is pumped to a mixer where another solution of chlorine dioxide is mixed in. The mixture flows into the bottom of the upflow tower and overflows into the top of the downflow tower. Filtrate is added at the bottom of the downflow tower and the solution is pumped to the D2 bleach washer (washer 55).

The washer displaces remaining chemicals and dissolved lignin and rethickens the stock. It is then pumped to the bleached high density storage tank where it is stored until transported to the bleach cleaning system prior to use in the pulp machine.

6.3.4.19 Stock Preparation

Before bleached stock can be used to make market pulp, it must be cleaned again to remove foreign material that may affect the quality of the final product. The consistency of the stock must be adjusted before it goes to the pulp machine. This part of the process is called "stock preparation" (Figure 6.11). Bleached stock from the high density storage tank is pumped to the screen mix chest. Filtrate is added to the chest to dilute the stock so it can be cleaned.

Dilute stock is then pumped through six stages of cleaners that use centrifugal force to fling out small dirt particles that remain. Six stages maximize cleaning efficiency and reject a minimum amount of stock along with the contaminants. Clean stock passes through two bleach deckers that wash and adjust the consistency of the stock. From the deckers, the stock is sent to the machine blending tank. Filtrate is added to dilute the stock to proper consistency for the machine.

"Broke" from various parts of the machine are added to the stock in the machine blending chest, or sent to the pulping group for reprocessing. Broke is "broken pulp" from sheet breaks, trim, etc. that is repulped for reuse on the machine.

6.3.4.20 Sheet Formation

The first step in making a pulp sheet from pulp stock is to form the sheet (Figure 6.12). When paper was first made by the Chinese, they filtered a dilute suspension of pulp fibres through a screen. The mat of fibres was pressed to remove water, then dried to make suitable writing paper. The modern pulp machine also takes a dilute mixture of pulp fibres in suspension and runs it through a wire mesh screen called the "Fourdrinier Wire" or just "wire". In this case though, the screen is a wide, endless mesh drive by rolls.

Dilute stock from the machine blending tank supplies the Headbox. The headbox spreads the pulp stock across the wire in a uniform flow, the full width of the machine. The wire is driven at a controlled speed by the couch roll (like "pooch") and supported by the breast and couch rolls. A series of return rolls take the wire back to the breast roll. Filtrate showers at each roll keep the wire clean.

As stock is applied to the wire, water drains through and a "web" forms. The web is supported by the Johnson wire table until enough water runs out that the web is supported on the wire itself. As the web is carried down the wire, vacuum boxes draw more and more filtrate out and it approaches the press section. Filtrate that drains from the sheet and wire is collected in the seal pit of reuse. A Devronizer steam shower applies low pressure steam to the pulp web to drive out entrained water. When the machine first starts or when a sheet breaks, the pulp web is diverted to the couch pit where it mixes with filtrate and is pumped to the broke chest.

6.3.4.21 Press Section

Presses are a series of felt-covered, rotating rolls which compress the sheet and squeeze water out (Figure 6.13). The water is absorbed by the felts and the pulp web is "consolidated" into a sheet strong enough to support itself as it moves through the dryer. Water is absorbed from the sheet by the felt, then removed from the felt as it crosses a "UHLE" box - a suction box which is under vacuum. The contact point between the felt covered press rolls is called the "press nip". The pulp web enters the first press section and is squeezed between the bottom drive roll and the top roll. The bottom roll is grooved and under vacuum at the nip point to remove water which passes through the felt to the bottom roll. As the pulp web leaves the nip, the web and felt separate, and water is removed from the felt as it passes over a "UHLE" box. The sheet is then squeezed between the top roll and the second press roll to remove more water and compress the sheet further. "UHLE" boxes again remove water from the felt.

In the third press section, the sheet is squeezed between the third press top and bottom rolls. Water pressed out is carried away by the felts and "UHLE" boxes remove it. When the sheet leaves the third press section, the fibres are compressed and enough water has been removed that the sheet supports itself as it passes into the dryer.

6.3.4.22 Dryer

Although most of the water is removed from the pulp sheet in the press, it is not completely dry. The remainder of the drying is done in a steam heated dryer (Figure 6.14). "A" & "B" Mills use different types of dryers. A-Mill has an "airborne" dryer, where the sheet is supported on hot air and "floats" as it moves through the dryer. In the B-Mill dryer, the pulp is supported on chains and rods and travels near steam-heated coils.

The sheet from the press is pulled through the dryer by the dryer pull roll and steam coils provide heat to evaporate the moisture from the sheet. Supply air fans blow fresh air over the coils and the hot air picks up the water vapour as it evaporates from the sheet. Exhaust fans carry the water vapour to an exchanger where water is sprayed into the stream to condense the vapour to warm water. Warm water is collected for reuse and exhaust air is carried away to atmosphere. The dry sheet then moves through a section of the dryer where it is cooled off and carried to the cutter and layboy. If the sheet breaks, it is directed to the dry end repulper where dilution is added. The mixture is repulped and sent to the broke chest for reprocessing.

6.3.4.23 Cutter and Layboy

The cutter and layboy (Figure 6.15) cut the cool, dry pulp sheet into 29" x 33 5/8" sheets (A-Mill) and stacks them into 550 lb (246 kg) bales. The sheet leaves the dryer and passes through a tension roll which keeps proper tension on the sheet. A perforator roll makes a series of small punctures in the sheet to meet export requirements. From the perforator roll, the sheet is cut by slitters into eight widths of 29" (A-Mill), or four widths of 335/8" (B-Mill) each. The sheets pass under a "worm" roll, which holds down and spreads the sheets. Every 335/8" (A-Mill), or 29" (B-Mill), the fly knife cuts the sheets to produce squares. The squares stack up on the lowering table until they reach a preset weight, then are discharged to bale finishing.

6.3.4.24 Bale Finishing

The bale finishing line wraps, ties, weighs and stencils the bales, then stacks them for delivery to the warehouse (Figure 6.16). Stacks of sheets from the layboy are placed on a conveyor by swing conveyors (2) and are weighed. The weight is then adjusted for shipping requirements before being moved into the bale press. The bale press compresses the bales into tight, square bales. Compressed bales are wrapped in a protective sheet by the wrapper, then tied by consecutive tying machines. The weighed bales are stenciled for identification and stacked four to five bales high. A clamp truck takes the completed bales of market pulp to the warehouse where they are stored until shipped.

6.3.4.25 Chemical Use

The chemical consumption (kg/ADt production and total kg/day) at Skeena Cellulose in 1992 is presented in Table 6.1. Data presented includes chemicals used in the chlorine dioxide generator, in kraft bleaching, liquor make-up and recovery, feedwater, in the lime plant, for peroxide bleaching, and in effluent treatment. Highest chemical consumption occurs in the kraft bleaching process and chlorine dioxide generator, which use caustic soda, chlorine, sodium chlorate and sulphuric acid in the pulp processing.

6.3.4.26 Chemical Recovery

Recovering chemicals from the pulping process is critical to a kraft pulp mill. If the chemicals are not recovered, it is far too expensive to operate the mill and causes a major pollution problem. The recovery and recaust areas which recover the valuable chemicals from the pulping process (Figure 6.17) and its associated equipment is constantly undergoing improvement, but is not 100% efficient. Some make-up of chemicals is therefore required. The more efficiently the equipment is operated, the more effective the recovery chemicals and the less make-up required.

6.3.4.27 Liquor Cycle

After digesting, the dissolved lignins and cooking chemicals are mixed and saturate the pulp fibres. The washers displace the chemicals and lignins from the pulp and this solution is called weak black liquor. Weak black liquor is pumped to the evaporators where steam is used to evaporate water and "thicken" the liquor (Figure 6.17).

The mill has two evaporator "trains" - one for each recovery boiler. Each "train" consists of several evaporators in series. As black liquor flows through each evaporator, it is concentrated, until at the final evaporator the solids content of the liquor is 50 to 55%. The liquor is brought to even higher concentration in the black liquor concentrators. These produce liquor of about 65% solids, after which it is discharged to storage tanks as strong black liquor. The resulting strong black liquor is mixed with the sodium sulphate (saltcake) recovered from the recovery boiler flue gas and becomes "heavy black liquor". Not all of the particulate is recovered from the gases, so saltcake is added to make up for the losses during this part of the cycle. The mixture of strong black liquor and saltcake is heated and pumped as fuel to the recovery boiler.

The main purpose of the recovery boiler is to burn the heavy black liquor. In the recovery furnace, the liquor releases heat from combustion of the lignins and undergoes various chemical reactions. The chemicals remaining after combustion form a molten smelt, however some of the chemicals become airborne in the boiler flue gas. These chemicals (saltcake) are recovered as the gas passes through electrostatic precipitators.

Electrostatic precipitators apply a very high differential electrical charge through the flue gas stream. The charged saltcake particles collect on plates and the clean flue gas is discharged to atmosphere. Collected saltcake is recovered through series of screws and conveyors prior to being mixed with the strong black liquor for use as a recovery boiler fuel. Heat released in the furnace generates steam in the boiler which is used for process and to drive the turbine generators - generating electricity. Molten smelt flows out the bottom of the boiler and into the dissolving tank. Weak wash from the weak wash storage tank is added to the dissolving tank and dissolves the smelt to form green liquor (Figure 6.17).

6.3.4.28 Recausticizing

Green liquor is pumped to the green liquor clarifier where unburned carbon particles (dregs) settle out (Figure 6.17). The dregs are washed by a dregs filter to recover usable chemicals. Filtrate (weak wash) is recycled and the washed dregs are hauled to landfill. Clear green liquor from the clarifier is sent to the slaker where lime is added and the mixture flows into the causticizers. The causticizers provide retention time for the chemical conversion (changing the green liquor into a mixture of white cooking liquor and lime mud) to proceed to completion.

The lime mud/white liquor mixture is pumped to the white liquor pressure filter where the two are separated. White liquor is pumped to white liquor storage for use by both "A" and "B" mill digesters and the lime mud is sent to the mud washers. The mud washers recover more of the white liquor chemicals still in the mud and the resulting solution is termed "weak wash". Weak wash is reused in the dissolving tank to dissolve more smelt.

Washed lime mud from the washer is sent to the lime mud filter where most of the water is removed to form lime cake. Lime cake is conveyed to the lime kilns (2) where it is burned to change it into "quicklime". The burned lime is then reused in the slaker to make more white cooking liquor. Some lime is always lost from the system due to spills, dust loss, etc. To make up for the loss lime rock (limestone) is added to the lime cake before it enters the kiln or fresh, purchased lime is added to the slaker. For the mill to operate economically, it is necessary to recover as much cooking chemical as possible. Recaust provides a uniform white liquor supply for the digesters, while recovering the greatest amount of soda possible from the lime mud.

6.3.4.29 Energy System

The mill has five boilers: three power boilers and two recovery boilers (Figure 6.18). Boilers No. 1 and No. 2 are the gas-burning boilers which are normally used as stand by units. Number 4 power boiler primarily burns hog fuel, with fossil fuel as a back-up or supplementary source. Boilers No. 5 and No. 6 are large recovery boilers which burn black liquor as the primary fuel and oil as an auxiliary fuel. Under ideal situations, the boilers are fired only on wood by-products; the recovered lignin from the kraft mills and hog fuel generated from our own woodroom and area sawmills. The three main boilers have a combined capacity to generate over a million lbs of steam /hr at a pressure of 600 psi.

High pressure steam is sent to two turbines, which generate a combined output of 32 to 35 megawatts (MW) power. The byproduct 175 and 75 psi steam from the turbines provides process steam requirements for the mill complex. Normal mill electrical requirement is 50 MW.

The volume not generated by our own turbines, generally 12 to 18 MW, is supplied by BC Hydro. Heat from the steam exhausted from the turbines or directly from the boilers, is given up to the mill process and condenses to water. The condensate is sent back to the boilers as feedwater and make-up is provided by the water treatment plant.

6.3.5 Treatment Facilities

The mill uses state-of-the-art technology to reduce the impact of the mill on the environment. Wash filtrates are reused in other parts of the process whenever possible. Effluent from the mill is collected from sewers, drains, trenches and sumps throughout the site and collected at a central point (effluent pumphouse). The acidic liquid effluent is neutralized by the addition of lime to form a pH controlled effluent. The neutralized liquid joins the caustic sewer and the general sewer flow and it is all pumped to the primary clarifier after the final pH is adjusted with acid or caustic.

The primary clarifier consists of a tank which is 280 ft in diameter x 15 ft water level. Here, any heavy material settles out and is removed as sludge. The supernatant then flows to the Unox tank (bio-reactor). The bio-reactor consists of a 7 million gallon rectangular tank which is divided into three separate compartments. Here, microorganisms are concentrated to a level which is sufficient to consume contaminants before the liquid flows to the secondary clarifiers. Pure oxygen, anhydrous ammonia and phosphoric acid are added to the bio-reactor in order to provide the essential nutrients for continual growth of the micro-organisms.

The discharge flow of liquid from the bio-reactor is divided at the splitter box, which in turn flows to two separate secondary clarifiers. Each clarifier is 280 ft in diameter x 18 ft deep with a volume of 8.33 million gallons. Here the microorganisms (bio-solids) are settled out and a portion of the sludge is removed as waste sludge while the remaining bio-solids are recycled back to the bio-reactor. Constant recycle of microorganisms is essential to maintain the required concentration in the bio-reactor in order to accommodate the consumption of contaminants in the effluent. The final treated effluent from the top of the secondary clarifiers flows to a foam trap. The trap catches any foam carried by the effluent and diffuses the treated effluent into Porpoise Harbour.

The total hydraulic retention time is 17.3 hours, based on a yearly average flow of 160,580 m^3/day. The primary clarifier has a capacity of 26,155 m^3/day, and the average hydraulic retention time is 3.9 hours. The total capacity of both secondary clarifiers is 62,832 m^3, with an average hydraulic retention time of 9.4 hours. The bio-reactor has a capacity of 26,495 m^3 and average hydraulic retention time is 2.6 hours (taking into account the recycle flow rate). The capacity of the spill tank is 37,850 m^3, and the maximum return flow from the spill tank back to the effluent pumphouse is 10.5 m^3/minute.

6.3.6 Fibre Losses

Average fibre loss to the sewers is approximately 11,445 t/yr. These fibre losses are recovered in the primary clarifier and are subsequently incinerated in the power boiler.

6.3.7 Flow Measurement Devices

Prior to the completion of the effluent treatment plant in October 1990, all effluent discharge flow was measured at Building 4 just prior to the foam trap and main diffuser. The device used was a bubble tube and an electronic flow meter. As of November 1990, two Fisher-Porter 48" magnetic flow meters (Model #10D1435A) have been employed to obtain precise flow measurements. One magnetic flow meter is utilized at the inlet to the effluent system, while the other is operated at the outlet of the secondary clarifiers.

In the spring of 1994, a Fisher-Porter flow meter was installed to record flows through Lagoon No. 1. The device is placed in the culverts between and Lagoons No. 1 and No. 2.

6.3.8 Effluent Monitoring Data

6.3.8.1 Volume

The volume of effluent discharged from the Skeena Cellulose diffuser between 1988 and 1993 is presented in Figure 6.19. Current effluent discharge rates are 160,580 m^3/day or 1.86 m^3/second, based on the yearly average. There appears to be an increase in total effluent discharged (m^3/ADt production) over time, with wide fluctuations in volume of effluent since mid-1991. However, according to Skeena Cellulose personnel, the bubble tube method for measurement of effluent likely underestimated the total volume discharged; as a result, earlier data may not accurately reflect the true volume of effluent entering Porpoise Harbour (T. Cant, Skeena Cellulose Inc., *pers. Comm.*).

Flows through Lagoon No. 1 have only been monitored since June, 1994. Initial readings indicate a flow rate of 12,000,000 USGD .

6.3.8.2 Biochemical Oxygen Demand

A marked decline in BOD_5 (t/d) is evident at Skeena Cellulose since April, 1991 (Figure 6.20). Prior to this date, BOD_5 ranged between 30 to 50 t/d. However, since the installation of the effluent treatment system in early 1991, BOD_5 values have declined to less than 10 t/d.

6.3.8.3 Total Suspended Solids

Total suspended solids (TSS) values in Skeena Cellulose effluent appear to have changed little over time (Figure 6.20). Since January 1988, TSS levels have generally ranged between 10 to 20 t/d. However, there has been a significant change in the nature of solids released by Skeena Cellulose. Prior to April, 1991, effluent solids included high concentrations of fibre and other by-products of the pulping process. Following completion of the effluent treatment facilities, fibre losses have been reduced significantly (over 95%), and the present solids discharge includes primarily biological solids.

6.3.8.4 pH and Conductivity

Skeena Cellulose effluent is monitored continuously to determine pH and conductivity. Average monthly pH values in Skeena Cellulose effluent have ranged between 6.0 and 7.9 pH units since December of 1992. The lowest pH value was recorded in July 1993 (4.0), and the highest in October 1993 (11.8).

Conductivity levels have ranged between 219 mmhos/cm and 2650 mmhos/cm during the same monitoring period. Average monthly conductivity readings have generally been between 1400 mmhos and 1600 mmhos since December 1992.

6.3.8.5 Adsorbable Organochlorine Halides

Concentration of adsorbable organic halides (AOX; kg/ADt production) discharged from Skeena Cellulose since January 1990 is presented in Figure 6.21. There has been a general trend of declining AOX values over time, especially since January 1992. Since that date, the maximum AOX value has been 2.8 kg/ADt production.

6.3.8.6 Dioxins/Furans

Concentrations of dioxins and furans have decreased markedly in Skeena Cellulose effluent discharged into Porpoise Harbour (Figure 6.22). Since February 1992, there has been a relatively consistent decline in the effluent concentration of 2,3,7,8-T_4CDD; concentrations of this compound have been below 10 ppq on all but one occasion (January 1993; 12 ppq) since October 1992. The most recent data (November 1993) indicated that Skeena effluent contained 3.6 ppq 2,3,7,8-T_4CDD; this is well below the Canadian Environmental Protection Act (CEPA) target of 15 ppq which must be met by all mills by January 1994.

Furan concentrations in effluent have also shown marked declines over time, especially since late 1992 (Figure 6.23). Since September 1992, 2,3,7,8-T_4CDF concentrations in effluent have been below 100 ppq (except the January 1993 sample; 190 ppq); since February 1993, all values have been below 50 ppq (the CEPA target for 1994). However, furan levels have fluctuated on two occasions in the last few years; in August 1991 and July 1992, values of 1,100 ppq were recorded in Skeena effluent. Despite these two high values, the quantity of dioxins and furans in Skeena effluent has declined considerably from levels recorded in the late 1980's. The reduction in dioxin and furan loading in the system has resulted in an overall decrease in concentrations of these compounds in sediment and biota collected in the vicinity of the mill (Dwernychuk *et al.*, 1993b, 1994 [*in prep.*]).

Corresponding with the decline in concentrations of dioxins and furans in Skeena Cellulose effluent in the past 5 years, are declines in Total 2,3,7,8-T_4CDD TEQs and CEPA TEQs (concentration of 2,3,7,8-T_4CDD + 0.1 X 2,3,7,8-T_4CDF concentration; Figure 6.24). As was observed with the dioxin and furan data, there has been a trend in declining TEQ values, especially since August 1992. Since February 1993, all CEPA TEQs have been below the (January 1994) target of 20 ppq.

6.3.8.7 Effluent Toxicity

Acute toxicity data for Skeena effluent analyzed between 1988 to 1993 are presented in Figure 6.25. Since February 1992, a 100% survival rate for rainbow trout (*Oncorhynchus mykiss*) has been obtained for all effluent samples tested; since June 1991, only two effluent samples tested (November 1991 and January 1992) have been toxic to the rainbow trout tested.

6.3.9 Other Discharge Points

The following section provides details of water chemistry data collected from Lagoon No. 1 and Zanardi Ditch since monitoring commenced in 1992. Parameters routinely monitored at these sites include pH, conductivity and TSS (daily), BOD (3 times per week), as well as toxicity tests using *Daphnia magna* (weekly) and rainbow trout (monthly). The Lagoon No. 1 sewer receives filter backwash, cooling water, and raw water weir overflow; Zanardi ditch receives storm runoff, as well as hog fuel leachate.

6.3.9.1 Lagoon No. 1 Outfall

Water quality data collected at Lagoon No. 1 between December 1992 to June 1994 indicate a considerable degree of variation in parameters examined (Figure 6.26). Note that these figures provide the range of values for each parameter (minimum and maximum) for each month. Values for pH have ranged between 2.7 and 10.7 units, but generally have remained in the range of 5 to 8 units. Conductivity ranged between 12 mmhos/cm and 240 mmhos/cm during the monitoring period; however, in December 1993, a conductivity reading of 600 mmhos/cm was recorded. Total suspended solids have generally ranged between 5 mg/L to 25 mg/l, but readings as high as 146 mg/l have been recorded (April 1993). BOD levels have fluctuated somewhat, but maximum values have been less than 10 mg/L for all but 3 sampling periods (Figure 6.26).

Results of 96-hour LC_{50} toxicity tests undertaken with release waters from No.1 Lagoon have been encouraging. Since December 1992, a 100% survival rate for rainbow trout has been obtained for all but one samples tested; the one exception was a 75% survival rate recorded in November 1993. *Daphnia* tests have also indicated non-toxicity (all samples >50% survival).

6.3.9.2 Zanardi Outfall

As was the case with Lagoon No. 1, water quality data indicate considerable variation in parameters examined (Figure 6.27). Values for pH have ranged between 5.9 and 9.3 units, but generally have remained near a value of 7 units (note one outlier of 12.4 units in February 1993). Conductivity ranged between 240 mmhos/cm and 1450 mmhos/cm during the monitoring period; however, in both February and December 1993, conductivity readings of 10,000 mmhos/cm were recorded. Maximum and minimum monthly values for total suspended solids indicate a wide range (1 to 581 mg/L), but most individual readings have been below 50 mg/l. BOD levels fluctuated markedly between December 1992 and August 1993, but have been more stable since the latter date; present values are in the 10 to 50 mg/L range (Figure 6.27).

All 96-hour LC_{50} toxicity tests undertaken at Zanardi outfall have been non-toxic to rainbow trout. Between December 1992 and May 1993, 4 *Daphnia* tests have indicated toxicity (samples <50% survival); all samples analyzed since June 1993 have been non-toxic.

6.3.10 Spills to the Receiving Environment

The following is a list of spills which were reported to the Provincial Emergency Program (PEP) between 1991 and 1993.

1991 Reportable Incidents

January 3	Saltcake loss from No. 5 R/B.
February 5	No. 2 sump pump (kiln) area failed.
February 17	Foam tank overflow.
February 22	T-50 ("B" mill) stock spill.
February 26	Leaking overflow line from concentrator sump.
March 5	Leaking sodium chlorate unloading line.
March 6	Foam tank overflow, storm sewer sump box overflow.
April 12	Foam tank overflow.
April 15	Foam tank overflow.
April 17	Foam tank overflow.
May 14	Bypass valve opened (discharge valve problems).
June 20	Bypass valve opened (power failure).
June 22/23	Bypass valve opened (power failure).
July 8	Bypass valve opened/sump box overflow (lift pump motor failure).
July 24	Bypass valve opened/wet well overflow (electrical power problems).
August 15	Bunker "C" spill (transferring of oil).
August 20	Sump box overflow.
September 1/2	Discharge into Lagoon No. 1 (draining of cont. cond. tank?).
September 22	Discharge into Lagoon No. 1 (No. 1 dig. in-line drainers plugged).
October 17	Bypass valve opened (electrical power problems).
November 14/15	Bypass valve opened (power failure).
November 16	Bypass valve opened (electrical power problems).
November 16/17	Bypass valve opened (electrical power problems).

November 17	Bypass valve opened (electrical power problems).

1992 Reportable Incidents

January 10	Bypass valve opened (power disruption).
January 25	Stock to Lagoon No. 1.
February 11	Foam trap overflow to Porpoise Harbour
February 12	Foam trap overflow to Porpoise Harbour.
February 22	Pulp and Liquor to ground, plugged cyclone.
April 3	Bale press oil to Lagoon No. 1.
April 4	Diesel fuel to Lagoon No. 1.
May 12	Stock to Lagoon No. 1.
May 28	Blowtank drain incident.
May 31	T-1 Transformer failure.
July 24	Bypass valve opened (power disruption).
August 13	Oil slick in Porpoise Harbour.
August 15	Acid to Lagoon No. 1.
September 5	Bunker C to Porpoise Harbour.
September 6	Bypass valve opened (power disruption).
September 12	Bypass valve opened (power disruption).
October 10	Hydraulic oil to Porpoise Harbour.
November 21	Power disruption, overflowed effluent pump hose.
November 24	Power disruption, opened bypass valve.
December 5	Antifreeze to Porpoise Harbour.

1993 Reportable Incidents

February 26	Lime mud to Zanardi.
February 26	Dillon screen sump to Porpoise Harbour (DFO).
March 31	93% H_2SO_4 storage tank in Chum Prep developed a leak on the bottom, went to Lagoon No. 1. PEP called at 10:40 a.m.
April 2	O/F of effluent pumphouse at 12:00 noon/Called PEP at 1:00 p.m. O/F was approximately 10 min.

April 16	O/F of effluent pumphouse at 9:40 a.m. to 9:55 a.m. due to power failure and loss of air compressors.
May 27	Caustic discharge to Porpoise Harbour via Bldg. 38. PEP and Vessel Traffic called at 11:10 to 11:15 a.m. DFO took samples. SPO sent samples to Beak for bioassay.
June 7	Power failure, lost lift pumps, bypass valve opens from 12:26 p.m. to 12:44 p.m. Called PEP at 12:35.
June 11	Power failure, lost air compressors, two effluent pumps tripped, wetwell overflowed to ground for approximately 2 to 3 min. Called PEP at 12:40 p.m.
August 3	Bypass valve opened from 9:45 p.m. to 10:02 p.m. due to lift pump problems associated with DES. Called PEP at 9:55 p.m.
August 4	Bypass valve opened from 2:23 p.m. to 2:52 p.m. due to total power outage caused by B.C. Hydro outage (thus causing No. 3 T/C to trip). PEP called at 2:40 p.m.
August 27	Spill of used oil when transferring from pumper truck to used oil storage and overfilled small transfer tank. Peter Laurie called PEP.
September 8	Expansion joint failed on No. 3 W/R effluent line to churn prep sewer spilling untreated effluent down to rail tracks at Chem Prep. PEP called at 8:55 a.m., spill observed at 8:15 a.m. and isolated at 8:30 a.m. (approximately).
September 11	Golden Pond overflowed to Porpoise Harbour due to malfunction of pump.
September 18	Overflow of foam trap to Porpoise Harbour.
October 18	Power failure, opened bypass valve at 14:12 p.m. and closed bypass at 14:41 p.m. DFO responded. Called PEP at 14:35 p.m. and EC at 14:42 p.m.
October 26	Chlorine leak on pipe bridge A-Mill.
October 26	Power outage and subsequent opening of bypass.
November 13	Overflow of foam trap to Porpoise Harbour (Ran out of defoamer).
November 20	Power outage, opened bypass for 3½ hr.
November 22	Overflow of foam trap to Harbour.

7.0 IMPLICATIONS FOR ENVIRONMENTAL EFFECTS MONITORING

The purpose of an EEM pre-design study is to collect and/or compile sufficient information to support the formulation of an EEM sampling program. Specifically, the pre-design study is intended to:

- delineate the spatial extent of the study area, including the zone of effluent mixing and representative reference areas;
- provide confirmation at the time of field sampling that the samples are representative of these areas (available where no field information exists);
- provide a description of habitat type at a level of resolution sufficient to allow siting of invertebrate and sediment sampling stations;
- document any potentially confounding or influencing factors that may have to be considered in the study design and/or interpretation of results;
- provide a knowledge of the relative abundance of fish in the study area sufficient to allow for the selection of a minimum of two sentinel fish species; and
- describe the quality and use of fisheries resources in the receiving environment to assist in the setting of statistical criteria in subsequent EEM cycles.

Information compiled during the pre-design study is reviewed briefly to support the formulation of an environmental effects monitoring program at Skeena Cellulose Inc. A specific first cycle study design for the Skeena mill will be prepared by Hatfield Consultants Ltd. in 1994.

PLUME DELINEATION

The plume delineation component of pre-design is important for establishing the location of both affected and reference sites. During Cycle 1, effluent exposure will be confirmed by simultaneous measurements of tracer compounds at the time of field sampling. At the Skeena facility, the zone of effluent mixing was determined by a critical review of oceanographic, physical, biological, and chemical data which had been collected in the receiving environment since 1961. Information sources which were useful for plume delineation included: 1) description of the submarine outfall and effluent diffusers; 2) oceanographic studies of the receiving environment (physical and chemical properties, currents and tides); 3) results of historical water quality monitoring in the vicinity of the outfall; 4) historical dye studies; 5) results of organochlorine monitoring of the receiving water, sediments and biota; and 7) benthic community composition studies. Despite the complicated hydrology of the receiving environment, results of the analysis permitted delineation of the effluent mixing zone without additional empirical data collection during the pre-design phase. For plume delineation purposes, three components of the effluent plume were defined, including an "effluent concentration field" corresponding to a zone where effluent concentrations of 1% or greater may occur, a "near-field study area" which encompasses the 1% area and surrounding waters where high organochlorine concentrations have been observed, and a "far-field extent of effluent concentration" which reflects the maximum area where pulpmill effluent contaminants have been detected. The effluent concentration field at Skeena is defined as a circle of radius 500 m around the diffuser in Porpoise Harbour (Figure 2.20). During Cycle 1, "affected" sites will be located within the near-field study area, and "reference" sites will be located outside of the far-field extent of effluent concentration.

HABITAT INVENTORY AND CLASSIFICATION FOR AFFECTED AND REFERENCE AREAS

Results of habitat classification and mapping are provided in Figures 3.1 to 3.4 (physical and biological habitat components) for Porpoise Harbour and Wainwright Basin. The areas covered by the habitat maps encompass the effluent concentration field. A potential reference site for Skeena is located in Kitkatla Inlet, Porcher Island (Figure 3.5). This reference location was chosen because of reasonably similar bathymetry, oceanographic characteristics, and freshwater influences. Physical and biological habitat mapping will be completed for the reference site during Cycle 1.

RESOURCE INVENTORY

A diverse invertebrate and fish community is present within, and adjacent to, the receiving environment of Chatham Sound and adjacent to Watson Island. Information reviewed in the resource inventory (Section 4.0) is sufficient to allow for the selection of two sentinel fish species at the EEM Design stage. While most commercial harvesting takes place outside of the effluent concentration field, adjacent areas are used both for spawning and rearing purposes. Areas in and around the Skeena River are used by local First Nations harvesters.

Closures and advisories for crab and shellfish adjacent to Skeena Cellulose Inc. have been imposed because of domestic and municipal sewage contamination, as well as the presence of organochlorine compounds originating from pulpmill effluent. Organochlorine monitoring programs sponsored by the pulpmill are ongoing, and will take precedence over the organochlorine monitoring requirements specified under the EEM regulations.

HISTORICAL RECEIVING ENVIRONMENT

A large body of information characterizes the receiving water quality, sediment quality, intertidal and benthic communities, and biological tissues of the Skeena receiving environment. Information in Section 5.0 will be useful for the design of the fish habitat sampling component of Cycle 1. Under EEM terminology, fish habitat sampling is synonymous with benthic invertebrate sampling.

MILL HISTORY

Detailed descriptions of Skeena mill history, effluent quality and current operations are provided in Section 6.0. Following the installation of primary and secondary treatment facilities, conventional effluent monitoring parameters, including biochemical oxygen demand, suspended solids, AOX, dioxin and furan concentrations and effluent toxicity have been reduced. These in-house process changes likely will result in reduced environmental impacts of the Skeena facility on the receiving environment.

In summary, this pre-design document provides the necessary background to design the first-cycle study at Skeena Cellulose Inc.

8.0 REFERENCES

Adkins, A.D., R.M. Harbo and P.A. Brean. 1981. A survey of commercial sea urchin (*Strongylocentrotus franciscanus*) populations in the Gulf Islands, November 1980. Can. MS Rep. Fish. Aquat. Sci. 1618.

Anon. 1992. Aquaculture: British Columbia's future. An industry assessment by the B.C. Salmon Farmers Association, the B.C. Shellfish Growers Association and the B.C. Trout Farmers Association.

Anon. 1993a. State of the environment report for British Columbia. B.C. Ministry of Environment, Lands and Parks and Environment Canada.

Anon. 1993b. Technical Guidance Document for aquatic environmental effects monitoring related to federal Fisheries Act requirements. Environment Canada and Department of Fisheries and Oceans. Version 1.0, April, 1993.

Archibald, D. and R. Bocking. 1983. Annual report summarizing 1981 to 1982 activities on crab habitat loss and dredge monitoring program. Prepared for National Harbours Board and Department of Fisheries and Oceans, Vancouver.

B.C. Water Investigations Branch. 1977. Prince Rupert pulp mill (CANCEL) monitoring programme: Survey of intertidal macro-algae, 1974-75. Victoria, B.C.

Beacham, T.D. 1984. Catch, escapement, and exploitation of chum salmon in British Columbia, 1951 to 1981. Can. Tech. Rep. Fish. Aquat. Sci. 1270.

Beak Consultants Ltd. 1977. Intertidal flora and fauna in Wainwright Basin and Porpoise Harbour, Sept.-Oct., 1977.

Beak Consultants Ltd. 1980. Biological and water quality studies in the marine environment near the Canadian Cellulose Pulp Mill, 1978 and 1979. A report by L.W. Dwernychuk for Canadian Cellulose Company Limited, Prince Rupert.

Beak Consultants Ltd. 1981. Biological and water quality studies in the marine environment near the Canadian Cellulose Pulp Mill, 1980. A report by L.W. Dwernychuk for Canadian Cellulose Company Limited, Prince Rupert.

Beak Consultants Ltd.. 1982. Water quality and biological studies in the marine environment near the B.C. Timber pulp mill, 1981. A report by L.W. Dwernychuk for B.C. Timber Ltd., Prince Rupert.

Bernard, F.R. 1980. Preliminary report on the potential commercial squid of British Columbia. Can. Tech. Rep. Fish. Aquat. Sci. 942.

Birch, J.R., E.C. Luscombe, D.B. Fissel and L.F. Giovando. 1985. West Coast data inventory and appraisal. Volume 1, Parts 1 and 2. Dixon Entrance, Hecate Strait, Queen Charlotte Sound and adjoining B.C. coastal waters: physical oceanography - temperature, salinity, currents, water levels and waves, 1903 through 1984. Can. Data Rep. Hydrol. Ocean Sci. 37: 302, 265 p.

Brothers, D.E. 1970. Results of oxygen surveys conducted on the waters contiguous to the Columbia Cellulose pulp mill at Port Edward, B.C., May to November, 1969. Dep. Fish. Can. Memorandum Rep.: 20 p.

Burgner, R.L. 1991. Life history of sockeye salmon (*Oncorhynchus nerka*). *In:* Groot, C. and L. Margolis [eds.]. *Pacific Salmon Life Histories.* Univ. British Columbia Press, Vancouver. pp. 1-117.

Canadian Hydrographic Service (CHS). 1977. *Sailing directions - British Columbia Coast (North Portion).* Vol 2, 7th Ed. Institute of Ocean Sciences, Sidney, B.C.

Cass, A.J. R.J. Beamish and G.A. McFarlane. 1990. Lingcod (*Ophiodon elongatus*). Can. Spec. Publ. Fish. Aquat. Sci. 109.

Coast Salish Fisheries Working Group (CSFWG). 1993. Development of a First Nations fisheries management model: Phase II. Strategic planning in stock assessment and stewardship. Available from: Musqueam Indian Band, 6370 Salish Drive, Vancouver, B.C. V6N 2C6.

Collicutt, L.D. and T.F. Shardlow. 1992. Strait of Georgia sport fishery creel survey statistics for salmon and groundfish, 1990. Can. MS Rep. Fish. Aquat. Sci. 2109.

Colodey, A.G. and P.G. Wells. 1992. Affects of pulp and paper mill effluents on estuarine and marine ecosystems in Canada: a review. J. Aquat. Ecosys. Health 1:15-40.

Colodey, A.G., L.E. Harding, P.G. Wells and W.R. Parker. 1990. Effects of pulp and paper mill effluents and their constituents on estuarine and marine environments in Canada: a brief review. Environmental Protection, Pacific, Yukon and Atlantic Region. Regional Program Report 90-08.

Cowardin, L.M., V. Carter, F.C. Golet and E.T. LaRoe. 1979. Classification of Wetlands and Deepwater Habitats of the United States. U.S. Fish and Wildlife Service, FWS/OBS-79/31.

Dayton & Knight Ltd. 1990. City of Prince Rupert. Wainwright landfill development. Treated leachate ocean disposal. Dayton & Knight Ltd. Consulting Engineers, West Vancouver, B.C.

Department of Fisheries and Oceans. 1993. Coastal/Estuarine Habitat Description and Assessment Manual. Part II. Habitat description procedures. Prepared by G.L. Williams and Associates Ltd., Coquitlam, B.C.

Dickson, F. 1992. Intertidal clams. *In:* Thomas, G.A. [ed.]. Shellfish stock assessments for the west coast of Canada in 1991 as reviewed by the Pacific Stock Assessment Review Committee (PSARC). Can. MS Rep. Fish. Aquat. Sci. 2169. pp. 206-221.

Drinnan, R.W. 1974. Prince Rupert Harbour provincial interagency study: Program 3, Task 3, Intertidal (beach) biology. B.C. Pollution Control Branch, Water Resources Service, Victoria, B.C. (*cited in* Hoos, 1975).

Drinnan, R.W. 1977. Prince Rupert pulp mill monitoring program - survey of intertidal macroalgae, 1974-1975. Water Investigations Branch, Ministry of Environment.

Drinnan, R.W. and I. Webster. 1974. Prince Rupert Harbour [Provincial] interagency study: Program 3, Tasks 1 and 2, Oceanography and water quality. Pollution Control Branch, Victoria, B.C.

Dwernychuk, L.W. 1985. Water quality and biological studies in the marine environment near the Westar Timber pulp mill, 1984. Report for Westar Timber Limited, Prince Rupert. IEC Beak Consultants Ltd., Richmond, B.C.

Dwernychuk, L.W. 1986. Water quality and biological studies in the marine environment near the Westar Timber pulp mill, 1985. Report for Westar Timber Limited, Prince Rupert. Hatfield Consultants Ltd., West Vancouver, B.C.

Dwernychuk, L.W. 1987. Water quality and biological studies in the marine environment near the Skeena Cellulose Pulp Mill, 1986. Report for Skeena Cellulose Inc., Prince Rupert. Hatfield Consultants Ltd., West Vancouver, B.C.

Dwernychuk, L.W. 1988. The marine receiving environment near Skeena Cellulose Inc.: A study on the physical, chemical and biological components of subtidal and intertidal systems (1987). 3 Vols. Prepared for Skeena Cellulose Inc. Hatfield Consultants Ltd., West Vancouver, B.C.

Dwernychuk, L.W. 1989a. Water quality and intertidal macroalgae assessments near Skeena Cellulose Inc., 1988. Prepared for Skeena Cellulose Inc., Prince Rupert. Hatfield Consultants Ltd., West Vancouver, B.C.

Dwernychuk, L.W. 1989b. Bottom sediments and biological tissues: a baseline organochlorine contamination survey in the marine environment near Skeena Cellulose Inc., January/February 1989. Report for Skeena Cellulose Inc., Prince Rupert. Hatfield Consultants Ltd., West Vancouver, B.C.

Dwernychuk, L.W. 1992. Intertidal macroalgae: Qualitative/photodocumentation survey. Skeena Cellulose Inc. 1992. Prepared for Skeena Cellulose Inc. Hatfield Consultants Ltd., West Vancouver, B.C.

Dwernychuk, L.W., G.S. Bruce, B. Gordon and G. Thomas. 1992a. Comprehensive organochlorine survey of the receiving environment in the vicinity of Skeena Cellulose Inc. 1990/91 (effluent/water/sediment/biological organisms). 2 Volumes. Prepared for Skeena Cellulose Inc. Hatfield Consultants Ltd., West Vancouver, B.C.

Dwernychuk, L.W., G.S. Bruce, B. Gordon and G. Thomas. 1992b. Organochlorine trend monitoring: (sediments/shrimp/prawn/crab), Skeena Cellulose Inc. 1991. Prepared for Skeena Cellulose Inc. Hatfield Consultants Ltd., West Vancouver, B.C.

Dwernychuk, L.W. and T.G. Boivin. 1993. Dioxin and furan levels in the Prince Rupert Harbour region, 1992 (sediment/crab). Prepared for Skeena Cellulose Inc. Hatfield Consultants Ltd., West Vancouver, B.C.

Dwernychuk, L.W., T.G. Boivin and G.S. Bruce. 1993a. Dioxin/furan monitoring program, Skeena Cellulose Inc. (sediment/crab/shrimp) 1992. Final report. Prepared for Skeena Cellulose Inc. Hatfield Consultants Ltd., West Vancouver, B.C.

Dwernychuk, L.W., T.G. Boivin and G.S. Bruce. 1993b. Dioxin/furan monitoring program, Skeena Cellulose Inc. (sediment/crab/shrimp) 1993. Final report. Prepared for Skeena Cellulose Inc. Hatfield Consultants Ltd., West Vancouver, B.C.

Dwernychuk, L.W., T.G. Boivin and G.S. Bruce. 1994 (*in prep.*). Dioxin/furan monitoring program, Skeena Cellulose Inc. (sediment/crab) 1994. Prepared for Skeena Cellulose Inc. Hatfield Consultants Ltd., West Vancouver, B.C.

Fargo, J. 1992. Flatfish. *In:* Leaman, B.M. [ed.]. Groundfish stock assessments for the west coast of Canada in 1991 and recommended yield options for 1992. Can. Tech. Rep. Fish. Aquat. Sci. 1866. pp. 83-107.

Fedorenko, A.Y. and P.E. Sprout. 1982. Abalone biology, fishery regulations, commercial catch (1952 to 1980), and current state of the resource in British Columbia. Can. MS Rep. Fish. Aquat. Sci. 1658.

Fish Habitat Inventory and Information Program (FHIIP). 1991. Stream Summary Catalogue. Subdistrict #4A, Lower Skeena. Department of Fisheries and Oceans, Vancouver, B.C.

Forsyth, S. 1993. Ad-hoc marine sentinel species meeting, 02/6/93, Pacific Biological Station. Draft Report - 13/7/93. Environment Canada Eco-Health Branch Memorandum, Ottawa.

EPA. 1986. Quality Critera for Water, 1986. EPA 440/05-86-001.

Garrett, C.L. 1983. An overview of PCBs and their current status in British Columbia. Department of Environment, Environmental Protection Service, Pacific and Yukon Region. Regional Program Report: 83-16.

Gotshall, D.W. 1978. Northern California Dungeness crab, *Cancer magister*, movements as shown by tagging. Calif. Fish Game 64:234-254.

Government of Canada. 1993. News Release. NR-PR-93-48E, August 27, 1993.

Goyette, D.E., D.E. Brothers, and D. Demill. 1976. Summary report of environmental surveys at Prince Rupert, 1961-1971. EPS unpublished manuscript. West Vancouver, B.C.

Haist, V. and J.F. Schweigert. 1992. Stock assessments for British Columbia herring in 1991 and forecasts of the potential catch in 1992. Can. MS Rep. Fish. Aquat. Sci. 2146.

Harbo, R. 1992. Horse clams. *In:* Thomas, G.A. [ed.]. Shellfish stock assessments for the west coast of Canada in 1991 as reviewed by the Pacific Stock Assessment Review Committee (PSARC). Can. MS Rep. Fish. Aquat. Sci. 2169. pp. 202-205.

Harbo, R. and G.A. Thomas. 1992. Sea urchins. *In:* Thomas, G.A. [ed.]. Shellfish stock assessments for the west coast of Canada in 1991 as reviewed by the Pacific Stock Assessment Review Committee (PSARC). Can. MS Rep. Fish. Aquat. Sci. 2169.

Harbo, R., S. Farlinger, K. Hobbs and G. Thomas. 1992. A review of quota management in the geoduck clam fishery in British Columbia, 1976 to 1990, and quota options for the 1991 fishery. Can. MS Rep. Fish. Aquat. Sci. 2178.

Hart, J.L. 1973. Pacific fishes of Canada. Fish. Res. Bd. Canada Bull. 180.

Hay, D.E., P.B. McCarter, R. Kronlund and C. Roy. 1989. Spawning areas of British Columbia herring: A review, geographical analysis and classification. Vol. 2 North Coast. Can. MS Rep. Fish. Aquat. Sci. 2019.

Healey, M.C. 1980. The ecology of juvenile salmon in Georgia Strait, British Columbia. *In:* McNeil, W.J. and D.C. Himsworth [eds.]. *Salmonid Ecosystems of the North Pacific.* Oregon State University Press, Corvallis. pp. 203-229.

Healey, M.C. 1991. Life history of chinook salmon (*Oncorhynchus tshawytscha*). *In:* Groot, C. and L. Margolis [eds.]. *Pacific Salmon Life Histories.* University of British Columbia Press, Vancouver. pp. 311-393.

Heard, W.R. 1991. Life history of pink salmon (*Oncorhynchus gorbuscha*). *In:* Groot, C. and L. Margolis [eds.]. *Pacific Salmon Life Histories.* Univ. British Columbia Press, Vancouver. pp. 119-230.

Heizer, S. 1992a. Octopus. *In:* Thomas, G.A. [ed.]. Shellfish stock assessments for the west coast of Canada in 1991 as reviewed by the Pacific Stock Assessment Review Committee (PSARC). Can. MS Rep. Fish. Aquat. Sci. 2169. pp. 227-230.

Heizer, S. 1992b. Squid. *In:* Thomas, G.A. [ed.]. Shellfish stock assessments for the west coast of Canada in 1991 as reviewed by the Pacific Stock Assessment Review Committee (PSARC). Can. MS Rep. Fish. Aquat. Sci. 2169. pp. 231-234.

Heizer, S. and G.A. Thomas. 1992. Sea Cucumbers. *In:* Thomas, G.A. [ed.]. Shellfish stock assessments for the west coast of Canada in 1991 as reviewed by the Pacific Stock Assessment Review Committee (PSARC). Can. MS Rep. Fish. Aquat. Sci. 2169. pp. 280-285.

Henderson, M.A. 1991. Sustainable development of the Pacific salmon resources in the Fraser River basin. *In:* Dorcey, A.H.J. [ed.]. Perspectives on Sustainable Development in Water Management: Towards Agreement in the Fraser River Basin. Vol. 1. Westwater Research Centre, University of British Columbia, Vancouver. pp. 133-154.

Higgins, R.J. and W.J. Schouwenburg. 1973. A biological assessment of fish utilization of the Skeena River estuary, with special reference to port development in Prince Rupert. Dept. Fish. Environ., Fish. Mar. Serv. Rep. 1973-1.

Ho, D.S.M. 1978. The marine receiving water monitoring program for pulp mill effluent at Prince Rupert. *In:* Preprints of papers presented at the 1978 Spring Conference, Canadian Pulp and Paper Assoc., Technical Section, Pacific Coast and Western Branches.

Hodgins, D.O. and M. Knoll. 1990. Effluent dispersion study for the Skeena Cellulose outfall in Porpoise Harbour, British Columbia. Prepared for Skeena Cellulose Inc. Seaconsult Marine Research Ltd., Vancouver, B.C.

Holman, W.N. 1974. Canadian Cellulose - Port Edward. Biological assessment report. Draft report for Pulp and Paper Review. Unpublished.

Hoos, L.M. 1975. The Skeena River estuary: Status of environmental knowledge to 1975: Report of the Estuary Working Group, Dept. of the Environment, Regional Board, Pacific Region. Environment Canada, Special Estuary Series; No. 3.

Howes, D.E., P. Wainwright, R. Baird, L. Berg, J. Cooper, J.M. Haggarty, J.R. Harper, E.H. Owens, P.D. Reimer and K. Summers. 1993 (*in press*). Oil spill response atlas for the southern Strait of Georgia. Environmental Emergency Service Branch, Ministry of Environment, Lands and Parks, Victoria, B.C. *as cited in* DFO, 1993.

Howes, D.E. and J.R. Harper. 1984. Physical Shorezone Analysis of the Saanich Peninsula. Ministry of Environment Technical Report #9. Victoria, B.C.

Howes, D.E. and E.H. Owens. 1980. Descriptive terminology and definitions of terms for shore zone classification. Unpubl. MS, MOE, Victoria, *as cited in* DFO 1993.

IEC Beak Consultants Ltd. 1983. Water quality and biological studies in the marine environment near the B.C. Timber pulp mill, 1982. 2 volumes. Prepared by L.W. Dwernychuk for B.C. Timber Limited, Prince Rupert. IEC Beak Consultants Ltd., Richmond, B.C.

IEC Beak Consultants Ltd. 1984. Water quality and biological studies in the marine environment near the B.C. Timber pulp mill, 1983. 2 volumes. Prepared by L.W. Dwernychuk for B.C. Timber Limited, Prince Rupert. IEC Beak Consultants Ltd., Richmond, B.C.

Joyce, M. 1992. Crab. *In:* Thomas, G.A. [ed.] 1992. Shellfish stock assessments for the west coast of Canada in 1991 as reviewed by the Pacific Stock Assessment Review Committee (PSARC). Can. MS Rep. Fish. Aquat. Sci. 2169. pp. 235-241.

Keefe, T.J. and E.P. Bergersen. 1977. A simple diversity index based on the theory of runs. Water Research 11:689-691.

Ker, Priestman, Keenan and Associates Limited. 1970. Pollution control and review program for Northern Pulp Operations, Canadian Cellulose Company Limited. File No. 678/2, Ker, Priestman, Keenan and Associates Limited, Victoria. 1970.

Ketchen, K.S., N. Bourne and T.H. Butler. 1983. History and present status of fisheries for marine fishes and invertebrates in the Strait of Georgia, British Columbia. Can. J. Fish. Aquat. Sci. 40:1095-1119.

Knapp, W. and I. Cairns. 1978. Canadian Cellulose pulp mill - Port Edward, B.C., fisheries resources of Fisheries and Marine Service Statistical Area 4. Department of Fisheries and the Environment, Fisheries and Marine Service.

Knapton, D. 1987. *Pers. comm.* and subdistrict files, DFO, Prince Rupert.

Kozloff, E.N. 1983. Seashore life of the northern Pacific coast. Douglas and McIntyre, Vancouver.

Kussat, R. 1968. Investigation of fish kills in Wainwright Basin and Porpoise Harbour. Unpubl. Project Rep. for Dep. Fish. Can.

Lands Directorate. 1984. Coastal resource folio - North Coast, British Columbia. Vol. II. Environment Canada, Vancouver, B.C.

Leaman, B.M. [ed.]. 1992a. Groundfish stock assessments for the west coast of Canada in 1991 and recommended yield options for 1992. Can. Tech. Rep. Fish. Aquat. Sci. 1866.

Leaman, B.M. 1992b. Pacific Halibut. *In:* Leaman, B.M. [ed.]. Groundfish stock assessments for the west coast of Canada in 1991 and recommended yield options for 1992. Can. Tech. Rep. Fish. Aquat. Sci. 1866. pp. 281-290.

Levy, D.A. 1985. Biology and management of surf smelt in Burrard Inlet. Westwater Research Centre Tech. Rep. 28. University of British Columbia, Vancouver.

Macdonald, J.S., I.K. Birtwell and G.M. Kruzynski. 1987. Food and habitat utilization by juvenile salmonids in the Campbell River estuary. Can. J. Fish. Aquat. Sci. 44: 1233-1246.

Maclean, D.B. 1986. Trace metals in *Mytilus edulis* (mussels) and sediments from Kitimat Arm and Porpoise Harbour. Min. Environ. Waste Manag. Rep. 86-03, Smithers; B.C.

McDaniel, N. 1982. The giant sea cucumber. Diver. March 1982: 26-27.

Manzer, J.I. 1956. Distribution and movement of young Pacific salmon during early ocean residence. Fish. Res. Board Can. Prog. Rep. 106:24-28.

Mason, J.C., A.C. Phillips and O.D. Kennedy. 1984. Estimating the spawning stocks of Pacific hake (*Merluccius productus*) and walleye pollock (*Theragra chalcogramma*) in the Strait of Georgia, B.C. from their released egg production. Can. Tech. Rep. Fish. Aquat. Sci. 1289.

NATO (North Atlantic Treaty Organization). 1988a. International Toxicity Equivalent Factor (I-TEF) method of risk assessment for complex mixtures of dioxins and related ompounds. Pilot study on international information exchange on dioins and related compounds. Committee on the Challenges of Modern Society. #186.

NATO. 1988b. Scientific basis for the development of the International Toxicity Equivalent Factor (I-TEF) method of risk assessment for complex mixtures of dioxins and related ompounds. Pilot study on international information exchange on dioins and related compounds. Committee on the Challenges of Modern Society. #188.

NATO. 1988c. Pilot study on information exchange on dioxins and related compounds, Final Report. Committee on the Challenges of Modern Society. #177.

Nehlson, W., J.E. Williams and J.A. Lichatowich. 1991. Pacific salmon at the crossroads: stocks at risk from California, Oregon, Idaho and Washington. Fisheries 16:4-21.

Neville, C.M. and R.J. Beamish. 1992. Pacific hagfish. *In:* Leaman, B.M. [ed.]. Groundfish stock assessments for the west coast of Canada in 1991 and recommended yield options for 1992. Can. Tech. Rep. Fish. Aquat. Sci. 1866. pp. 267-280.

Packman, G.A. 1977. Environmental surveillance in the vicinity of the Canadian Cellulose Co. Ltd. Pulpmill at Prince Rupert, B.C. EPS Pacific Reg. Prog. Rep.; EPS 5-PR-77-8

Packman, G.A. 1979. Pulp mill environmental assessment: Canadian Cellulose Ltd., Northern Pulp Operations, Port Edward, British Columbia. Environmental Protection Branch, Environmental Protection Service, Pacific Region. Regional Program Report: 79-7. February 1979. 27 p + app.

Pearson, T.H., and R. Rosenberg. 1978. Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. Oceanogr. Mar. Biol. Ann. Rev. 16:229-311.

Pomeroy, W.M.. 1983a. B.C. Timber Pulp Mill, Porpoise Harbour: An assessment of mill impact on the receiving environment (1979-1982). Department of Environment, Environmental Protection Service, Pacific Region. Regional Program Report: 83-09. June 1983. 54 p.

Pomeroy, W.M. 1983b. Environmental impacts of bottom deposits originating from B.C. coastal pulp mills: a general summary. *In:* Pomeroy, W.M. [ed.]. Proceedings of Pulp Mill Effluent Monitoring: An Informative Development Program Sponsored by the Environmental Protection Service - March 17 and 18, 1983. EPS Rept. 83-15.

Quayle, D.B. 1988. Pacific oyster culture in British Columbia. Can. Bull. Fish. Aquat. Sci. 218.

Quayle, D.B. and N. Bourne. 1972. The clam fisheries of British Columbia. Bull. Fish. Res. Board Can. 179.

Repap Enterprises Inc. 1994. Annual report. Repap Enterprises Inc., 1250 Rene Levesqu Blvd. West, Montreal, Quebec.

Richards, L.J. and K.L. Yamanaka. 1992. Lingcod. *In:* Leaman, B.M. [ed.]. Groundfish stock assessments for the west coast of Canada in 1991 and recommended yield options for 1992. Can. Tech. Rep. Fish. Aquat. Sci. 1866. pp. 23-55.

Romaine, M.J. [ed]. 1984. North coast resources folio. Lands Directorate, Environment Canada, Vancouver.

Rowse, D.J. 1975. Receiving waters, northern pulp operations, Canadian Cellulose Co. Ltd., 1974-1975.

Rutherford, K.L. 1992. Catch and effort statistics of the Canadian groundfish fishery on the Pacific coast in 1990. Can. Tech. Rep. Fish. Aquat. Sci. 1868.

Salo, E.O. 1991. Life history of chum salmon (*Oncorhynchus keta*). *In:* Groot, C. and L. Margolis [eds.]. *Pacific Salmon Life Histories.* Univ. British Columbia., Vancouver. pp. 231-309.

Sandercock, F.K. 1991. Life history of coho salmon. *In:* Groot, C. and L. Margolis [eds.]. *Pacific Salmon Life Histories.* Univ. British Columbia., Vancouver. pp. 395-445.

Saunders, M.W. 1992a. Pacific hake. *In:* Leaman, B.M. [ed.]. Groundfish stock assessments for the west coast of Canada in 1991 and recommended yield options for 1992. Can. Tech. Rep. Fish. Aquat. Sci. 1866. pp. 143-164.

Saunders, M.W. 1992b. Walleye pollock. *In:* Leaman, B.M. [ed.]. Groundfish stock assessments for the west coast of Canada in 1991 and recommended yield options for 1992. Can. Tech. Rep. Fish. Aquat. Sci. 1866. pp. 175-187.

Saunders, M.W. and G.A. McFarlane. 1992. Sablefish. *In:* Leaman, B.M. [ed.]. Groundfish stock assessments for the west coast of Canada in 1991 and recommended yield options for 1992. Can. Tech. Rep. Fish. Aquat. Sci. 1866. pp. 109-142.

Serbic, G. 1991. The salmon escapement database and reporting system. Can. Tech. Rep. Fish. Aquat. Sci. 1791.

Simons, H.A. (International). 1977. Preliminary design study. Effluent outfalls and diffusers in Porpoise Harbour and Chatham Sound. Prepared for Canadian Cellulose Co. Ltd. (now Skeena Cellulose Ltd.). H.A. Simons (International) Ltd., Vancouver, B.C. (*cited in:* Hodgins and Knoll, 1990).

Stanley, R.D. 1992. Shelf rockfish. *In*: Leaman, B.M. [ed.]. Groundfish stock assessments for the west coast of Canada in 1991 and recommended yield options for 1992. Can. Tech. Rep. Fish. Aquat. Sci. 1866. pp. 201-220.

Stewart, F.L. 1975. The seasonal availability of fish species used by the Coast Tsimshians of northern British Columbia. Syesis 8:375-388.

Stokes, J.W. 1953. Pollution survey of the Watson Island area, June 1953. Fish. Mar. Serv., MS Rep., Vancouver: 4 p.

Stucchi, D.J. and U. Orr 1993. Circulation and water property study of Prince Rupert Harbour, summer 1992. Can. Tech. Rep. Hydrog. Ocean Sci. No. 154.

Tetra Tech, Inc. 1986. Development of sediment quality values for Puget Sound. Volume 1. Prepared for Resource Planning Associates. Tetra Tech, Inc., Bellevue, Washington.

Thomas, G.A. 1992. Shellfish stock assessments for the west coast of Canada in 1991 as reviewed by the Pacific Stock Assessment Review Committee (PSARC). Can. MS Rep. Fish. Aquat. Sci. 2169.

Thompson, J.M. 1981. Preliminary report on the population biology and fishery of walleye pollock Theragra chalcogramma off the Pacific coast of Canada. Can. Tech. Rep. Fish. Aquat. Sci. 1031.

Thomson, B.L., M.W. Saunders and M.S. Smith. 1991. Dogfish. *In:* Fargo, J. and B.M. Leaman. Groundfish stock assessments for the west coast of Canada in 1990 and recommended yield options for 1991. Can. Tech. Rep. Fish. Aquat. Sci. 1778. pp. 165-178.

Thomson, R.E. 1981. Oceanography of the British Columbia coast. Can. Spec. Publ. Fish. Aquat. Sci. 56.

Tunnicliffe, V. *In Press*. Biodiversity: the marine biota of British Columbia, In Our living legacy. Proceedings of a conference on biodiversity of British Columbia, Victoria, British Columbia. October 1991 (*cited in* Anon., 1993).

Tyler, A.V. and C.M. Hand. 1992. Pacific cod. *In:* Leaman, B.M. [ed.]. Groundfish stock assessments for the west coast of Canada in 1991 and recommended yield options for 1992. Can. Tech. Rep. Fish. Aquat. Sci. 1866. pp. 57-82

Walden, C.C. 1964. Disposal of effluents from existing sulfite and proposed Kraft mills at Watson Island, B.C. B.C. Research Council abridged Rep. 61-253-B-1 for Celgar Limited: 15 p.

Waldichuk, M. 1961. Observations in marine waters of the Prince Rupert area, particularly with reference to pollution from the sulphite pulp mill on Watson Island, September 1961. Fish Res. Board Can. Misc. Rep. (Biol.) 23 p.

Waldichuk, M. 1962. Observations in marine waters of the Prince Rupert area, particularly with reference to pollution from the sulphite pulp mill on Watson Island, September, 1961. Fish. Res. Bd. Can. Manuscr. Rep. 733.

Waldichuk, M. 1966. Effects of sulfite wastes in a partially enclosed marine system in British Columbia. J. Water Pollut. Contr. Fed. 38(9):1484-1505.

Waldichuk, M. and E.L. Bousfield. 1962. Amphipods in low-oxygen marine waters adjacent to a sulphite pulp mill. J. Fish. Res. Board Can. 19: 1163-1165.

Waldichuk, M., J.R. Markert and J.H. Meikle. 1968. Physical and chemical oceanographic data from the west coast of Vancouver Island and the northern British Columbia coast, 1957-1967: Volume II, Fisher Channel - Cousins Inlet, Douglas Harbour - Kitimat Arm and Prince Rupers Harbour and its contiguous waters. Fish. Res. Bd. Can. Manuscr. Rep. Ser. 990.

Water Survey of Canda (WSC). 1991. Historical streamflow summary. British Columbia. Environment Canada (Inland Waters Directorate, Water Resources Branch), Ottawa.

Werner, A.E. 1968. Gases from sediments in polluted coastal waters. Pulp Paper Mag. Can. 69:127-136.

Williams, G.L. 1991. Prince Rupert area coastal fish habitat bibliography. G.L. Williams Associates Ltd., Coquitlam B.C.

Yamanaka, K.L. and L.J. Richards. 1992. Inshore rockfish. *In:* Leaman, B.M. [ed.]. Groundfish stock assessments for the west coast of Canada in 1991 and recommended yield options for 1992. Can. Tech. Rep. Fish. Aquat. Sci. 1866. pp. 221-266.

9.0 GLOSSARY

Acute	With reference to toxicity tests with fish, usually means an effect that happens within 4 to 7 days, or an exposure of that duration. An acute effect could be mild or sub-lethal, if it were rapid.
ADI	Acceptable Daily Intake. The amount of a substance that is considered safe to take into the body, on a daily basis, for a lifetime. This is almost always calculated for humans. The value of ADI is decided by a regulatory body, after considering relevant scientific data.
Air Dry	The term "Air Dry" signifies 90% dry fibre and 10% moisture (1 ADt = 900 kg OD pulp).
ADt	Air-dried tonne.
AOX	Adsorbable Organic Halogens. The amount of AOX measured in a sample under specified conditions. Essentially, the organohalides are adsorbed onto activated carbon, then incinerated, with the release of the free halogens, which are measured by coulometric methods. Since chlorine is the only halogen used in significant quantities in kraft pulp mills, AOX is a way of determining the TOCl in a sample, but under different laboratory conditions. There is no precise mathematical relationship between AOX and TOCl values, but they are roughly proportional to each other, and AOX is normally the higher.
Benthic	Of or living on or in the bottom of a water body.
Benthos	Organisms which live on or in the bottom of a water body.
Bioaccumulation	A general term, meaning that an organism stores within its body a higher concentration of a substance than is found in the environment. This is not necessarily harmful. For example, freshwater fish must bioaccumulate common salt if they are to live. Many toxicants, such as arsenic, can be handled and excreted by aquatic organisms, so they are not included among the dangerous bioaccumulative substances.
Bioconcentration	Accumulation of a chemical directly from the water to a higher concentration in an aquatic organism. The bioconcentration results from simultaneous processes of uptake and elimination.

Bioconcentration Factor	(BCF) The concentration of a specific chemical in an aquatic organism, divided by the concentration of the chemical in the water in which the organism has been living. BCF is usually determined experimentally. Dangerous bioaccumulative toxicants usually have BCF's with values in the thousands or tens of thousands.
BCTMP	Bleached Chemi-Thermomechanical Pulp.
BK, BKM, BKME	Abbreviations for Bleached Kraft, Bleached Kraft Mill, and Bleached Kraft Mill Effluent. All referring to a pulp mill that operates by kraft or sulfate process, and bleaches some or all of the product.
Black Liquor	A liquid in the kraft process composed of spent pulping chemicals and wood residues. Weak black liquor refers to concentrations under 20% solids, strong black liquor to concentrations over 50% solids.
Bleaching	With reference to kraft pulp manufacture, a process whereby the pulp is given a white appearance instead of a light brown one. The bleaching process functions by removing lignins and other coloured substances from the pulp, rather than by changing their apparent colour.
BOD	Biochemical Oxygen Demand is a property of water or wastewater determined by measuring the quantity of oxygen consumed by a sample under controlled conditions (20°C, neutral pH) for a defined time period. The most commonly used period is 5 days, written as BOD_5. The use of the 5-day "BOD" test is common in North America and has been adopted in this report. BOD is expressed as mg/L ("parts per million"), as is dissolved oxygen, or as a weight, as in "kg of BOD per tonne of pulp".
Bone Dry (BD)	See Oven Dry.
Broke	Waste, or sub-standard pulp that used to be discarded in the past, but is now reprocessed.
Brown Stock	Kraft slush pulp prior to bleaching.
Caustic	Common name for sodium hydroxide (NaOH).
Caustic Extraction	Bleaching stage where highly coloured organics are dissolved with alkali, normally NaOH.
CDEH	Abbreviations used to denote bleach sequence; C= gaseous chlorine; D = chlorine dioxide; E = extraction; H = sodium hypochlorite.

Chlorinated Organic Substance — An organic substance that has one or more chlorine atoms attached to the molecule. The term should not be used interchangeably with "organochlorine" (q.v.). The amount of a chlorinated organic is measured as the weight of the complete molecule, and in kraft mill effluent that amount would be about 13 times higher than a measurement expressed as the amount of chlorine, which is the method of measuring organic chlorine or "organochlorine". The common measures, AOX and TOC1, express amounts in terms of halogen or chlorine, not the entire molecule. See also organochlorine.

Chronic — Long-lasting or continued. Can refer to the effect or the duration of exposure. In mammalian toxicology, it usually signifies exposures lasting at least one-tenth of a lifetime. In aquatic toxicology, it sometimes is used to mean a full life-cycle test.

COD — Chemical Oxygen Demand. A similar concept to BOD, except that the measurement of amount of oxygen consumed is based on rapid chemical oxidation of the sample. BOD and COD are generally poorly correlated. COD is used sometimes, particularly in Europe, because the test is rapid and reproducible

Concentration Units Table

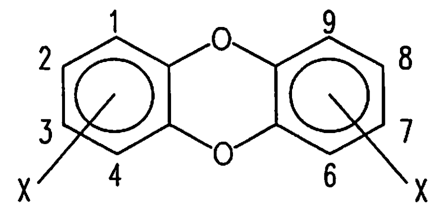
Concentration Units	Abbreviation	Units
Parts per million	ppm	mg/kg or µg/g or mg/L
Parts per billion	ppb	µg/kg or ng/g or µg/L
Parts per trillion	ppt	ng/kg or pg/g or ng/L
Parts per quadrillion	ppq	pg/kg or fg/g or pg/L

Condition Factor — A measure of the plumpness or fatness of aquatic organisms. For oysters, values are based on the ratio of the soft tissue dry weight to the volume of the shell cavity.

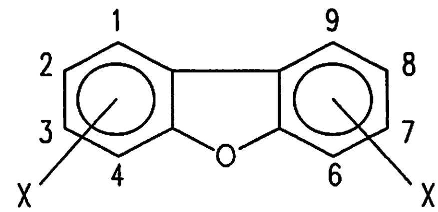
Cook — Normal term for the chemical pulping process in the digester where the fibre is separated from lignin by chemicals under pressure, at elevated temperatures as described in the pulping process section of the manual.

Daphnia — A freshwater micro-crustacean found in ponds, lakes or streams. Sometimes referred to as water fleas. Genus *Daphnia*.

Dioxins/Furans — Polychlorinated dibenzo-para-dioxins (PCDDs) and dibenzofurans (PCDFs) are often simply called dioxins, although they are two separate groups of substances with similar effects. There are 210 different compounds, of which 17 are the most toxic. The adjoining figure shows the basic structures of dioxins and furans and how the atoms are numbered.



Dibenzo-p-dioxin



Dibenzofuran

DO — Dissolved oxygen, normally measured in milligrams/litre and widely used as a criterion of receiving water quality.

EC_{50} — Median effective concentration as LC_{50}, except that it may apply to any effect, lethal or non-lethal. The effect as well as the exposure-time must be specified.

Fecundity — Ability to produce offspring rapidly and in large numbers.

Fetch — Distance travelled by wind or waves across open water.

Filtrate — The liquid that passes through a filter. In kraft pulp processing, filtrate is usually white water, black liquor or lime mud washings.

Freshet — The flood of a river from heavy rain or melted snow.

Furnish — The specific mixture of raw materials, both pulp and chemicals, from which a particular grade is manufactured, ready to be delivered to the paper machine.

Green Liquor — A liquid in the kraft process composed of the chemicals obtained from the recovery furnace, primarily sodium sulphide and sodium carbonate in aqueous solutions.

Groundwood — Pulp produced by mechanically defibering wood with revolving grindstones and refining plates.

Halocline	A vertical salinity gradient within a body of water that is greater than the gradients above and below it.
Hog Fuel	Term for wood waste fuel widely used in pulp and paper industry boilers. It includes some of the following: bark, sawdust, reject chips, sticks, branches, cutoffs and other saw mill and wood harvesting wastes. The major component usually is bark.
Homologues/Congeners	All polychlorinated dibenzo-para-dioxins are homologous with each other. Thus tetrachloro- and pentachloro-dioxins are homologues. Congeners and homologues are synonymous.
Infauna	Animals which live just below the surface of the seabed.
Isobath	A line on a map connecting places having equal incidence of depth.
Isomers	Compounds with the same number and kind of constituent atoms, but with different molecular structures are called isomers. Thus 1,2,3,4-tetrachlorodibenzo-para-dioxin is an isomer of 2,3,7,8-tetrachloro-dibenzo-para-dioxin.
Isopleth	A line on a map connecting places having equal incidence of a meteorological feature.
Kappa Number	A measure of lignin in pulp, according to a standard laboratory procedure. Widely used as a tool for control of mill operations. Bleachable grades of unbleached kraft pulp generally have a Kappa number from 5 to 35, depending on the wood species and the extent of delignification.
kg/t	Kilograms per tonne. In this report, used to describe the amount of some material (kg) that is used, or produced, per tonne of air-dried pulp manufactured. The air-dry weight of pulp includes about 10% moisture.
KM, KME	Kraft mill and kraft mill effluent. See BK.
Knotter	A type of screening equipment used to separate knots and other oversized and unwanted material from wood pulp.
Kraft	A particular process for manufacturing pulp from wood. This can be used to produce a strong brown paper. Wood is cooked at high temperature and pressure with sodium salts in an alkaline medium. To be economically feasible, the cooking chemicals must be reclaimed and recycled, and most of the waste dissolved organics from the wood must be burned for heat and power. The pulp may be

	bleached using a variety of technologies, including chlorine-free bleaching.
LC_{50}	Median lethal concentration. The concentration of a substance that is estimated to kill half of a group of organisms. The duration of exposure must be specified (e.g., 96-hour LC_{50}).
Lignin	Naturally occurring phenolic polymer found between cell walls of woody tissues. Lignin is the glue that binds cellulose fibres together in wood and must be removed during the paper making process.
Lipophilicity	The measure of a substance's relative solubility in an oil-like matrix.
LOEC	The lowest observed effect concentration. The lowest concentration that causes a significant adverse effect in a sublethal test.
Macroinvertebrates	Invertebrate (without backbone) animals that are visible to the eye.
Market Pulp	Pulp products such as kraft bleached softwood pulp sold to customers outside the producing company for machine furnish.
mg/L	Milligrams per litre of solution. Roughly speaking, parts per million. This is the common unit for measuring concentrations of substances in water quality monitoring.
Microtox	An automated (Beckman Instruments Inc.) rapid screening assay which determines the EC_{50} concentration of a chemical or effluent which reduces the amount of incident light emitted by a culture of fluorescent bacteria (*Photobacterium phosphoreum*).
NCG	Non-condensable gases. Emitted from several parts of the kraft pulping process which do not condense in the commonly installed condensing equipment. TRS and/or methanol are the predominant components.
ng	Nanogram (10^{-9} gram or one billionth of a gram).
NOEC	The no observed effect concentration. The highest concentration in a sub-lethal toxicity test that does not cause a significant adverse effect, in comparison to the controls.
NSSC	Neutral sulphite semi-chemical pulping.

Organochlorine	Chlorine that is attached to an organic molecule. The amount present is expressed as the weight of the chlorine. There are thousands of such substances, including some that are manufactured specifically as pesticides because of their toxicity.
Oven Dry (OD)	Pulp or paper dried in an oven by a standard laboratory procedure to the point where it contains no moisture. The term Bone Dry (BD) is commonly used synonymously. Oven dry weight divided by 0.9 equals the air dry weight, in standard practice.
Partition Coefficient	The ratio of the equilibrium concentration of a chemical in equal volumes of two mutually immiscible liquids, in contact with one another.
Pelagic	Refers to organisms which swim or drift in the water column.
Periphyton	Attached freshwater or marine algae; mainly filamentous.
pg	Picogram (10^{-12} gram or one trillionth of a gram).
pH	A measure of the acid or alkaline nature of water or some other medium. Specifically, pH is the negative logarithm of the hydronium ion concentration (H_3O^+). Practically, pH 7 represents a neutral condition in which the acid hydrogen ions balance the alkaline hydroxide ions. Values of pH below 7 represent acid conditions and values above 7 are alkaline. A change of one unit, for example from 7 to 6, represents a ten-fold increase in hydrogen ion activity, and thus a ten-fold increase in the "acidic" nature of a water. Soft northern waters typically range from pH 6 to 7.5; hard waters of southern Ontario are close to pH 8. The pH of the water can have an important influence on the toxicity of chemicals in kraft pulp mill effluents.
Phytoplankton	Plant life, mostly microscopic, found floating or drifting in the oceans or large bodies of freshwater; forms the basis of most aquatic food chains as the main primary producer.
Planktonic	Refers to organisms inhabiting the water column and subject to the currents therein, not free swimming.
Plume	The main pathway for dispersal of effluent within the receiving waters, prior to its complete mixing.

Pre-treatment	Describes initial treatment processes before an effluent reaches primary treatment. The processes are designed to remove grit, coarse material and debris; to neutralize acid or alkaline wastes; to equalize the effluent characteristics and flows by mixing the collected effluent streams; and directing occasional large flows or concentrated streams which are a normal part of pulp mill operations to spill tanks or basins.
Primary Treatment	Intended to remove suspended solids from the effluent, normally includes dewatering the recovered settled solids or sludge to facilitate disposal to landfill or combustion process. Primary treatment is a pre-requisite for most secondary treatment processes.
Pycnocline	A zone in a water column where density changes rapidly.
Rapid Infiltration	A system for tertiary treatment of effluent, involving passage of effluent through a naturally occurring, porous soil bed, into receiving waters. Normally a number of soil beds are available and are alternated periodically. The principal function of this type of treatment is to remove effluent colour.
Recovery Furnace	A unit used to burn recovered cooking liquor to produce steam and to reprocess cooking chemicals. Frequently known as the recovery boiler.
Salinity	A measure of the quantity of dissolved salts in seawater. Formally defined as the total amount of dissolved solids in seawater - in parts per thousand (o/oo) by weight when all the carbonate has been converted to oxide, the bromide and iodide replaced by chloride, and all organic matter completely oxidized.
Secondary Treatment	A stage of purification of a liquid waste in which micro-organisms decompose organic substances in the waste. In the process, the micro-organisms may use oxygen (aerobic treatment) or may reduce wastes in an oxygen free (anaerobic) environment. The UNOX treatment system at Crofton Pulp and Paper is aerobic.. Oxygen usually is supplied by mechanical aeration and/or large surface area of treatment ponds (lagoons). Most secondary treatment also greatly reduces toxicity.
Sentinel Species	A monitoring species selected to be representative of the local receiving environment.
Shive	Small bundle of fibres that has not been separated completely in the pulping operation.

Shrinkage	Term normally applied to the pulp loss in bleaching due to removal of lignin. Usually expressed as percent. Pulp typically shrinks about 7% on bleaching.
Sludge Filter	Equipment used to concentrate suspended solids recovered from an effluent by a clarifier.
Sublethal	A concentration or level that would not cause death. An effect that is not directly lethal.
Suspended Solids	Particles of matter suspended in the water. Measured as the oven dry weight of the solids, in mg/L, after filtration through a standard filter paper. Suspended solids usually are considered particles that will not pass through a filter with pore size of 0.45 micrometres. Less than 25 mg/L is considered clean water, whereas an extremely muddy river may have about 200 mg/L of suspended solids.
t/d	Tonnes (metric) per day.
Tainting Propensity	Inclination or tendency to cause an off-flavour in food.
2,3,7,8-TCDD	2,3,7,8-tetrachlorodibenzo-para-dioxin, the most toxic dioxin.
2,3,7,8-TCDF	2,3,7,8-tetrachlorodibenzofuran.
TEQ	Toxic Equivalents.
Thermocline	Zone in a water column where water temperature changes rapidly.
Total-TEQs	TEQs are calculated by multiplying the concentration of each congener with its respective International Toxicity Equivalency Factor (ITEF), to normalize concentrations to the level that would be produced by an equivalent amount of 2,3,7,8-TCDD, then summing all the concentrations.
TMP	Thermomechanical pulp.
TOCl	Total organically bound chlorine. Quantity of organically bound chlorine in a sample, determined according to a standard method. This is similar to AOX, except that TOCl is absorbed onto an ion-exchange resin, instead of activated carbon. This is a measure of the total chlorine in organic compounds, many of which may be unidentified.
Total Suspended Solids	See Suspended Solids.

Toxic Unit (TU)	Measure of the toxic strength of an effluent. It estimates the amount of toxicity released, not the concentration of toxic material in that effluent. Toxic units are the reciprocal of the LC_{50} (expressed as a percentage), multiplied by 100%, so the value is dimensionless in terms of chemical units. It can be thought of as a "fish unit", with a species designated (usually rainbow trout). A value of 1.0 TU means that the effluent is lethal; less than 1.0 TU represents a non-lethal effluent; and 2.0 TU means that the concentration of toxicants is at twice the lethal level. $\text{Toxic Units (TU)} = \dfrac{100\%}{LC_{50} \text{ in } \%}$
Toxicity Emission Factor (TEF)	Represents the daily discharge of toxicity (based on an effluent's LC_{50} value) per unit of production. For pulp mills, this factor is determined by multiplying the toxicity unit by volume effluent discharged per tonne of pulp produced. Toxicity Emission Factor (TEF) = TU x (volume of flow in m^3/tonne of pulp).
Toxicity Emission Rate (TER)	Represents the amount of toxicity (based on an effluent's LC_{50} value) discharged daily in an effluent. This value is the product of the effluent's toxic units and the daily volume of the effluent released. Mills can be compared by expressing the amount of toxicity in terms of production, i.e., per air-dried tonne of pulp (or other product), thus evaluating the toxicological desirability of the processes being used. Toxicity Emission Rate (TER) = TU x (volume of flow in m^3/day).
TRS	Total Reduced Sulphur. A general term for sulphur gases emitted from the kraft process, excluding sulphur dioxide and trioxide. Generally considered to include hydrogen sulphide, dimethyl sulphide, dimethyl disulphide and methyl mercaptan. These gases cause the classic kraft mill odour. They are generated by the reaction of sodium sulphide with some of the wood components. TRS is normally expressed as elemental sulphur.
TSS	See Suspended Solids.
TU	See Toxic Unit.
White Water System	The water recovered from formation of paper on the Foerdrinier machine; usually with a high degree of internal recycling within the paper mill.

White Liquor	A liquid in the kraft process composed of the chemicals used in the digester to cook the wood chips. Primarily sodium sulphide and sodium hydroxide in aqueous solution.
µg	Microgram (10^{-6} gram or one millionth of a gram).
µg/L	Micrograms per litre. Roughly speaking, a part per billion, or one-thousandth of the strength of a mg/L.
°/oo	Parts per thousand.
v/v	volume/volume - used to define dilution ratios for two liquids.

LIST OF TABLES

Table 4.1 Trawl-caught finfish resources of British Columbia coastal waters.

Family and Common Name	Scientific Name
Acipenseridae	
Green sturgeon	*Acipenser medirostris*
Anarhichadidae	
Wolf-eel	*Anarrhichthys ocellatus*
Anoplopomatidae	
Sablefish	*Anoplopoma fimbria*
Embiotocidae	
Pile perch	*Rhacochilus vacca*
Gadidae	
Pacific, true, or gray cod	*Gadus macrocephalus*
Pacific hake	*Merluccius productus*
Walleye pollock	*Theragra chalcogramma*
Salmonidae	
Pink salmon	*Oncorhynchus gorbuscha*
Sockeye salmon	*Oncorhynchus nerka*
Chum salmon	*Oncorhynchus keta*
Chinook salmon	*Oncorhynchus tshawytscha*
Coho salmon	*Oncorhynchus kisutch*
Steelhead trout	*Oncorhynchus mykiss*
Hexagrammidae	
Lingcod	*Ophiodon elongatus*
Hexanchidae	
Sixgill shark	*Hexanchus griseus*
Pleuronectidae	
Arrowtooth flounder or turbot	*Atheresthes stomias*
Petrale sole	*Eopsetta jordani*
Rex sole	*Glyptocephalus zachirus*
Flathead sole	*Hippoglossoides elassodon*
Butter sole	*Isopsetta isolepis*
Rock sole	*Lepidopsetta bilineata*
Yellowfin sole	*Limanda aspera*
Dover sole	*Microstomus pacificus*
English sole	*Parophrys vetulus*
Starry Flounder	*Platichthys stellatus*
Sand sole	*Psettichthys melanostictus*

Source: Rutherford, 1992.

Table 4.1 (cont'd)

Family and Common Name	Scientific Name
Rajidae	
Big skate	*Raja binoculata*
Longnose skate	*Raja rhina*
Scorpaenidae	
Rougheye rockfish	*Sebastes aleutianus*
Pacific ocean perch	*Sebastes alutus*
Aurora rockfish	*Sebastes aurora*
Redbanded rockfish	*Sebastes babcocki*
Shortraker rockfish	*Sebastes borealis*
Silvergray rockfish	*Sebastes brevispinis*
Copper rockfish	*Sebastes caurinus*
Darkblotched rockfish	*Sebastes crameri*
Splitnose rockfish	*Sebastes diploproa*
Greenstriped rockfish	*Sebastes elongatus*
Widow rockfish	*Sebastes entomelas*
Yellowtail rockfish	*Sebastes flavidus*
Rosethorn rockfish	*Sebastes helvomaculatus*
Quillback rockfish	*Sebastes maliger*
Black rockfish	*Sebastes melanops*
China rockfish	*Sebastes nebulosus*
Tiger rockfish	*Sebastes nigrocinctus*
Bocaccio	*Sebastes paucispinis*
Canary rockfish	*Sebastes pinniger*
Redstripe rockfish	*Sebastes proriger*
Yellowmouth rockfish	*Sebastes reedi*
Yelloweye rockfish	*Sebastes ruberrimus*
Harlequin rockfish	*Sebastes variegatus*
Sharpchin rockfish	*Sebastes zacentrus*
Shortspine thornyhead	*Sebastolobus alascanus*
Squalidae	
Spiny dogfish	*Squalus acanthias*

Source: Rutherford, 1992.

Table 4.2 The commercially important invertebrates of British Columbia.

Classification - Common Name[1]	Scientific Name
PHYLUM MOLLUSCA	
CLASS GASTROPODA	
abalone (northern, pinto)	*Haliotis kamschatkana*
CLASS BIVALVA	
geoduck (king clam)	*Panope abrupta (=P. generosa)*
horse clam (gaper clam)	*Tresus capax & Tresus nuttalli*
manila clam	*Tapes philippinarum*
littleneck (native) clam	*Protothaca staminea*
butter clam	*Saxidomus giganteus*
razor clam	*Siliqua patula*
blue (bay) mussel	*Mytilus edulis*
California (sea) mussel	*Mytilus californianus*
pink (smooth, swimming) scallop	*Chlamys rubida*
spiny (pink, swimming) scallop	*Chlamys hastata*
PHYLUM CRUSTACEA	
CLASS MALACOSTRACEA	
euphausiids (krill)	*Euphausia pacifica*
prawn (spot shrimp)	*Pandalus platyceros*
smooth pink shrimp	*Pandalus jordani*
northern (spiny) pink shrimp	*Pandalus borealis*
sidestripe shrimp	*Pandalopsis dispar*
coonstripe shrimp	*Pandalus danae*
humpback shrimp	*Pandalus hypsinotus*
Dungeness crab	*Cancer magister*
red rock crab	*Cancer productus*
red (Alaska) king crab	*Paralithodes camtschatica*
golden (brown) king crab	*Lithodes aequispina*
tanner crab	*Chionoecetes bairdi*
CLASS CIRRIPEDIA	
gooseneck barnacles	*Policipes polymerus*
PHYLUM ECHINODERMATA	
CLASS ECHINOIDEA	
red sea urchin	*Strongylocentrotus franciscanus*
green sea urchin	*Strongylocentrotus droebrachiensis*
CLASS HOLOTHUROIDEA	
California sea cucumber	*Parastichopus californicus*

Source: Thomas, 1992.

[1] Phyla and class names according to George, J.D. and J.J. George, 1979. Marine Life. An illustrated encyclopedia of invertebrates in the sea. Douglas & McIntyre Ltd., Vancouver, B.C.

Table 4.3 Landings of marine invertebrates (tonnes) in British Columbia, 1981 to 1990.

Invertebrate	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Intertidal Clams										
Razor	30	68	31	101	90	142	142	155	117	114
Butter	120	103	77	131	252	159	69	83	42	93
Manila	317	597	1049	1677	1914	1894	3608	3833	2728	1452
Native Littleneck	179	241	325	295	192	285	373	288	428	462
Mixed	161	155	280	409	478	369	87	27	159	148
Total Intertidal Clams	807	1164	1762	2613	2926	2849	4279	4386	3474	2269
Geoduck	2704	3135	2636	3483	5370	5006	5734	4553	4087	3980
Horse Clam	57	321	21	7	6	96	355	328	115	125
Shrimp	581	415	411	408	678	768	2644	2211	2211	1816
Prawn	358	274	331	381	514	550	620	708	894	688
Crab	1317	1002	960	1155	1165	1321	1631	1406	1406	2166
Abalone	85	54	56	58	42	52	49	48	49	50
Octopus			37	25	34	53	130	205	205	185
Sea Urchin										
Red			982	1764	1815	2067	2223	1951	2645	3084
Green								434	570	452
Sea Cucumber				95	346	786	1722	1930	1101	621
Scallop		8	11	18	53	68	66	66	77	69
Plankton	19	0	47	103	131	166	130	249	380	360
Squid			71	14	111	79	86	8	70	47
Mussels			tr	1	tr	2	2	3	4	1
Gooseneck Barnacles						2	32	18	34	37
Total Tonnes	5928	6373	7325	10125	13191	13865	19703	18504	17322	15950

Source: Thomas, 1992.

Table 4.4 Landed value ($000) of marine invertebrates in British Columbia, 1981 to 1990.

Invertebrate	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Intertidal Clams										
Razor	24	55	24	123	95	127	126	137	124	130
Butter	42	36	33	55	138	75	40	40	44	46
Manila	323	611	1043	1813	2278	2762	6003	7023	5919	3748
Native Littleneck	195	263	329	311	202	327	474	357	580	703
Mixed	175	169	293	455	575	510	132	36	196	217
Total Intertidal Clams	759	1134	1722	2757	3288	3801	6775	7593	6863	4844
Geoduck	2434	2814	1818	2937	4777	4294	6184	9762	12967	10336
Horse Clam	42	235	12	5	6	63	309	300	144	138
Shrimp	912	652	1095	1022	1180	1240	4609	2802	2985	2453
Prawn	2019	1545	2154	2464	3379	3734	4326	5724	7694	6320
Crab	3556	2703	3320	4558	4719	5661	6452	5555	5012	9545
Abalone	721	457	464	530	442	734	973	1076	1170	1347
Octopus			80	56	82	136	381	629	655	612
Sea Urchin										
Red			358	712	763	1011	1276	1108	1627	1907
Green								569	953	895
Sea Cucumber				22	94	236	768	961	998	775
Scallop		17	45	56	139	212	244	285	321	317
Plankton	6	0	19	42	89	113	102	192	223	300
Squid			95	17	184	127	123	113	94	52
Mussels		tr	tr	tr	0	tr	tr	tr	tr	1
Gooseneck Barnacles							5	478	478	407
Total Tonnes	10449	9557	11182	15178	19142	21362	32527	37147	42184	40249

Source: Thomas, 1992.

Table 4.5 **Inventory of aquatic habitats in the vicinity of Prince Rupert - Skeena Cellulose Inc.**

Habitat Location	Principal Fisheries Resources	
	Marine	Freshwater
Chatham Sound	• salmonids (adult/juvenile) • herring spawning • Dungeness crab • sea urchins, sea cucumber • intertidal clams • shrimp	• pink salmon (La Hou Creek)
Digby Island	• herring spawning • intertidal clam • Dungeness crab	
Prince Rupert Harbour	• pink salmon (migrating adults/juveniles) • Dungeness crab • shrimp and prawn	• pink and coho salmon (all significant creeks)
Morse Basin/Watson Island	• salmon (adult/juvenile) • herring rearing • Dungeness crab • shrimp and prawn	• sockeye, pink, chum, coho, and chinook salmon, Dolly Varden char, cutthroat trout
Flora Bank	• salmon rearing • Dungeness crab (Kitson Island)	
Porcher Island	• salmon (adult/juvenile) • herring spawning • intertidal clams	• pink salmon and some coho salmon
Skeena River and estuary	• all salmon (adult/juvenile) • smelt species • herring • some groundfish • Dungeness crab	• dominant sockeye and pink salmon runs and all other major species are present • largest steelhead producer in B.C.

Table 4.6 **Inventory of the fish and invertebrate resources in the vicinity of Prince Rupert - Skeena Cellulose Inc.**

Species/Group	Important Locations/Areas
Juvenile salmonids	marine nearshore habitats throughout area; Skeena River estuary and nearby passages and shoals
Chinook salmon	Skeena River and Ecstall River
Pink salmon	all significant streams
Chum salmon	Ecstall River and Skeena River
Coho salmon	Skeena River and Ecstall River Kloiya River Oona Creek Shawatlan River Hays Creek
Sockeye salmon	Skeena River and Ecstall River Shawatlan River Kloiya River
Groundfish	Chatham Sound Porcher Island/Hecate Strait
Shrimp and prawn	Chatham Sound (northeast and south) Prince Rupert Harbour Morse Basin, Wainwright Basin, Porpoise Harbour
Dungess crab	throughout marine waters
Intertidal clams	Dundas Island Digby Island Porcher Island
Sea urchins and sea cucumber	Chatham Sound

Table 4.7 Fish species of the Skeena River and estuary.

SCIENTIFIC NAME	COMMON NAME
Acipenser medirostris	green sturgeon
A. transmontanous	white sturgeon
Agonus acipenserinus	sturgeon poacher
Alosa sapidissima	American shad
Ammodytes hexapterus	needlefish or Pacific sandlance
Anarrhichthys ocellatus	wolf-eel
Anoplopoma fimbria	sablefish
Apristurus brunneus	brown cat shark
Artedius fenestralis	padded sculpin
Atheresthes stomias	turbot or arrowtooth flounder
Aulorhychus flavidus	tube-snout
Blepsias cirrhosus	silverspotted sculpin
Bothragomus swanii	deep-pitted poacher
Brosmophycis marginata	red brotula
Careproctus melanurus	blacktail snailfish
Catostomus catostomus	longnose sucker
C. commersoni	white sucker
C. macrocheilus	largescale sucker
Chrosomus eos	redbelly dace
Citharichthys sordidus	mottled sanddab
Clinocottus acuticeps	sharpnose sculpin
C. embryum	calico sculpin
Clupea harengus pallasi	Pacific herring
Coregonus clupeaformis	lake whitefish
Cottus aleuticus	coastrange sculpin
C. asper	prickly sculpin
Couesius plumbeus	lake chub
Cymatogaster aggregata	shiner perch
Damalichthys vacca	pile perch
Delolepis gigantea	giant wrymouth
Engraulis mordax	anchovy
Enophrys bison	buffalo sculpin
Entosphenous tridentatus	Pacific lamprey
Eopsetta jordani	petrale sole or brill
Eumicrotremus orbis	spiny lumpsucker
Gadus macrocephalus	Pacific cod
Galeorhinus galeus	soupfin shark
Gasterosteus aculeatus	threespine stickleback
Glyptocephalus zachirus	rex sole
Gobiesox masandricus	flathead clingfish
Hexagrammos decagrammus	kelp greenling
H. stelleri	white-spotted greenling
Hippoglossoides elassodon	flathead sole
Hippoglossus stenolepis	Pacific halibut
Hydrolagus colliei	ratfish
Hypomesus pretiosus	surf smelt
Inopsetta ischrya	hydrid sole

Source: Hoos, 1975.

Table 4.7 (cont'd)

SCIENTIFIC NAME	COMMON NAME
Isopsetta isolepis	butter sole
Lampetra richardsoni	western brook lamprey
Lepidopsetta bilineata	rock sole
Leptocottus armatus	staghorn sculpin
Limanda aspera	yellowfin sole
Liparis fucensis	slipskin snailfish
Lota lota	burbot
Lycodopsis pacifica	blackbelly eelpout
Lyopsetta exilis	slender sole
Mallotus villosus	capelin
Merluccius productus	Pacific hake
Microgadus proximus	Pacific tomcod
Microstomus pacificus	Dover sole
Mylocheilus caurinus	peamouth chub
Myoxocephalus polyacanthocephalus	great sculpin
Nectoliparis pelagicus	tadpole snailfish
Oncorhynchus gorbuscha	pink salmon
Oncorhynchus keta	chum salmon
O. kisutch	coho salmon
O. nerka	sockeye salmon
O. n. kennerlyi	kokanee
O. tschawytscha	chinook salmon
Ophiodon elongatus	lingcod
Osmerus mordax	rainbow smelt
Parophrys vetulus	lemon sole
Platichthys stellatus	starry flounder
Pleuronichthys coenosus	C-O sole
P. decurrens	curlfin sole
Porichthys notatus	midshipman
Poroclinus rothrocki	whitebarred prickleback
Prosopium coulteri	pygmy whitefish
P. williamsoni	mountain whitefish
Psettichthys melanostictus	sand sole
Ptychocheilus oregonensis	northern squawfish
Radulinus taylori	spinynose sculpin
Raja binoculata	big skate
R. rhina	longnose skate
R. stellulata	starry skate
Rhamphocottus richardsoni	grunt sculpin
Rhinichthys cataractae	longnose dace
Richardsonius balteatus	redside shiner
Salmo clarki clarki	coastal cutthroat trout
S. gairdneri	rainbow trout
S. gairdneri	steelhead trout
Salvelinus malma	dolly varden
S. namaychush	lake trout
Scorpaenichthys marmoratus	cabezon
Sebastes aleutianus	blackthroat rockfish
S. alutus	Pacific ocean perch

Source: Hoos, 1975.

Table 4.7 (cont'd)

SCIENTIFIC NAME	COMMON NAME
S. brevispinis	silvergray rockfish
S. caenaematicus	shortraker rockfish
Sebastes caurinus	copper rockfish
S. crameri	blackmouth rockfish
S. diploproa	splitnose rockfish
S. elongatus	greenstripe rockfish
S. entomelas	widow rockfish
S. flavidus	yellowtail rockfish
S. helvomaculatus	rosethorn rockfish
S. maliger	quillback rockfish
S. melanops	black rockfish
S. paucispinis	bocaccio
S. piniger	orange rockfish
S. proriger	redstripe rockfish
S. reedi	yellowmouth rockfish
S. ruberrimus	red snapper
S. rubrivinctus	flag rockfish
S. zacentrus	sharpfin rockfish
Sebastolobus alascanus	spinycheek rockfish
Spirinchus thaleichthys	longfin smelt
Squalus suckleyi	Pacific dogfish
Thaleicthys pacificus	eulachon
Theragra chalcogramma	whiting, bigeye, or walleye pollock
Torpedo californica	Pacific electric ray
Trichodon trichodon	sandfish
Zaprora silensus	prowfish

Source: Hoos, 1975.

Table 4.8 Fish community assessments performed relevant to the vicinity of Skeena Cellulose Inc.

Source[1]	Significant Findings or Conclusions
Manzer 1956	• investigation of the distribution of young salmonids in the vicinity of the Skeena River estuary • estuary identified as important for rearing
Higgins and Schouwenburg 1973	• identified the importance of the Skeena River estuary for various salmon species • sockeye yearlings spend several months in the estuary • pink underyearlings remain in estuary (DeHorsey Banks & Flora Bank) about one month • estuary is important for coho yearlings and chinook yearlings and underyearlings
Hoos 1975	• comprehensive review of the Skeena River fisheries resources, habitat, pollution, geology, land use • reviewed the fisheries resources of Chatham Sound • over 100 fish species were identified to be found within the vicinity of the Skeena River and estuary • approximate distributions of important fisheries resources were identified • potential impact of human activity oin area resources discussed
Knapp and Cairns 1978	• comprehensive review of the finfish and invertebrate resources of Management Area 4 • special attention paid to resources in the vicinity of the Skeena Cellulose pulpmill • both freshwater and marine resources described
Unpublished (DFO Prince Rupert) 1984 to 1986	• beach seining in the Skeena River estuary, Inverness Passage, Lelu Island, Flora Bank areas
Dwernychuk 1988	• beach seining in Morse Basin, Wainwright Basin, Porpoise Harbour, and Inverness Passage • yearling and underyearling salmonids, herring, and smelt obtained in catches • distribution of above species throughout study area; herring most common in catches from Porpoise Harbour
FHIIP 1991	• descriptions of the annual escapements of spawning adult salmon to principal streams of Management Area 4 • provided descriptions of enhancement activities, disturbances, and extent of spawning areas for salmon and some trout and char populations

[1] Full citation listed in the References.

Table 4.9 **Evaluation of species against EEM Adult Fish Survey criteria for sentinel species.**

Species	Score[1]	Exposed	Benthivore	Spawning	Abundance	Longevity	Fecundity	Age To Maturity	Sample Size	Comments
FINFISH										
English sole	8	Yes	Yes	Yes	20 - Female more common?		Relatively high	3 years	20 Poss.	Deep
Stickleback	7	Yes	Pelagic benthic	Yes, but prolonged	High	1 to 2 years	Low		20 Poss.	Shallow
Starry flounder	6	Yes	Yes	Yes	High	5 to 7 years	Moderate		20 Poss.	Shallow
Staghorn sculpin	5	Yes	Yes	?	High	3 to 5 years	Moderate			Shallow
Surf perch	5	Yes	No	Yes	High - site specific	?	Low	?		Long shot
Gunnels and eelpout	4	Yes	Yes	?	High	5 to 7 years	Moderate to Low			Liver and gonad WTS difficult
Cabezon	2 - 3	Yes	Yes		Low	Older than flounder	Moderate to high	2 to 3 years	20 - Diff.	
Herring	1	Yes	No	Yes	High	6 to 7 years	High	3 years		Migratory
Rockfish	1	Yes	Yes		Localized	60+ years	High	Teenagers		Too old
Tubesnout	1	Yes	No	Yes		5 years	Low	Low		
Ratfish	0	Yes	Yes	?			Low			No true liver or skeleton

Source: Forsyth, 1993.

[1] Score is a collective rating by group based on matches to EEM sentinel species criteria with 10 high, 0 low.

Table 4.9 (cont'd)

Species	Score[1]	Exposed	Benthivore	Spawning	Abundance	Longevity	Fecundity	Age To Maturity	Sample Size	Comments
NON-FINFISH										
Oysters	8	Yes		Yes -alternative triploid	High	High	Med.	Alternatives	20 Poss.	Use triploids
Bivalves: • geoduck • horseclam • mussels	 6 6 7	Yes		Triggered environmentally	High	Short to very long geoducks (over 100)		Variable	More than 20 needed	
Crabs	6	Yes			High	5 to 6			More than 20	
Amphipods	2	Yes	0mnivorous		High	Less than 1 year				Dissections time consuming
Shrimp	1	Yes			High				1,000 needed	Alt. - disease susceptibility

Source: Forsyth, 1993.
[1] Score is a collective rating by group based on matches to EEM sentinel species criteria with 10 high, 0 low.

Table 5.1 **Receiving environment studies conducted near Skeena Cellulose Inc., Prince Rupert area, B.C.**

Date	Source	Water Quality	Sediment	Intertidal/ Benthic	Biota Tissues
1953	Stokes, 1953	X		X	
1961	Waldichuk, 1961	X			
1961	Waldichuk and Bousfield, 1962	X		X	
1961-1962	Waldichuk, 1966	X			
1964	Walden, 1964	X			
1968	Werner, 1968		X		
1968	Kussat, 1968	X			X
1969	Brothers, 1970	X			
1970	Ker, Priestman, Keenan and Associates Limited, 1970	X			
1961-1970	Goyette *et al.*, 1976	X		X	
1974	Drinnan and Webster, 1974	X			
1974	Drinnan, 1974			X	
1974	Holman, 1974				X
1974	Packman, 1977	X	X	X	
1974-1975	Drinnan, 1977			X	
1974-1975	Rowse, 1975	X			
1974-1975	B.C. Water Invest. Branch, 1977			X	
To 1975	Hoos, 1975	X	X	X	X
1977	Beak Consultants Ltd., 1977	X		X	
1977	Simons, 1977	X			
1977-1978	Packman, 1979	X			
1977-1982	Garrett, 1983		X	X	X
1978	Ho, 1978	X			
1978-1979	Beak Consultants Ltd., 1980	X		X	
1980	Beak Consultants Ltd., 1981	X		X	
1981	Beak Consultants Ltd., 1982	X		X	
1982	IEC Beak Consultants Ltd., 1983	X		X	
1979-1982	Pomeroy, 1983a	X	X	X	
1983	IEC Beak Consultants Ltd., 1984	X		X	
To 1984	Birch *et al.*, 1985	X			
1984	Maclean, 1986				X
1984	Dwernychuk, 1985	X		X	
1985	Dwernychuk, 1986	X		X	
1986	Dwernychuk, 1987	X		X	
1987	Dwernychuk, 1988	X	X	X	
1988	Dwernychuk, 1989a	X		X	
1989	Dwernychuk, 1989b		X		X
1990-1991	Dwernychuk *et al.*, 1992a	X	X	X	X
1991	Dwernychuk *et al.*, 1992b		X		X
1992	Dwernychuk, 1992			X	
1992	Dwernychuk *et al.*, 1993a		X		X
1992	Dwernychuk and Boivin, 1993		X		X
1993	Dwernychuk *et al.*, 1993b		X		X

Table 5.2 **Summary of trace metal content in sediments near Skeena Cellulose Inc., Prince Rupert, B.C., 1979 to 1981[1] and 1987[2].**

Station[3]	Cd[4]	Cu	Mn	Ni	Pb	Zn	Cr	Hg
B2, B4 T1	<1.18-1.90 0.58-0.87	41.5-50.0 52.8-56.0	441-512 442-531	25.5-34.0 25 - 28	9.4 20-24	91.5-110 123-127	37.2 38.2-56.0	0.27-0.366 0.070-0.282
B5, B6, B7 T2	<1.16-2.20 0.53-1.8	39.0-69.0 43.3-56.3	460.5-529 467-530	22.2-37.2 24-30	8.7-12.5 11-20	94.9-193 106-124	38.3-39.7 37.2-39	0.21-1.46 0.072-0.083
O2 T3	1.2 0.38-0.74	54.4 39.1-42.5	520.0 453-478	26.3 24-25	9.7 15-21	92.9 107-114	- 32.1-40.4	0.25 0.063-0.075
B8, B9 T4	1.1-1.62 0.29-0.51	37.0-51.5 39.3-45.7	461-499 484-517	19.9-32.8 25-27	<9.3-9.6 16-21	91.0-114 105-113	34.7-38.3 33.2-40.2	0.21-0.459 0.060-0.074
B10 T5	<1.15-1.3 0.27-0.32	35.0-43.6 31.9-39.9	465-500 436-515	22.3-30.6 22-28	8.7 14-16	89.8-104 92.4-108	35.7 32.1-33.6	0.22-0.287 0.057-0.063
B10, B11 T6	1.18 0.23	37.3-47.6 39.5-39.9	480-498 527-555	27.8-32.6 23-26	<9.4 5-16	93.0-105 107-108	36.7 33.9-34.6	0.813 0.066-0.074
B12 T7	<1.2 0.22-0.32	41.0 41.7-45.1	525 500-582	31.8 25-26	- 19-24	96.5 109-120	- 34.2-34.5	- 0.065-0.073
Lagoon 2 Wainwright Basin[2]	-	22.3	276	15	4	53.4	34.7	0.170
Chatham Sound[1]	<0.3-0.5	32.8-34.8	645-746	25-26	9.0-12.0	104-108	-	0.28-0.29

All units in µg/g dry weight.

1 Source: Pomeroy, 1983a. Stations "B#" - 1979 to 1981, "O#" - 1981.

2 Source: Dwernychuk, 1988. Stations "T#" - range of values for sites along transect. T7 used as reference.

3 See Figure 5.5.

4 Cadmium analyses by graphite furnace.

Table 5.3 **Sediment organochlorine studies near Skeena Cellulose Inc., Prince Rupert, B.C., 1987 to 1993.**

Date	Source	Significant Findings
1987	Dwernychuk, 1988	• Environment Canada study: PCB/Aroclor 1260 only chlorinated organic detected: Wainwright Basin 0.26 µg/g; Porpoise Harbour north basin 0.03 µg/g; Porpoise Channel 0.01 µg/g.
1989	Dwernychuk, 1989	• Monitored chlorinated catechols and guaiacols. Highest concentrations at SS3 (diffuser): TCG 10 to 14 ng/g, TeCG 18-47 ng/g, TCC 12 to 23 ng/g, TeCC 18 to 41 ng/g. • SS4 next highest (range 9 to 15 ng/g). • SS1 (Morse Basin) range <5 to 7 ng/g. SS5 ND. • Dioxin and furan - see Figure 5.6.
1990	Dwernychuk *et al.*, 1992a	• Chlorinated catechols and guaiacols highest at Station 2 (Wainwright Basin): 25 to 30 ng/g. • Porpoise Harbour stations moderate (Stations 6 and SS3): 2.4 to 25 ng/g. • Morse Basin (SS3): <1.0 to 4.9 ng/g. • Dioxins and furans ND or very low.
1991	Dwernychuk *et al.*, 1992b	• Highest guaiacols at Station SS1 6.9 ng/g TCG, 6.8 ng/g TeCG. Station SS3 3.8 ng/g TCG, 4.5 ng/g TeCG. • Catechols were not detected. • Dioxins and furans similar to 1989 levels (Figure 5.6).
1992	Dwernychuk *et al.*, 1993a	• Guaiacols are considerably higher this year at SS3: mean TCG 30.8 ng/g, TeCG 19.5. SS1 mean TCG 10.0 ng/g, TeCG 4.5 ng/g. • Catechols were not detected. • Dioxins and furans decrease from 1989 and 1991.
1992	Dwernychuk and Boivin, 1993	• Two stations sampled in Prince Rupert Harbour (SS13, SS14). • Dioxins (<0.4 pg/g) and furans (1.8 pg/g SS13, 5.8 pg/g SS14) low.
1993	Dwernychuk *et al.*, 1993b	• Guaiacols slightly increasing since 1989. Mean 1993 levels at SS1: 11.0 ng/g TCG, 5.6 ng/g TeCG. SS3 levels: 17.4 ng/g TCG, 5.9 ng/g TeCG. • New catechol methods - no comparable data. • Dioxins and furans continue to decrease (Figure 5.7).

ND = non-detected
TCG = trichloroguaiacol
TeCG = tetrachloroguaiacol
TCC = trichlorocatechol
TeCC = tetrachlorocatechol

Table 5.4 **Summary of select subtidal macroinvertebrate parameters near Skeena Cellulose Inc., Prince Rupert, B.C., June/July, 1979 to 1990.**

Station	Parameter	1979	1980	1981	1982	1983	1986	1987	1990
1	No. M^{-2}	5,329	5,313	68,379	18,581	362	24,376	68,732	10,583
	No. Taxa	33	27	24	21	7	22	13	30
	(%N/%C)		(9/20)	(68/3)	(86/2)	(76/2)	(80/6)	(98/<1)	(<1/0)
	TU	0.8036	0.8742	0.4883	0.2486	0.4040	0.3454	0.0355	0.1178
2	No. M^{-2}	1,430	7,520	3,021	4,506	5,912	19,960	1,885	6,215
	No. Taxa	5	14	15	26	33	39	19	44
	(%N/%C)		(0/1)	(2/0)	(4/1)	(2/1)	(3/<1)	(<1/0)	(7/<1)
	TU	0.1616	0.3010	0.4715	0.6471	0.6352	0.7533	0.3457	0.4202
5	No. M^{-2}	1,693	3.954	26,112	17,731	331	253,00	314,251	
	No. Taxa	15	21	20	33	12	7	38	
	(%N/%C)		(90/2)	(56/26)	(88/2)	(19/0)	49	(98/<1)	
	TU	0.7313	0.1853	0.6140	0.2195	0.8435	(82/1)	0.0323	
							0.3259		
6	No. M^{-2}	2,815	70,037	54,588	15,135	119	24,579	134,288	23,574
	No. Taxa	36	30	27	26	8	52	72	75
	(%N/%C)		(78/11)	(73/18)	(90/1)	(5/0)	(28/5)	(89/<1)	(28/5)
	TU	0.8976	0.3889	0.4332	0.1887	0.7489	0.8626	0.2021	0.7956
8	No. M^{-2}	3,899	10,455	11,729	3,597	2,414	19,282	80,576	143,380
	No. Taxa	42	59	41	42	23	94	82	60
	(%N/%C)	(-/-)	(5/5)	(12/25)	(15/5)	(2/0)	(9/2)	(66/<1)	(67/1)
	TU	0.7576	0.8688	0.8818	0.9200	0.5414	0.9498	0.5375	0.5111
9	No. M^{-2}						40,971	93,380	22,692
	No. Taxa						102	86	94
	(%N/%C)						(27/3)	(94/<1)	(17/3)
	TU						0.8974	0.1238	0.9084

Sources: Dwernychuk, 1988; Dwernychuk *et al.*, 1992a.
No. M^{-2} = number of organisms/m^2.
No. Taxa = number of taxa at that station.
(%N/%C) = Percentage of sample that consisted of nematodes/percent *Capitella capitata*.
TU = Keefe-Bergersen diversity index.

Table 5.5 **Summary of organochlorine, dioxin and furan studies in biota tissues near Skeena Cellulose Inc., Prince Rupert, B.C., 1989 to 1993.**

Date	Source	Significant Findings
1989	Dwernychuk, 1989b	• Chloroguaiacols ND (<5.0 ng/g) in crab muscle, hepatopancreas, pink shrimp and lemon sole. • Coonstripe shrimp in Porpoise Harbour - 14 ng/g TCG. • Dioxin/furan highest in crab hepatopancreas in Porpoise Harbour: 140 pg/g dioxin, 3,200 pg/g furan. Hepatopancreas in Morse Basin: 25 pg/g dioxin, 610 pg/g furan. Chatham Sound: 15 pg/g dioxin, 370 pg/g furan. • Coonstripe shrimp moderate dioxin (5.7 to 5.9 pg/g) and furan (120 to 130 pg/g) near diffuser and at Coast Island, Chatham Sound. • Mussels: 7.5 pg/g dioxin, 180 pg/g furan near diffuser.
1990	Dwernychuk *et al.*, 1992a	• Chlorinated guaiacols ND in crab muscle. Crab hepatopancreas guaiacols highest in Wainwright Basin (25 ng/g TCG, 7.5 ng/g TeCG); still present in Chatham Sound (7.8 ng/g TCG). • Other guaiacol concentrations found in Porpoise Harbour biota: pink shrimp (2.7 ng/g TCG, 1.0 ng/g TeCG); English sole liver (15 ng/g TCG, 2.6 ng/g TeCG). • Dioxin/furan in crab: muscle - low levels near Watson Island; hepatopancreas - highest in Wainwright Basin, Porpoise Harbour and Coast Island (50 to 87 pg/g dioxin, 950 to 1,500 pg/g furan). • Dioxin/furan ND or trace in pink shrimp; sole liver (flathead) highest in Morse Basin (110 pg/g dioxin, 320 pg/g furan). Sole muscle ND or trace dioxin/furan.
1991	Dwernychuk *et al.*, 1992b	• Guaiacols somewhat reduced in crab hepatopancreas (13 to 16 ng/g TCG, 5.2 to 6.8 ng/g TeCG); ND in shrimp. • Crab hepatopancreas: dioxins 66 to 100 pg/g, furans 1,100 to 1,700 pg/g at diffuser and Wainwright Basin - similar to year 1990. All others considerably lower (max. 7.7 pg/g dioxin, 150 pg/g furan). • Dioxin <2.0 pg/g, furan <20 pg/g in shrimp - lower than in 1989.

ND = non-detected
TCG = trichloroguaiacol
TeCG = tetrachloroguaiacol

Table 5.5 (cont'd)

Date	Source	Significant Findings
1992	Dwernychuk *et al.*, 1993a	• Crab hepatopancreas dioxins/furans: slight decrease in levels from 1991. Wainwright Basin highest (50 pg/g dioxin, 1,100 pg/g furan); diffuser next (36 to 46 pg/g dioxin, 680 to 840 pg/g furan). • Shrimp dioxin and furan levels slightly reduced: max. 1.1 pg/g dioxin, 16 pg/g furan.
1992	Dwernychuk and Boivin, 1993	• Added Stations SC10 and SC11 for crab. (Figure 5.10). • Crab hepatopancreas: dioxins 7.1 to 8.8 pg/g; furans 150 to 260 pg/g at those stations.
1993	Dwernychuk *et al.*, 1993b	• Crab hepatopancreas: gradually decreasing trend. New 1992 stations slightly lower in 1993. Highest at Wainwright Basin (38 pg/g dioxin, 810 pg/g furan). • New stations surrounding Digby Island (SC12 to 14): dioxins (1.1 to 2.6 pg/g), furans (25 to 44 pg/g). • TEQ's 1991-1993 indicate general reducing trend. However, not clear at SC1, SC4 and SC5 - Figure 5.10. Highest TEQ (151.4 pg/g) in 1993 was SC2 (Wainwright Basin). • Shrimp - dioxin and furan levels decreased from 1989 and have remained low. Still detected in Morse Basin and Porpoise Harbour.

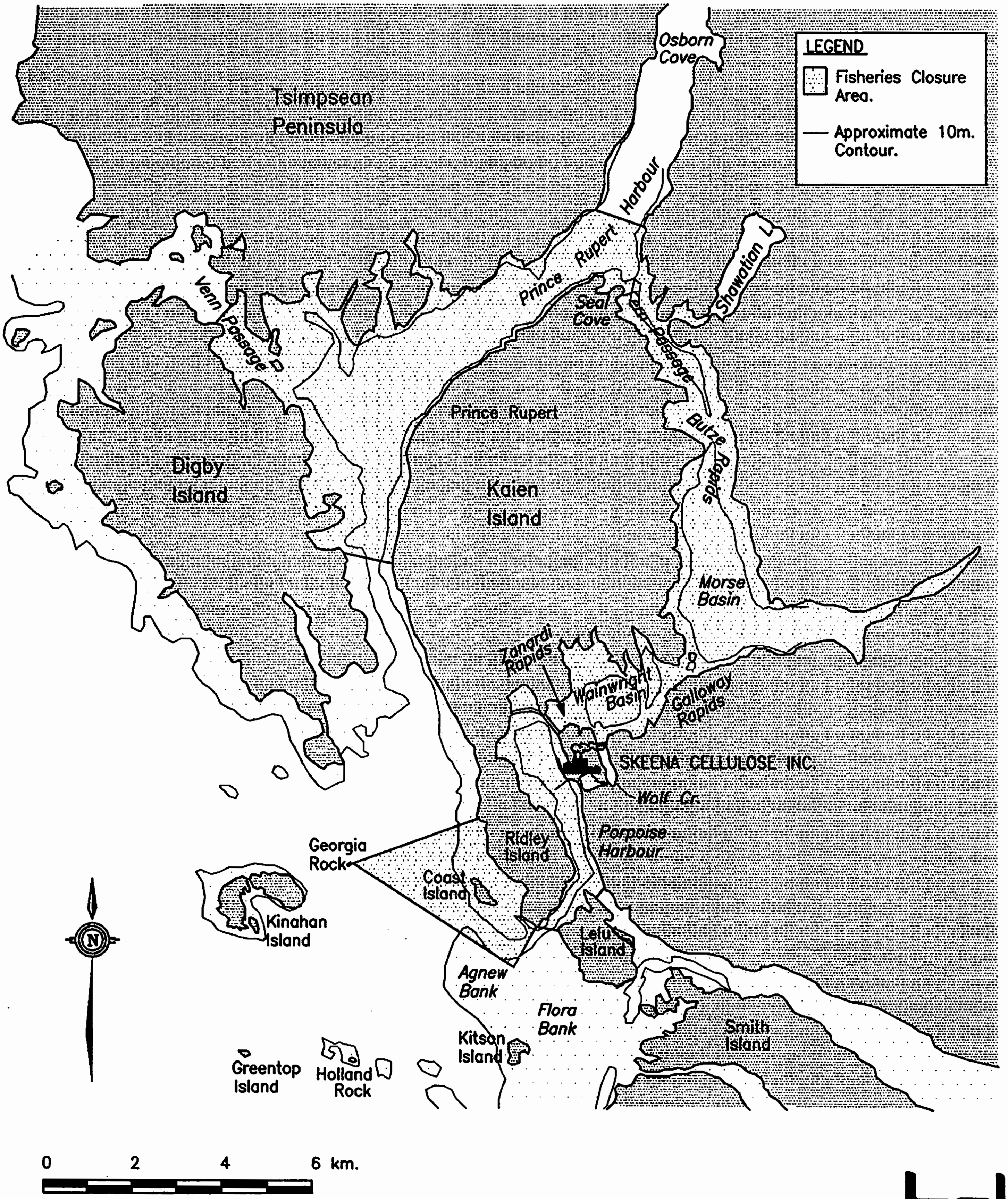
ND = non-detected
TCG = trichloroguaiacol
TeCG = tetrachloroguaiacol

Table 6.1 Chemical consumption at Skeena Cellulose Inc., 1992.

Department/Chemical used	Formula	Chemical usage (kg/ADt production)	Total kg/day
Chlorine dioxide generator			
Sulphuric acid	H_2SO_4	27.7	32,548
Sodium chlorate	$NaClO_4$	43.9	51,583
Kraft bleaching			
Chlorine (purchased)	Cl_2	36.3	42,653
Caustic soda	NaOH	50.9	59,808
Oxygen	O_2	6.5	7,638
Talc	$MgSO_4$	2.4	2,820
Kraft mill defoamers	–	1.0	1,175
Liquor makeup and recovery			
Caustic soda	NaOH	5.5	6,463
Saltcake	Na_2SO_4	2.2	2,585
Feedwater chemicals			
Caustic soda	NaOH	1.8	2,115
Sulphuric acid	H_2SO_4	1.5	1,763
Lime plant			
Quicklime	CaO	12.8	15,040
Limerock	$CaCO_3$	19.5	22,913
Peroxide bleaching			
Hydrogen peroxide	H_2O_2	0.7	823
Sulphur dioxide	SO_2	2.0	2,350
Enzyme	–	0.3	353
Effluent treatment			
Caustic soda	NaOH	0.5	588
Phosphoric acid	H_3PO_4	0.5	588
Sulphuric acid	H_2SO_4	7.5	8,813
Ammonia	NH_3	1.2	1,410
Defoamer	–	0.6	705
Polymer	–	0.02	24
Oxygen	O_2	47.9	56,283

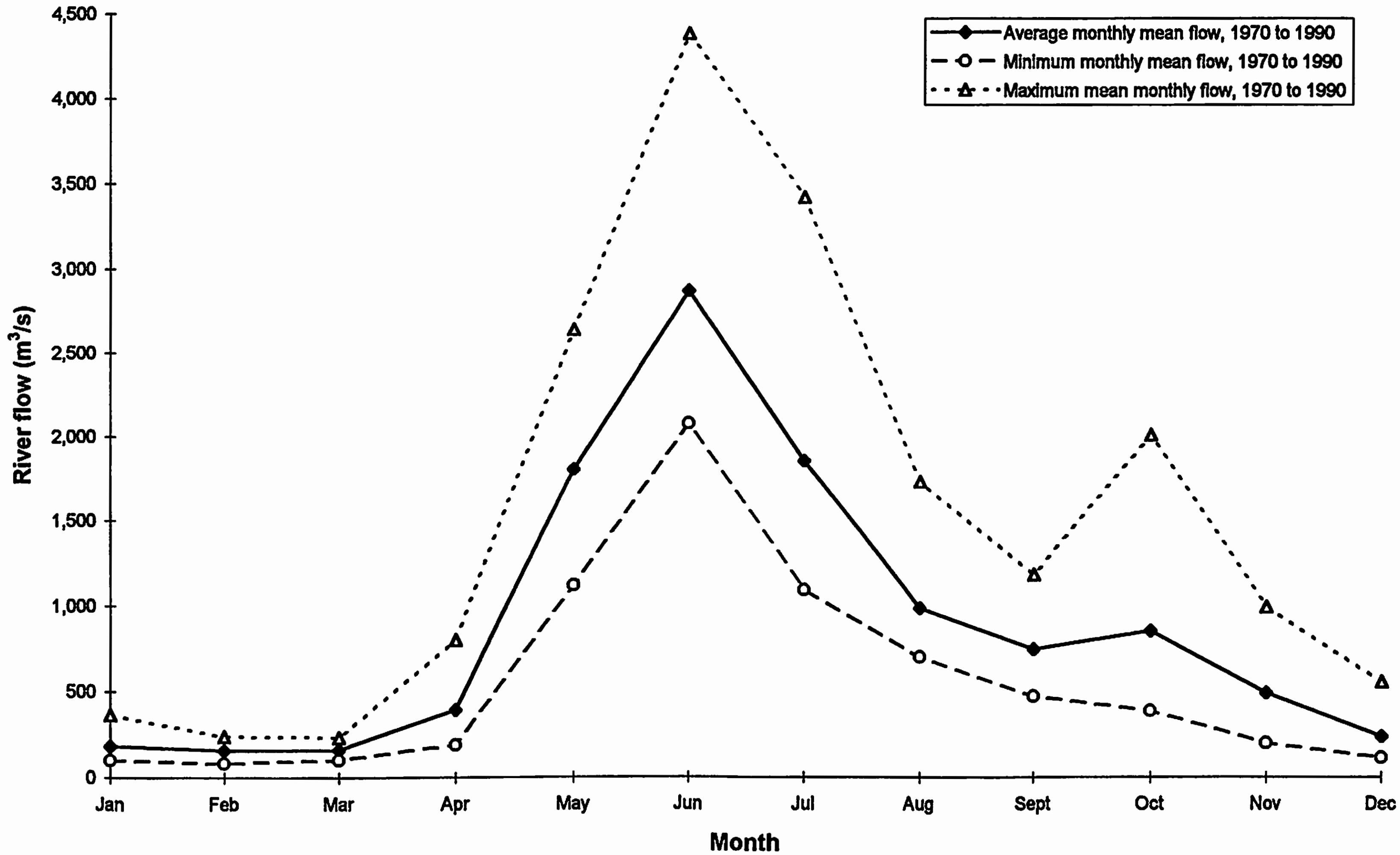
LIST OF FIGURES

FIGURE 2.1 The Kaien Island Area, showing the location of the Skeena Cellulose Inc. pulpmill.



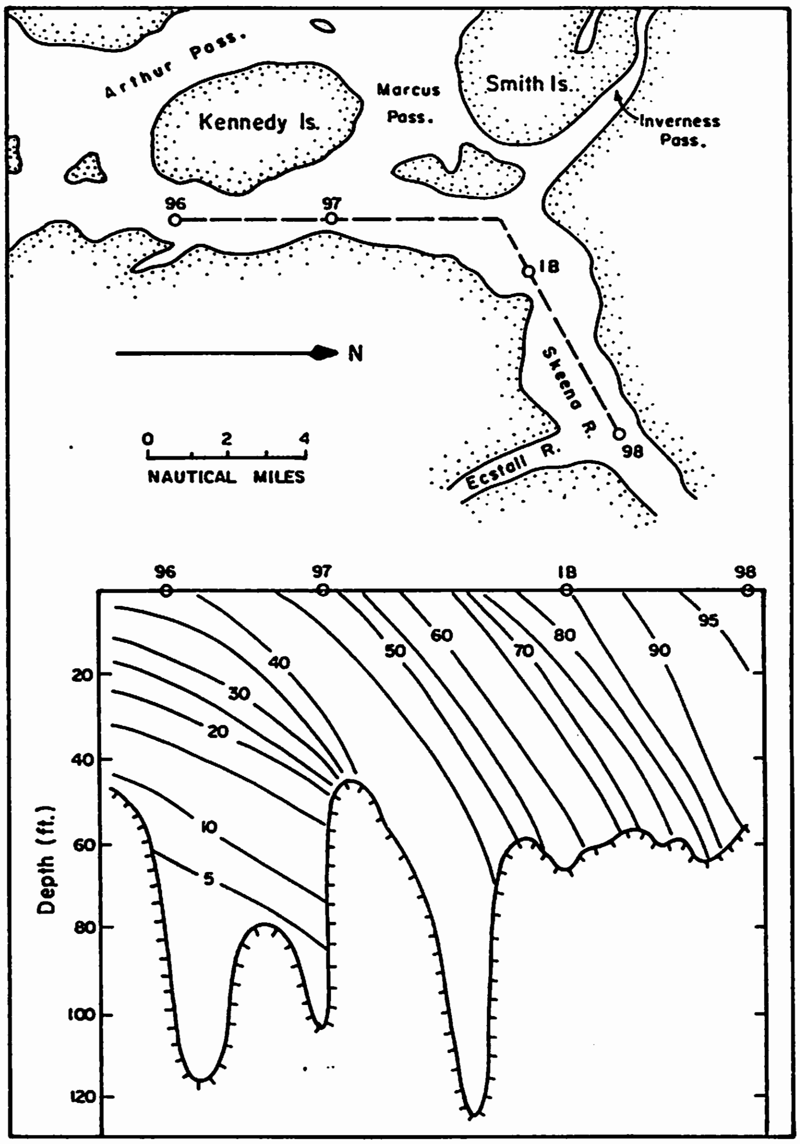
hcl

Figure 2.2 Mean monthly discharges from the Skeena River, 1970 to 1990.



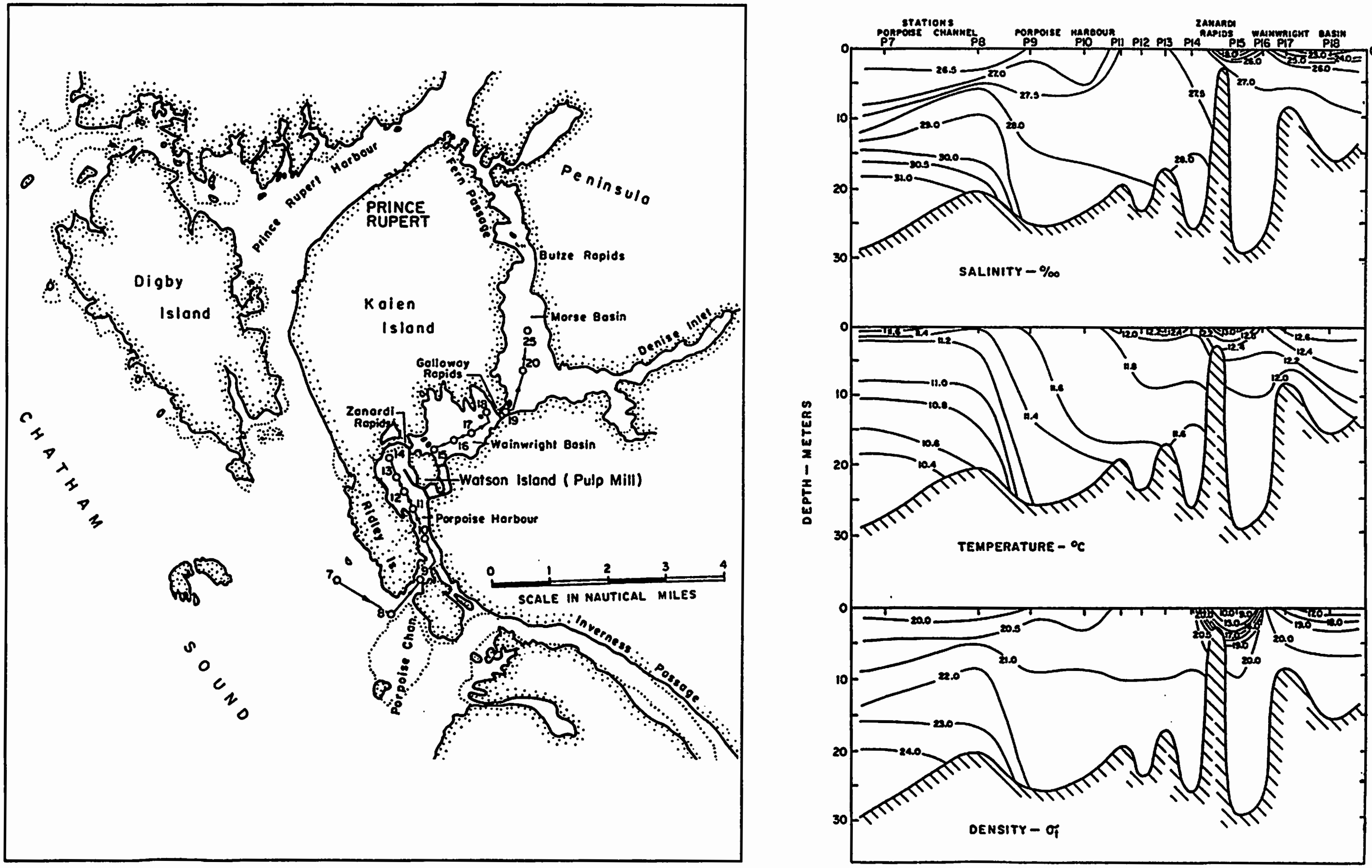
Souce: data from Water Survey of Canada, 1991.

Figure 2.3 **Percent concentration of fresh water near the mouth of the Skeena River, September 7, 1948, illustrating vertical mixing of the water column.**



Source: Hoos, 1975.

Figure 2.4 Evidence of vertical mixing of the water column in the Porpoise Harbour-Wainwright Basin-Morse Basin system.



Modified from: Waldichuk, 1968.

Figure 2.5 Location of diffuser outfall at Skeena Cellulose Inc.

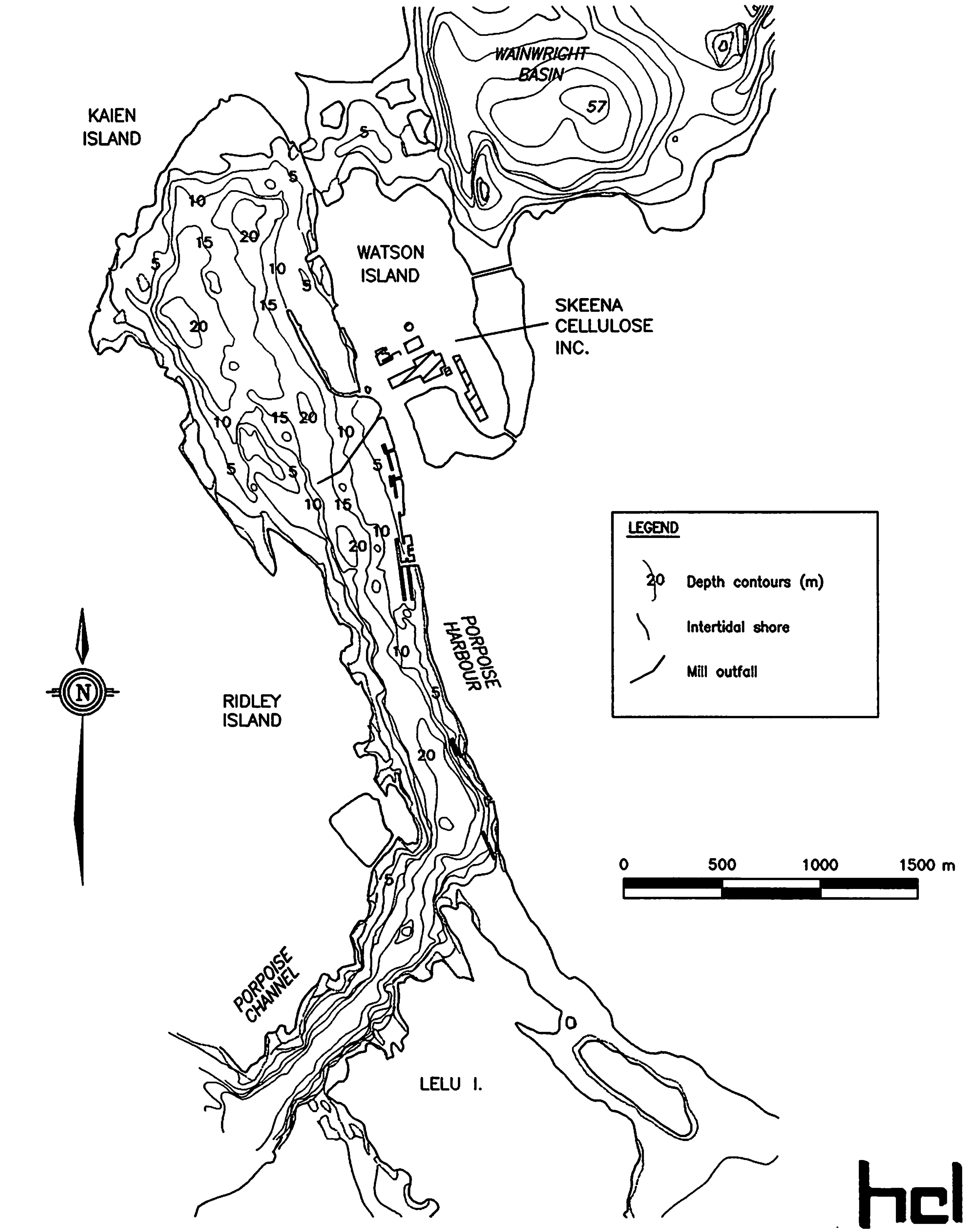
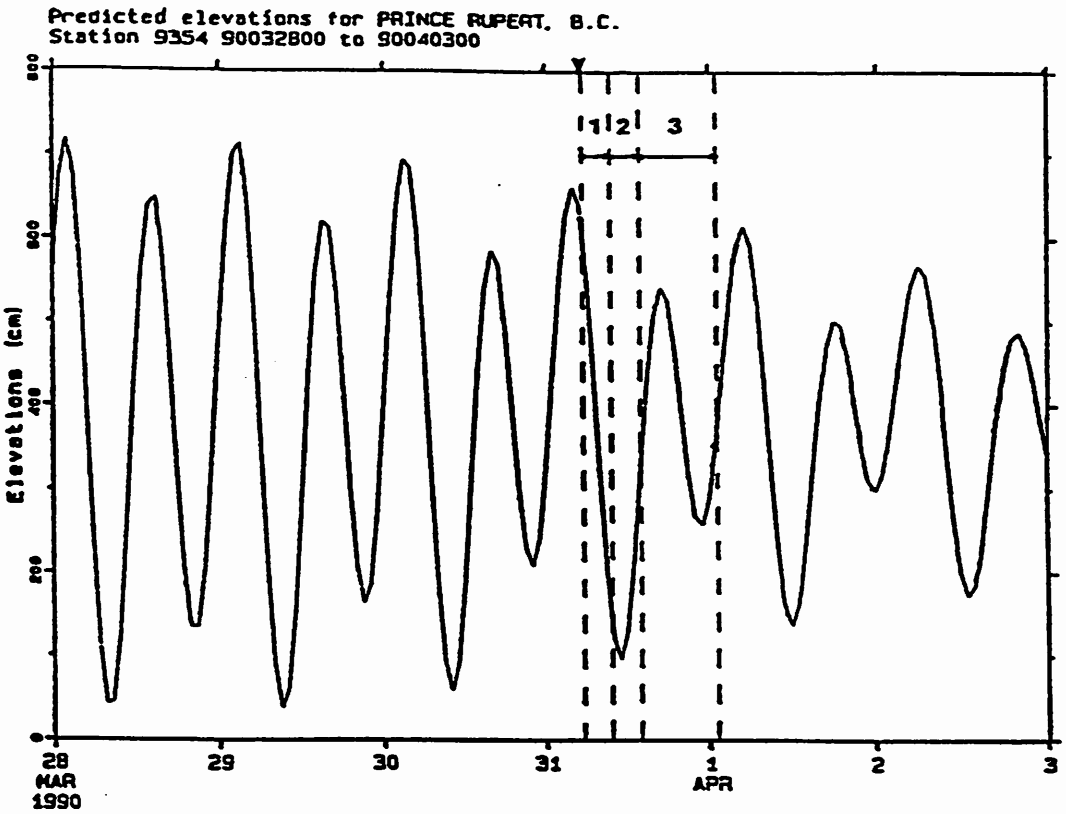
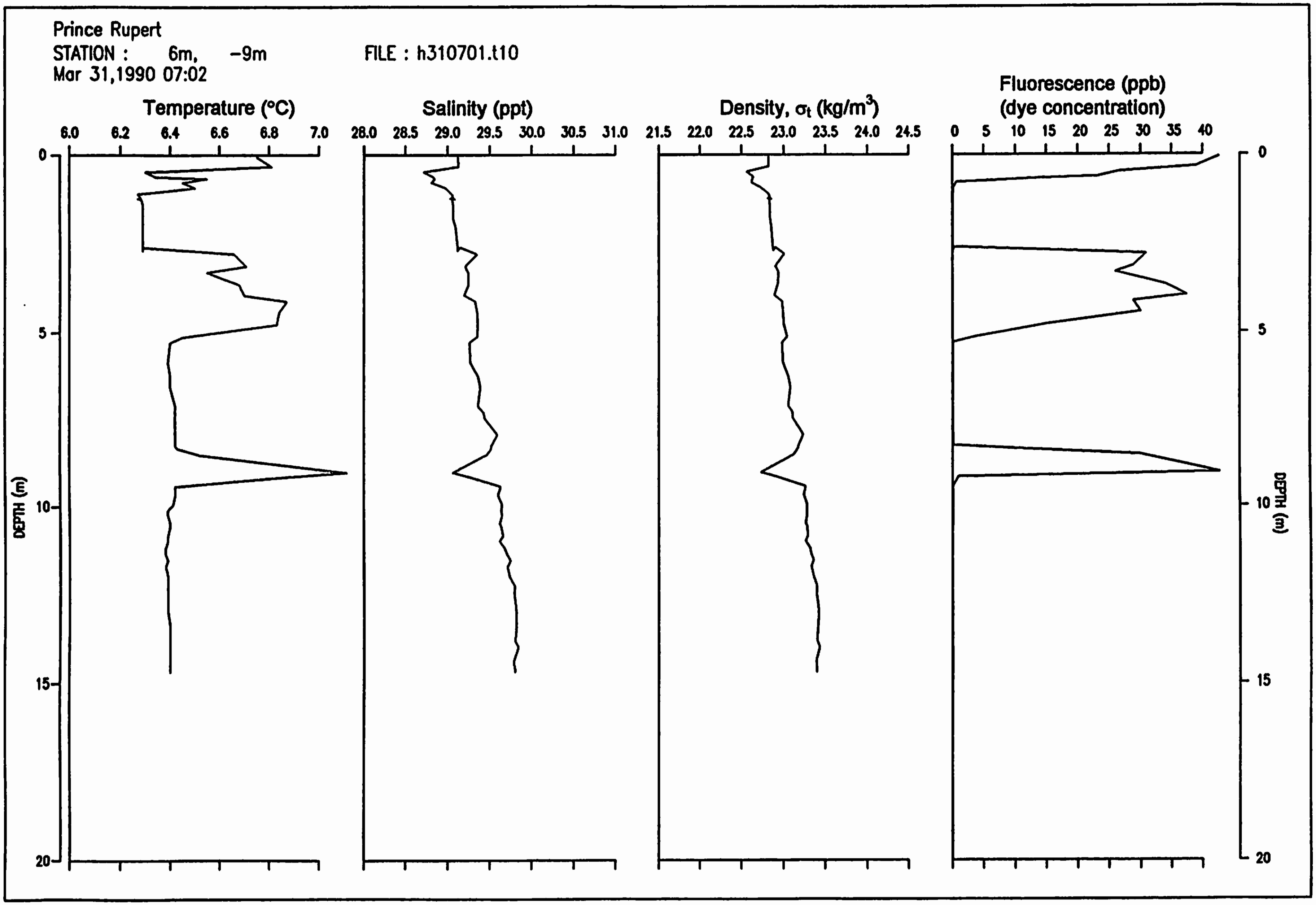


Figure 2.6 **Tidal fluctuations at Prince Rupert during the dye dispersion study.**



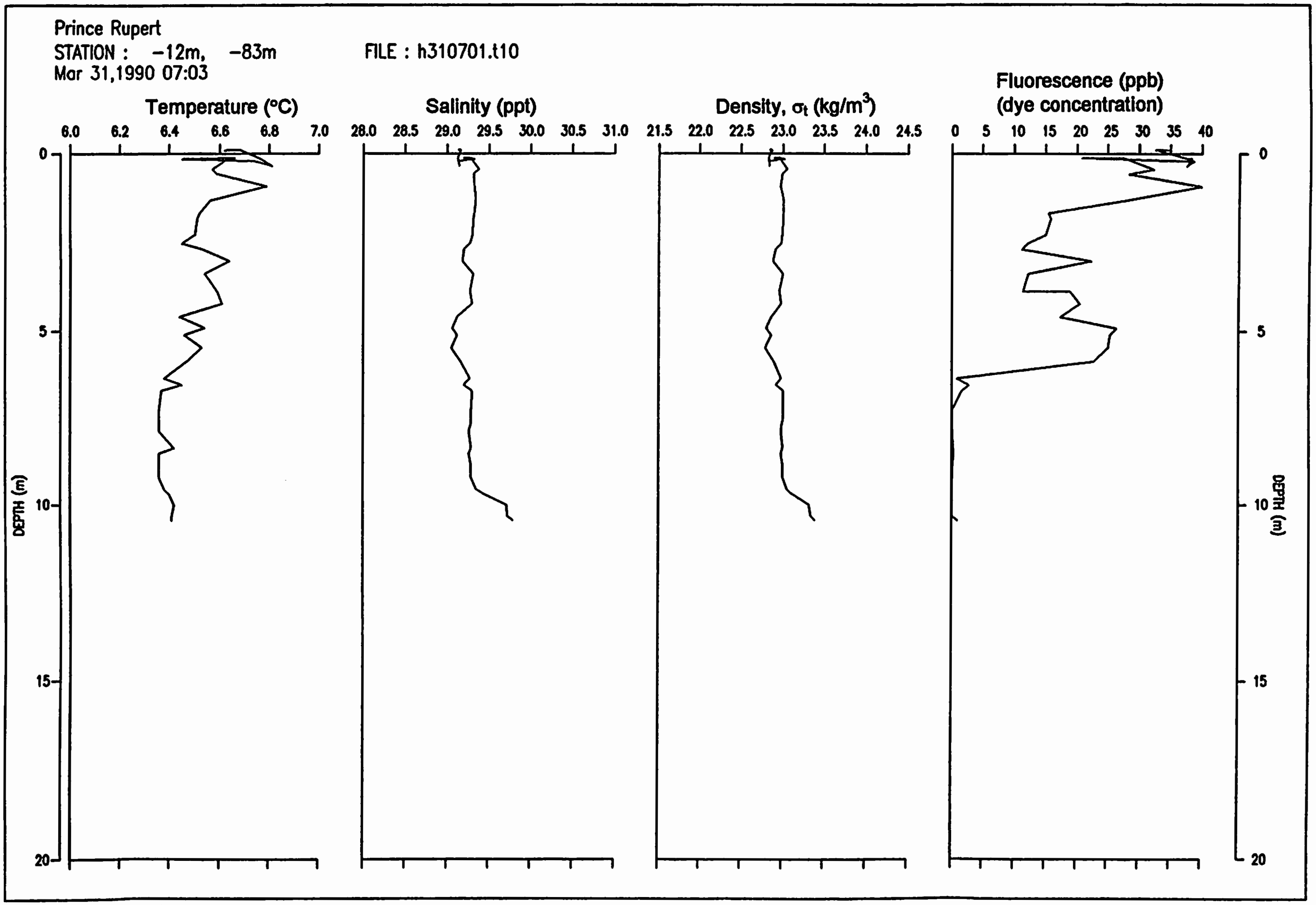
Source: Hodgins and Knoll, 1990.

Figure 2.7 **Vertical distribution of effluent above the diffusers during the dye study.**



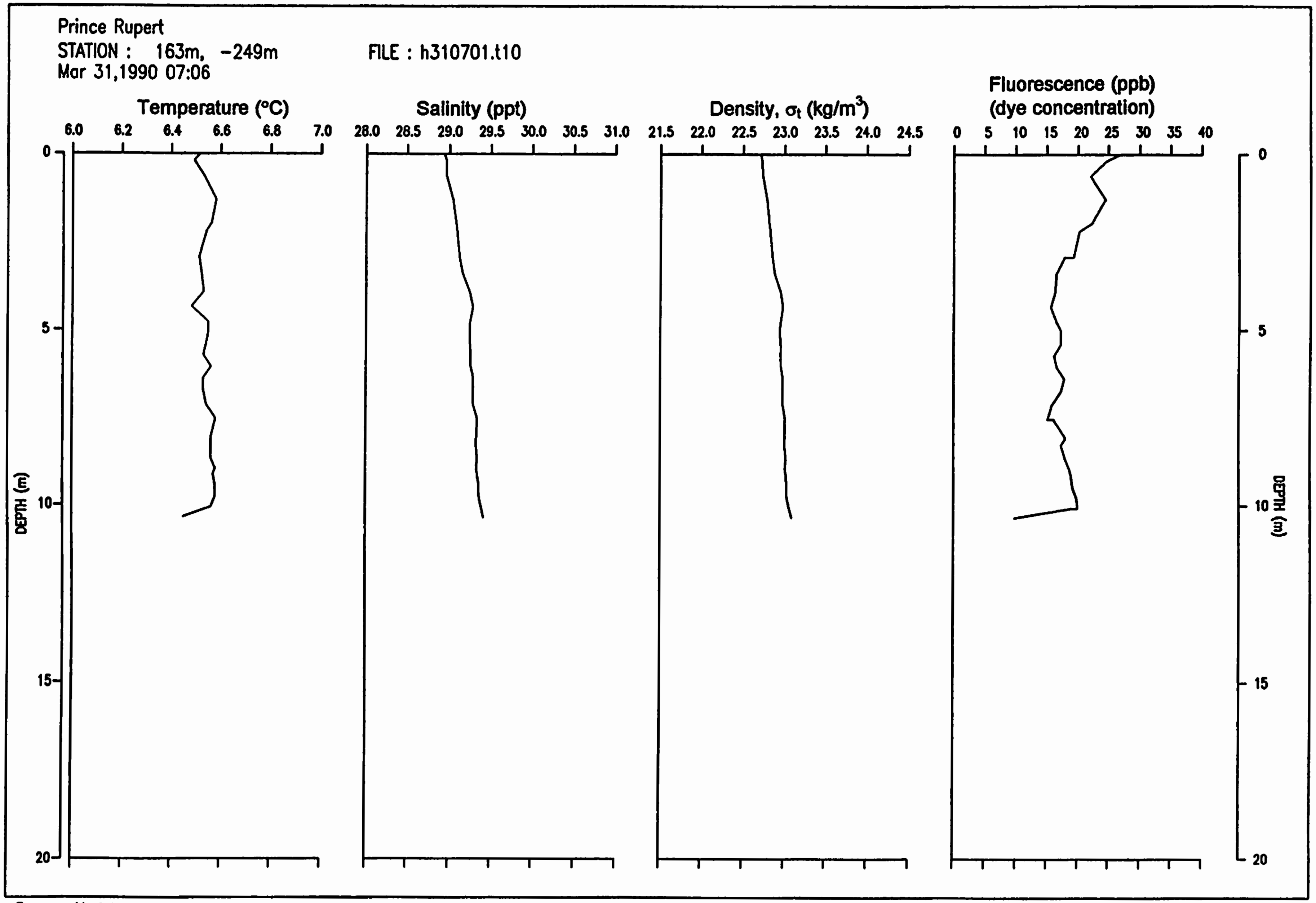
Source: Hodgins and Knoll, 1990.

Figure 2.8 **Vertical distribution of effluent 80 metres south of the diffusers during the dye study.**



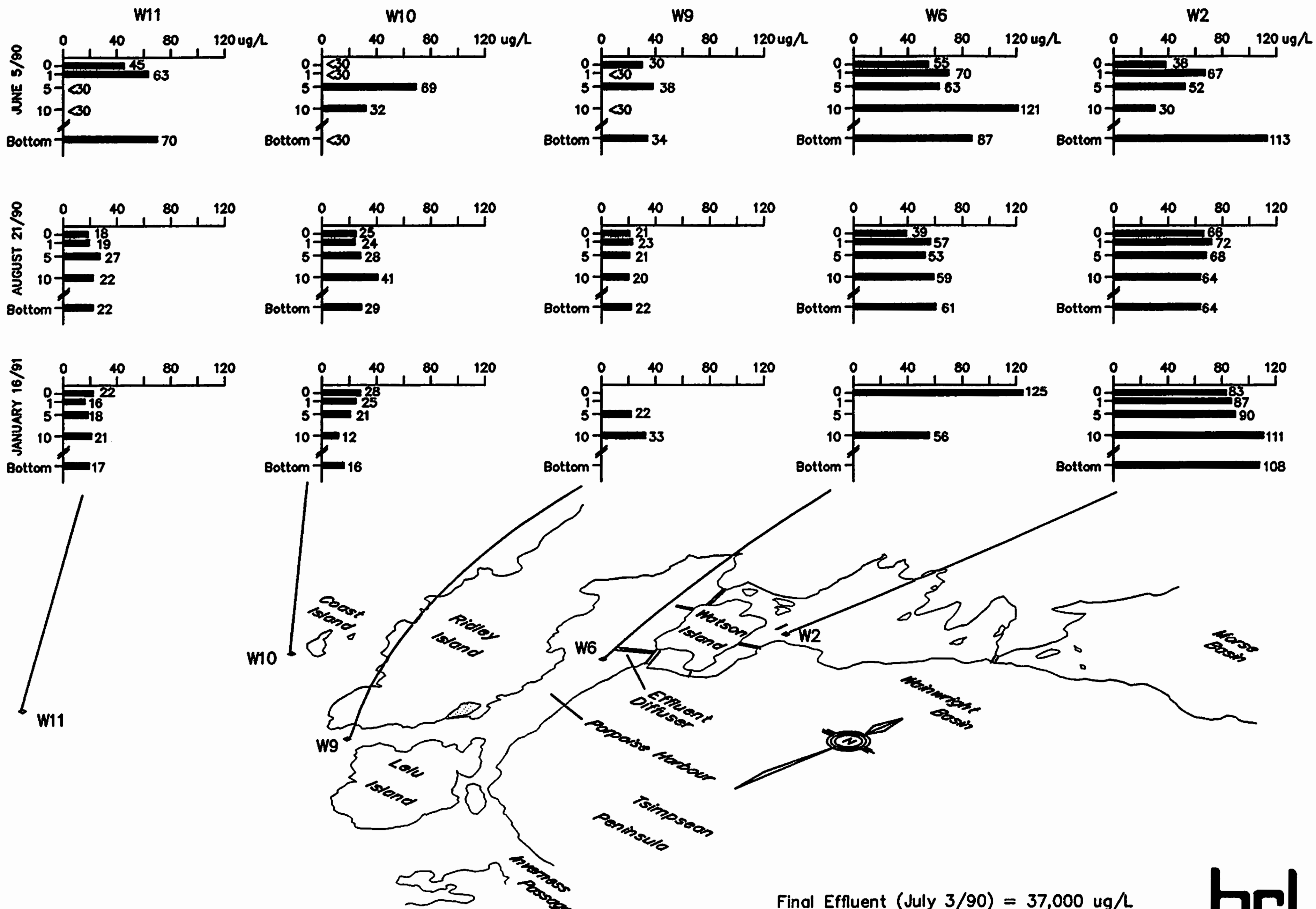
Source: Hodgins and Knoll, 1990.

Figure 2.9 **Vertical distribution of effluent 250 metres south of the diffusers during the dye study.**



Source: Hodgins and Knoll, 1990.

Figure 2.10 Water Quality; Adsorbable Organic Halide (AOX); June and August 1990, and January 1991; Skeena Cellulose Inc., Prince Rupert.

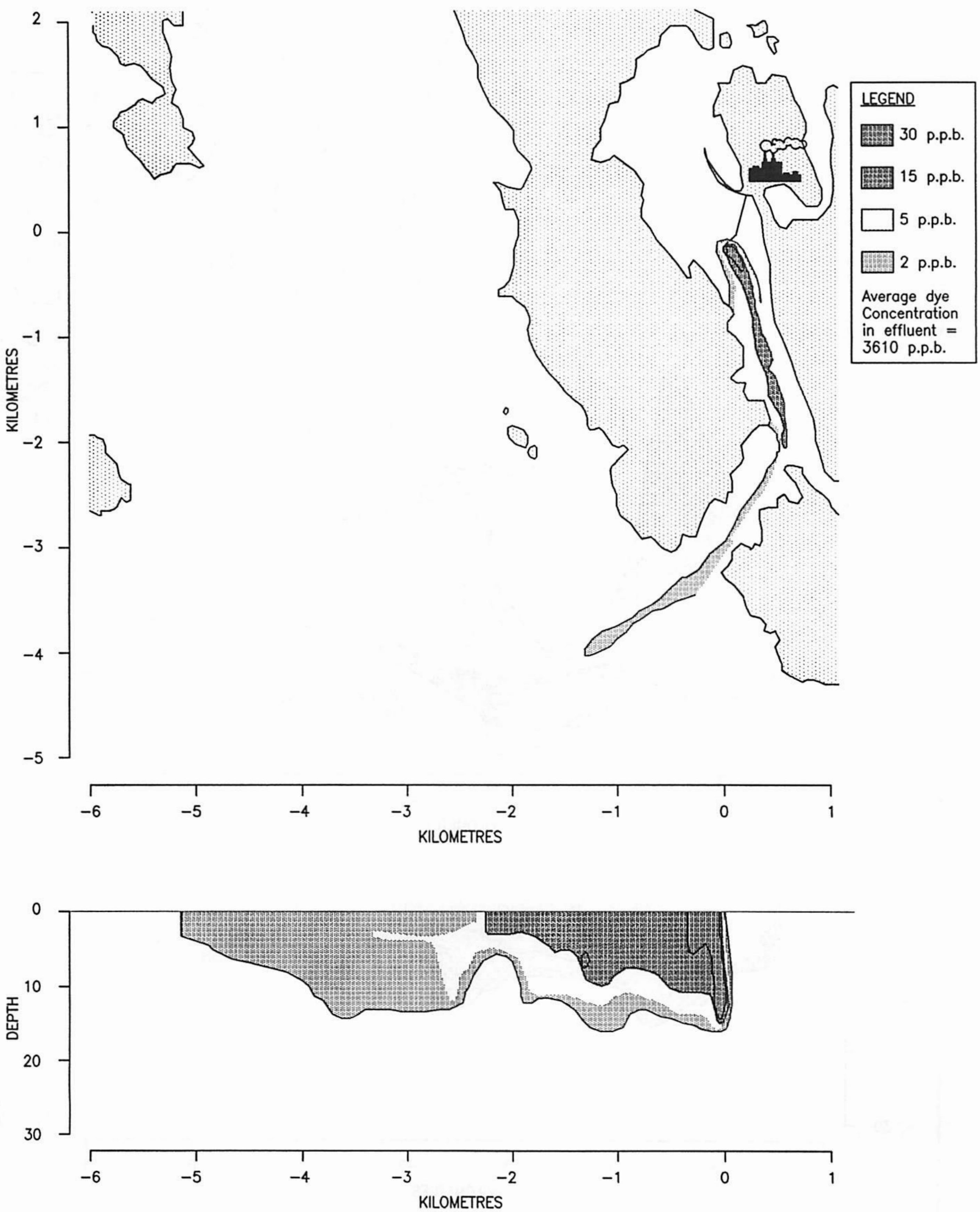


Final Effluent (July 3/90) = 37,000 ug/L

hcl

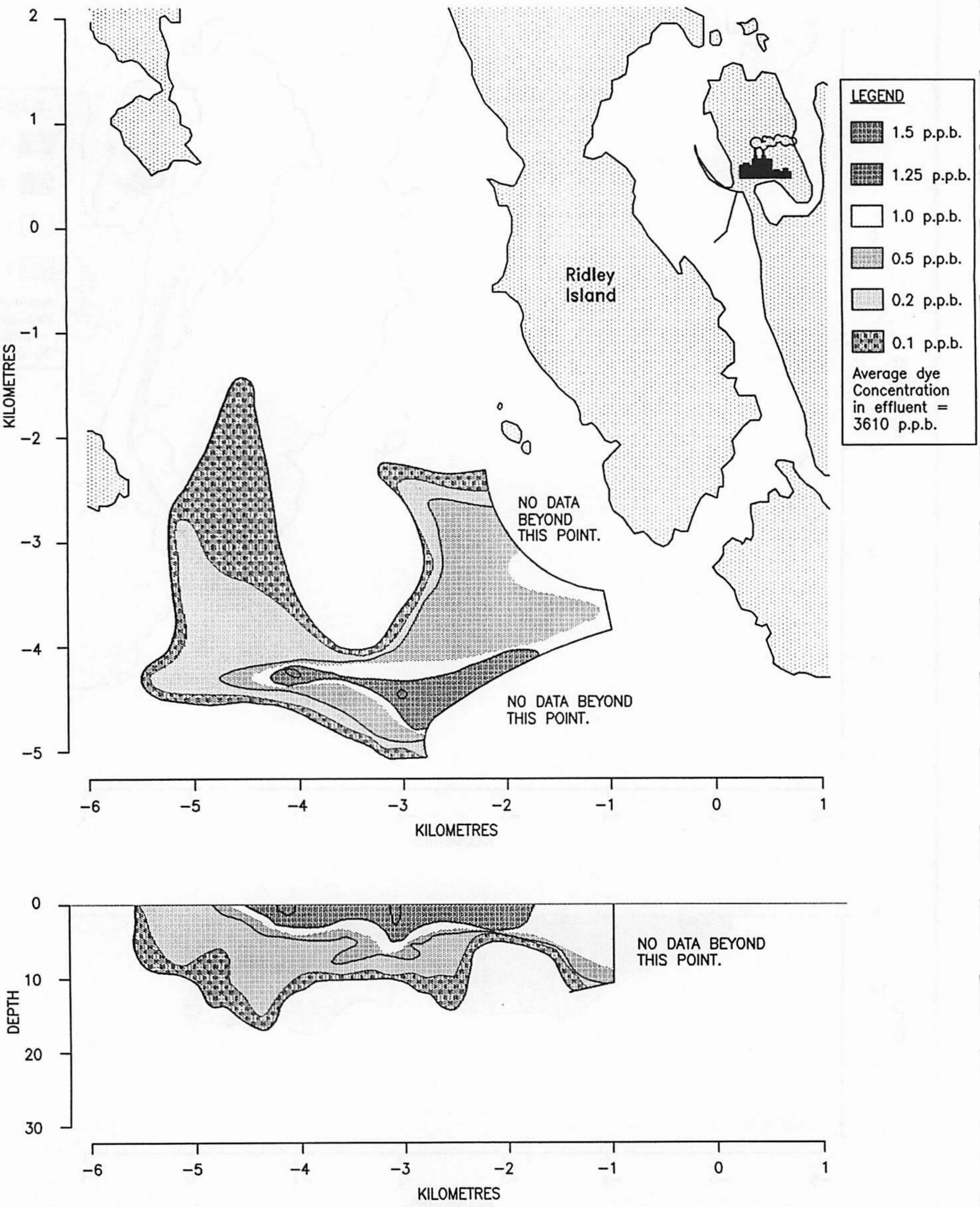
Source: [illegible] et al.

Figure 2.11 Effluent dispersion from the Skeena Cellulose Inc. mill 0.5 to 5.5 hours after effluent injection.



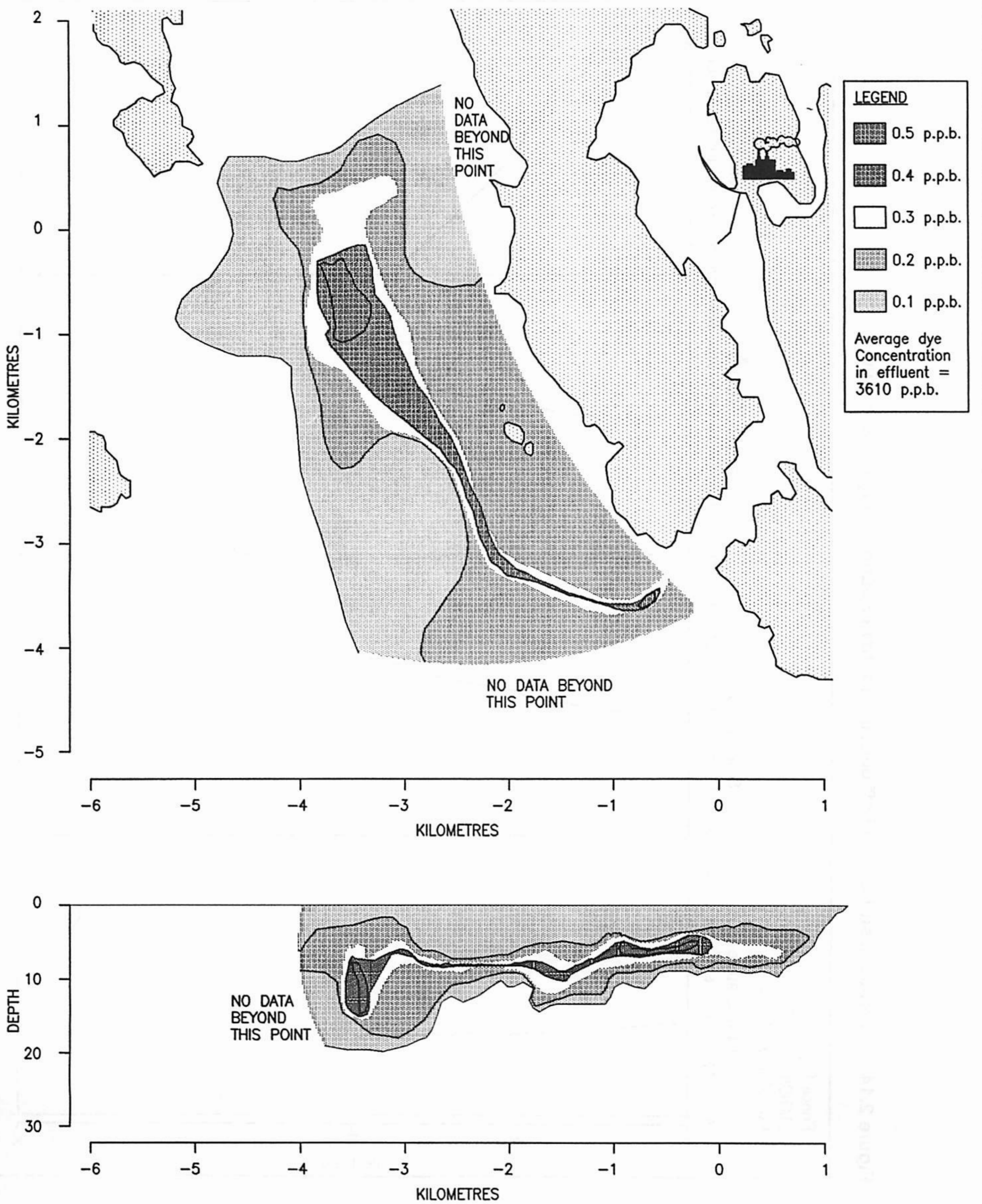
SC-559: EFFLUDIS.DWG

Figure 2.12 Effluent dispersion from the Skeena Cellulose Inc. mill 5.5 to 10.5 hours after effluent injection.



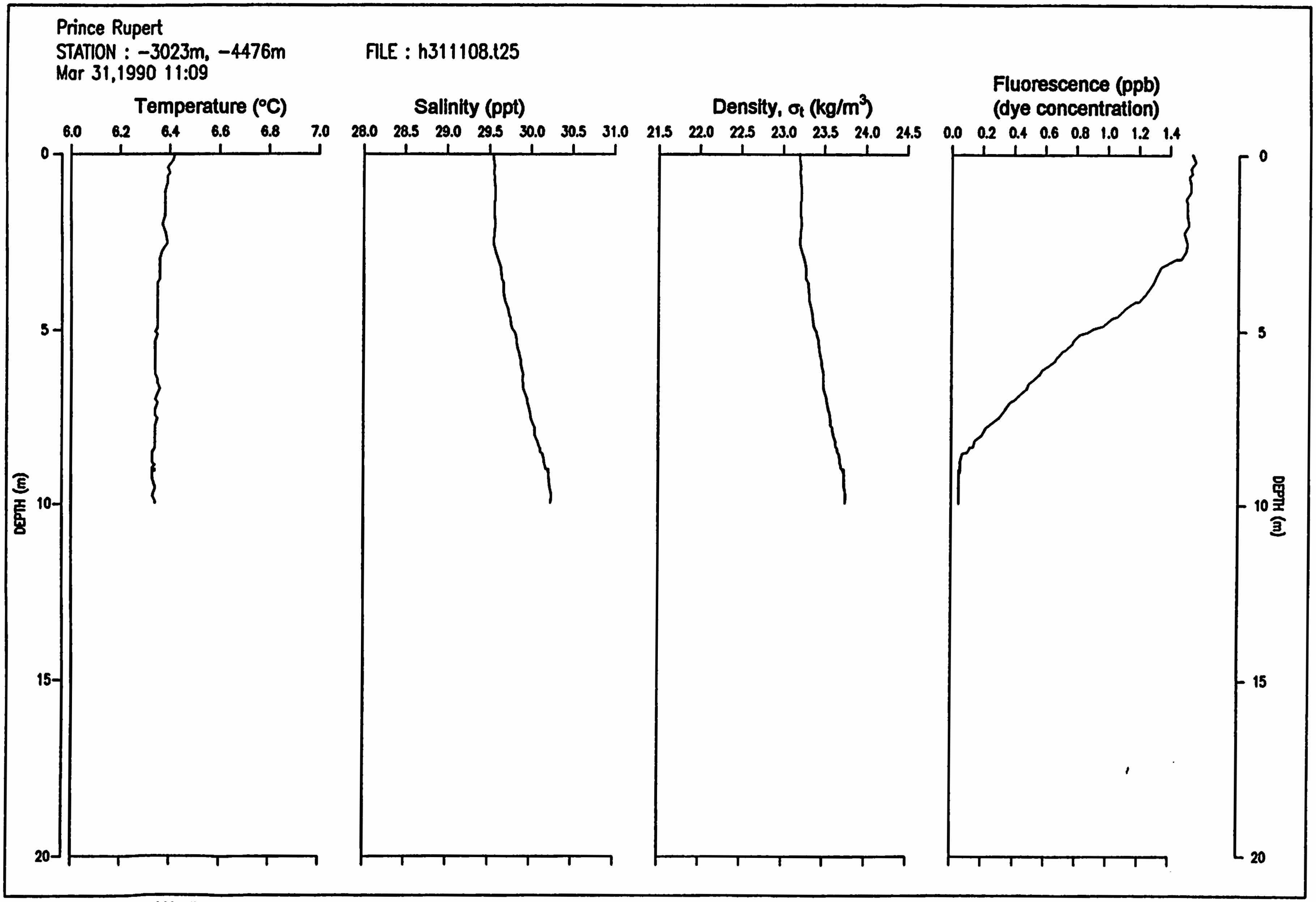
SC-559: EFFLUDIS.DWG

Figure 2.13 Effluent dispersion from the Skeena Cellulose Inc. mill 10.5 to 18 hours after effluent injection.



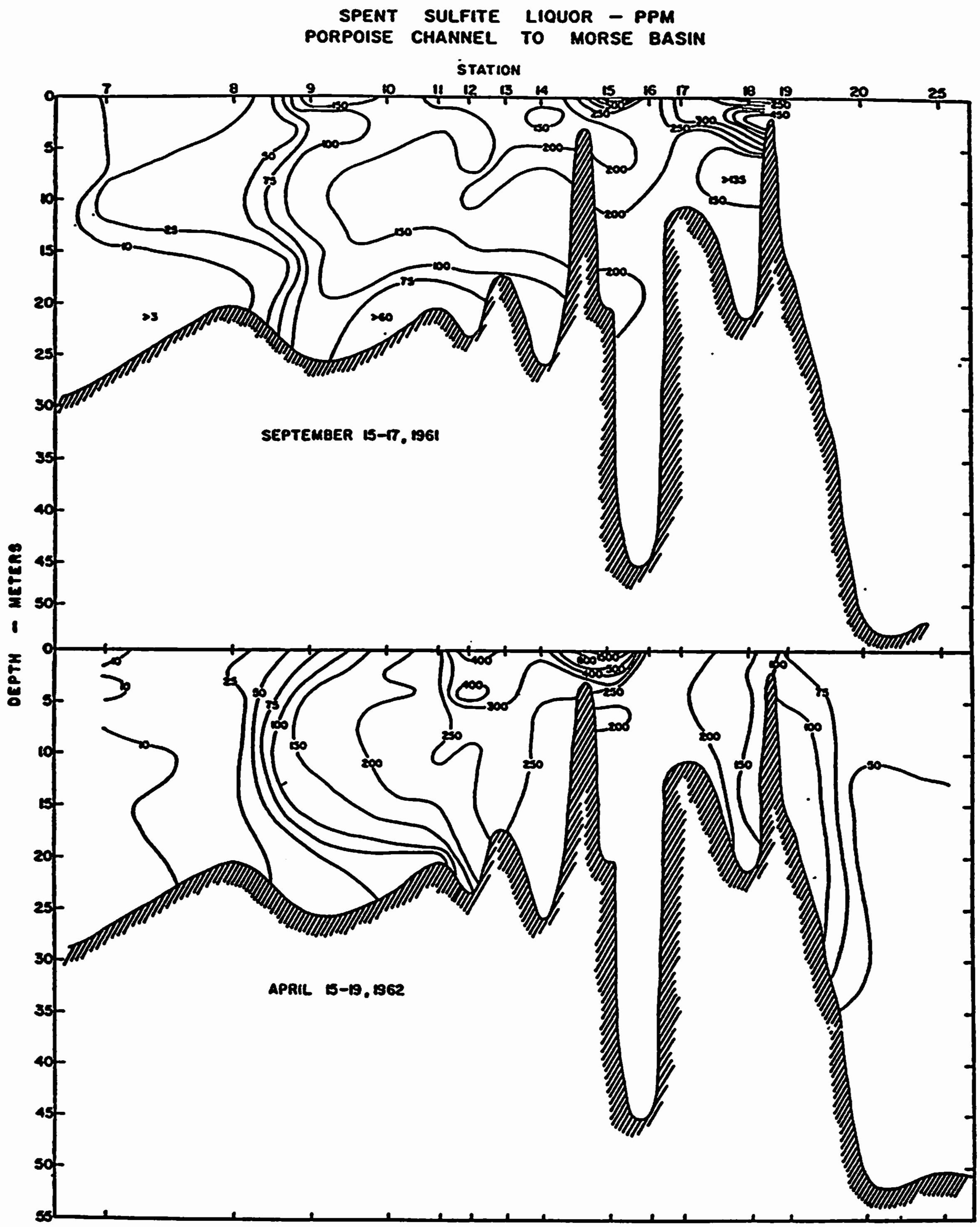
SC-559: EFFLUDIS.DWG

Figure 2.14 Vertical distribution of effluent in Chatham Sound during the dye study.



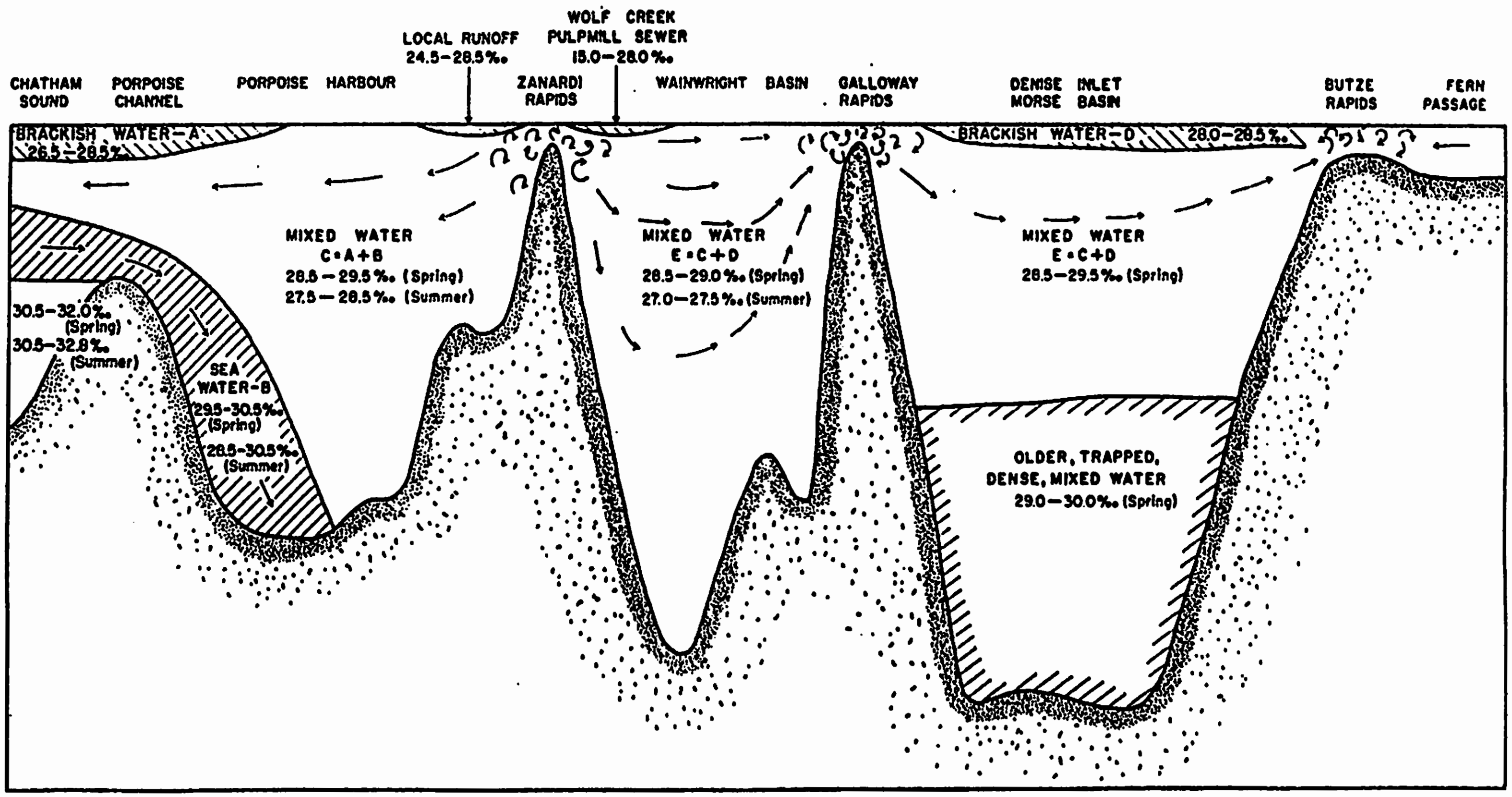
Source: Hodgins and Knoll, 1990.

Figure 2.15 **Vertical distribution of sulphite effluent discharged to Wainwright Basin, September 1961 and April 1962. Upper panel suggests effluent dispersion into Morse Basin; lower panel suggests effluent dispersion to Porpoise Channel. For station locations, see Figure 2.4.**



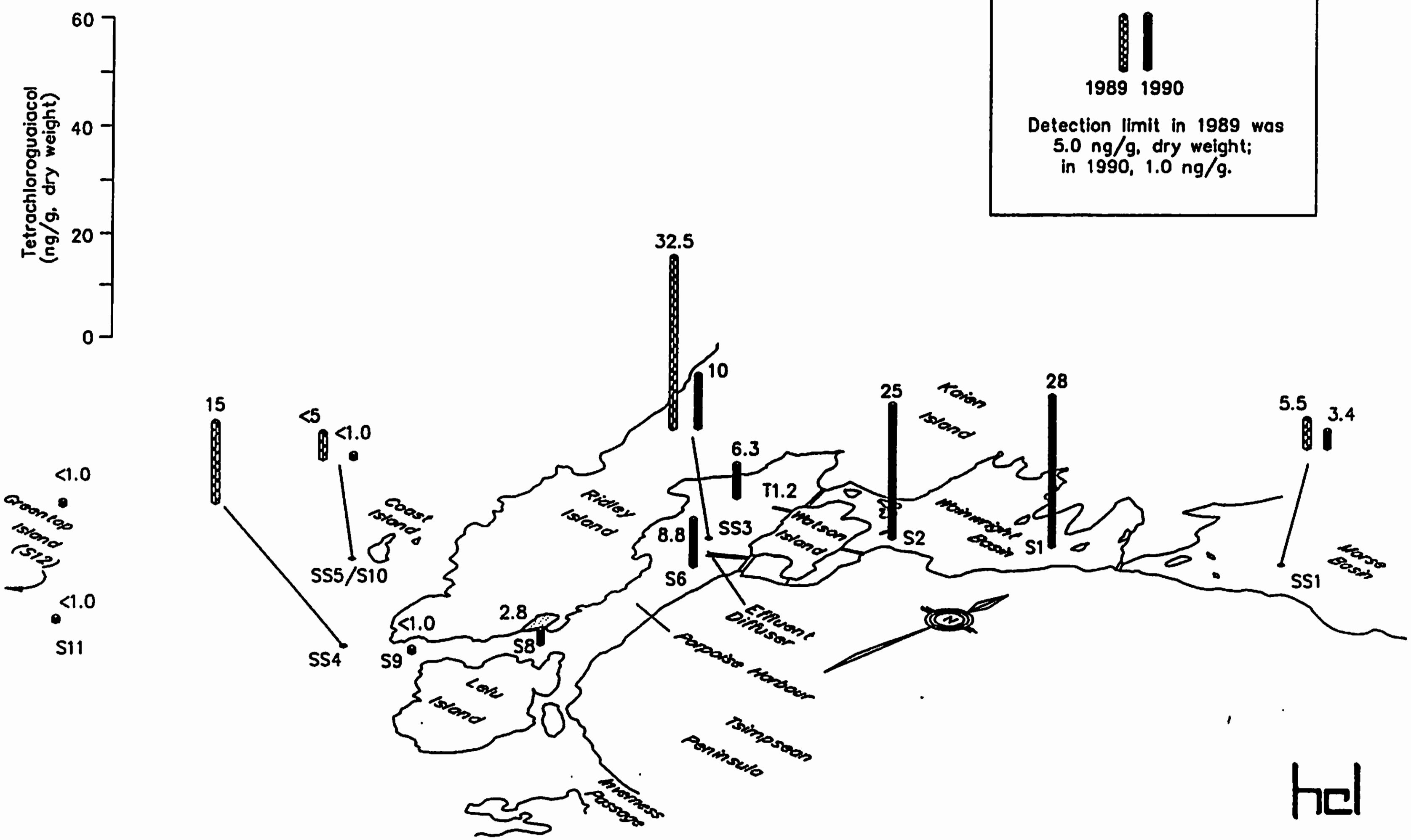
Source: Waldichuk, 1968.

Figure 2.16 **Hypothetical mechanism for net water exchange in the Porpoise Harbour-Wainwright Basin-Morse Basin system.**



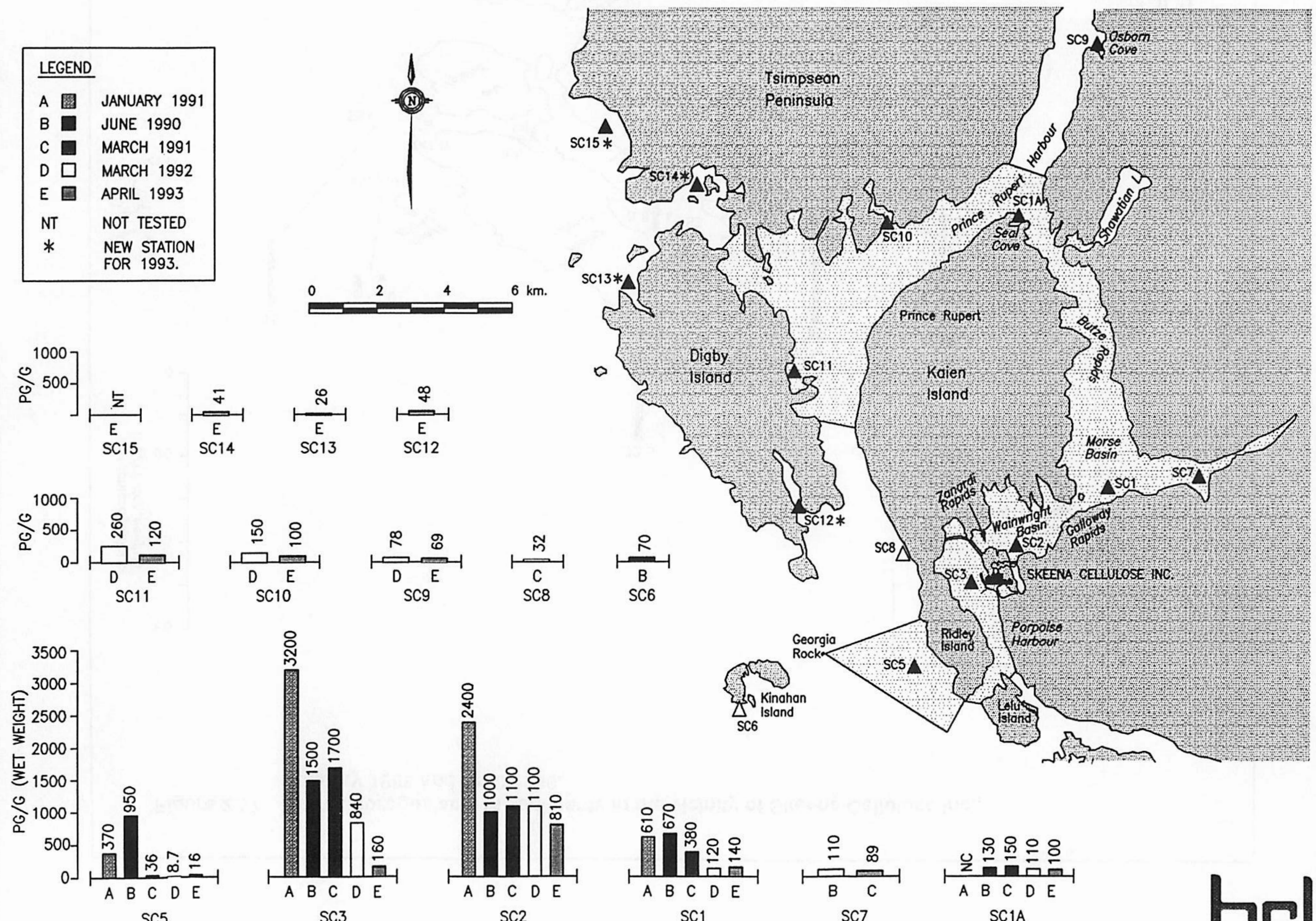
Source: Waldichuk, 1968.

Figure 2.17 Tetrachloroguaiacol in sediments in the vicinity of Skeena Cellulose Inc., January 1989 and April 1990.



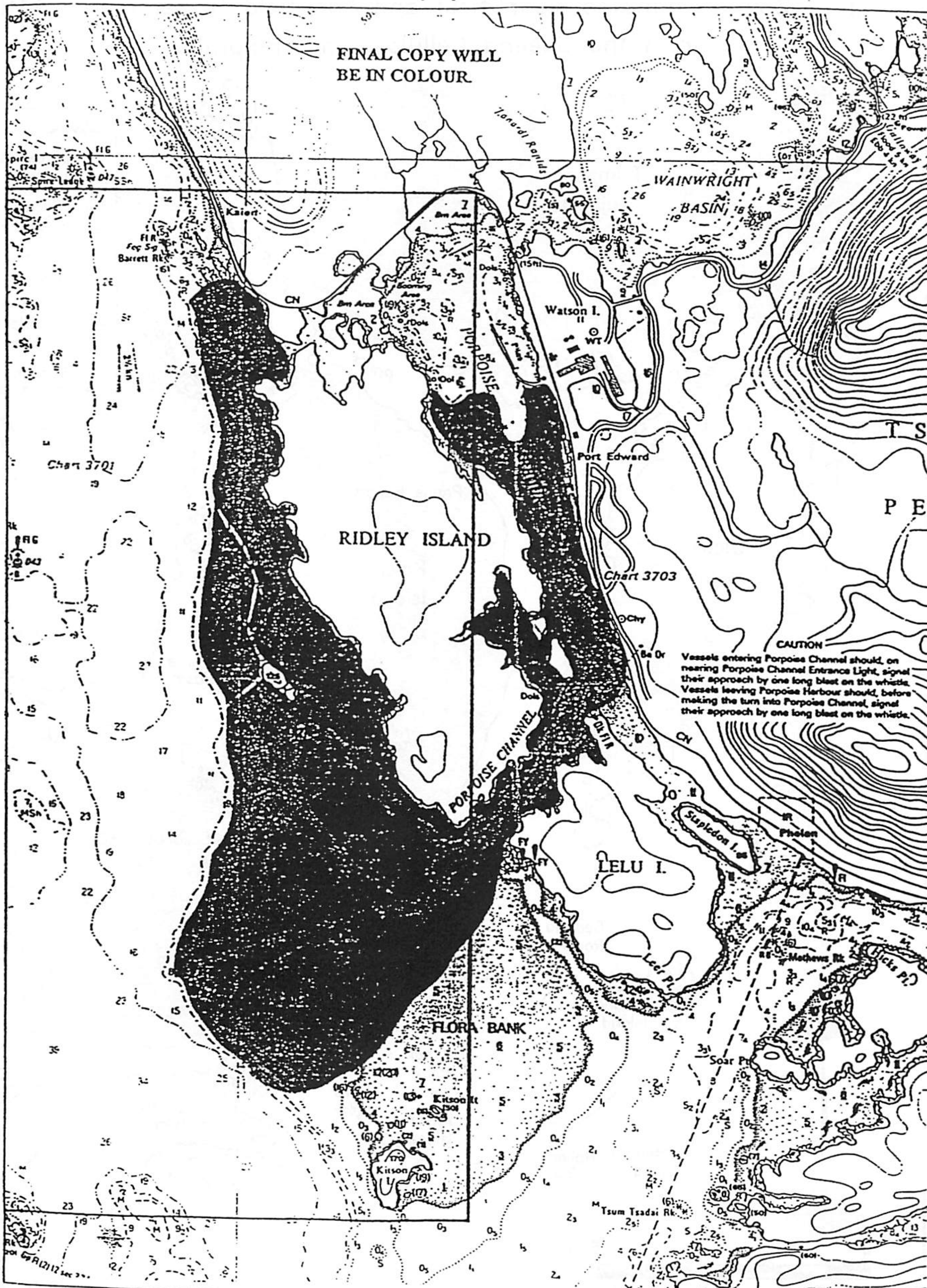
Source: Dwernychuk *et al.*, 1992.

Figure 2.18 Prince Rupert Dungeness Crab Hepatopancreas, 2,3,7,8–TCDF, 1989 to 1993.



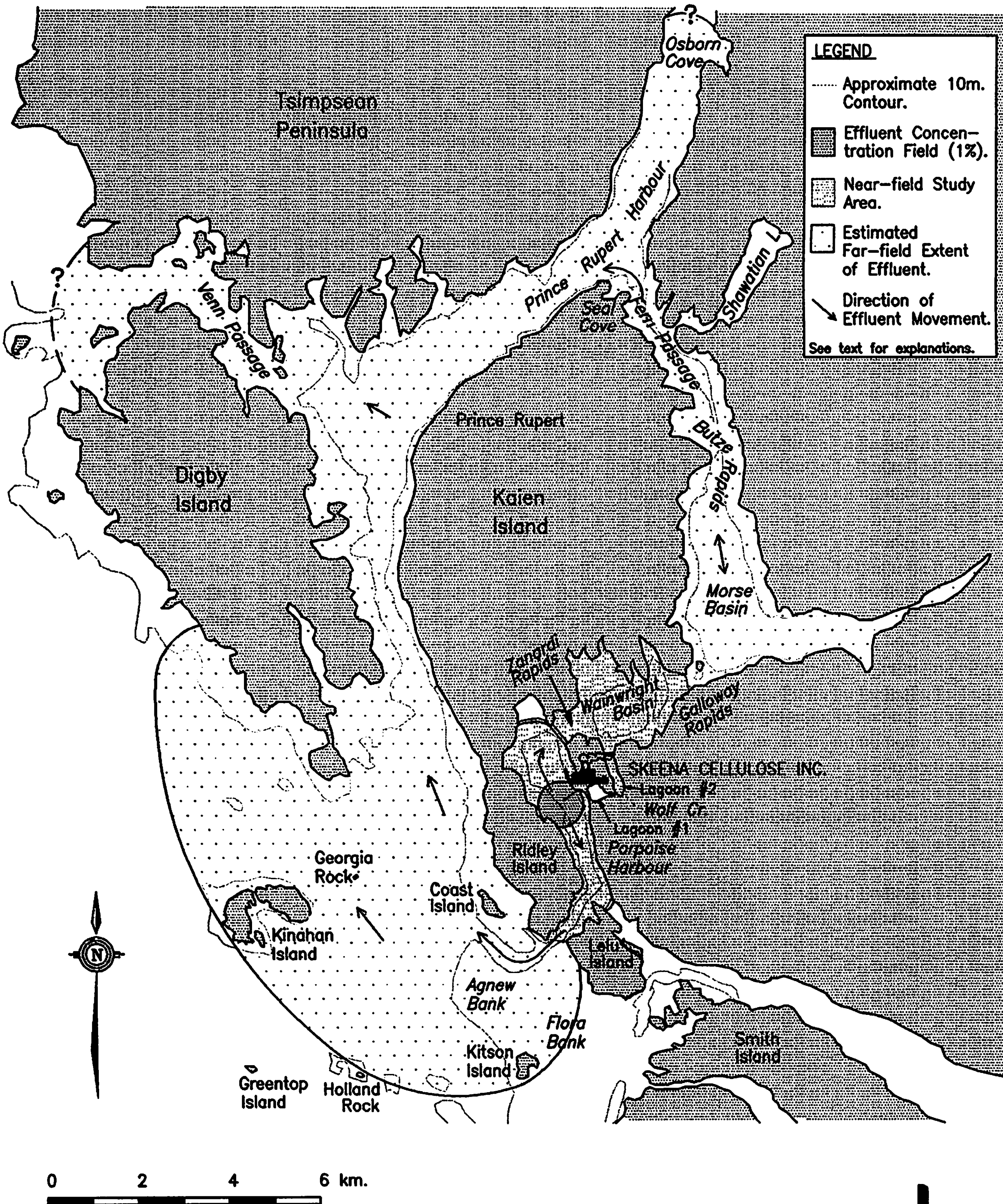
Source: ...ychuk et al., 199...

Figure 2.19 **Seabed and shoreline areas expected to be contacted by effluent south of the Skeena Cellulose Inc. pulpmill.**



Source: Hodgins and Knoll, 1990.

Figure 2.20 Estimated Near-field and Far-field Dispersion of Effluent from the Skeena Cellulose Inc. Pulpmill.



hcl

SC-559: SK-PLUME.DWG

Figure 3.1 PHYSICAL HABITAT COMPONENTS : PORPOISE HARBOUR

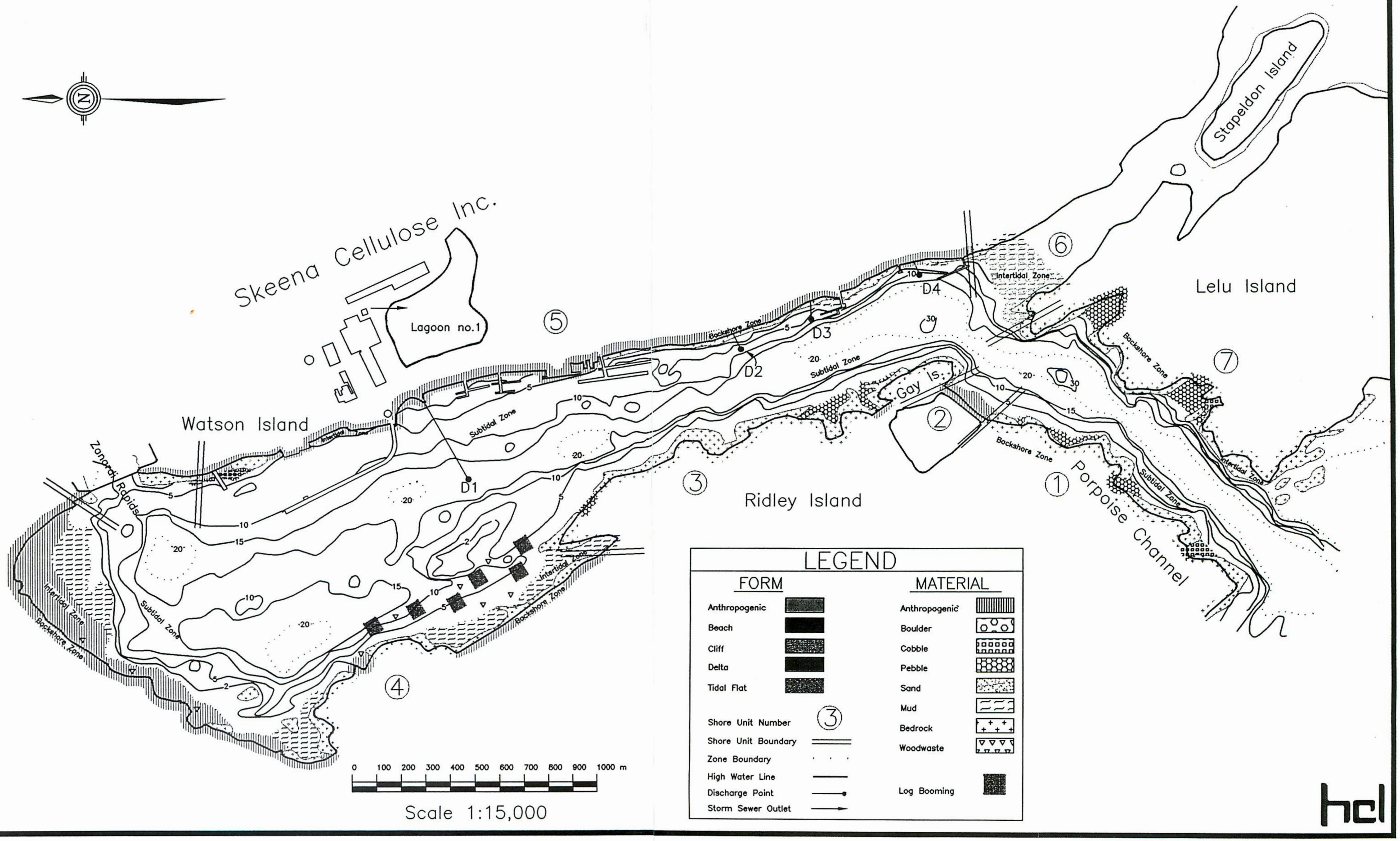


Figure 3.2 BIOLOGICAL HABITAT COMPONENTS: PORPOISE HARBOUR

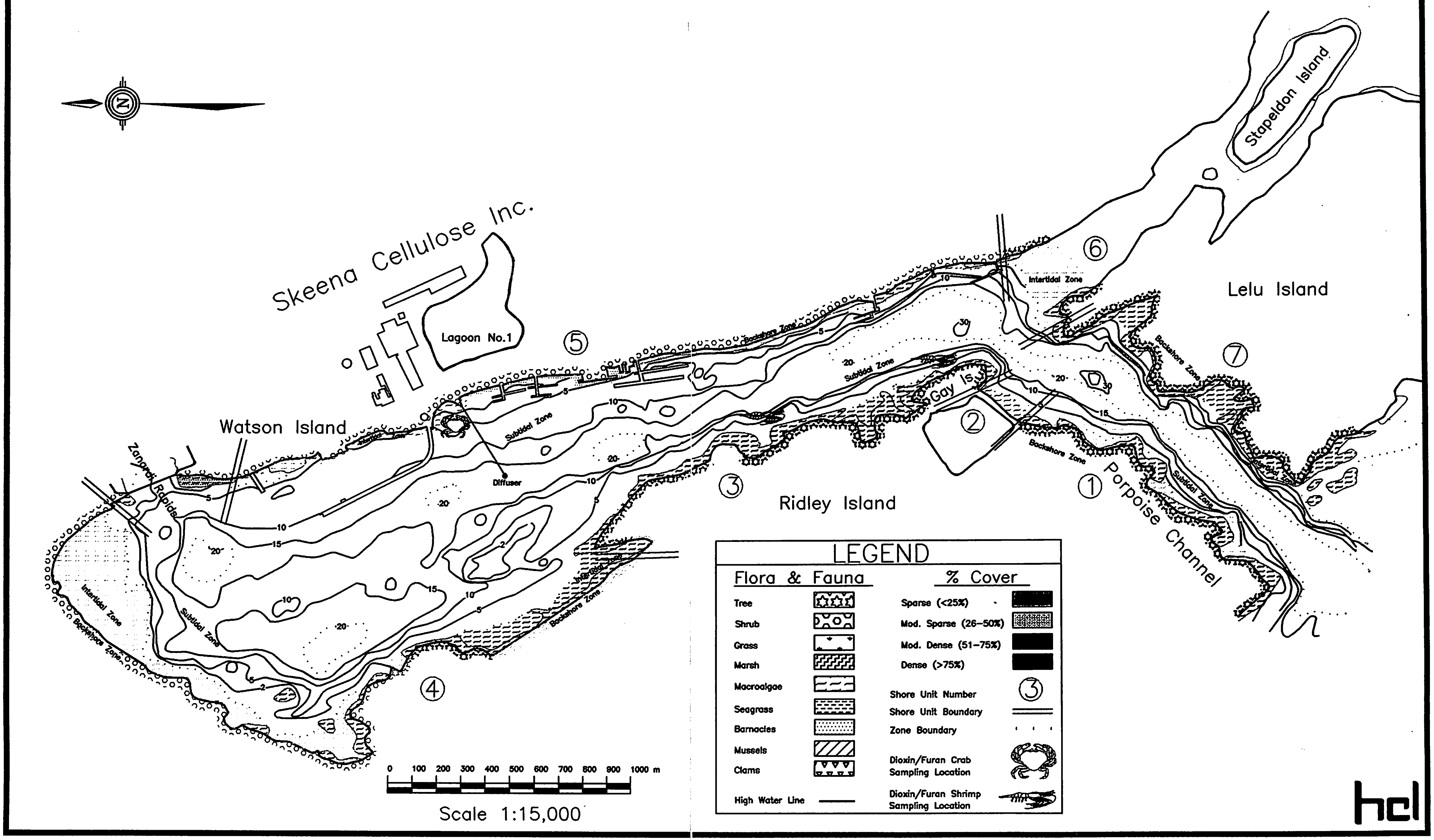


Figure 3.3 PHYSICAL HABITAT COMPONENTS : WAINWRIGHT BASIN

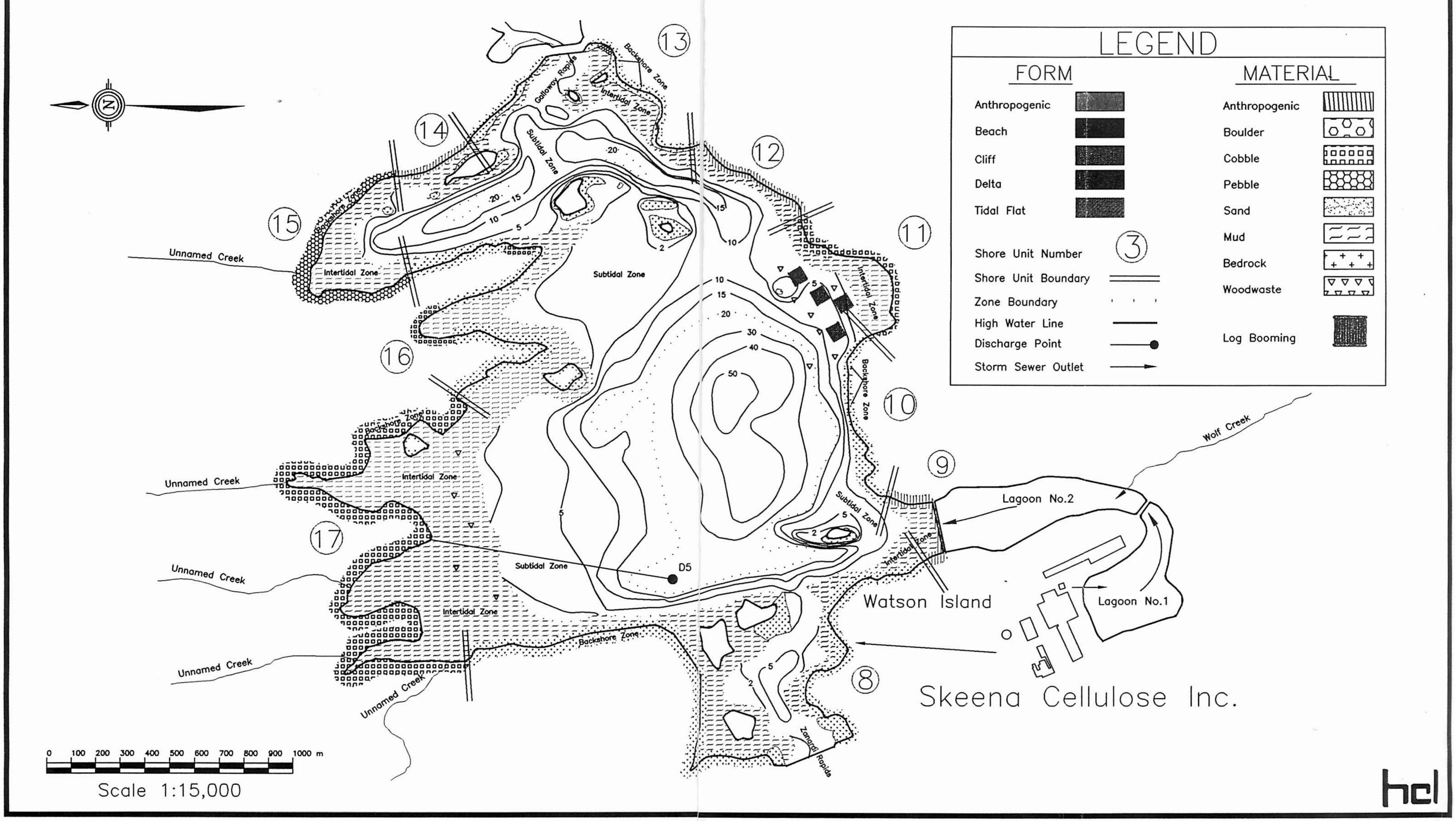


Figure 3.4 BIOLOGICAL HABITAT COMPONENTS : WAINWRIGHT BASIN

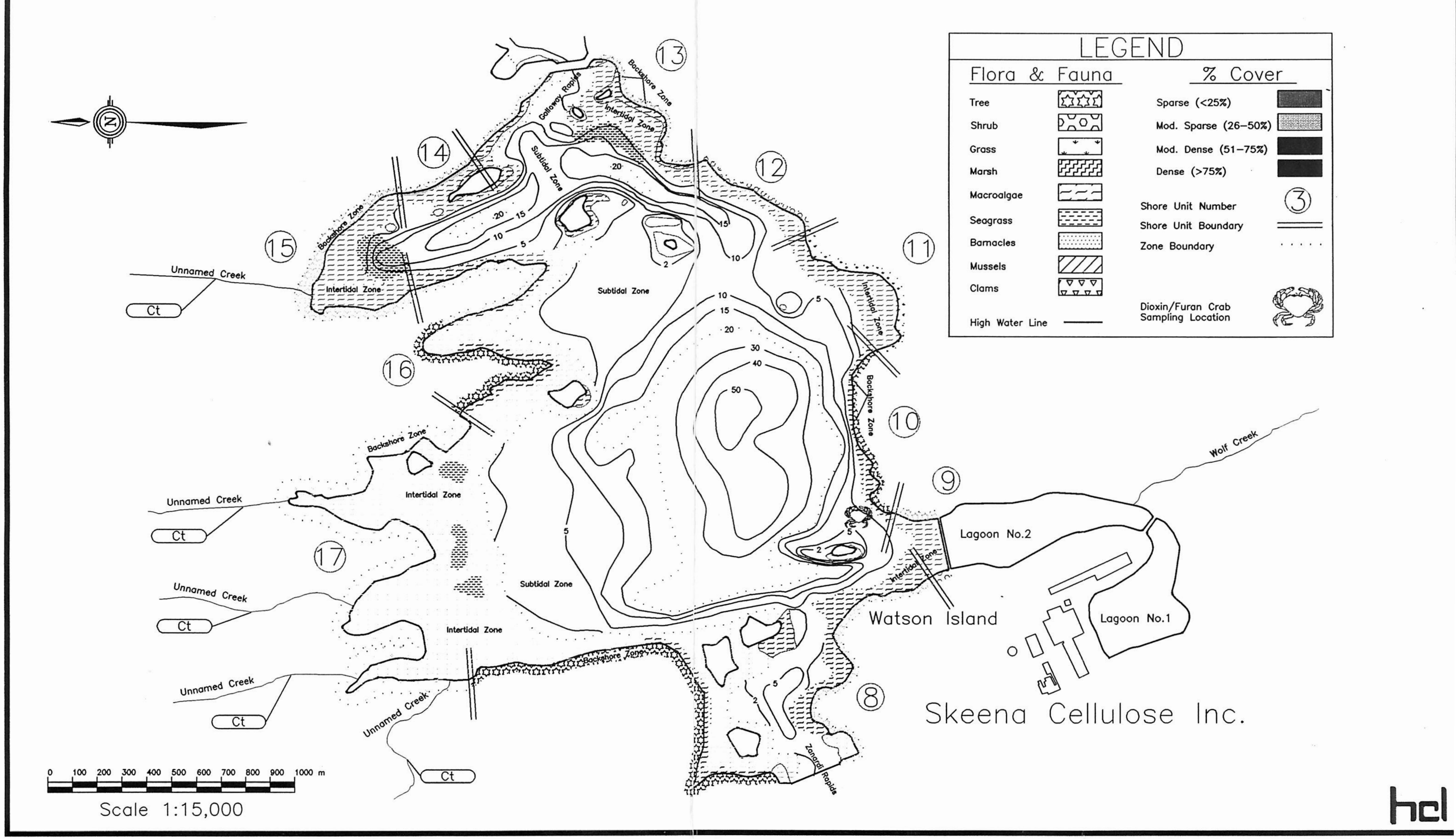
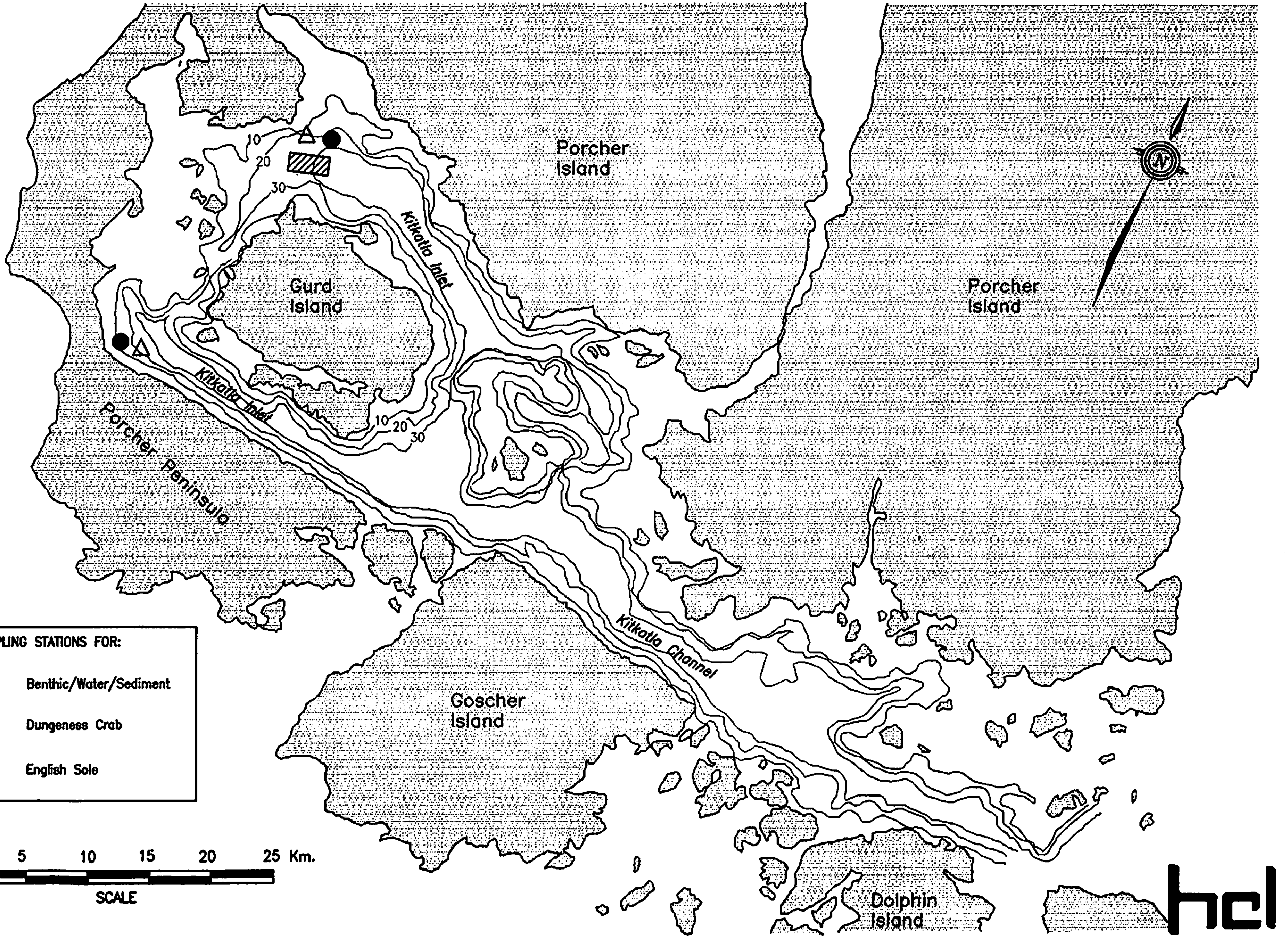
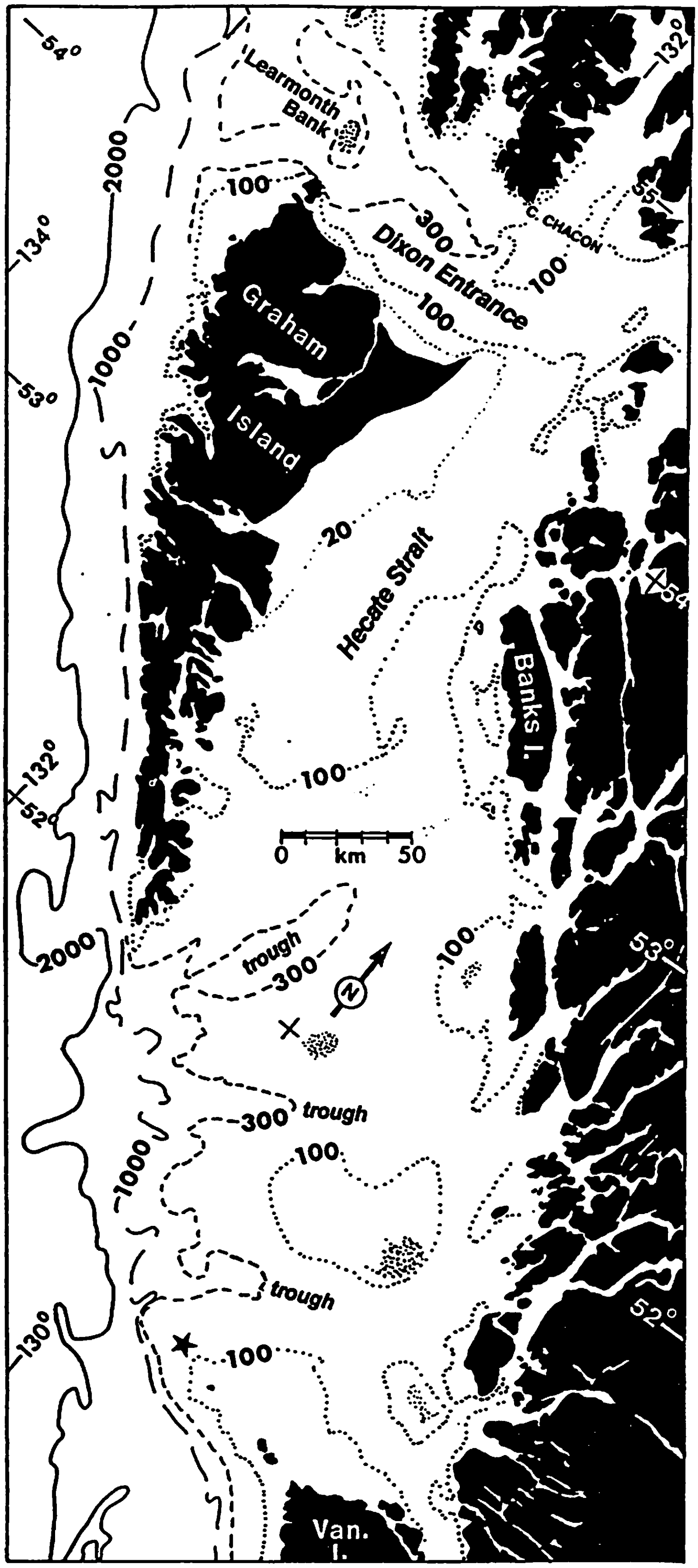


Figure 3.5 Reference Area for First Cycle EEM Studies, Kitkatla Inlet, Including Sampling Stations.



SC-559: KITKATLA.DWG

Figure 4.1 **The major geographical features of Hecate Strait.**



Source: Thomson, 1981.

Figure 4.2 **Major and minor Department of Fisheries and Oceans Statistical Areas for the Pacific coast.**

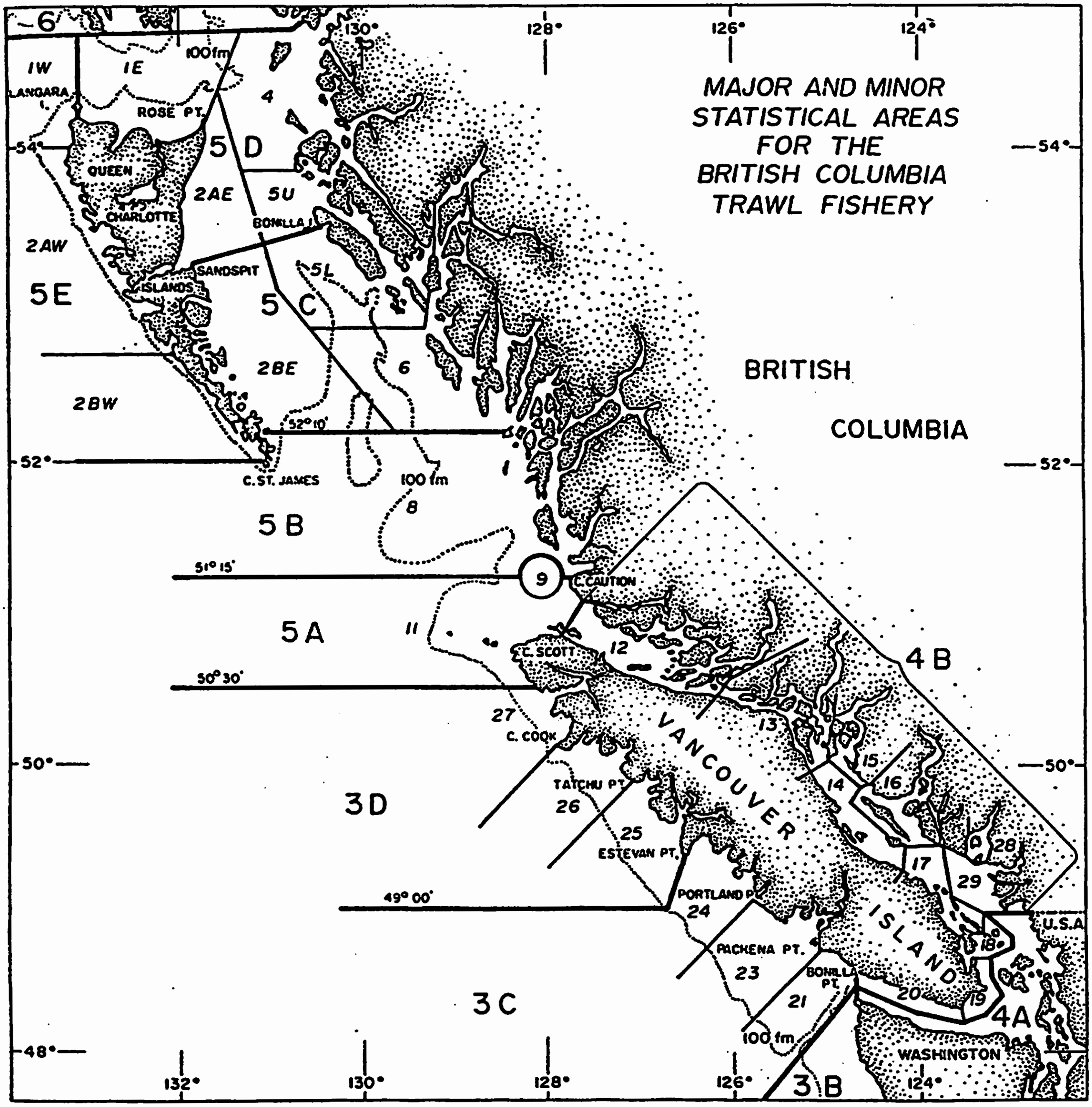
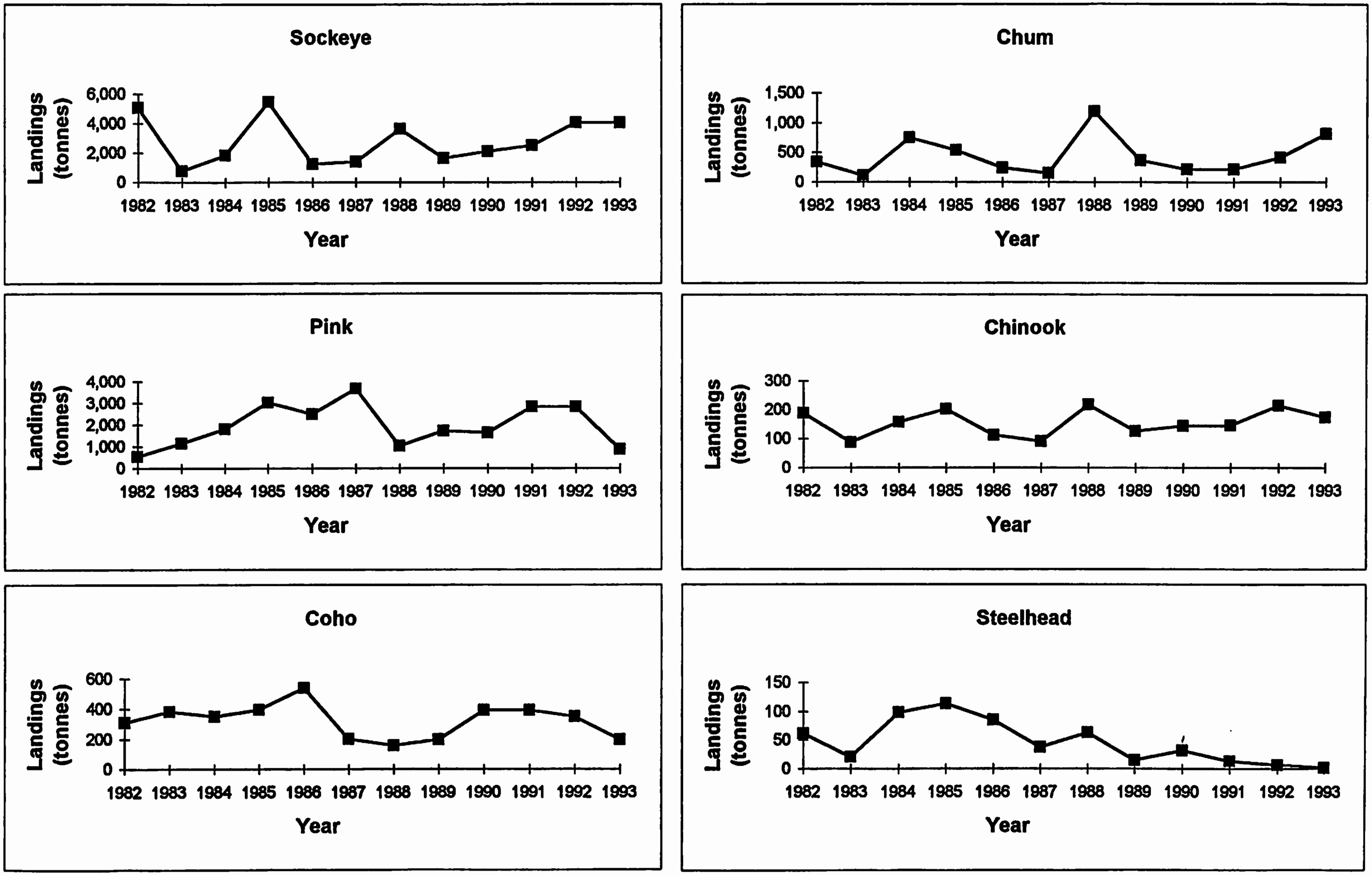
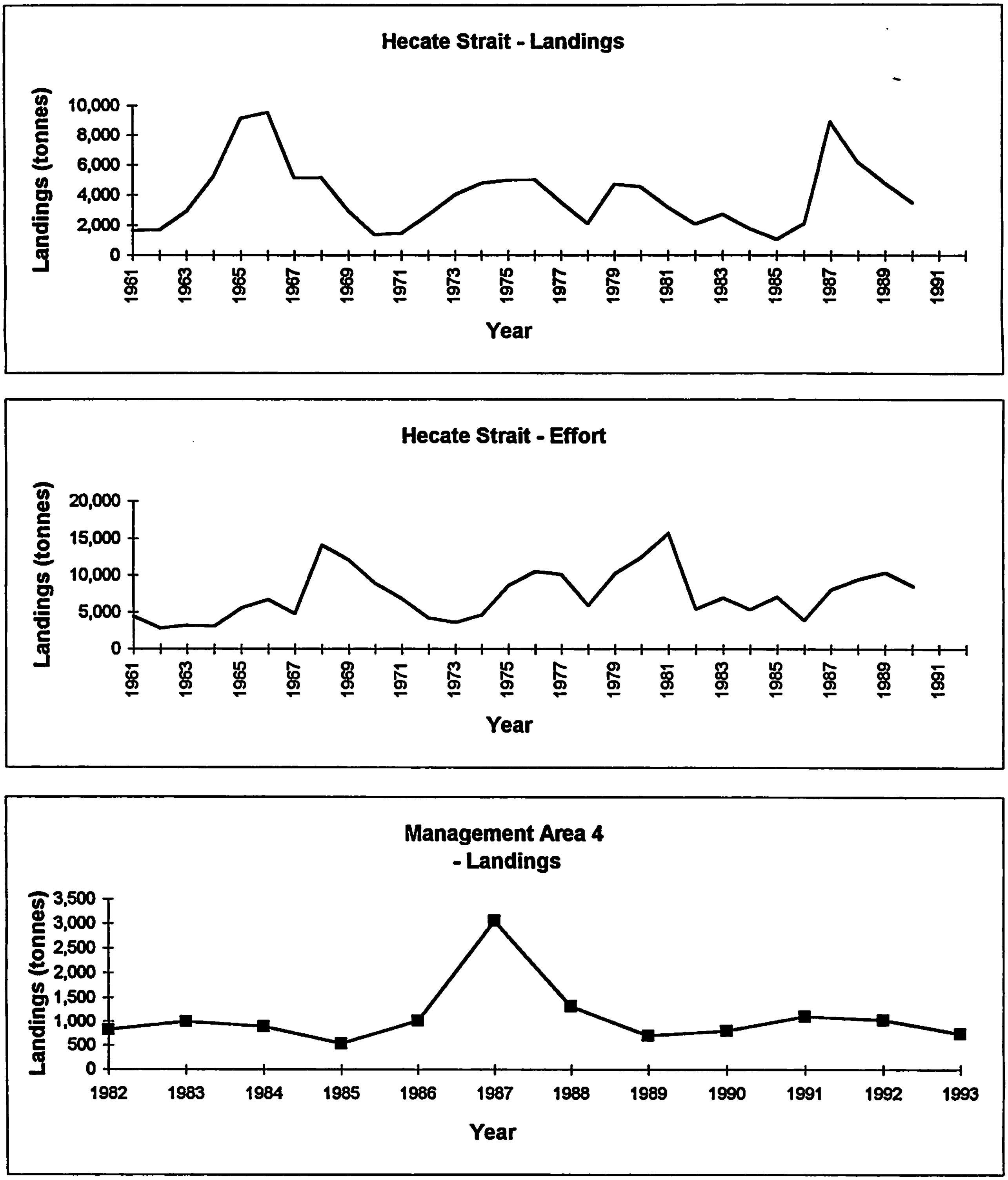


Figure 4.3 **Commercial landings of sockeye, pink, coho, chum, and chinook salmon and steelhead trout in Management Area 4, Prince Rupert, 1982 to 1993 (1993 data are preliminary).**



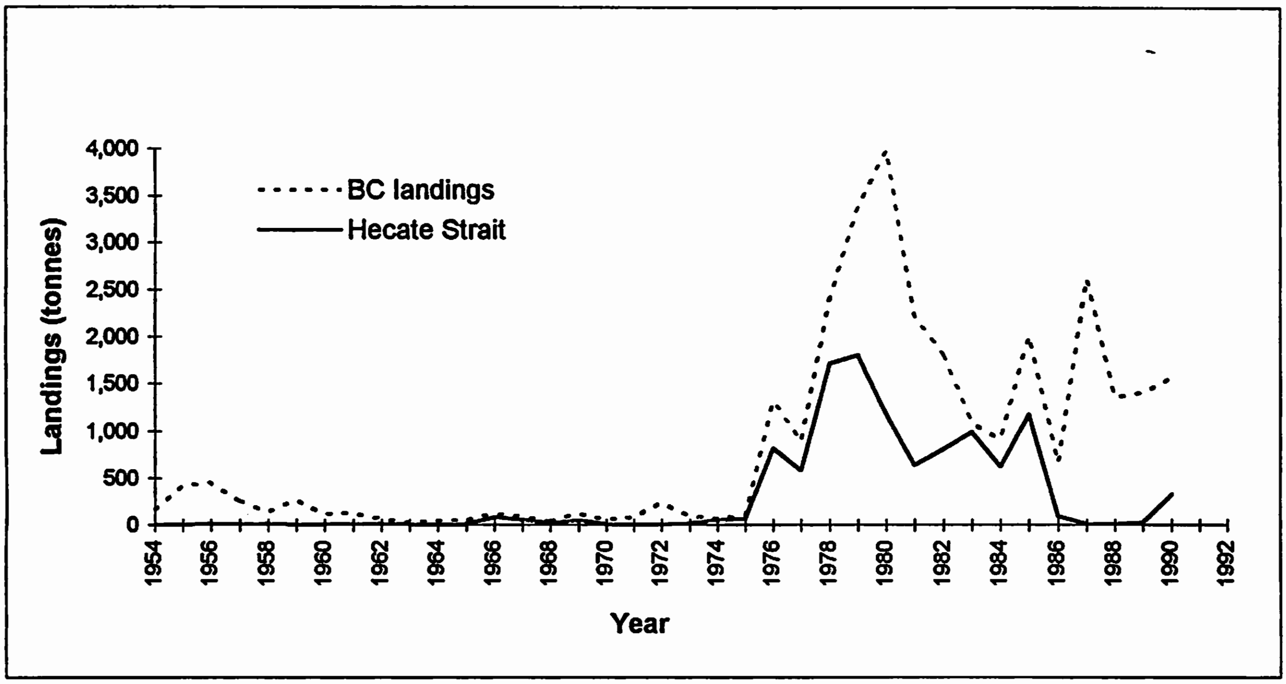
Source: DFO, Fisheries Data Management Unit.

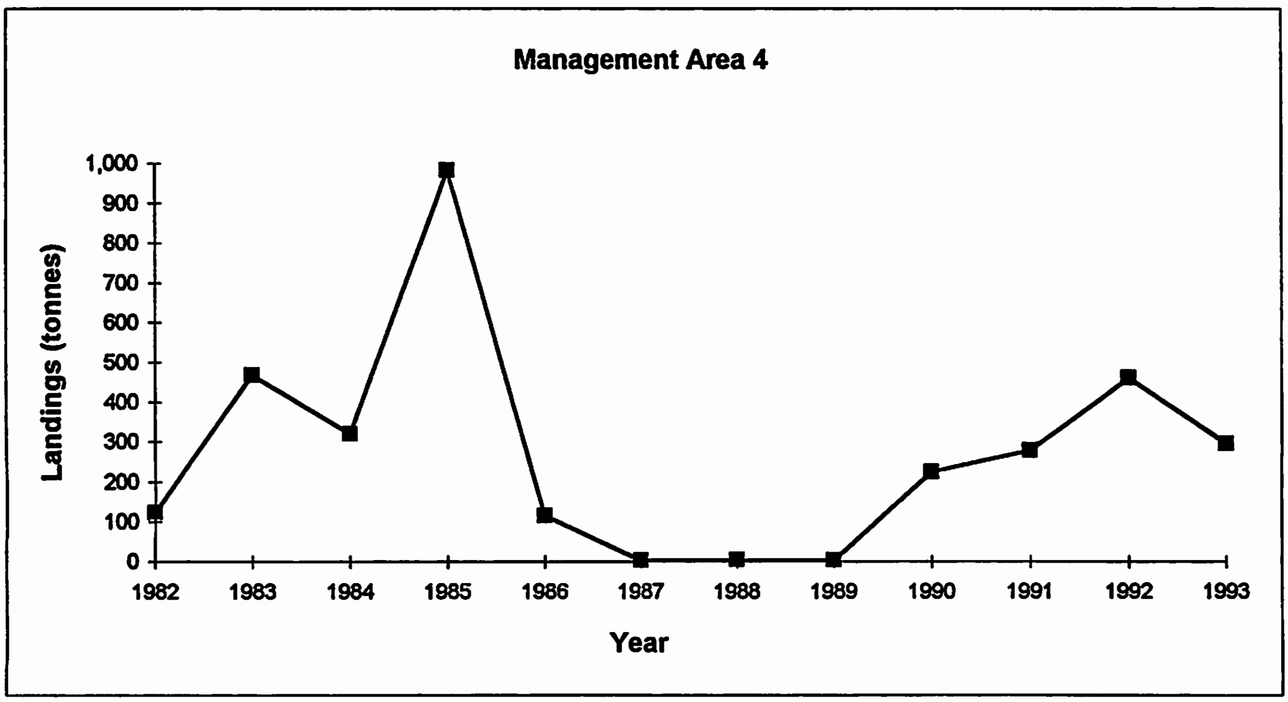
Figure 4.4 Pacific cod landings and effort from Hecate Strait, 1961 to 1990, and from Management Area 4, Prince Rupert, 1982 to 1993 (1993 data are preliminary).



Source: Tyler and Hand, 1992; DFO, Fisheries Data Management Unit.

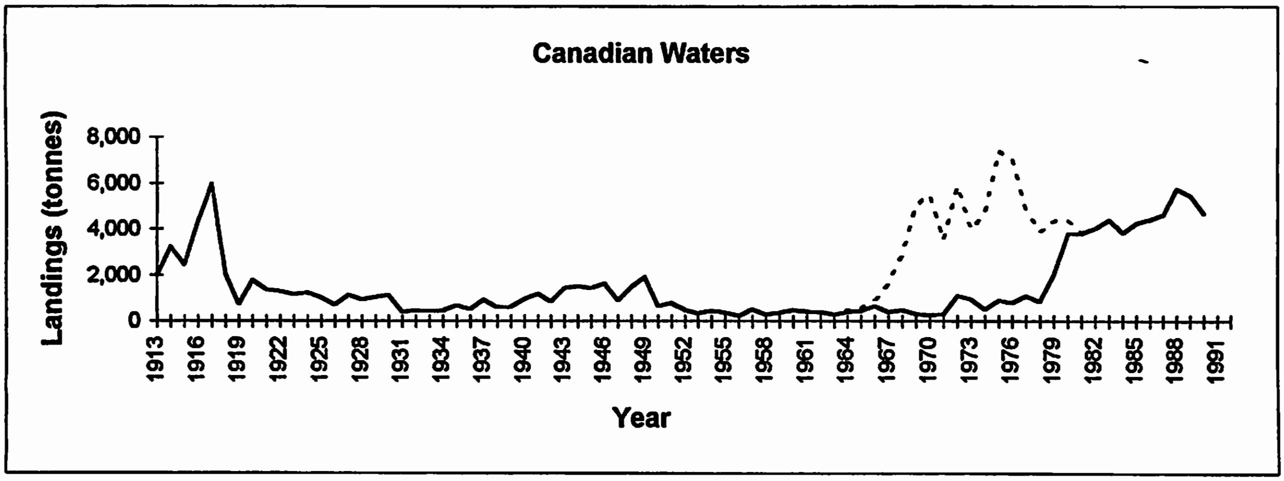
Figure 4.5 **Total landings of walleye pollock from British Columbia and Hecate Strait, 1954 to 1990, and from Management Area 4, Prince Rupert, 1982 to 1993 (1993 data are preliminary).**

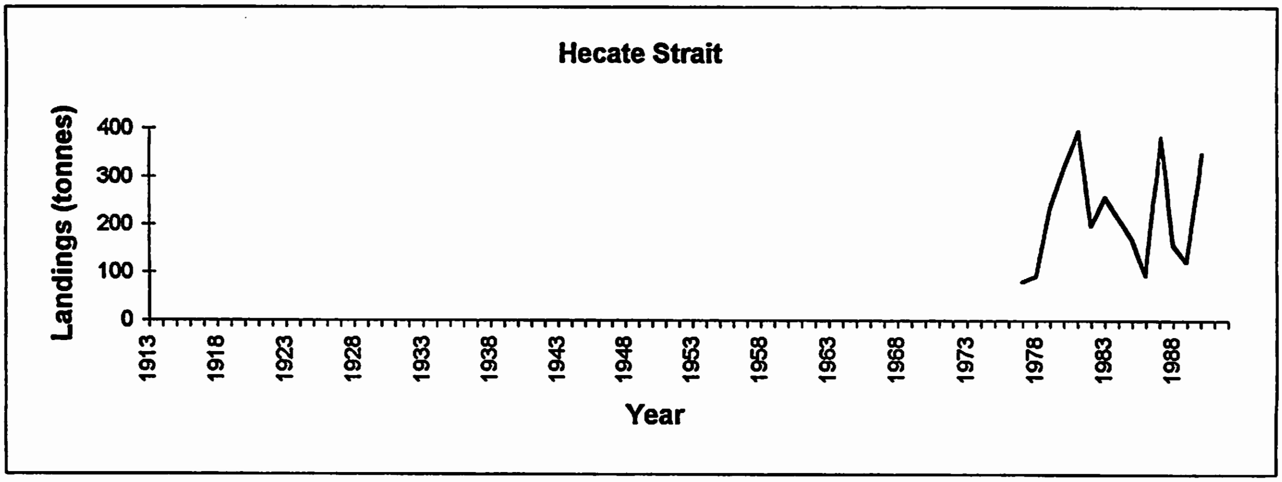


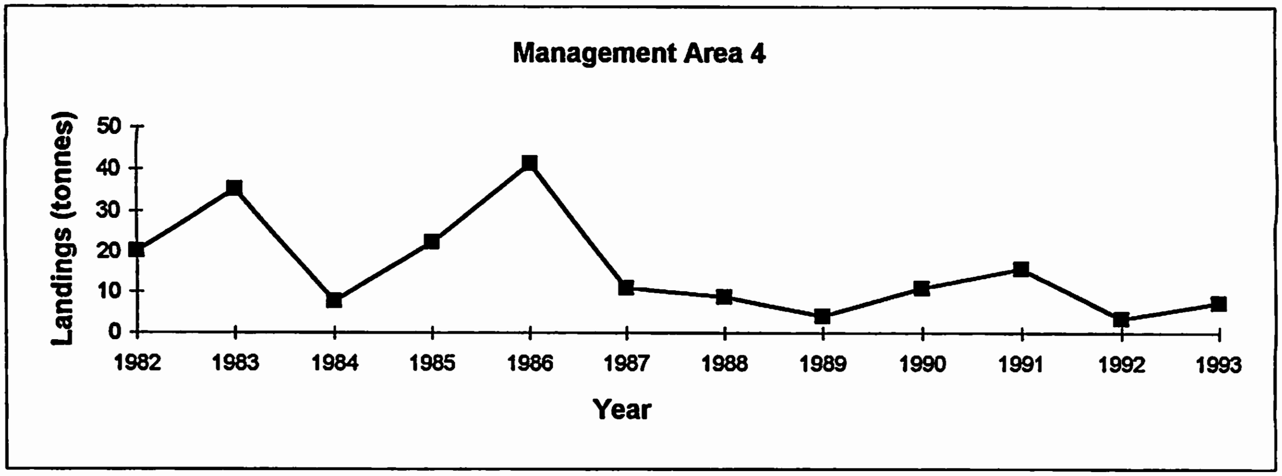


Source: Saunders, 1992a; DFO, Fisheries Data Management Unit.

Figure 4.6 **Domestic and foreign catch of sablefish in Canadian waters and Hecate Strait, 1913 to 1990, and landings from Management Area 4, Prince Rupert, 1982 to 1993 (1993 data are preliminary).**

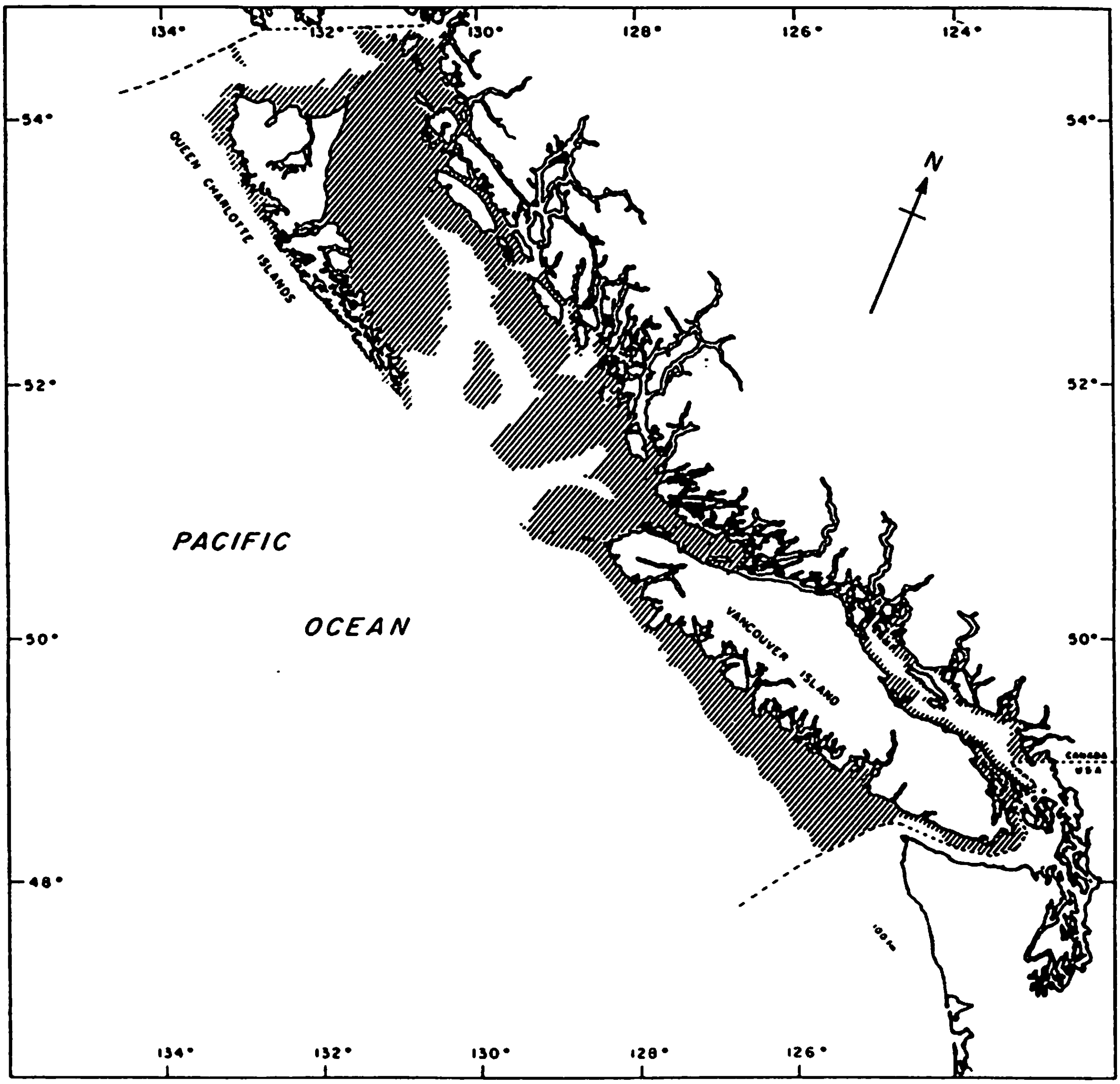






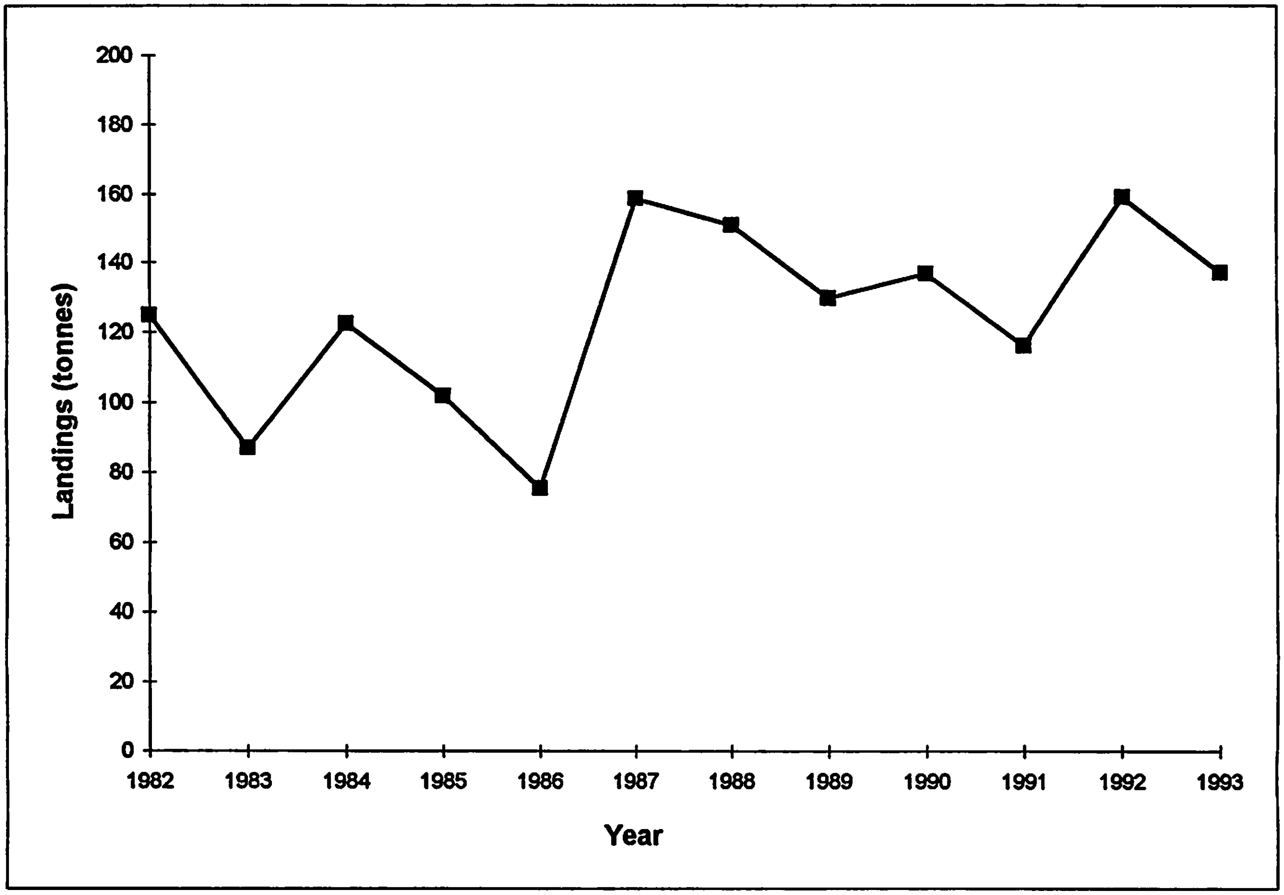
Source: Saunders and McFarlane, 1992; DFO, Fisheries Data Unit.

Figure 4.7 **Distribution of lingcod off the British Columbia coast.**



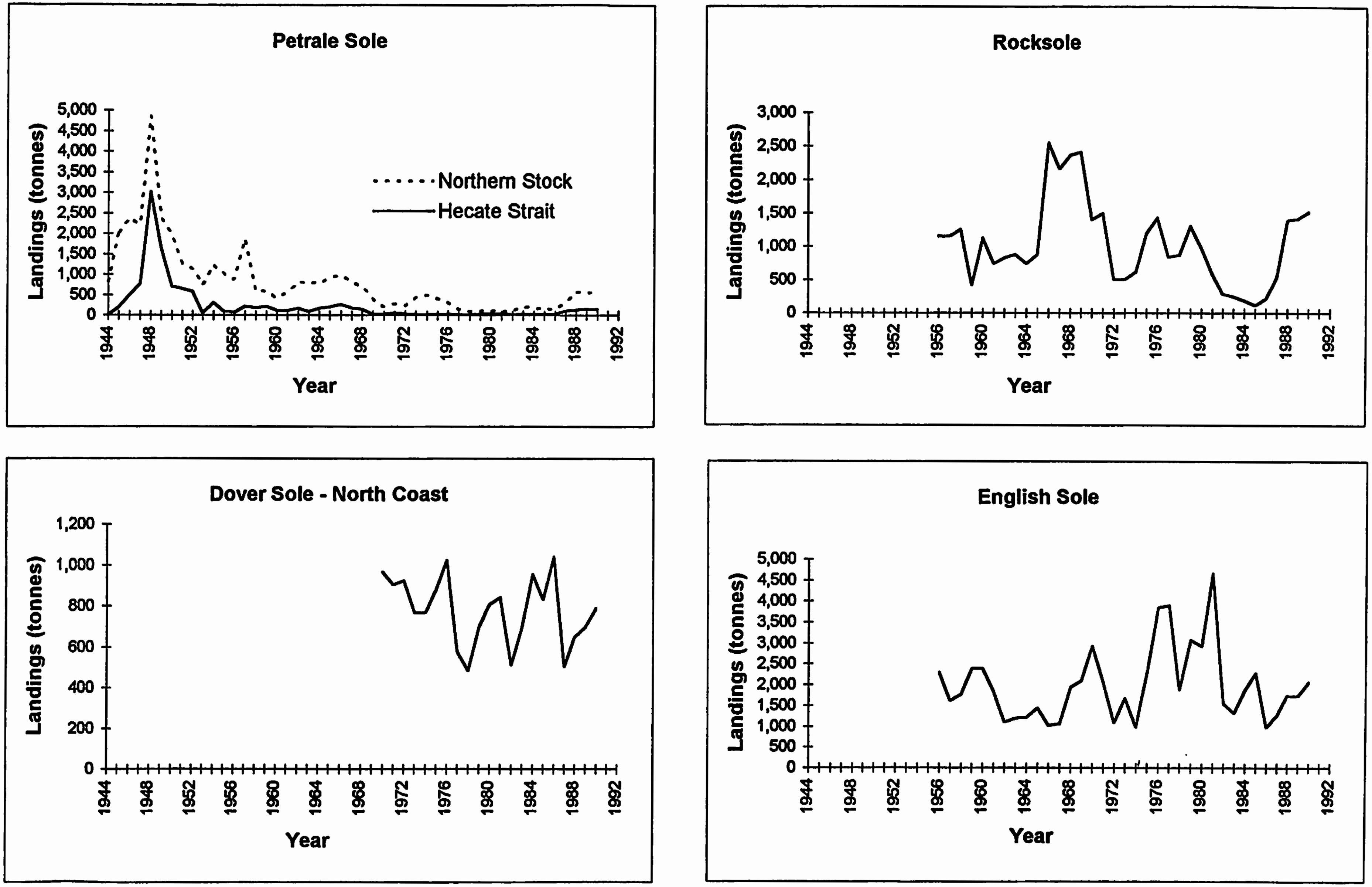
Source: Cass *et al.*, 1990.

Figure 4.8 **Commercial lingcod landings in Management Area 4, Prince Rupert, 1982 to 1993 (1993 data are preliminary).**



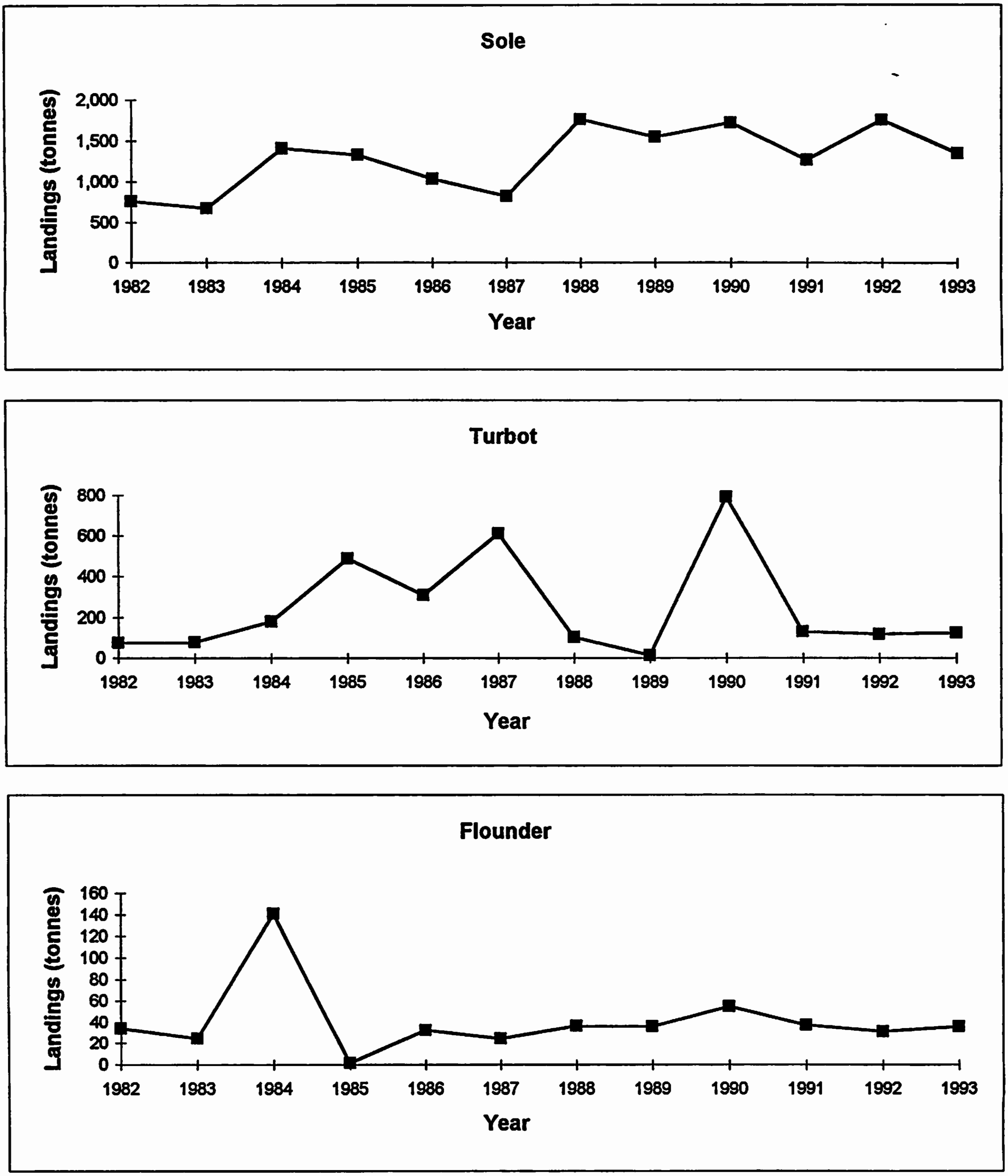
Source: Richards and Yamanaka, 1992; DFO, Fisheries Data Management Unit.

Figure 4.9 **Landings of sole species from Hecate Strait and vicinity, 1944 to 1990.**



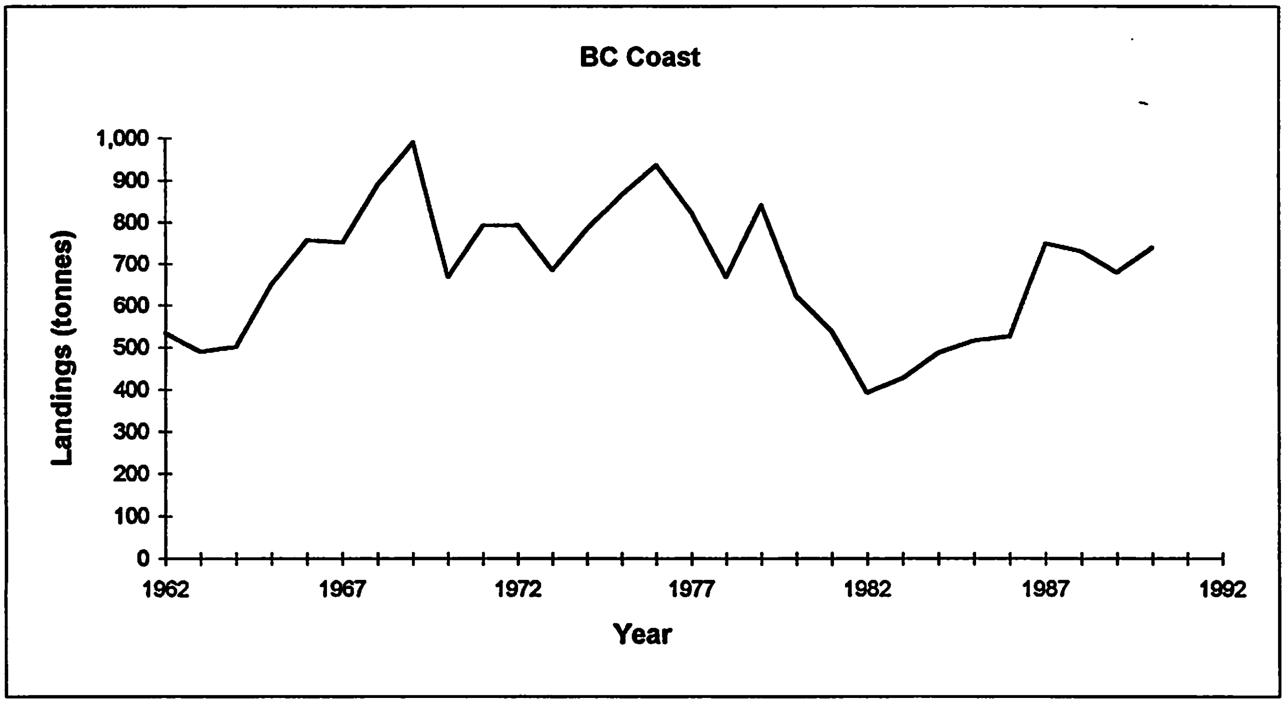
Source: Fargo, 1992.

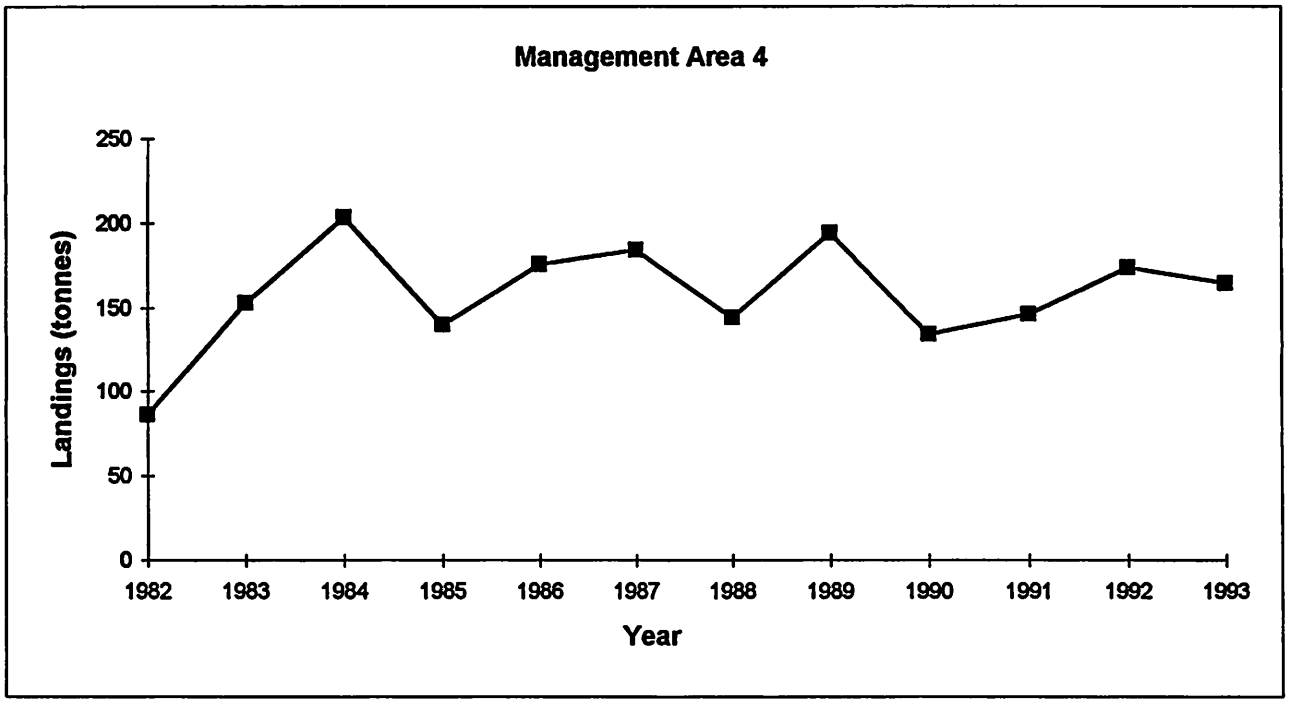
Figure 4.10 Landings of flatfish species (excluding halibut) in Management Area 4, Prince Rupert, 1982 to 1993 (1993 data are preliminary).



Source: DFO, Fisheries Data Management Unit.

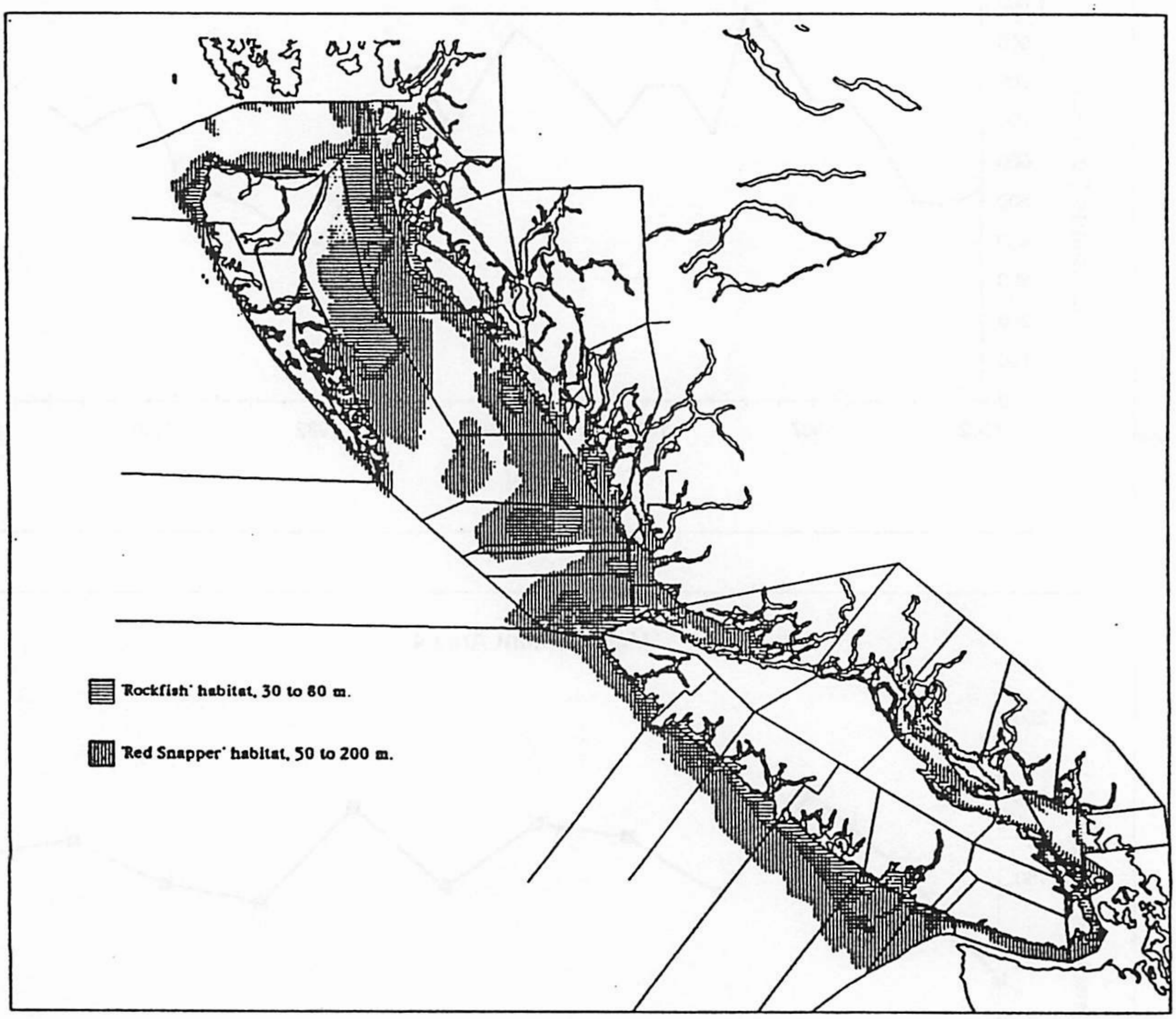
Figure 4.11 Pacific halibut landings from the British Columbia coast, 1962 to 1990, and from Management Area 4, Prince Rupert, 1982 to 1993 (1993 data are preliminary).





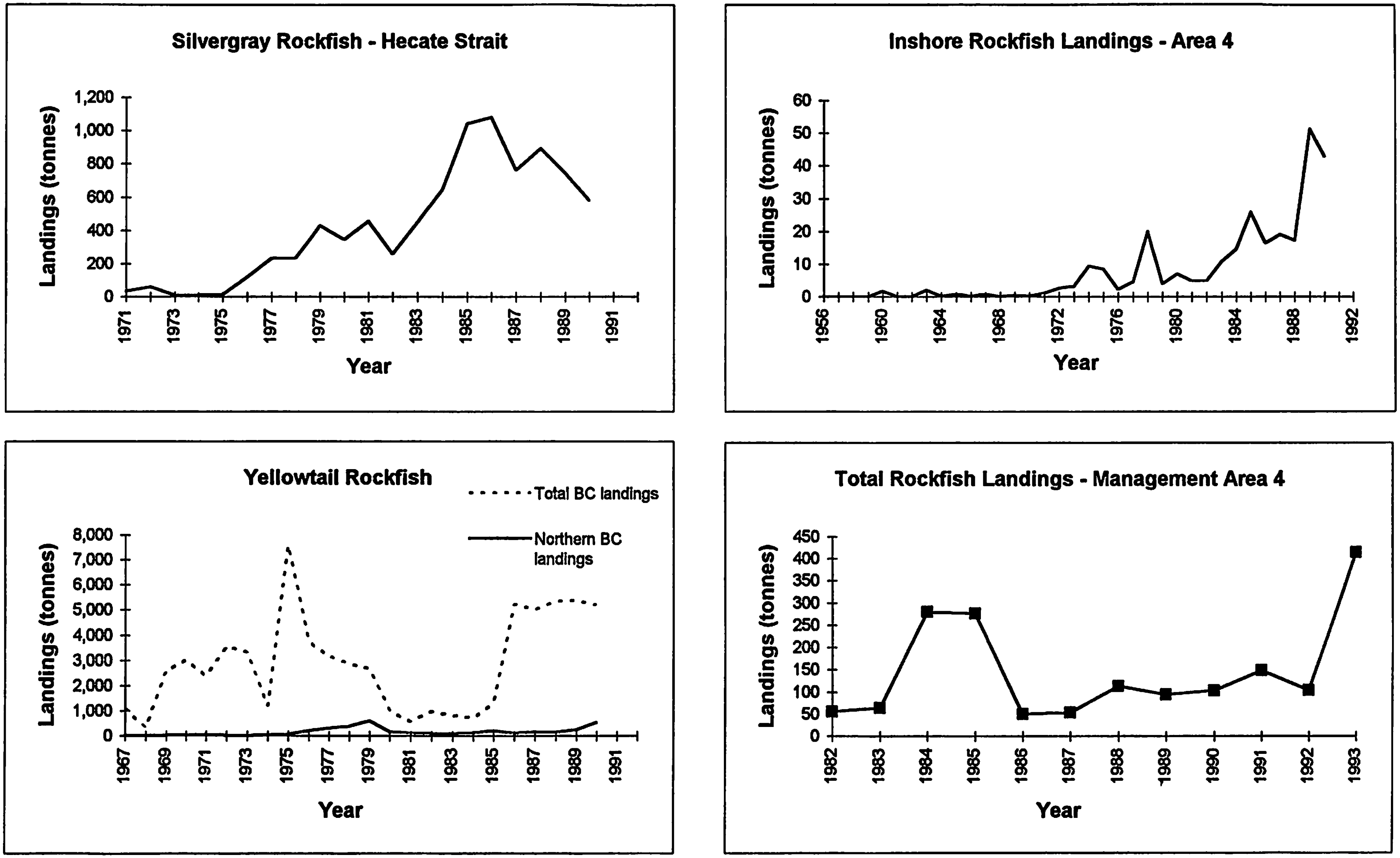
Source: Leaman, 1992b; DFO, Fisheries Data Management Unit.

Figure 4.12 Distribution of available yelloweye rockfish (red snapper) and inshore rockfish habitat off the British Columbia coast.



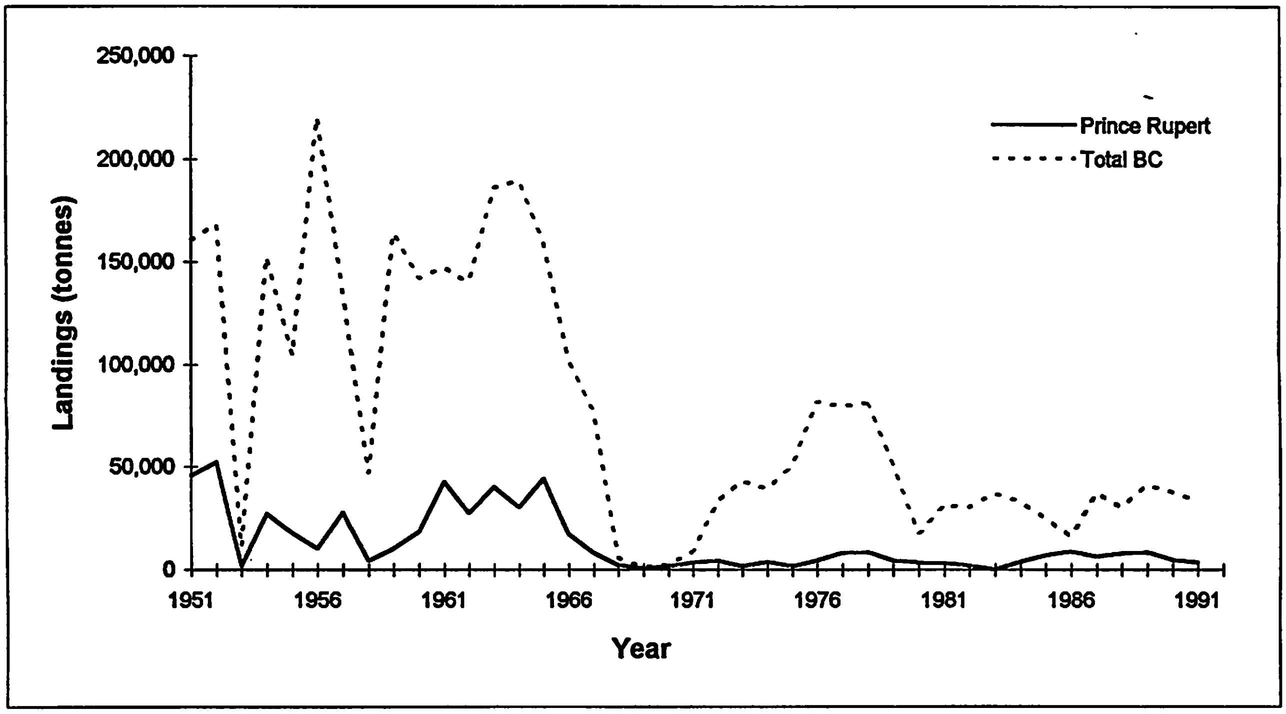
Source: Yamanaka and Richards, 1992.

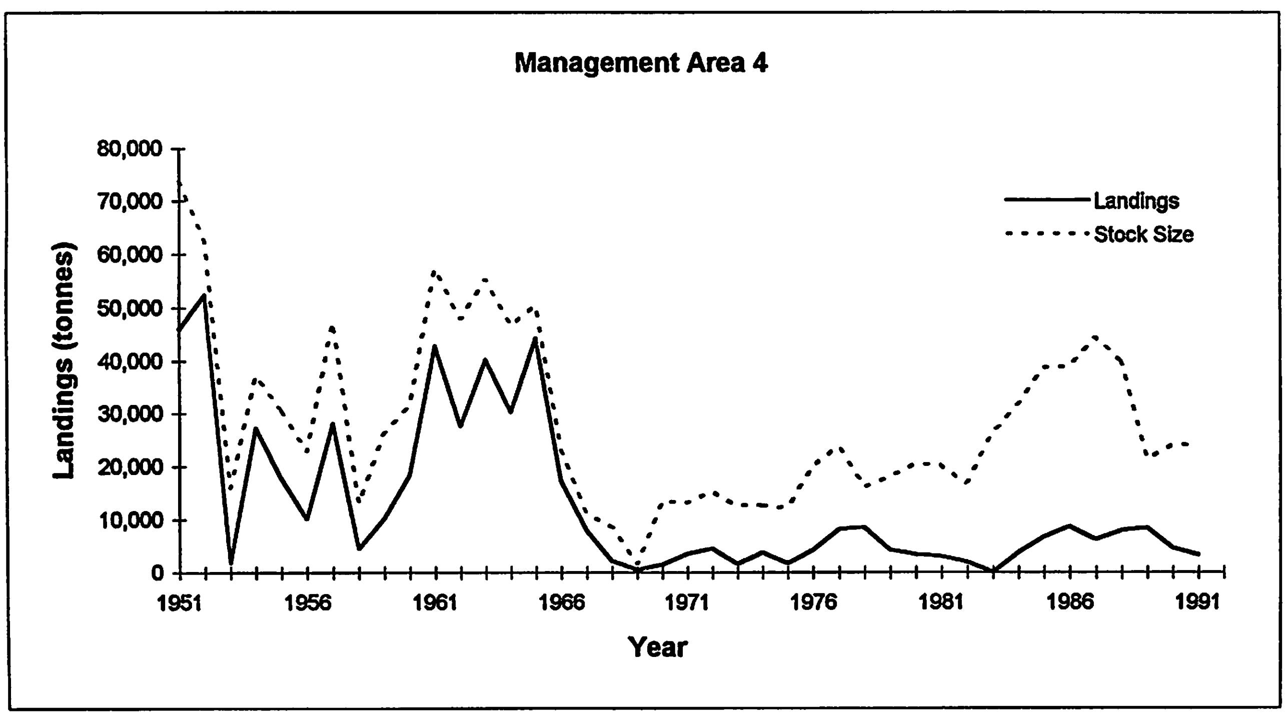
Figure 4.13 **Commercial landings of silvergray, yellowtail, and inshore rockfish in north coast waters, 1956 to 1993 (1993 data are preliminary).**



Source: Yamanaka and Richards, 1992; DFO, Fisheries Data Management Unit.

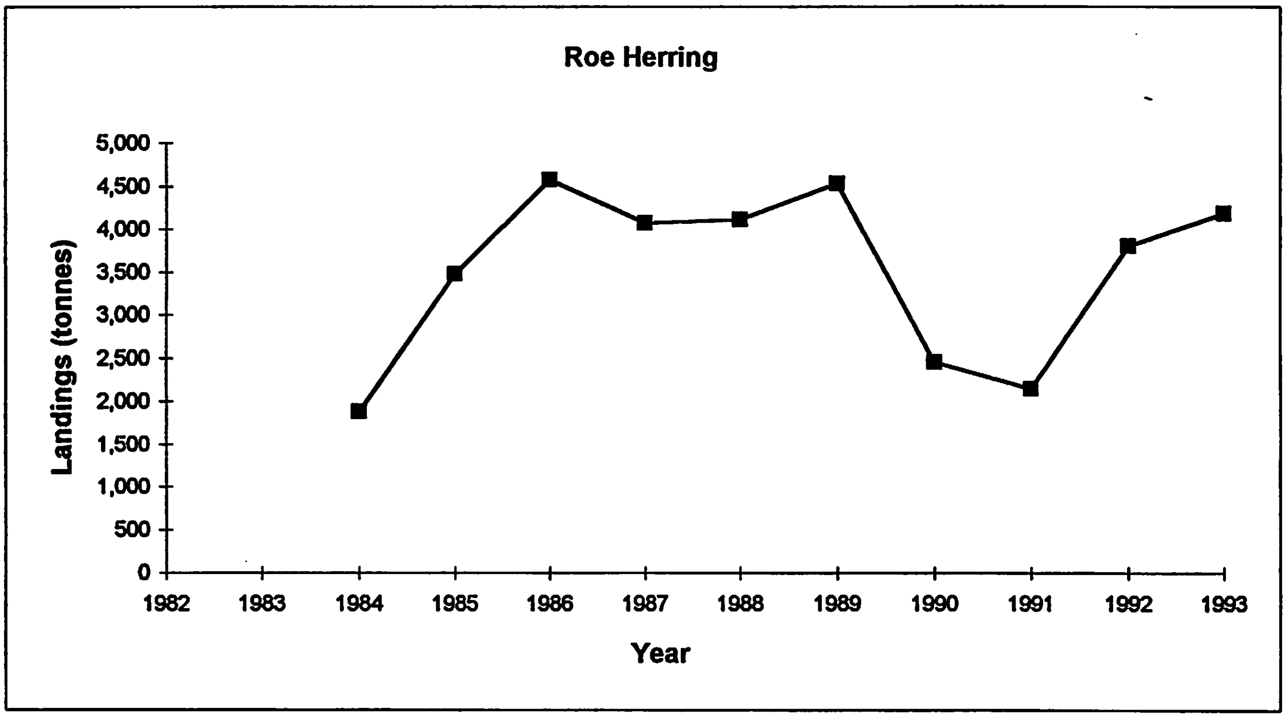
Figure 4.14 Herring commercial landings in British Columbia, and landings and stock size in Management Area 4, 1951 to 1990.

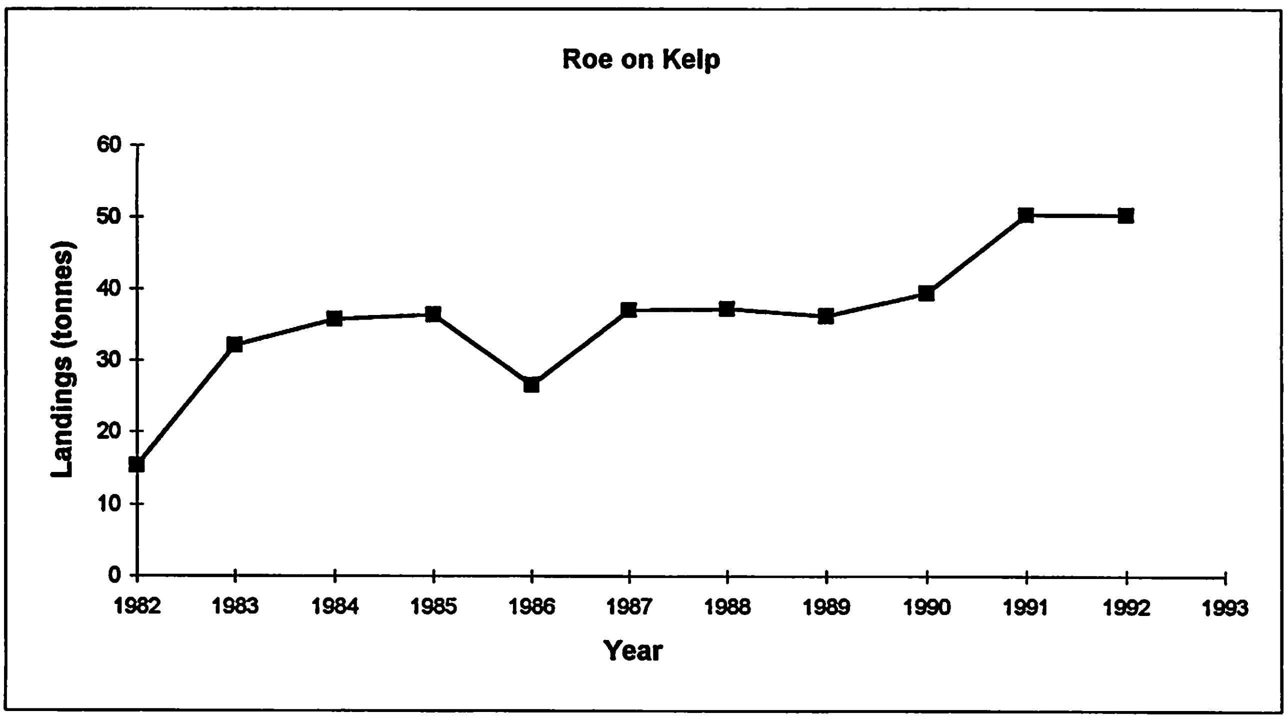




Source: Haist and Schweigert, 1992.

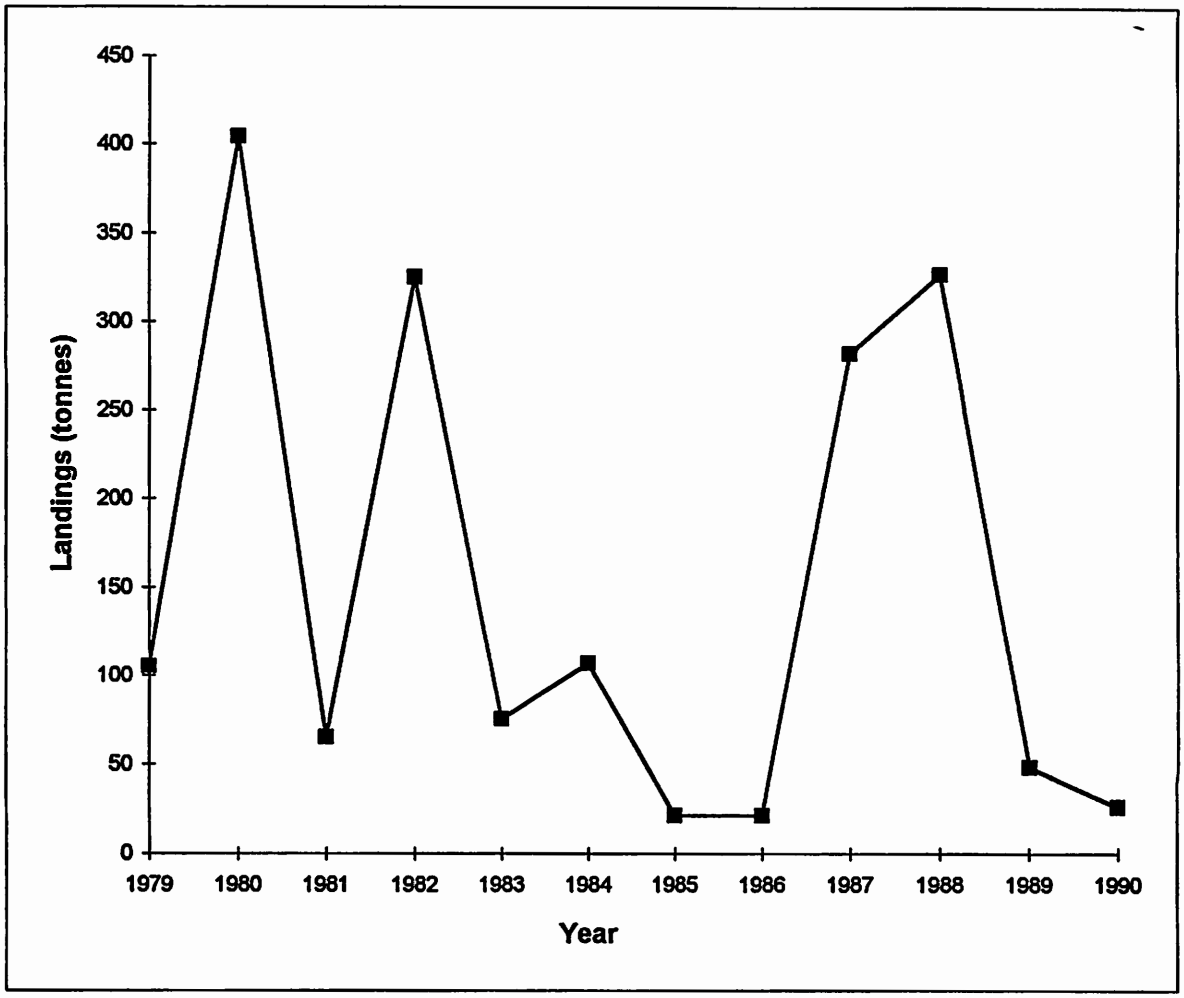
Figure 4.15 **Roe herring and "roe on kelp" harvest in Management Area 4, Prince Rupert, 1982 to 1993 (1993 data are preliminary).**





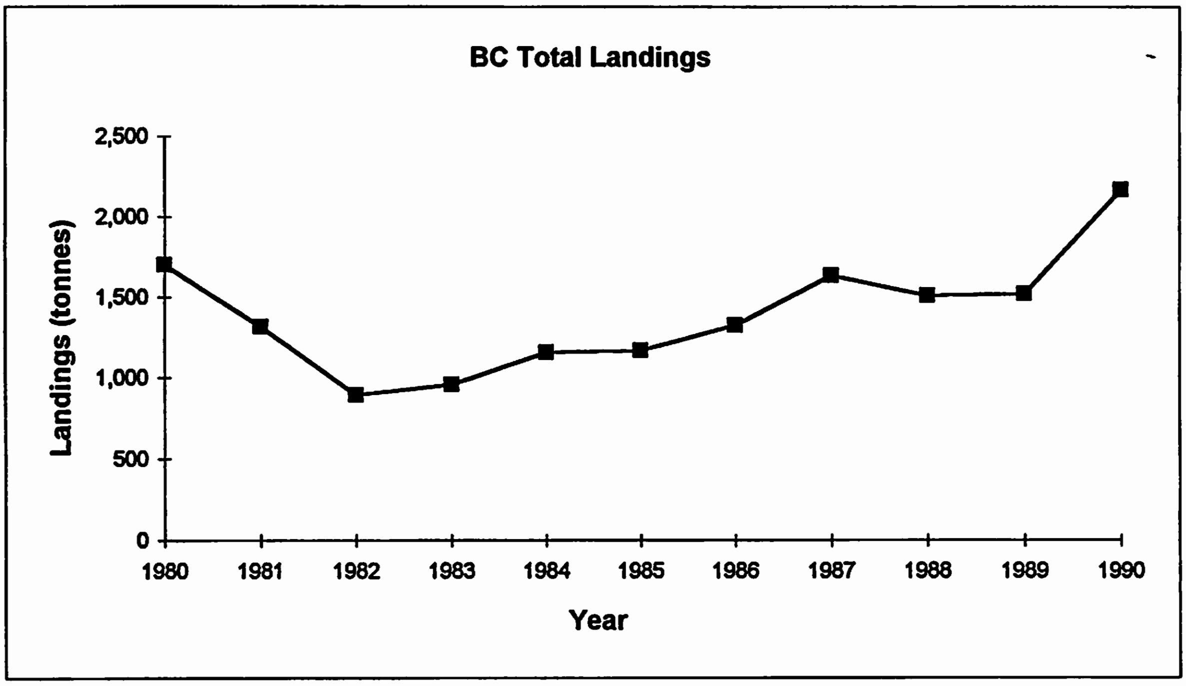
Source: DFO, Fisheries Data Management Unit.

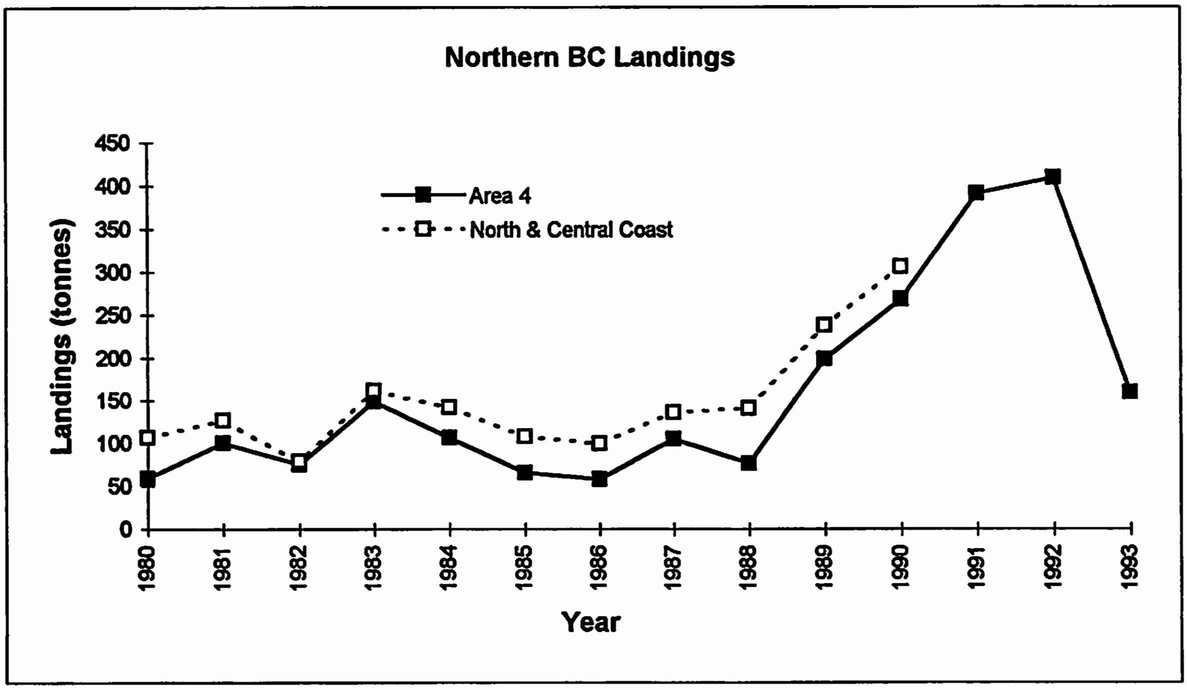
Figure 4.16 **Dogfish landings for Hecate Strait, 1979 to 1990.**



Source: Thomson *et al*., 1992.

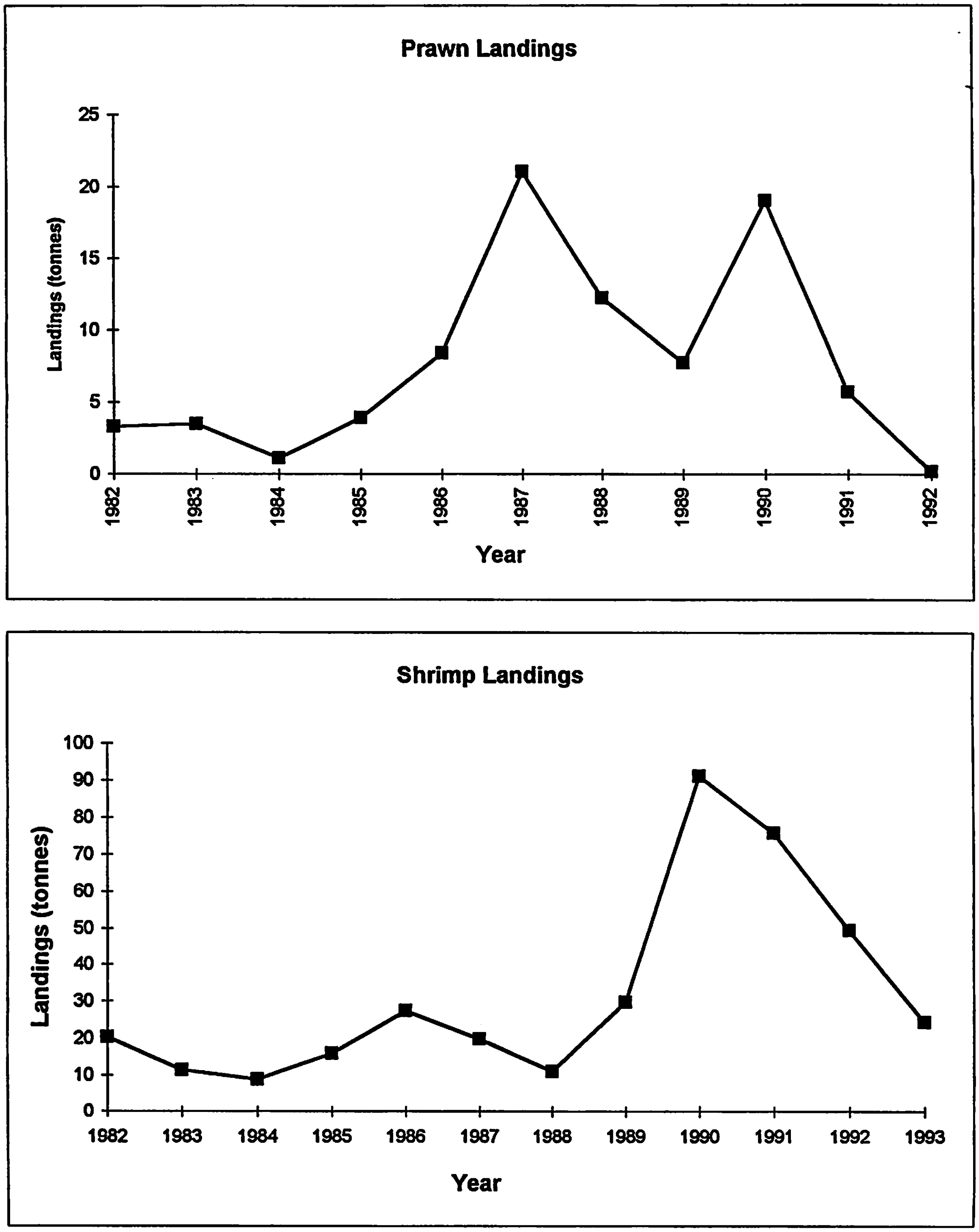
Figure 4.17 **Commercial crab landings (aggregate of all species) for British Columbia, north and central coast, and Management Area 4, Prince Rupert, 1980 to 1993 (1992 and 1993 data are preliminary).**





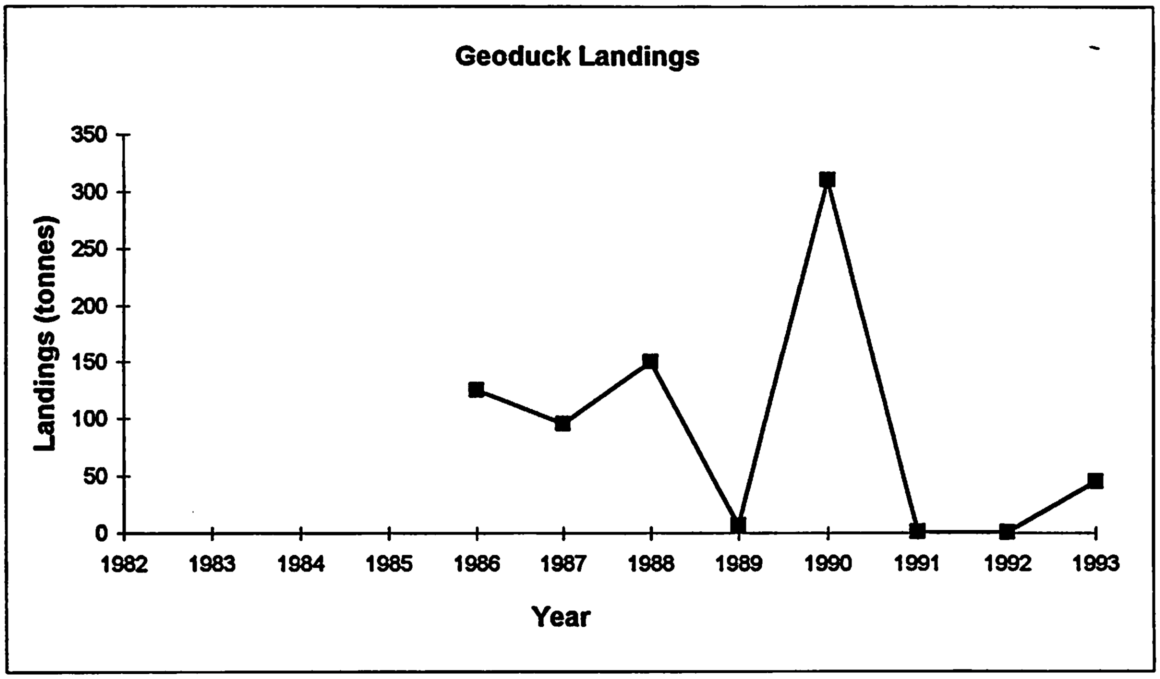
Source: Joyce, 1992; DFO, Fisheries Data Management Unit.

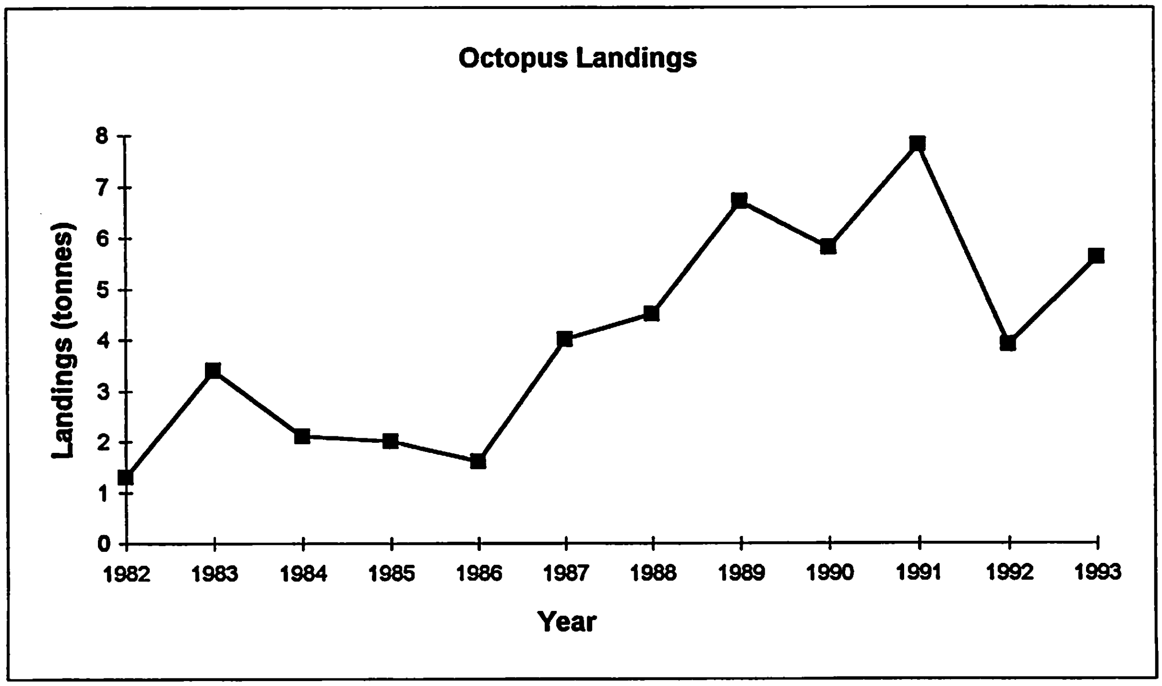
Figure 4.18 Prawn and shrimp landings in Management Area 4, Prince Rupert, 1982 to 1993 (1992 and 1993 data are preliminary).



Source: DFO, Fisheries Data Management Unit.

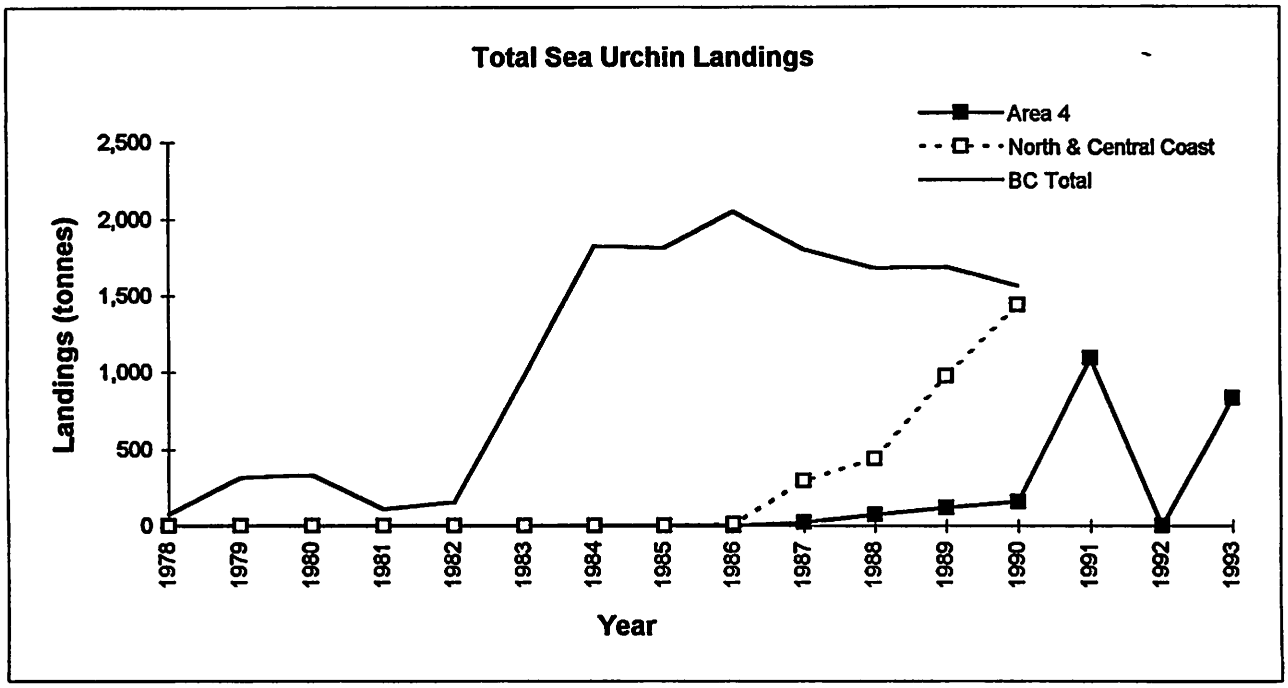
Figure 4.19 **Geoduck and octopus landings in British Columbia, northern British Columbia, and Prince Rupert waters, 1982 to 1993 (1992 and 1993 data are preliminary).**

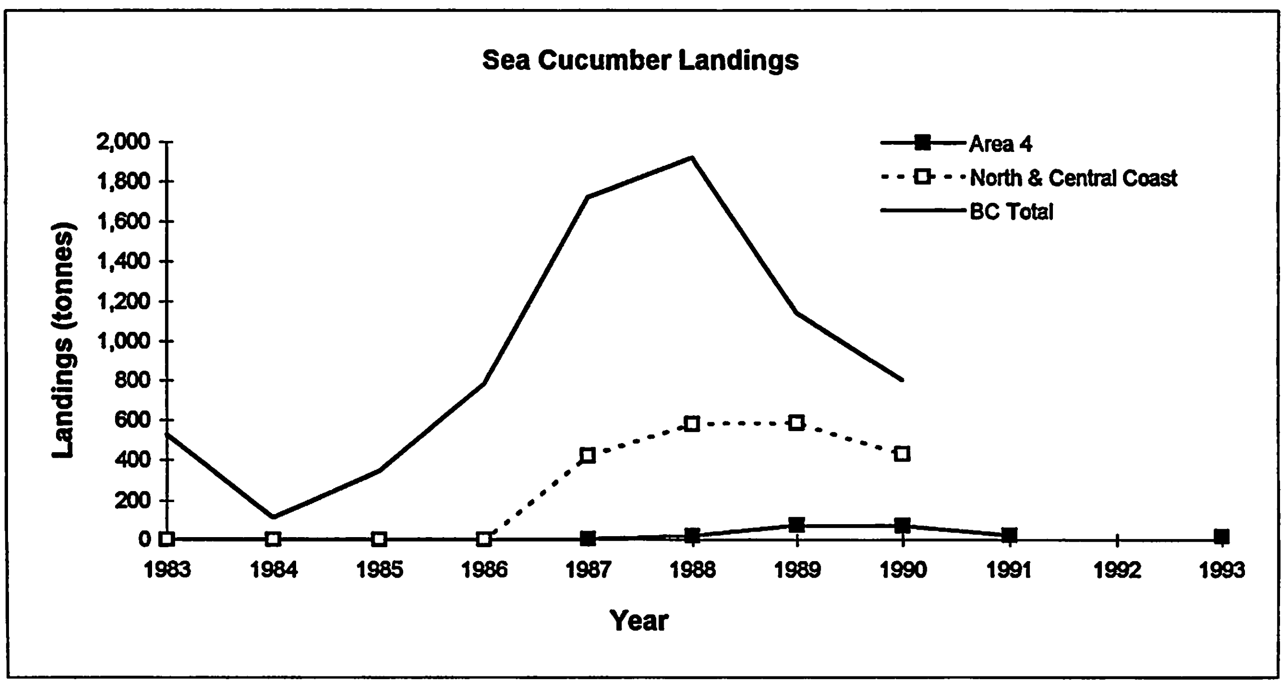




Source: DFO, Fisheries Data Management Unit.

Figure 4.20 **Sea urchin (green and red) and sea cucumber landings in British Columbia, northern British Columbia, and Prince Rupert waters, 1978 to 1993 (1992 and 1993 are preliminary).**





Source: Harbo, 1992; Harbo and Thomas, 1992; Heizer and Thomas, 1992; DFO, Fisheries Data Management Unit.

Figure 4.21 Department of Fisheries and Oceans; Statistical Area 4A - Skeena River.

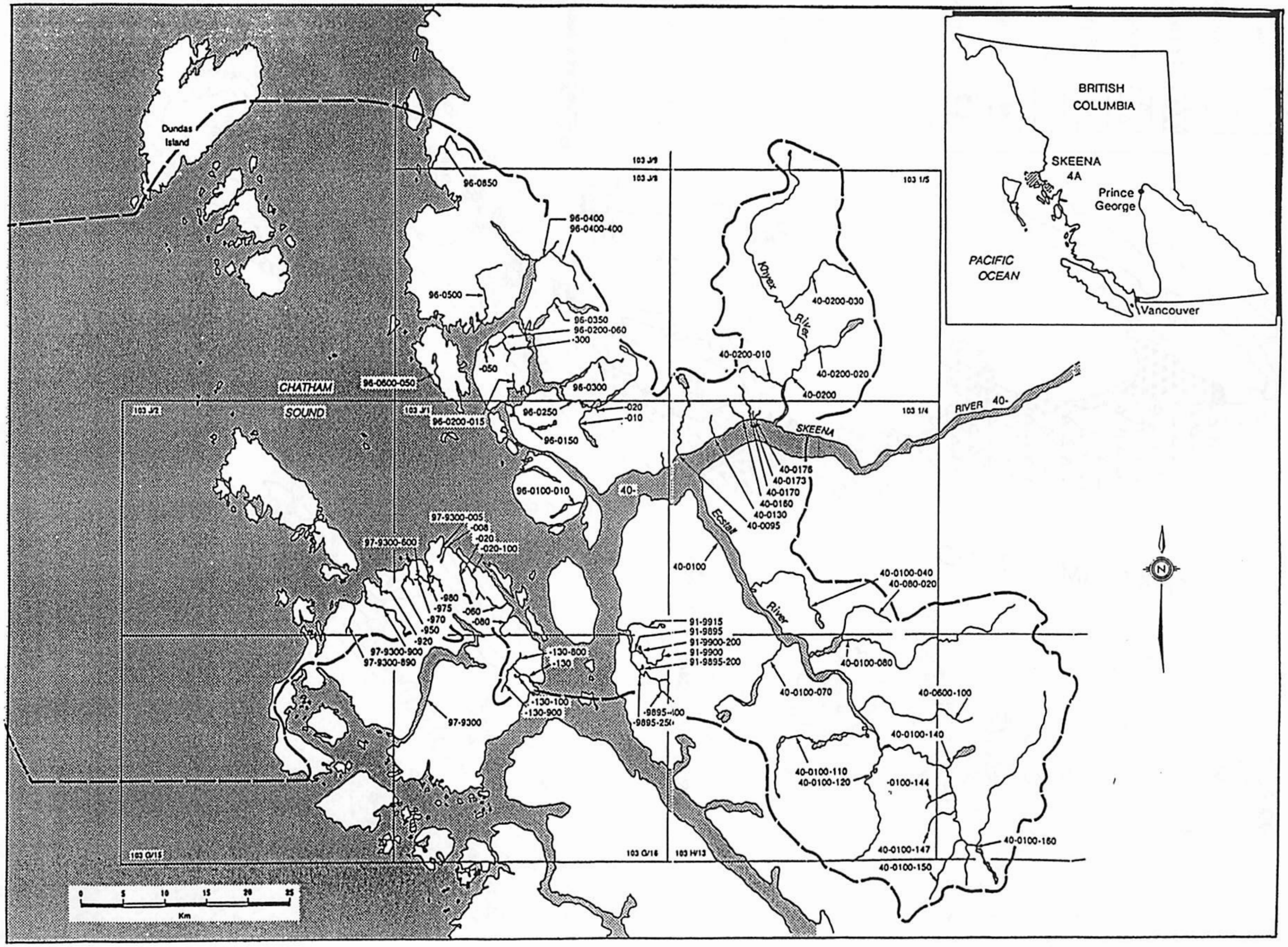
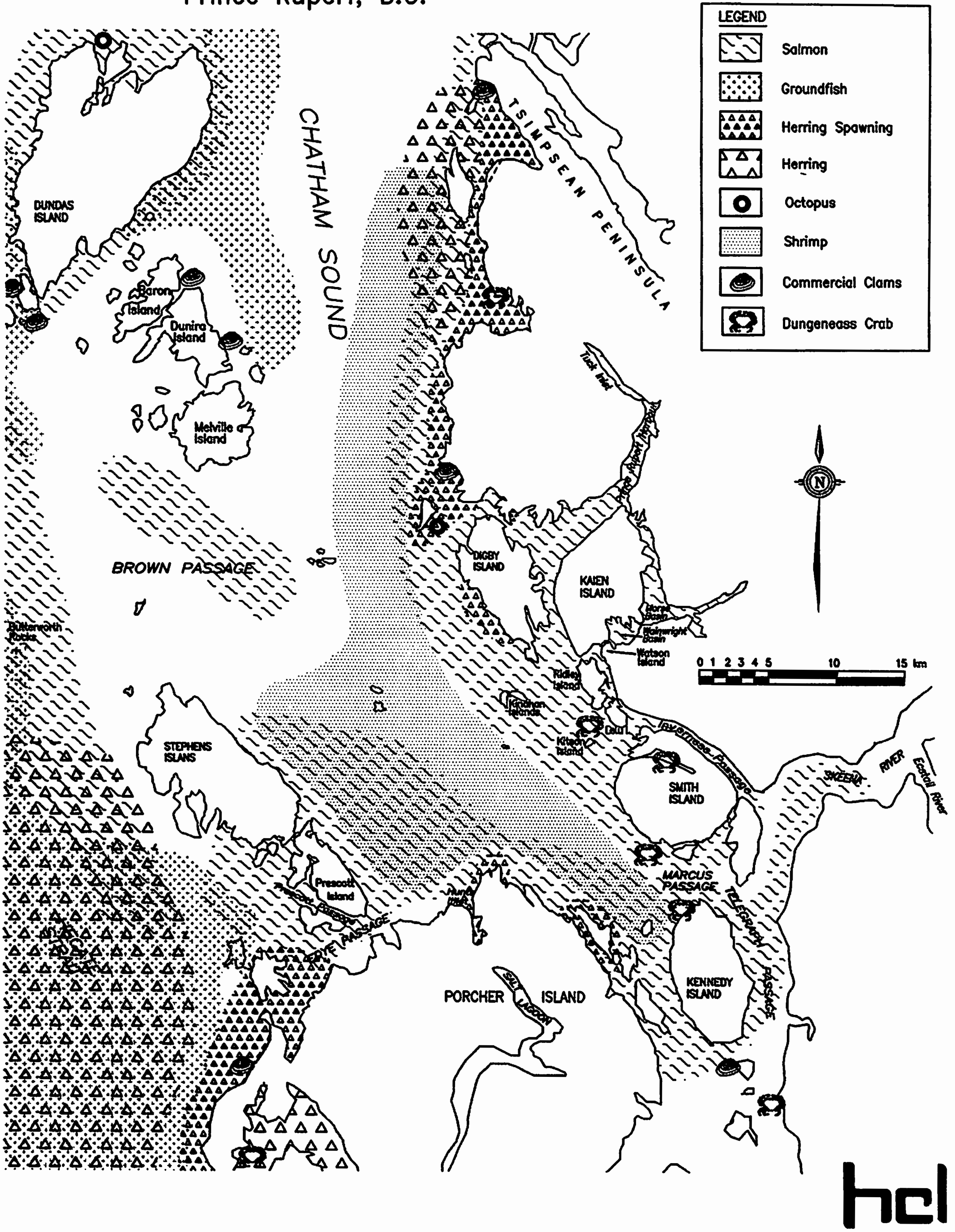
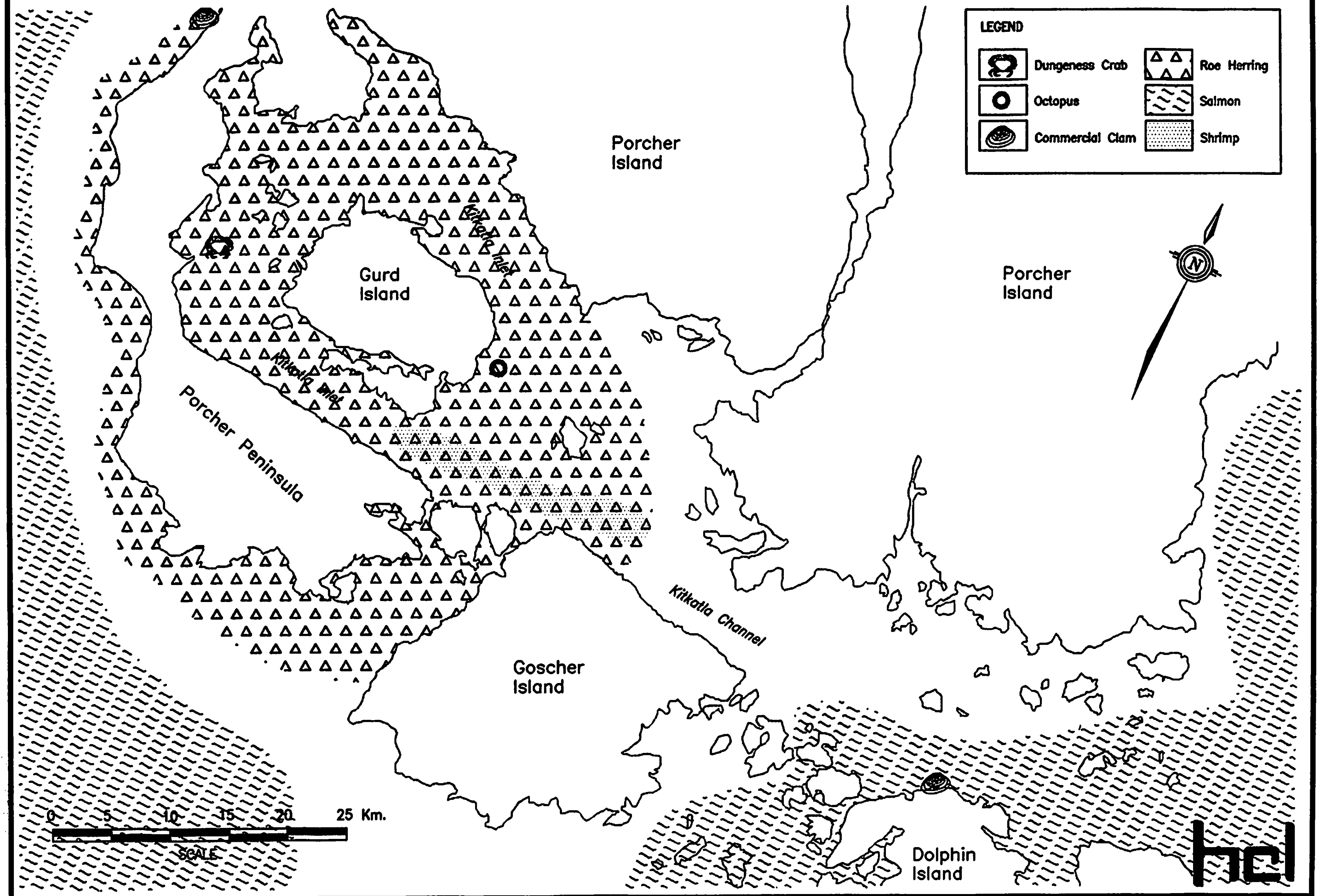


Figure 4.22a Marine Finfish and Invertebrate Resources in the Vicinity of Prince Rupert, B.C.



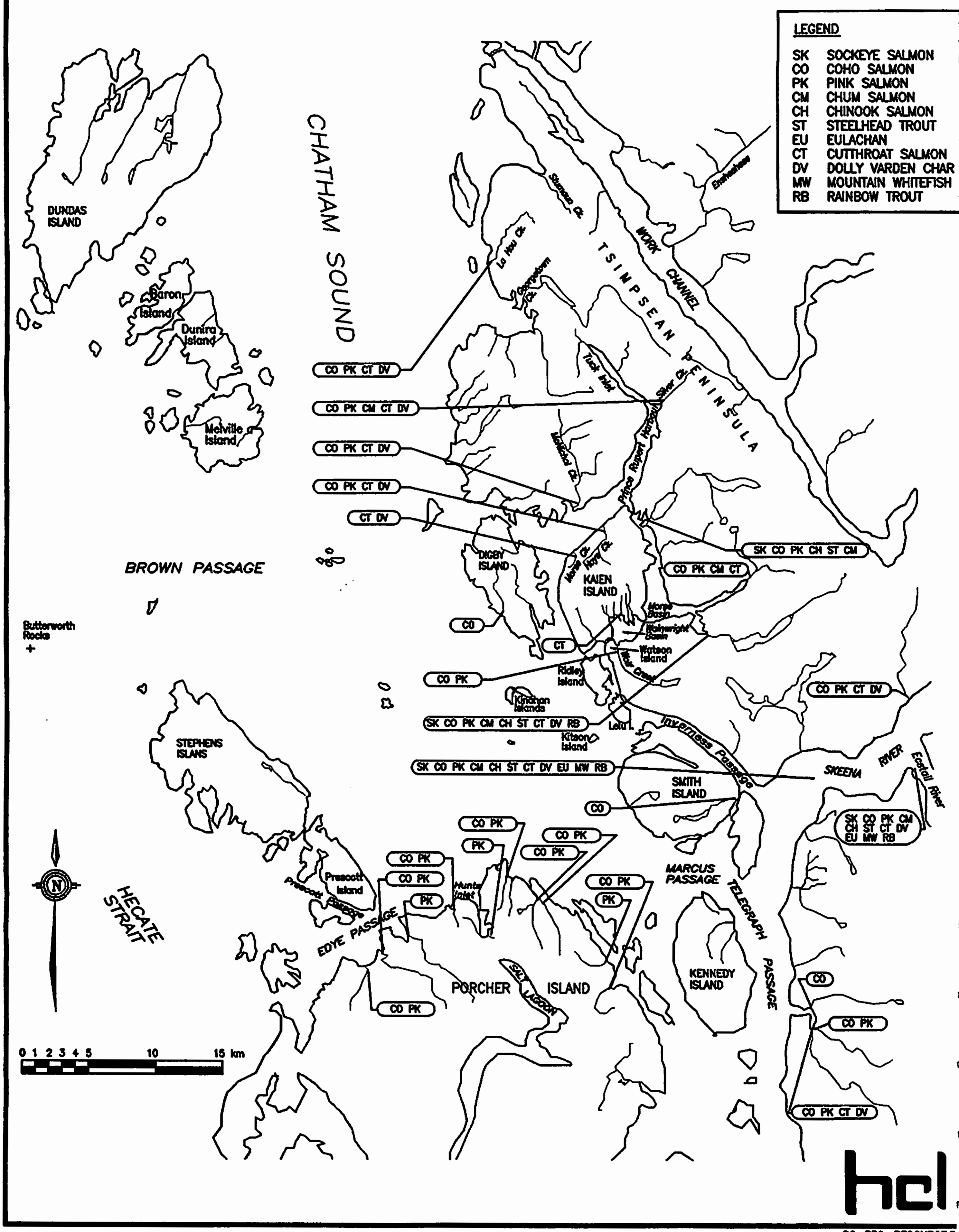
SC-559: RESOURCE.DWG

Figure 4.22b Marine Finfish and Invertebrate Resources in the Vicinity of the Proposed Reference Area for First Cycle EEM Studies, Kitkatla Inlet.



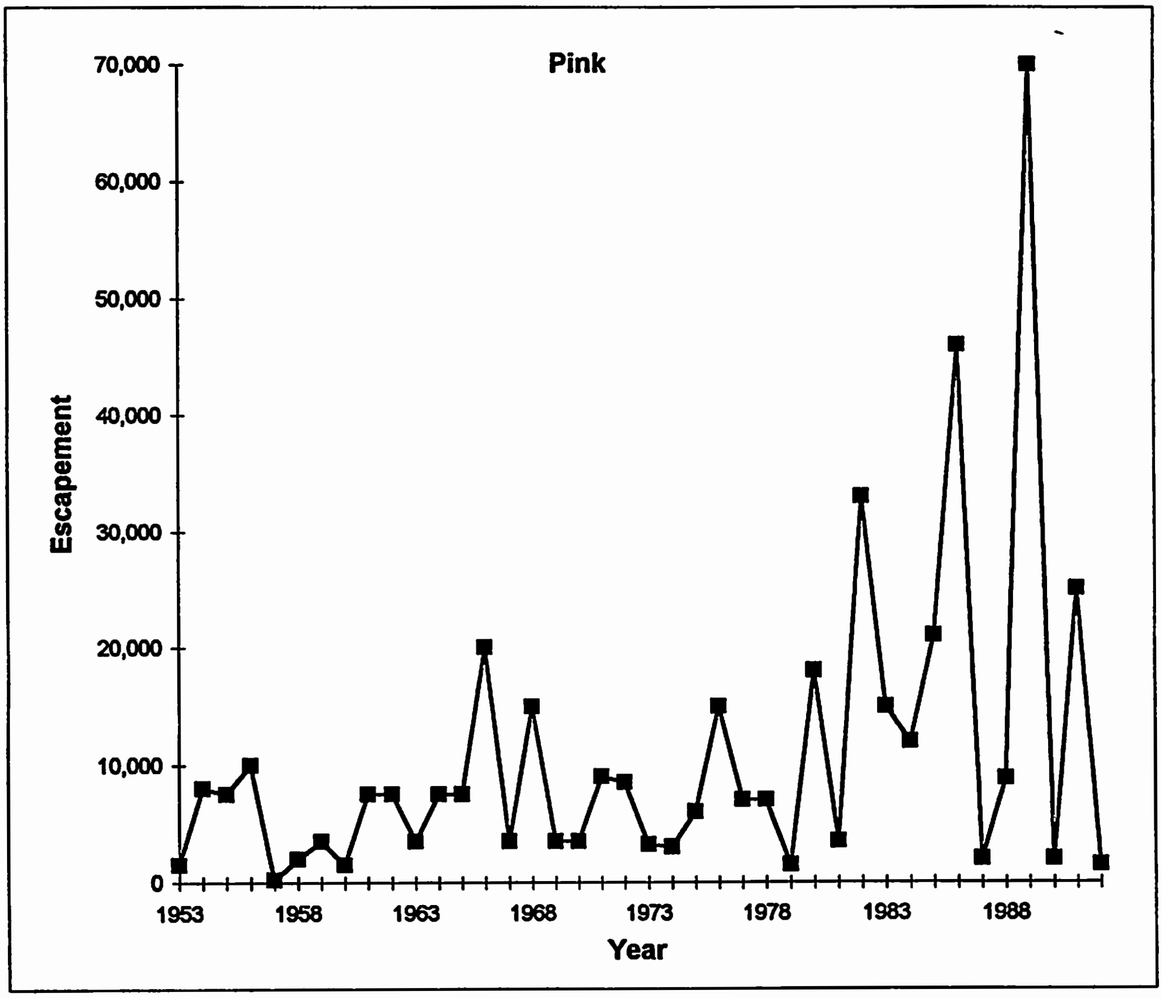
SC-559: KITKATLA.DWG

Figure 4.23 Freshwater Resources in the Vicinity of Prince Rupert, B.C.



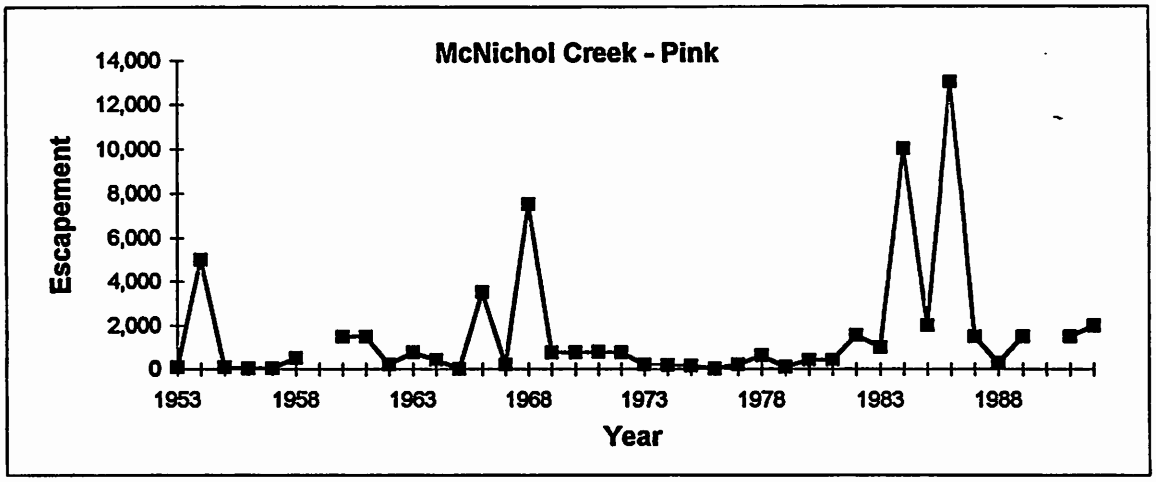
SC-559: RESOURCE.D

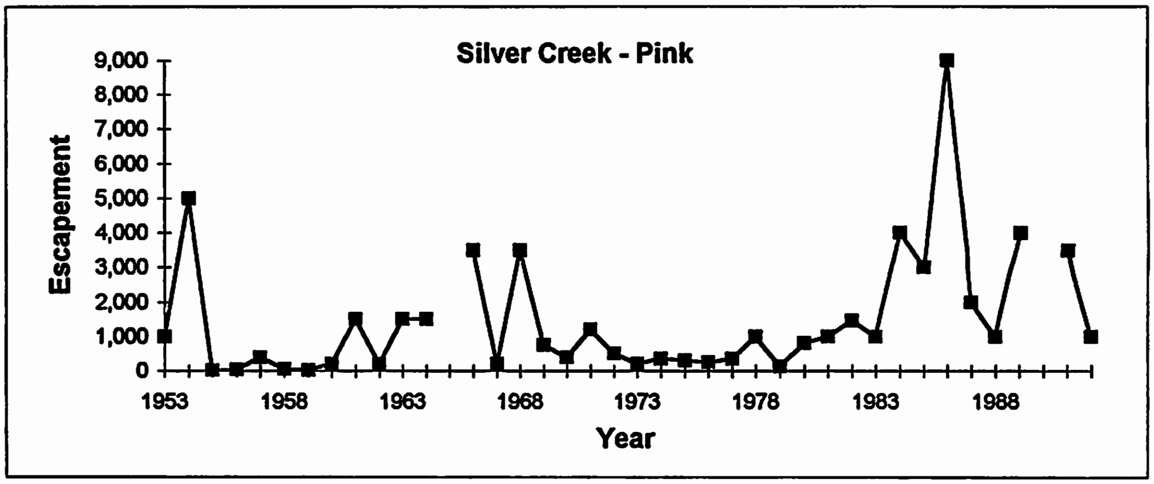
Figure 4.24 **Adult pink salmon escapements to La Hou Creek, 1953 to 1992.**

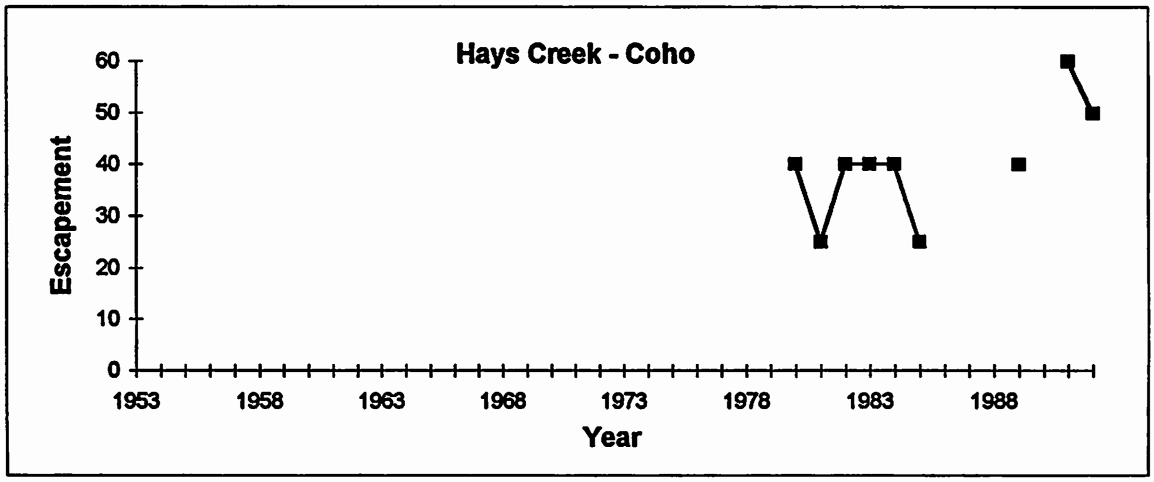


Source: G. Serbic, DFO Nanaimo.

Figure 4.25 **Adult pink salmon escapements to McNichol Creek and Silver Creek and adult coho escapements to Hays Creek, 1953 to 1992.**

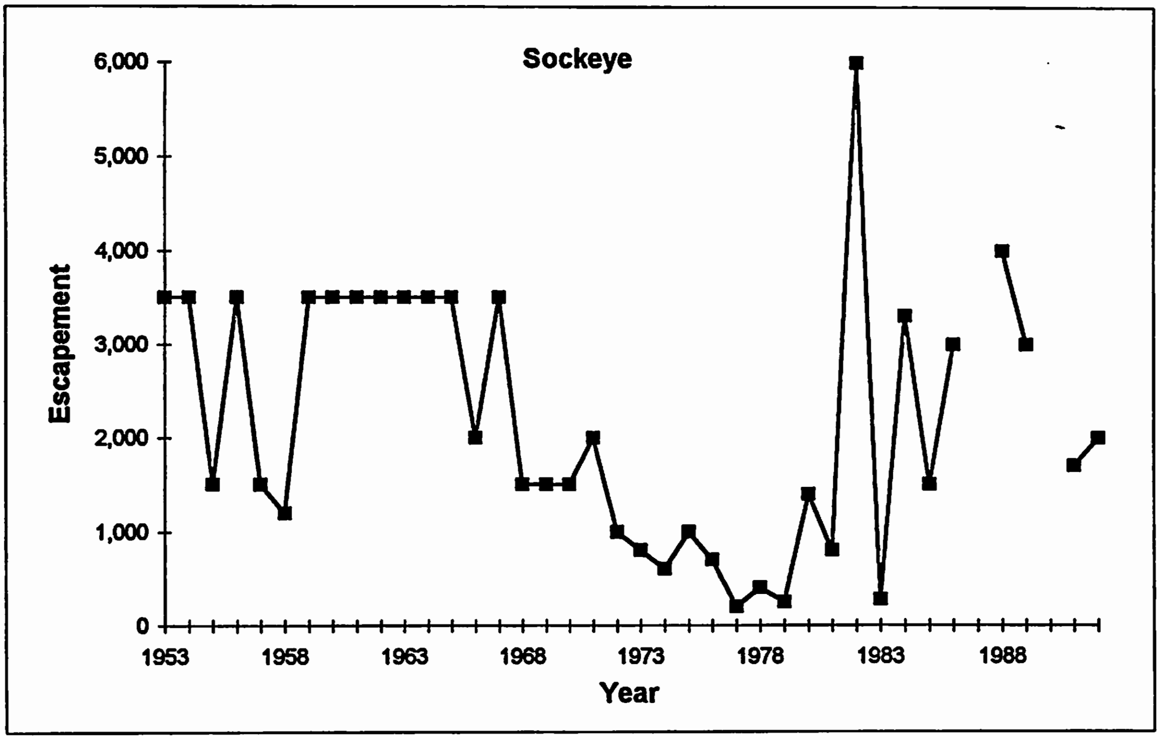


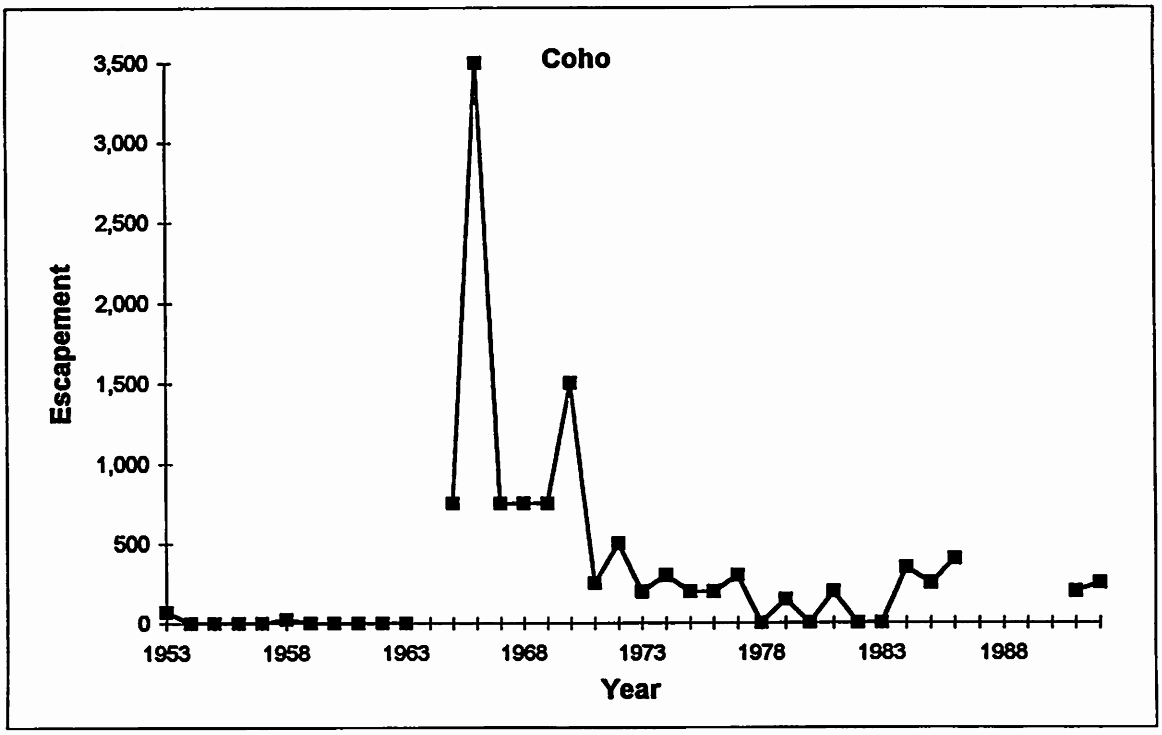




Source: G. Serbic, DFO Nanaimo.

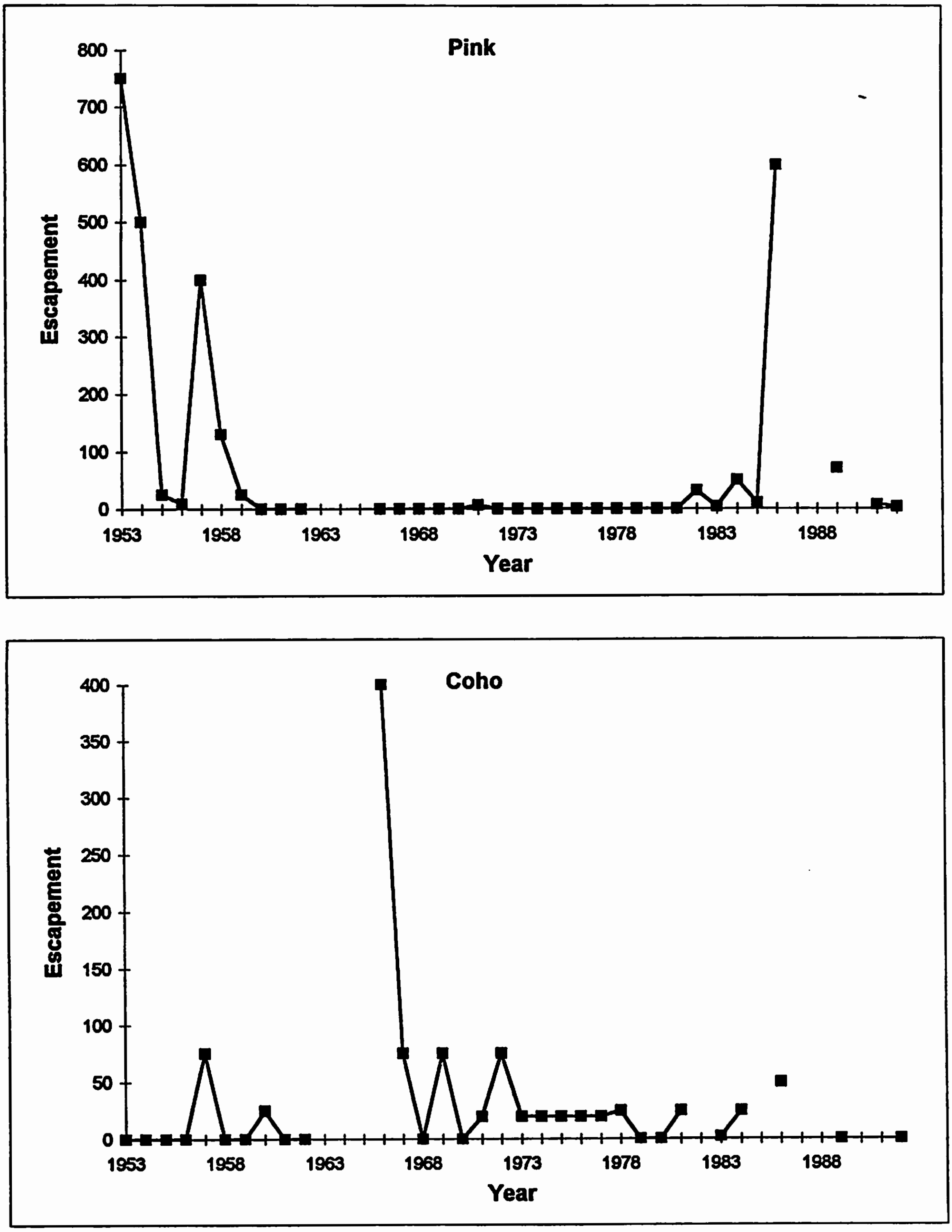
Figure 4.26 **Adult sockeye and coho salmon escapements to Shawatlan River, 1953 to 1992.**





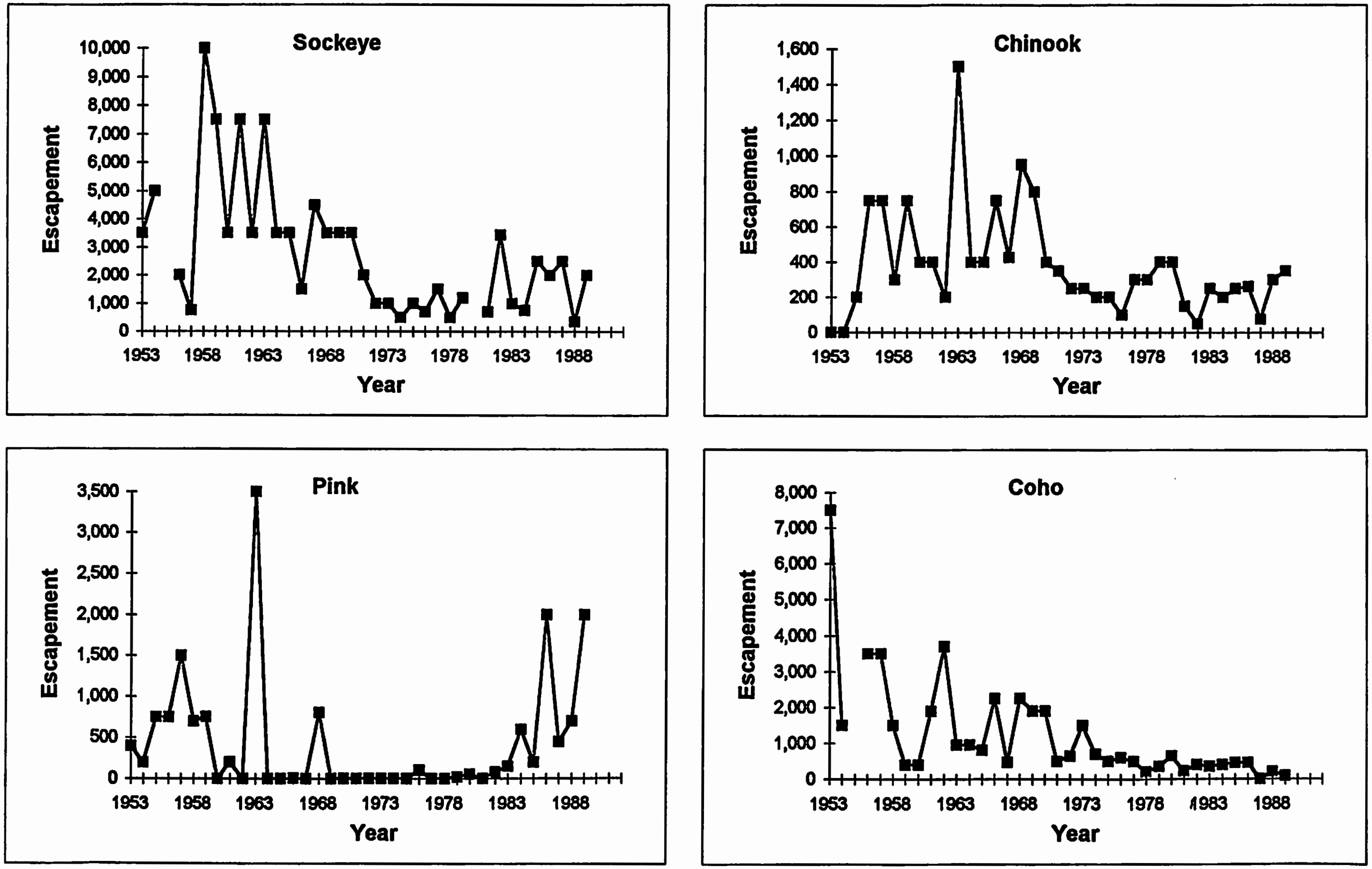
Source: G. Serbic, DFO Nanaimo.

Figure 4.27 **Adult pink and coho salmon escapements to Denise Creek, 1953 to 1992.**



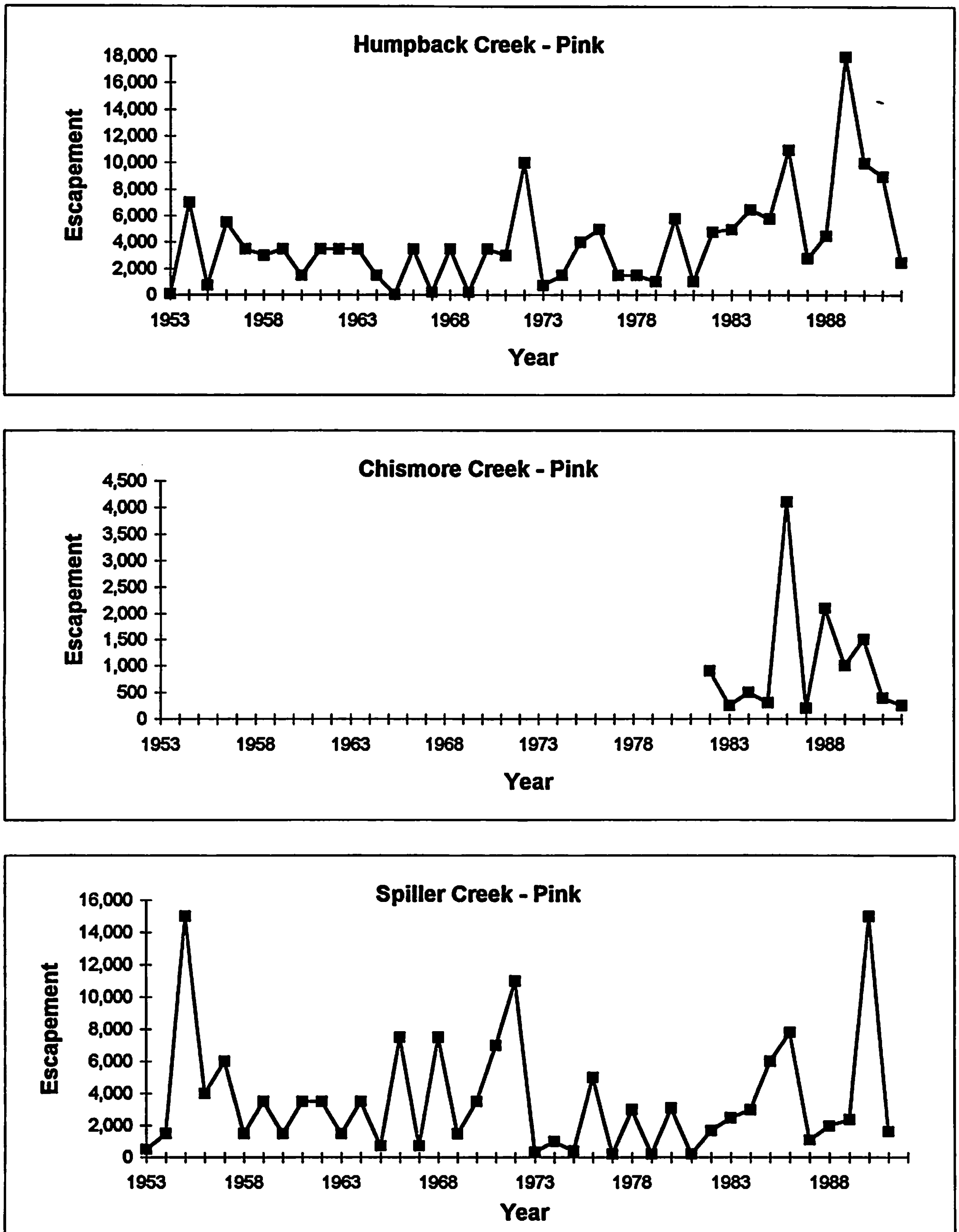
Source: G. Serbic, DFO Nanaimo.

Figure 4.28 Adult sockeye, pink, chinook, and coho escapements to Kloiya River, 1953 to 1992.



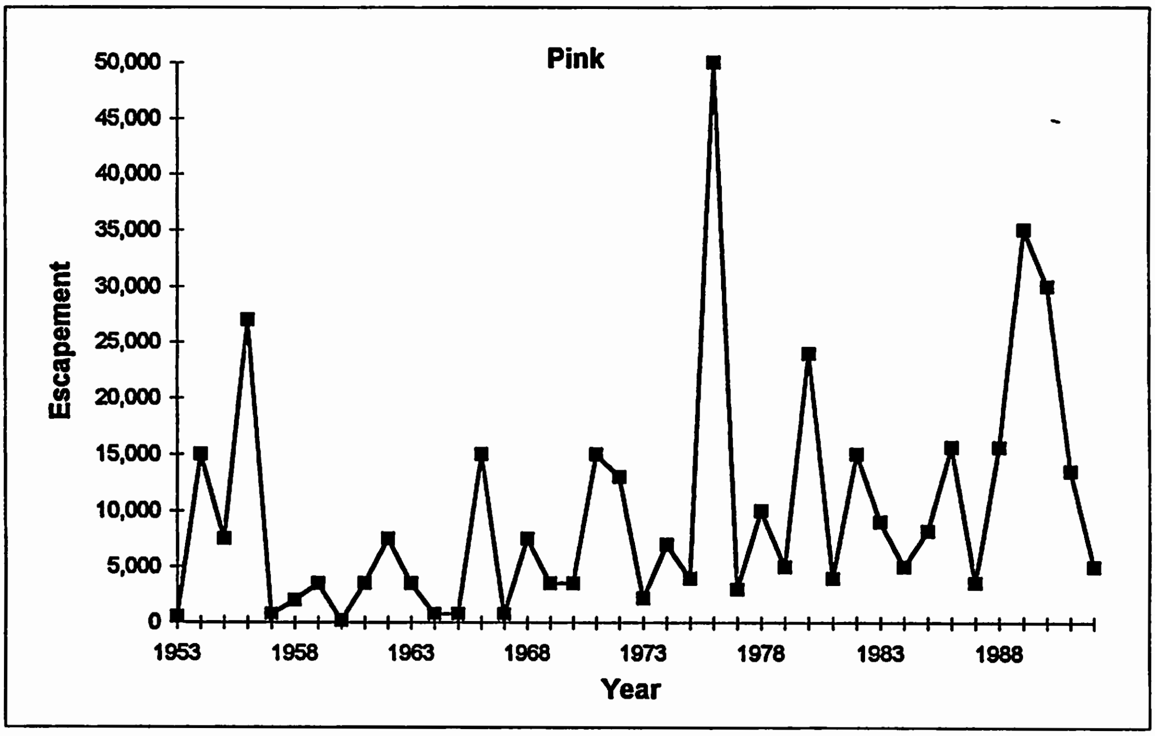
Source: G. Serbic, DFO Nanaimo.

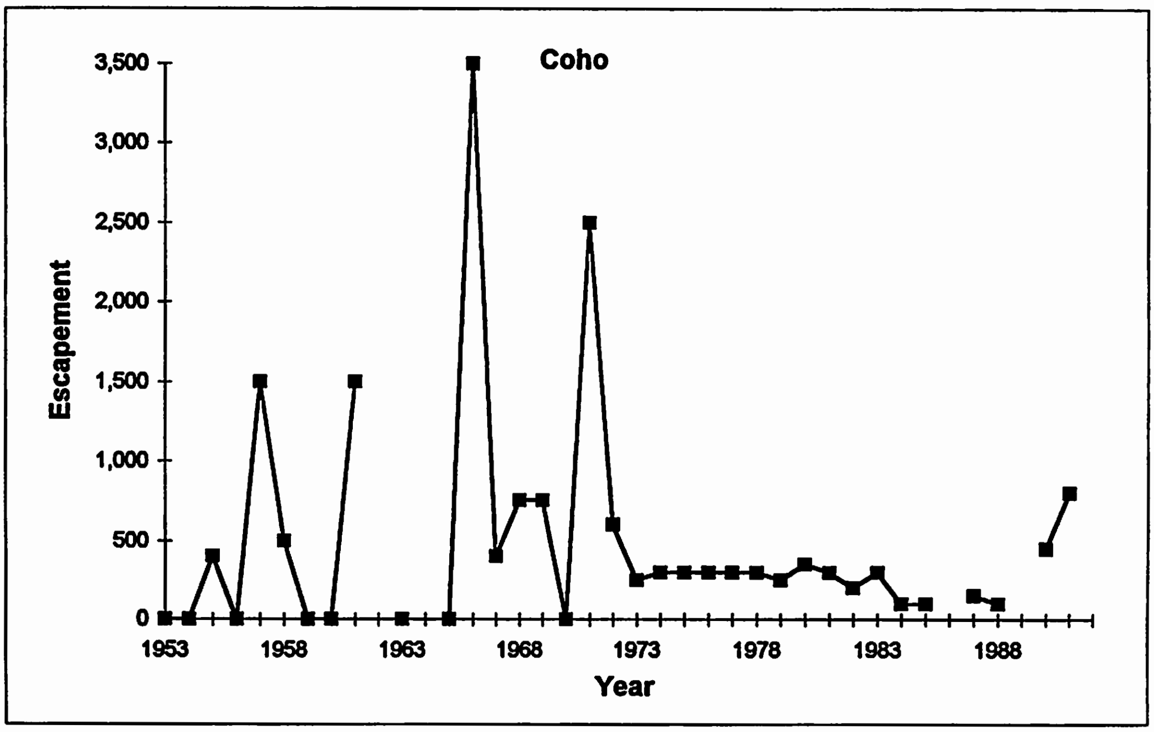
Figure 4.29 **Adult pink salmon escapements to Humpback Creek, Chismore Creek, and Spiller Creek, 1953 to 1992.**



Source: G. Serbic, DFO Nanaimo.

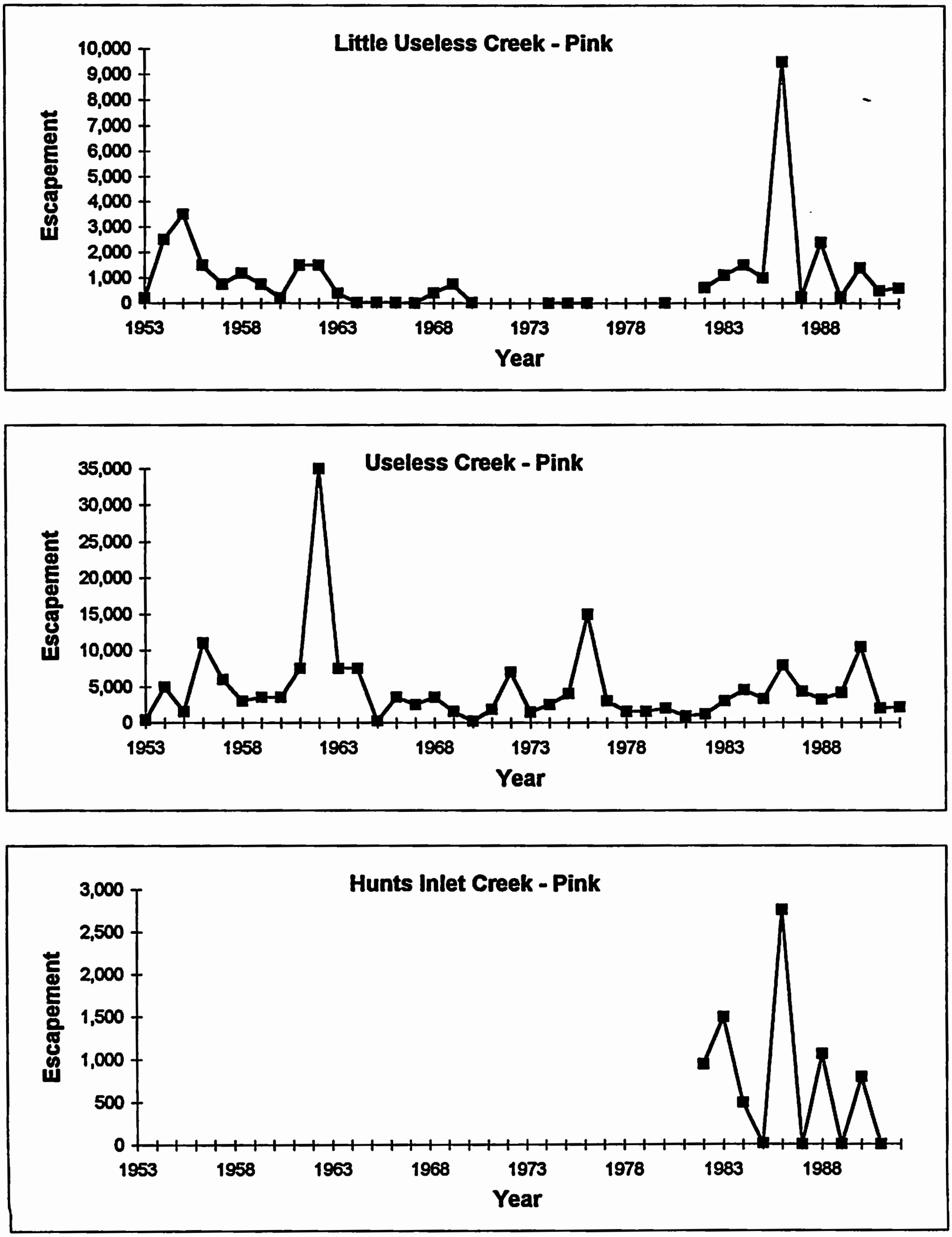
Figure 4.30 **Adult pink and coho salmon escapements to Oona Creek, 1953 to 1992.**





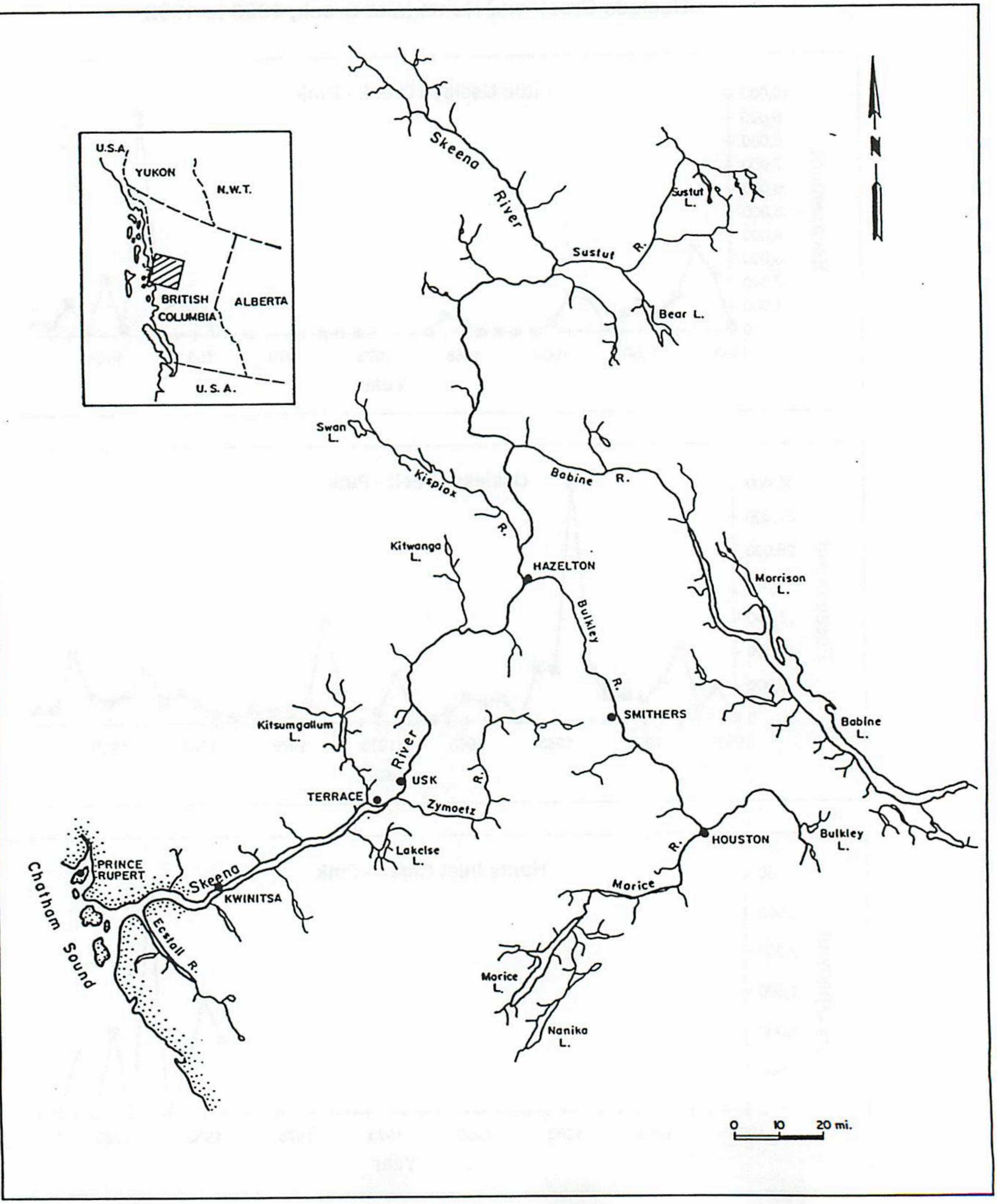
Source: G. Serbic, DFO Nanaimo.

Figure 4.31 **Adult pink salmon escapements to Little Useless Creek, Useless Creek and Hunts Inlet Creek, 1953 to 1992.**



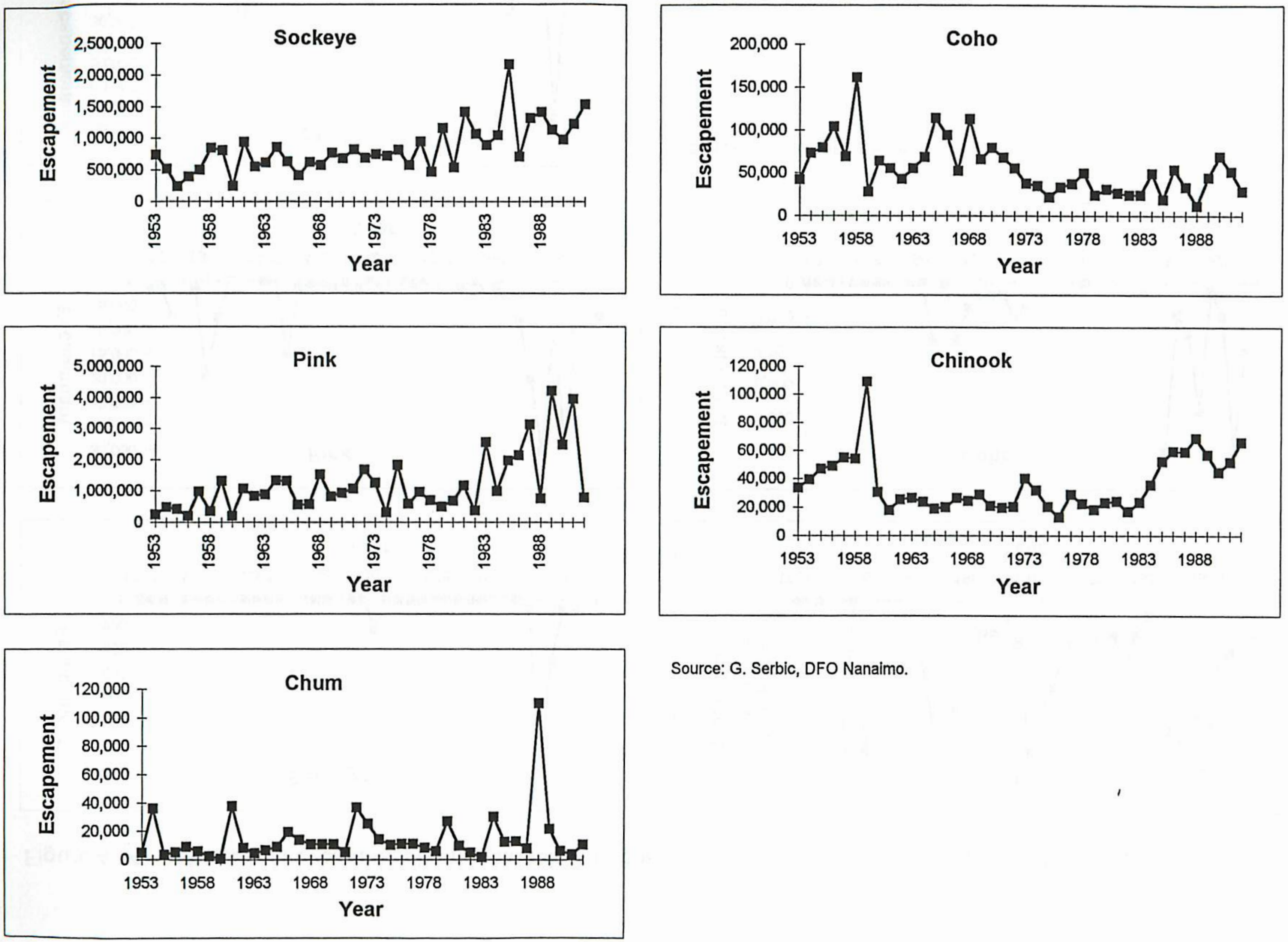
Source: G. Serbic, DFO Nanaimo.

Figure 4.32 Skeena River watershed.



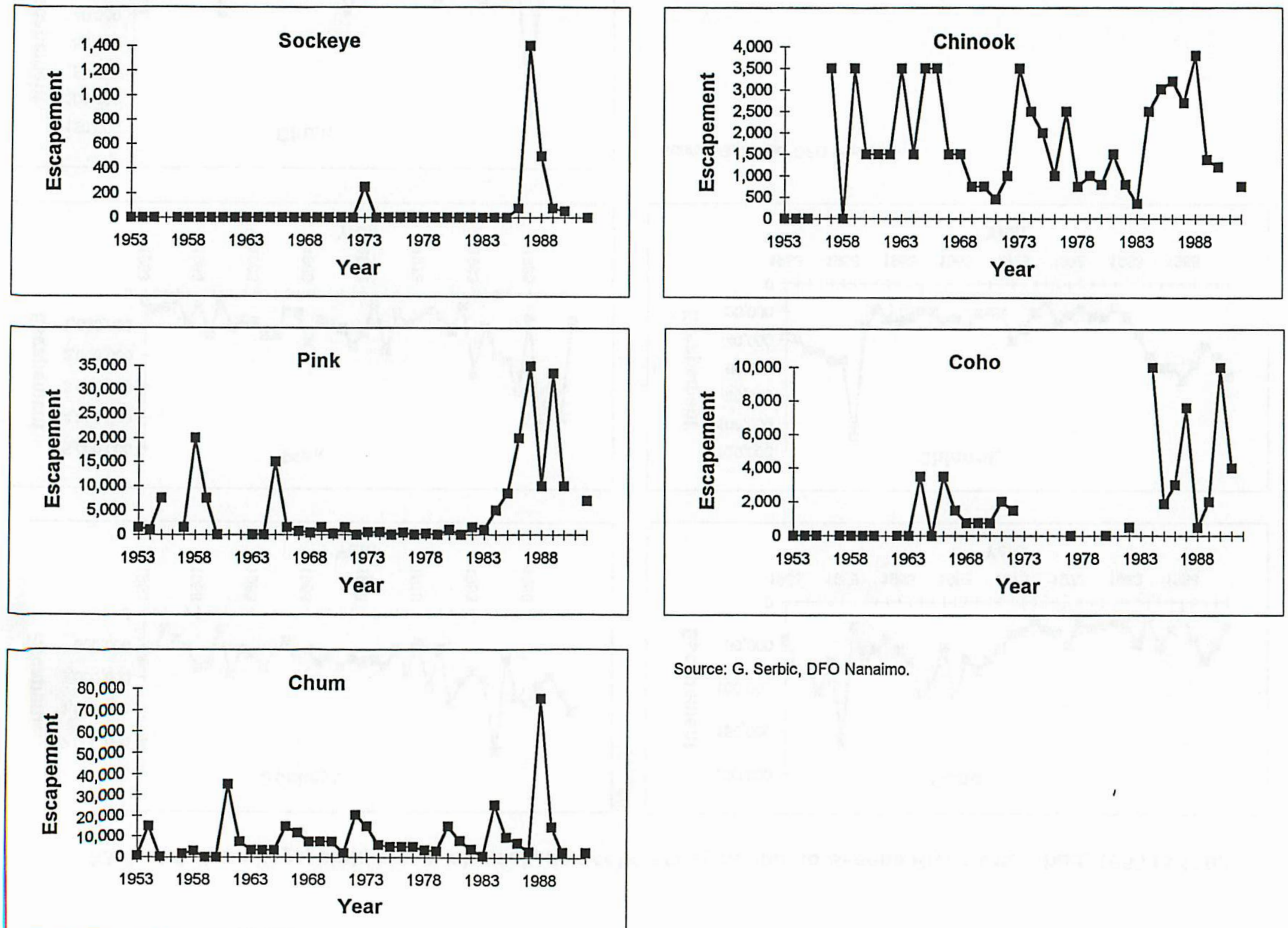
Source: Hoos, 1975.

Figure 4.33 Adult sockeye, pink, chum, chinook, and coho escapements to Skeena River watershed, 1953 to 1992.



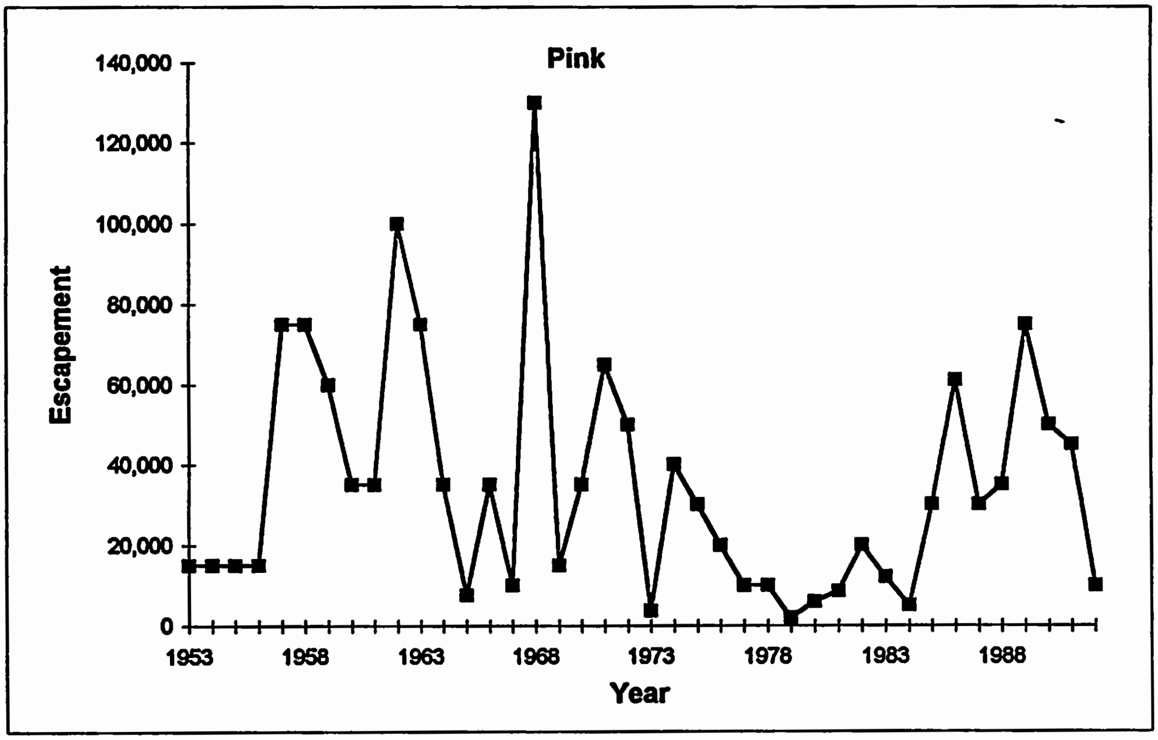
Source: G. Serbic, DFO Nanaimo.

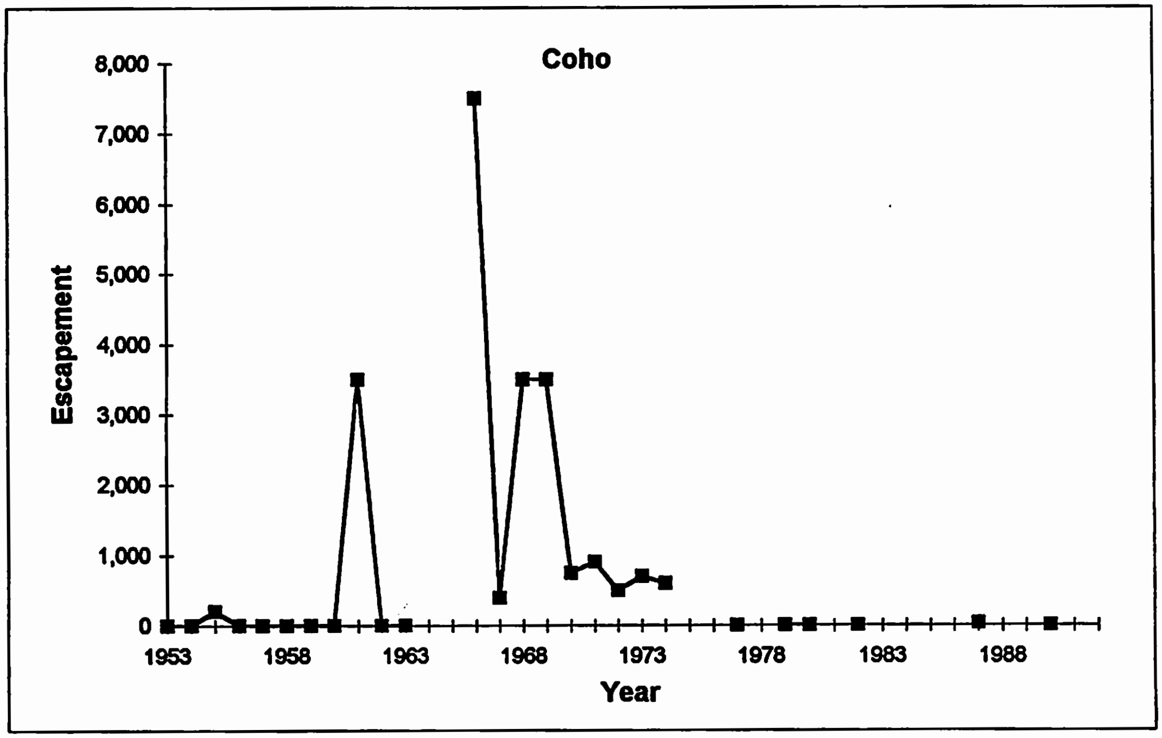
Figure 4.34 Adult sockeye, pink, chum, chinook, and coho escapements to Ecstall River, 1953 to 1992.



Source: G. Serbic, DFO Nanaimo.

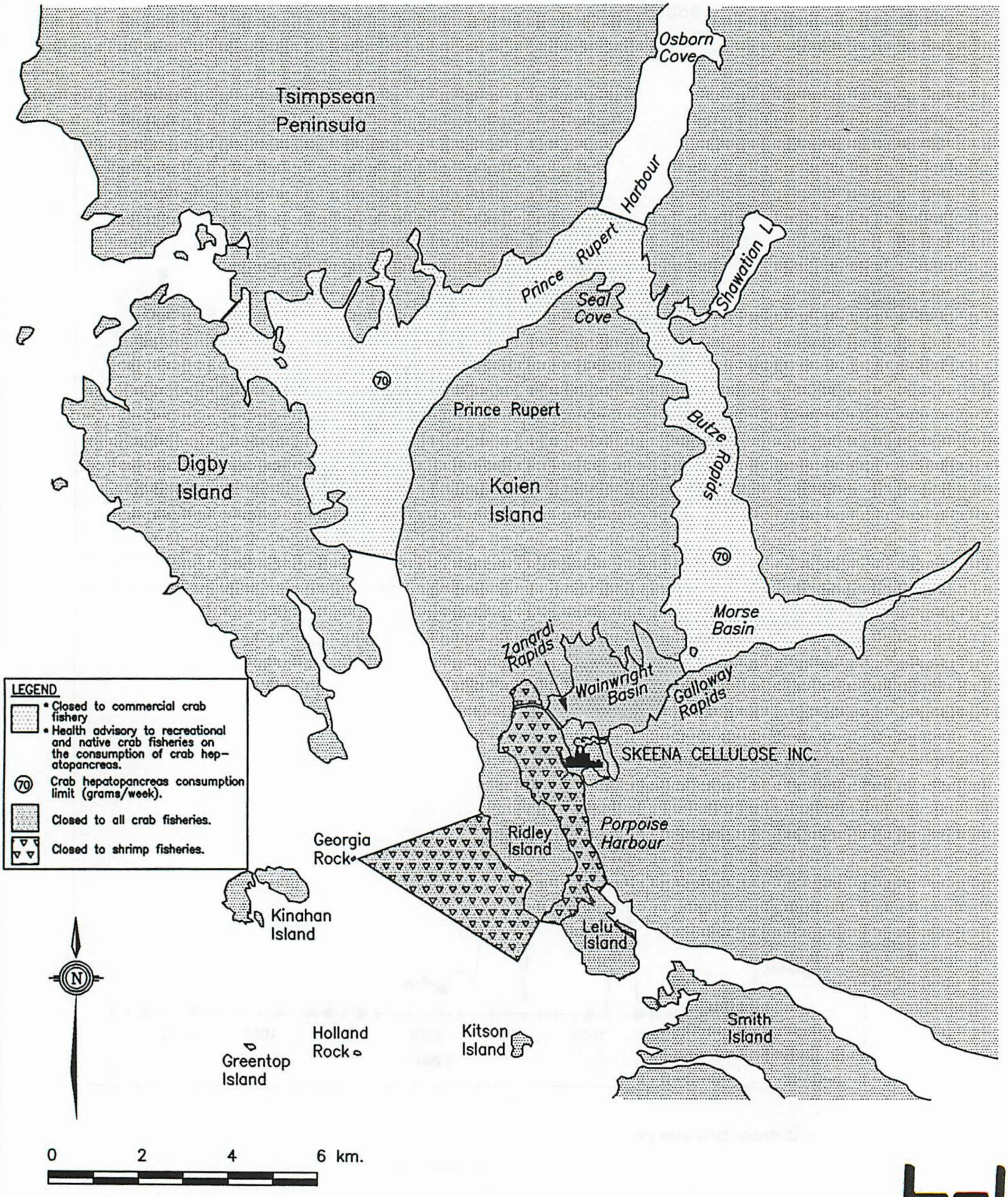
Figure 4.35 **Adult pink and coho salmon escapements to Moore Cove Creek, 1953 to 1992.**





Source: G. Serbic, DFO Nanaimo.

Figure 4.36 Fisheries Closures and Consumption Advisories in the Vicinity of Skeena Cellulose Inc. due to the Presence of Dioxins.

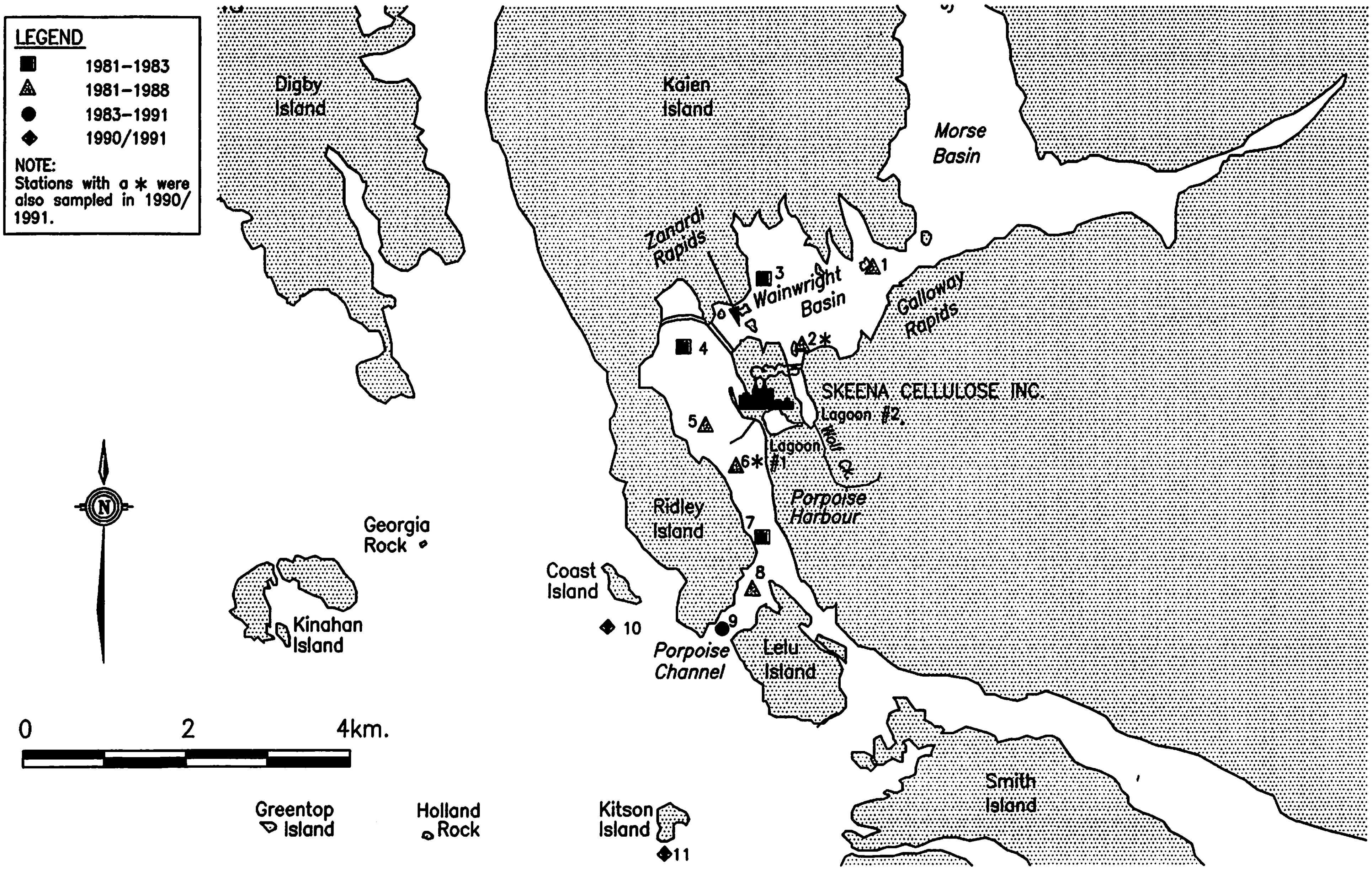


Source: Government of Canada (1993).

hcl

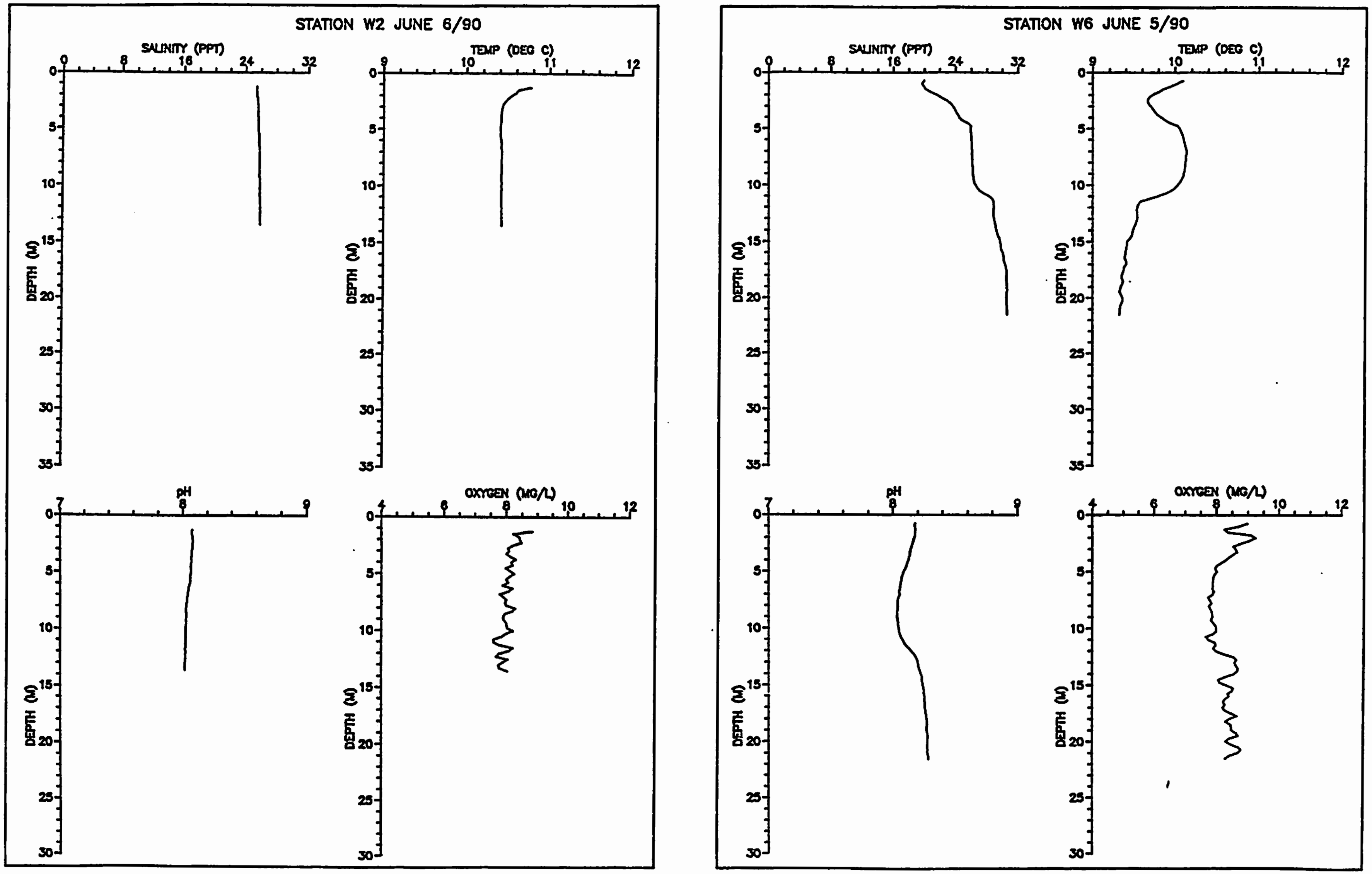
SC-559: CLOSU

Figure 5.1 Water Quality Monitoring Stations at Skeena Cellulose Inc., Prince Rupert B.C., 1981 to 1991.



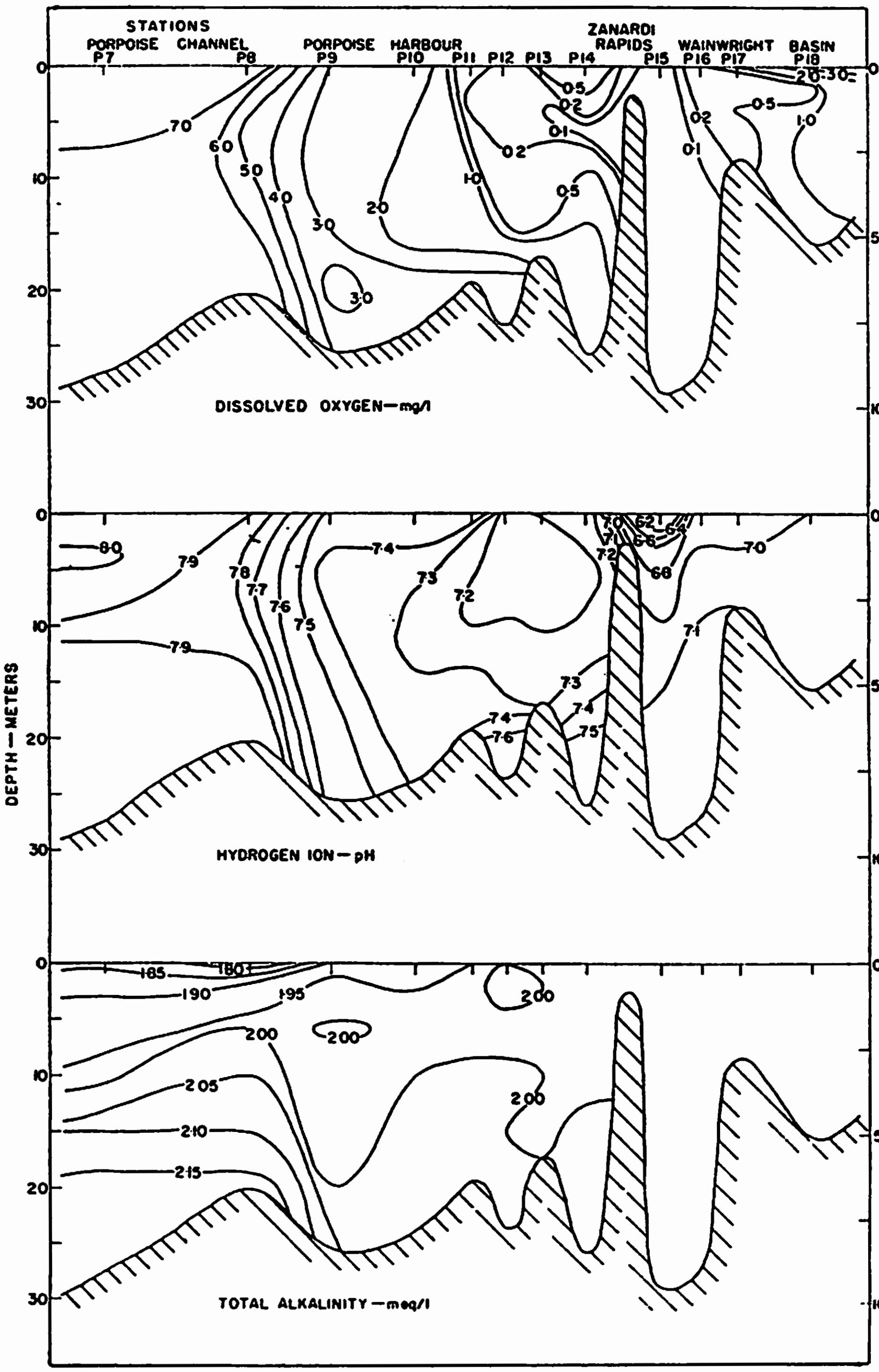
Source: Beak Consultants Ltd.,1984; Dwernychuk, 1989a; Dwernychuk et al., 1992a.

Figure 5.2 Selected water quality parameters, Stations 2 and 6, Skeena Cellulose Inc., Prince Rupert, B.C., June 1990.



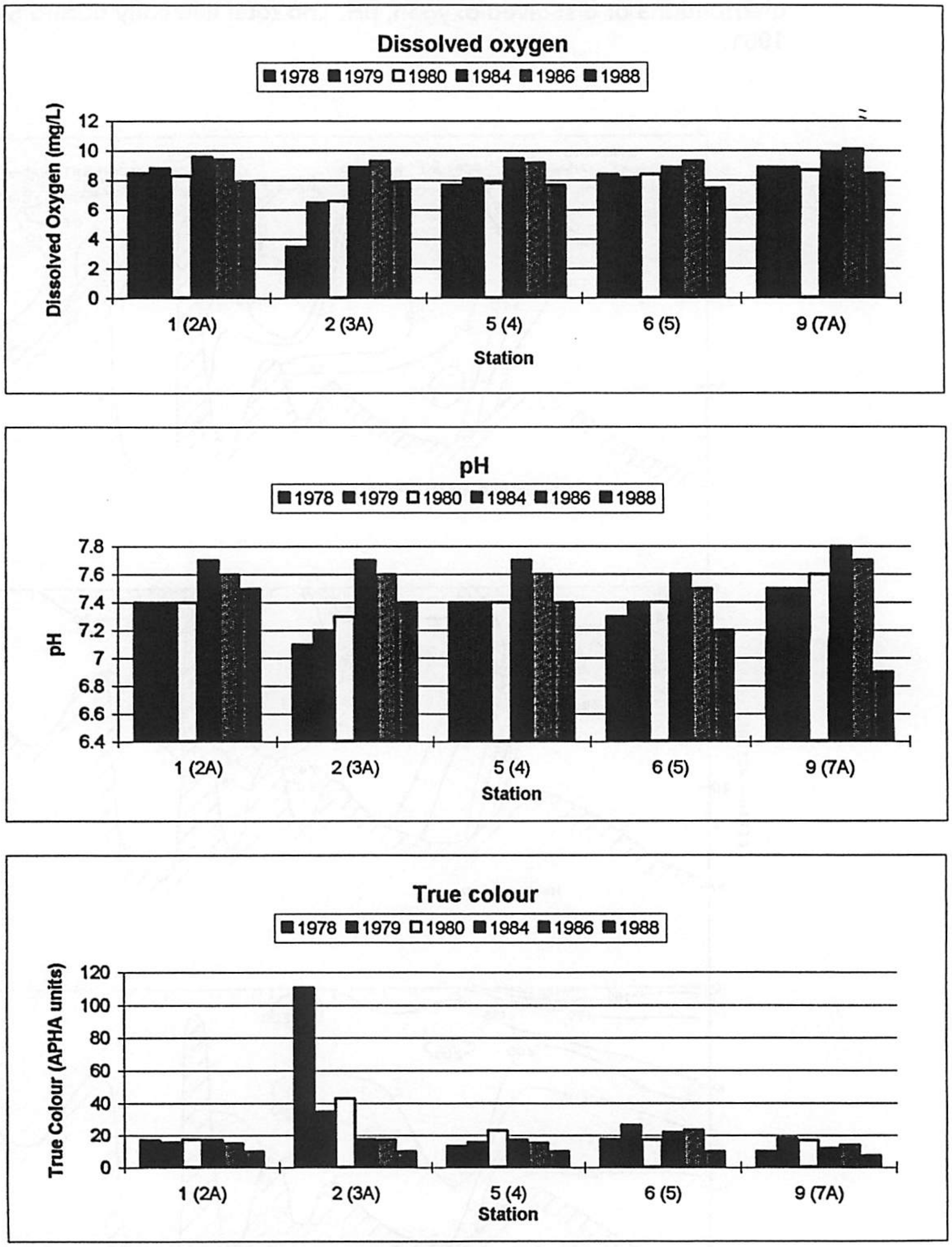
Source: Dwernychuk *et al.*, 1992a.

Figure 5.3 **Sections through Porpoise Harbour and Wainwright Basin showing vertical distributions of dissolved oxygen, pH, and total alkalinity during September 1961.**



Source: Waldichuk, 1966.

Figure 5.4 **Means of surface water quality data for dissolved oxygen, pH, and true colour at Skeena Cellulose Inc., selected years between 1978 and 1988.**

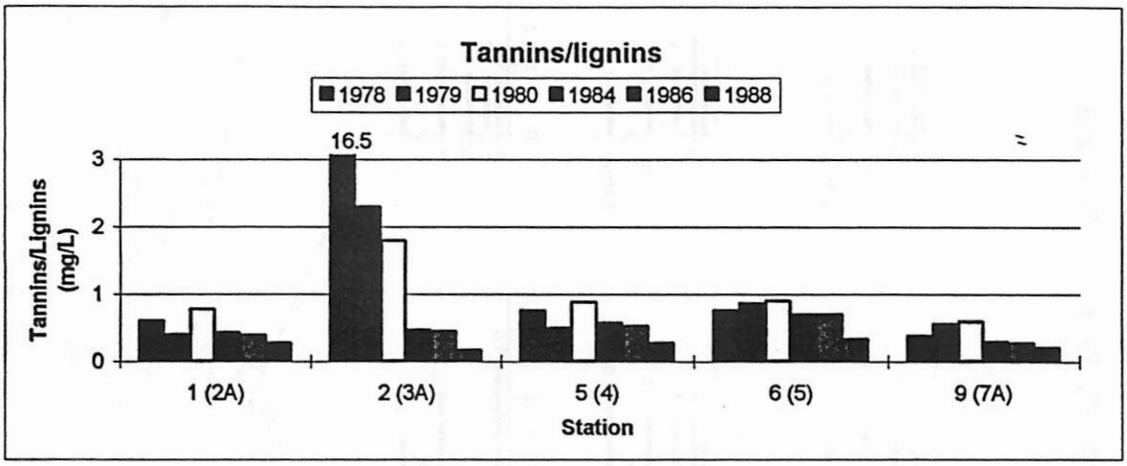


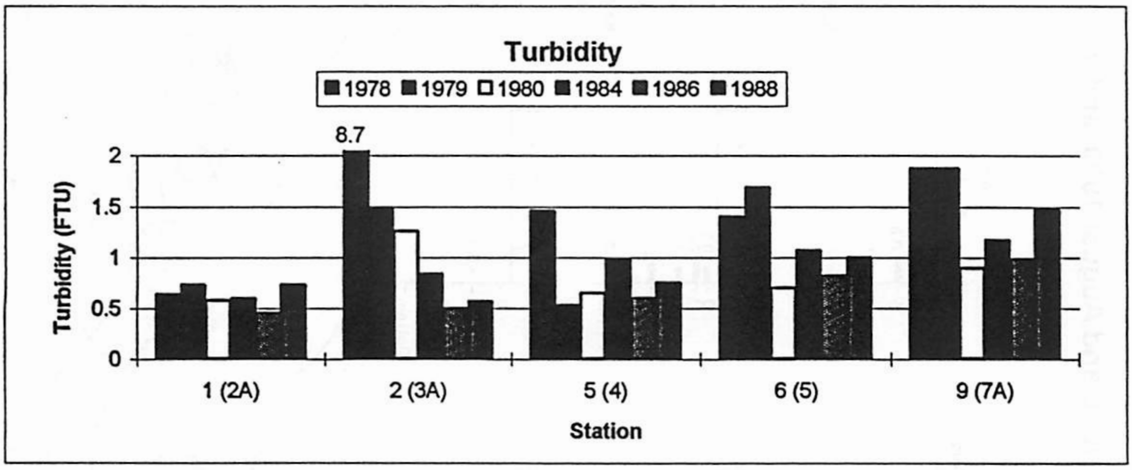
Source: Beak Consultants Ltd., 1980, 1981; Dwernychuk, 1985, 1987, 1989a.

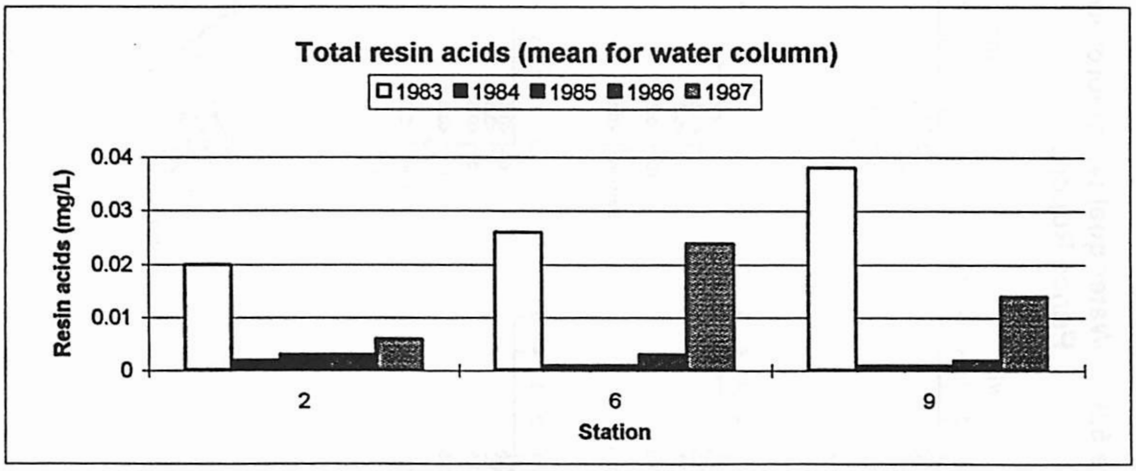
Stations in parentheses were the numbers used in 1978 and 1979.

hcl

Figure 5.5 **Means of surface water quality data for tannins/lignins, turbidity, and resin acids at Skeena Cellulose Inc., selected years between 1978 and 1988.**



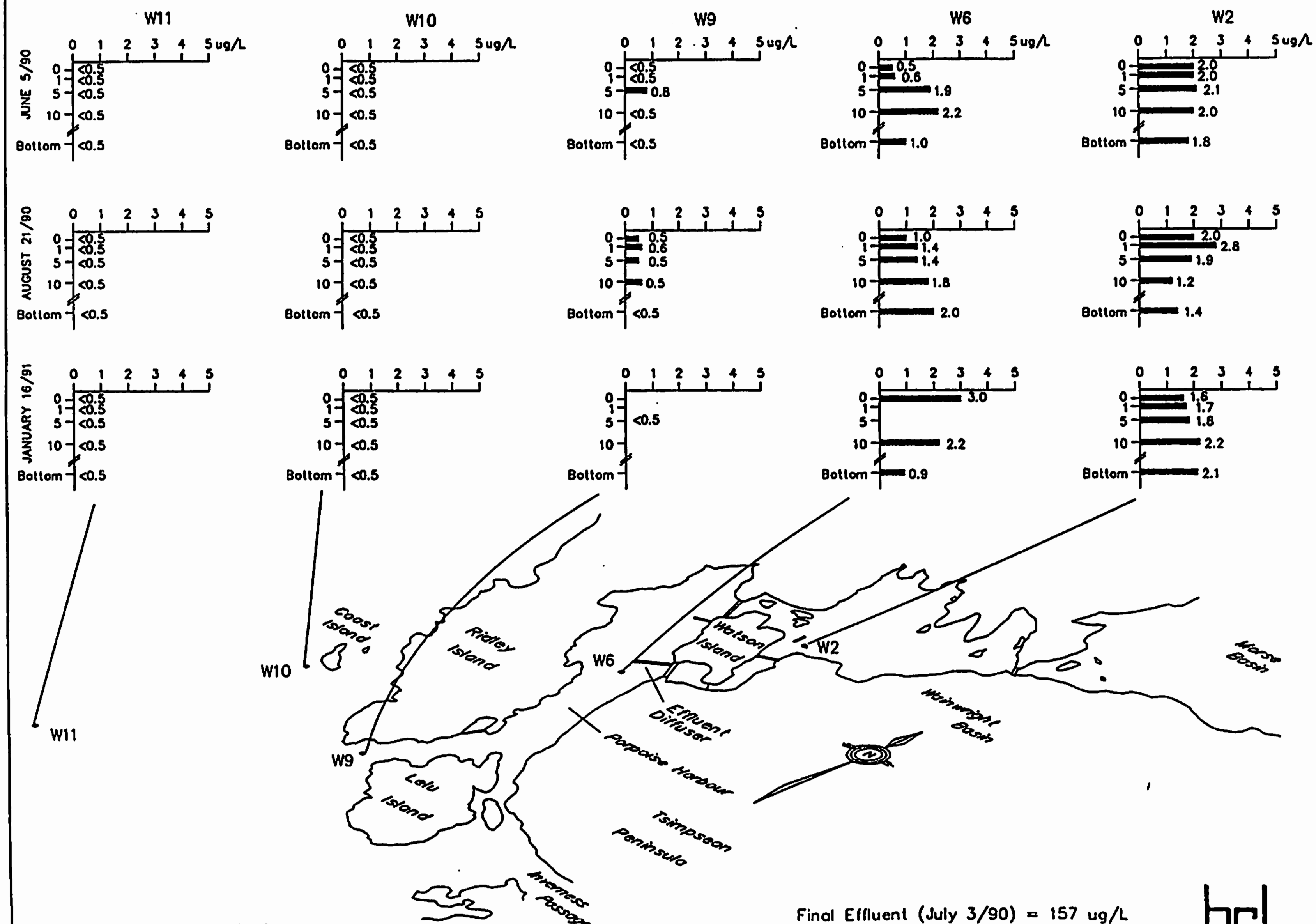




Source: Beak Consultants Ltd., 1980, 1981; Dwernychuk, 1985, 1987, 1989a.

Stations in parentheses were the numbers used in 1978 and 1979.

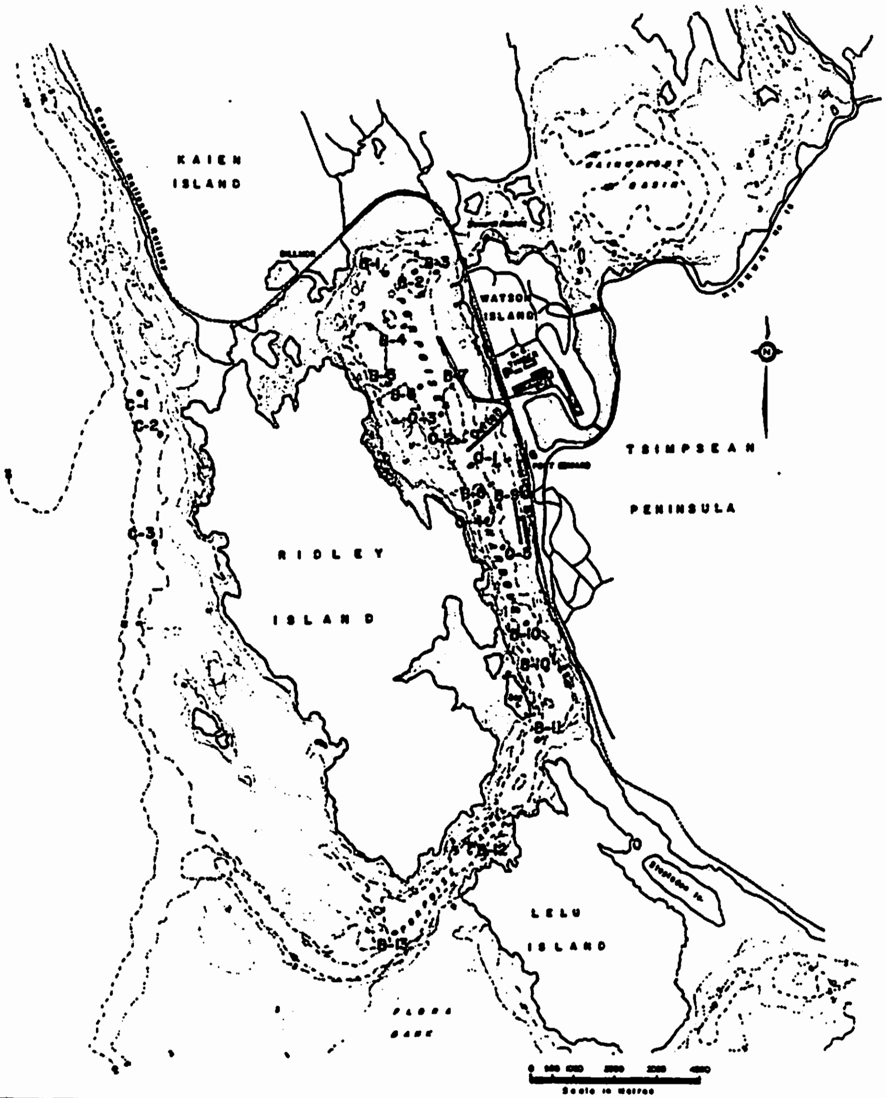
Figure 5.6 Water quality: chloroform; June and August 1990, and January 1991; Skeena Cellulose Inc., Prince Rupert.



Source: Dwernychuk *et al.*, 1992a.

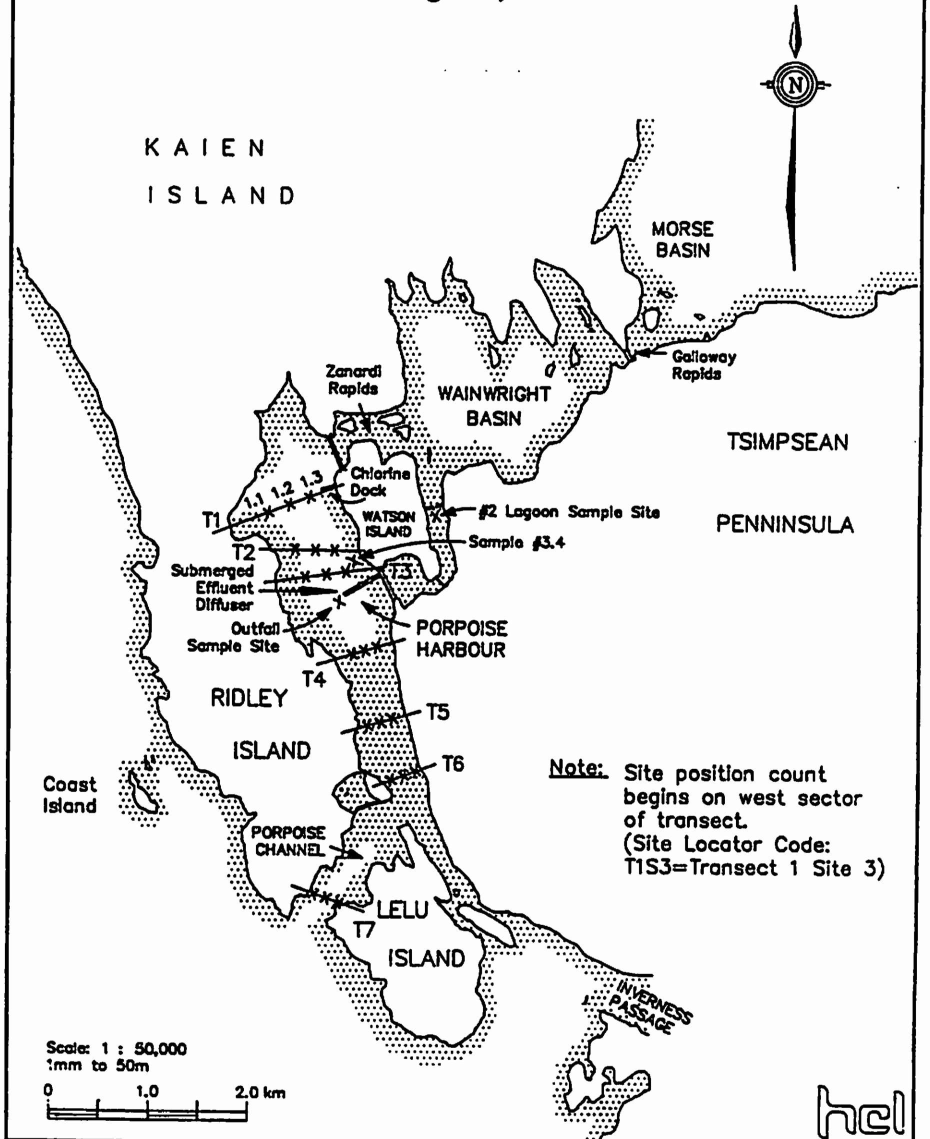
Figure 5.7 Sediment trace metal sampling stations.

a. Environment Canada; 1979 to 1981.



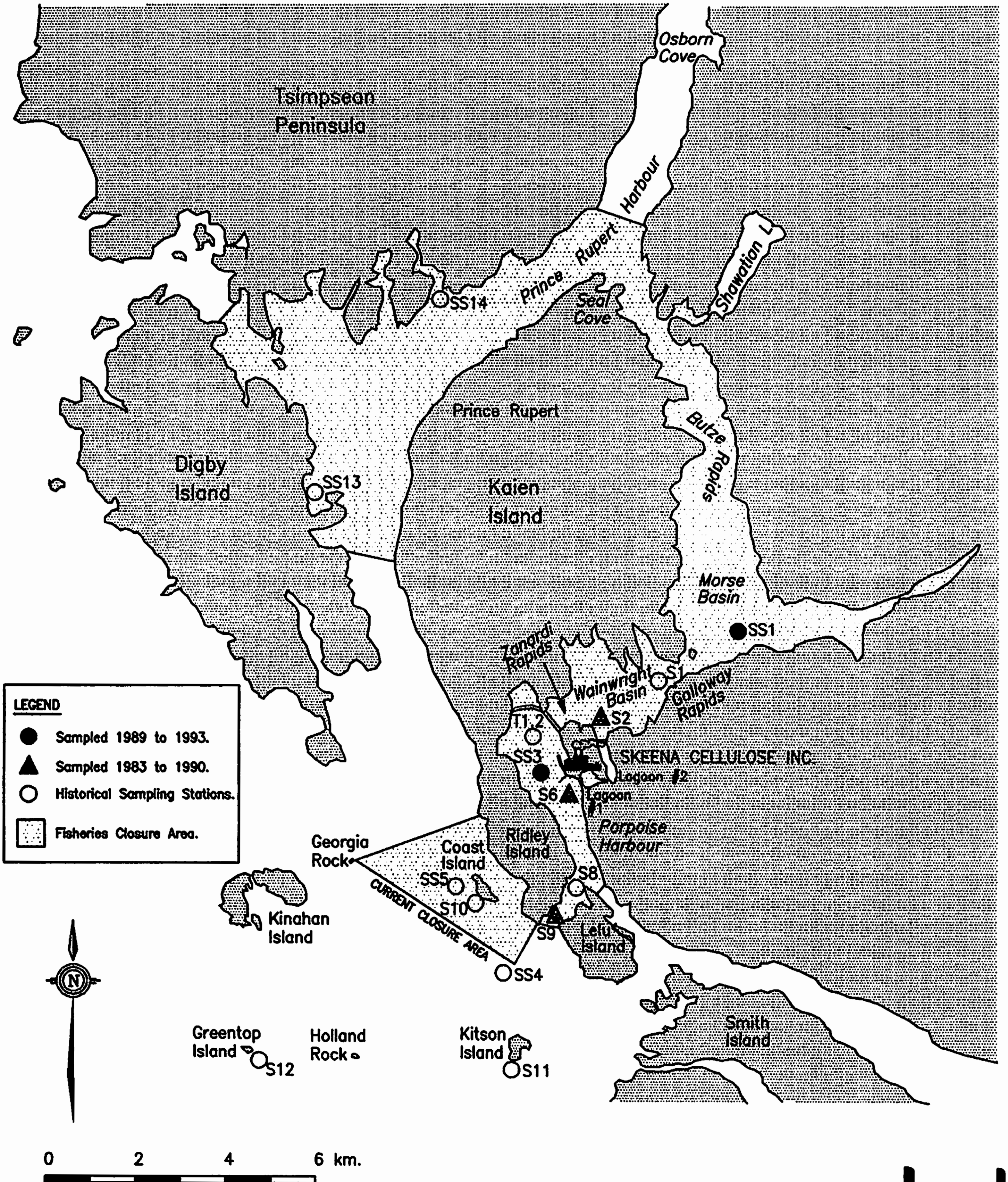
Source: Pomeroy, 1983a.

b. Approximate location of transects and sites, July 1987; Environment Canada Program; Skeena Cellulose Inc.



Source: Dwernychuk, 1988.

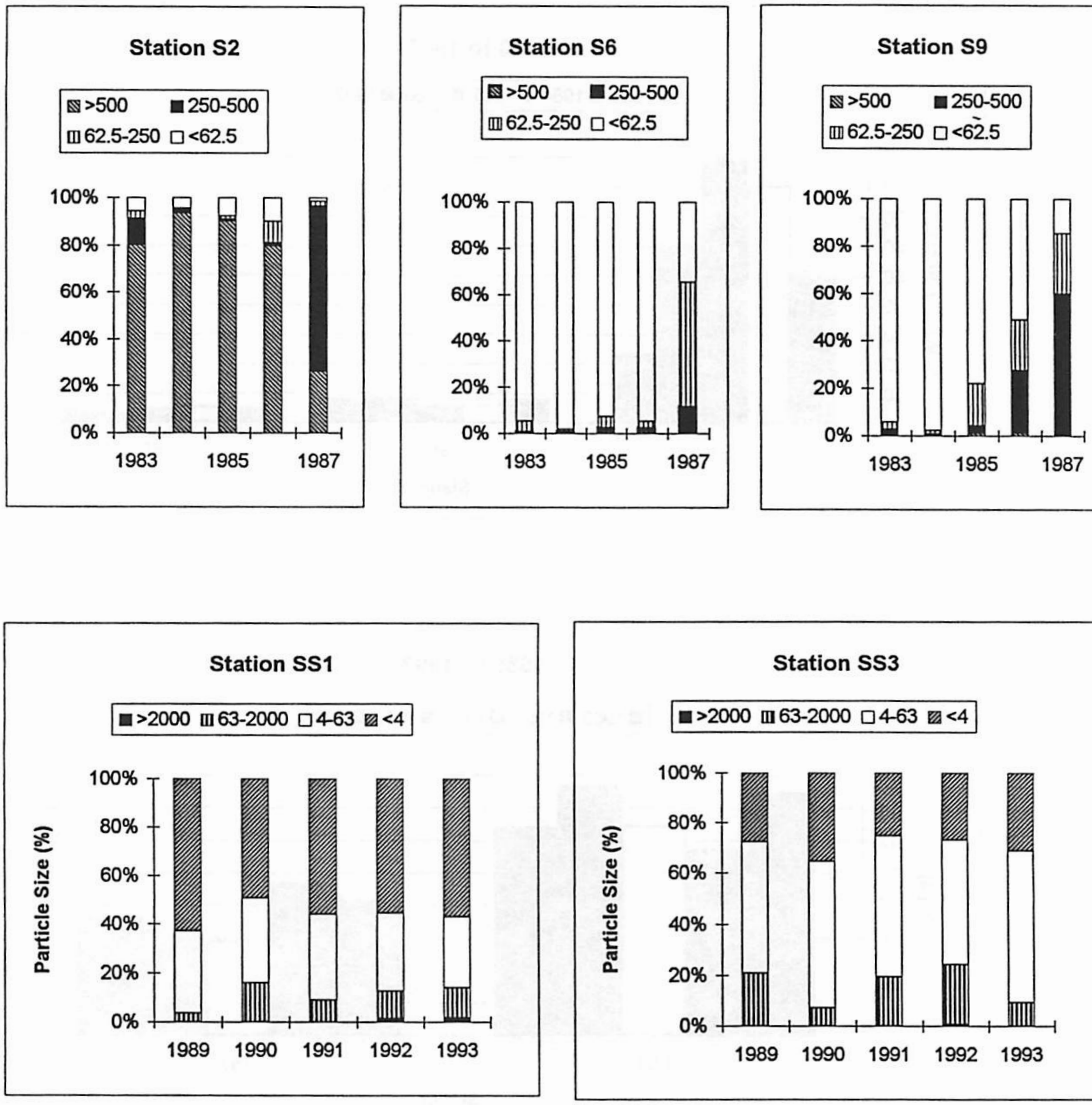
Figure 5.8 Sediment Sampling Locations, 1989 to 1993; Skeena Cellulose Inc., Prince Rupert.



Source: Dwernychuk et al., 1993b.

SC-547 SED-STN

Figure 5.9 Particle size data for sediments collected near Skeena Cellulose Inc., 1983 to 1993.

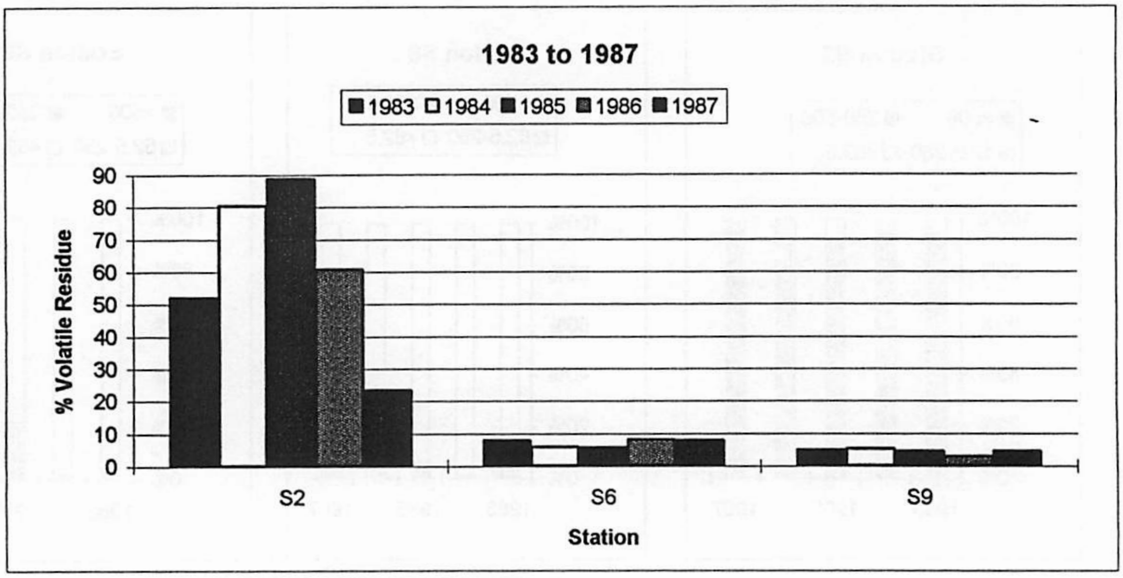


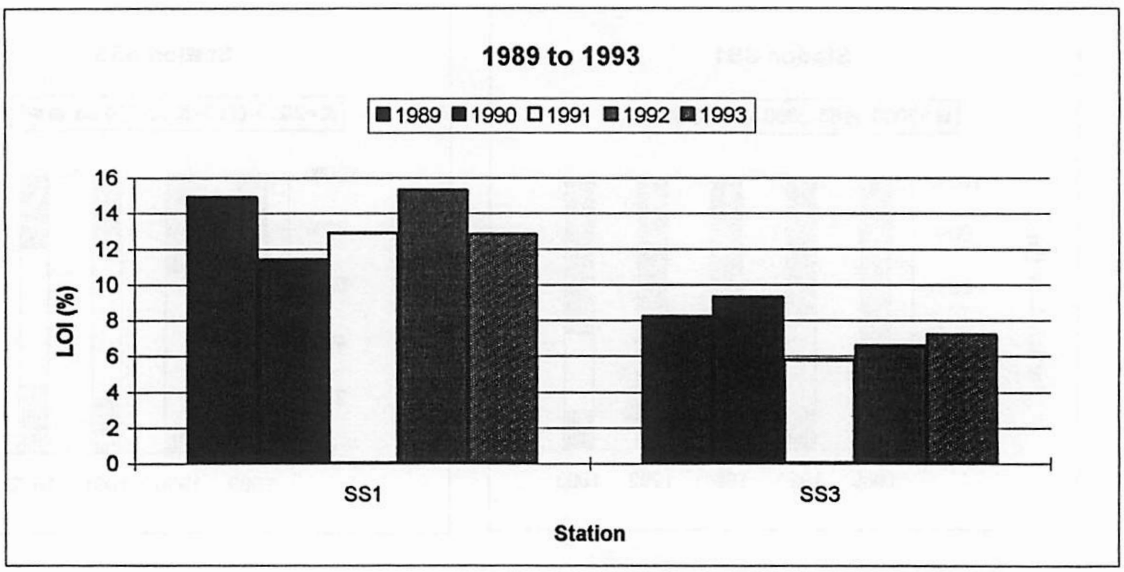
Source: Dwernychuk, 1988, 1989b; Dwernychuk *et al.*, 1992a, 1992b,1993a, 1993b.

See Figure 5.8 for station locations.

Particle size:		
	gravel	> 2000 microns
	sand	63 - 2000 microns
	silt	4 - 63 microns
	clay	< 4 microns

Figure 5.10 Volatile residue in sediments near Skeena Cellulose Inc., 1983 to 1993.



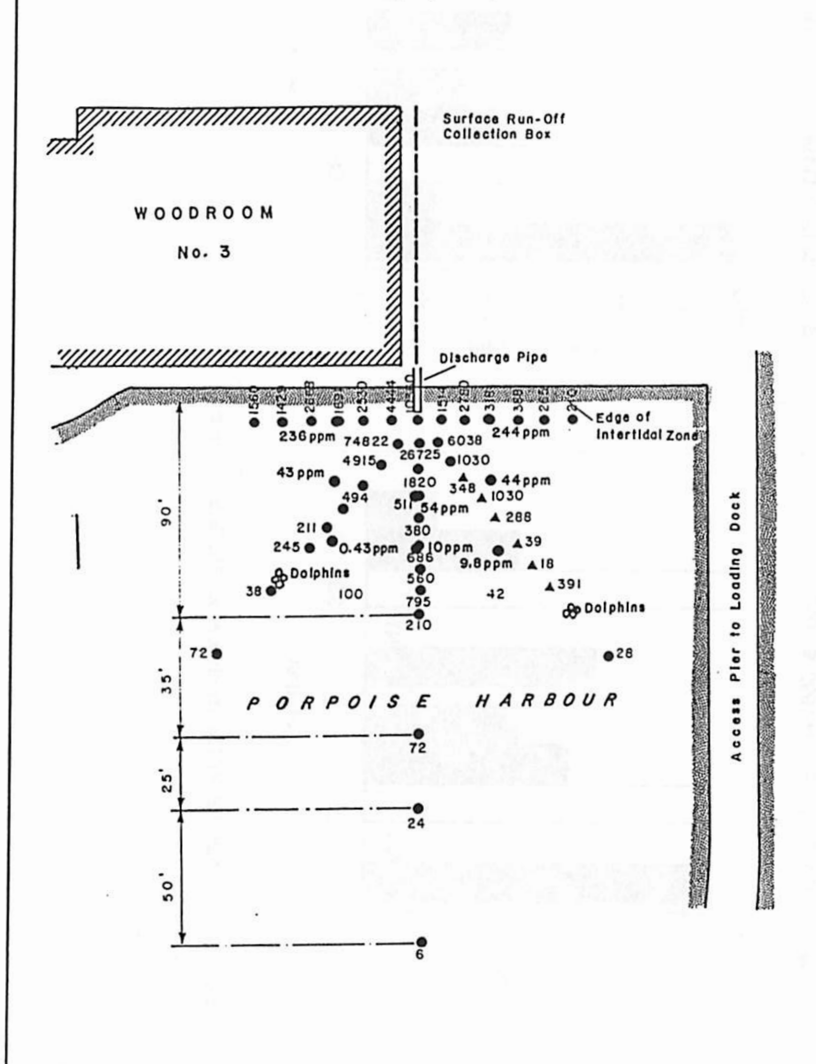


Source: Dwernychuk, 1988, 1989b; Dwernychuk et al., 1992a, 1992b, 1993a, 1993b.

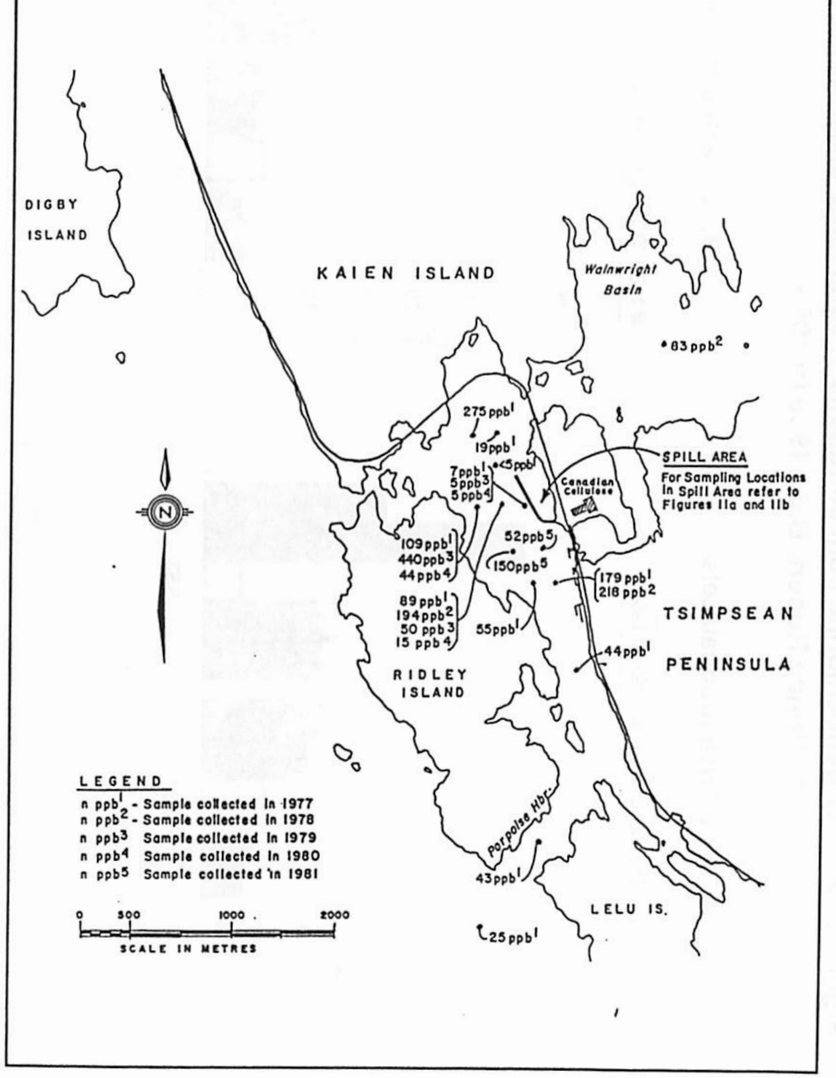
See Figure 5.8 for station locations.

Figure 5.11 Concentrations (ppm/dry weight) in sediments from the PCB spill area in Porpoise Harbour.

a. At the pulpmill, 1977.

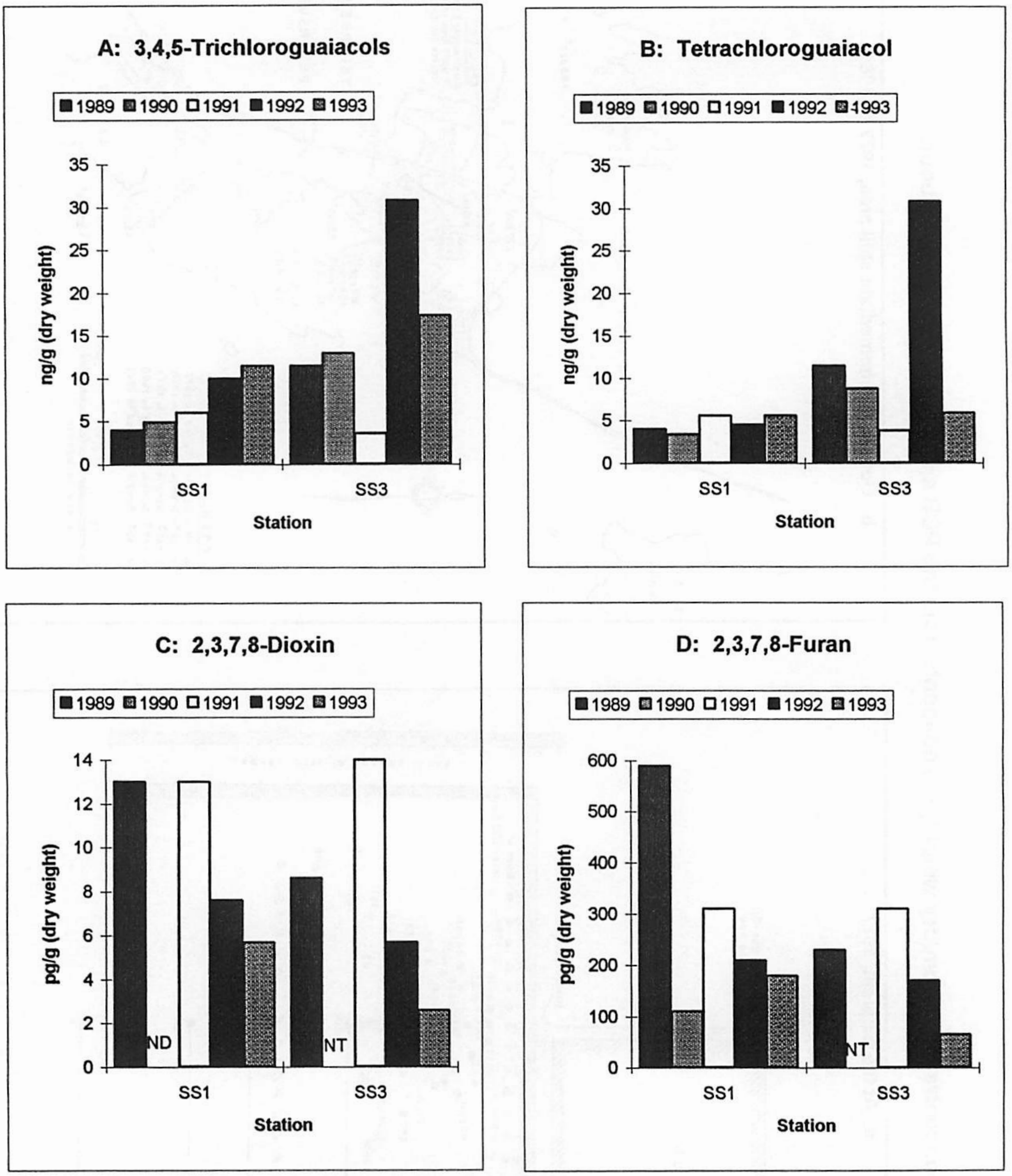


b. Outside the immediate spill area, 1977 to 1981.



Source: Garrett, 1983.

Figure 5.12 **Organochlorine concentrations in sediments at Skeena Cellulose Inc., Prince Rupert, B.C., 1989 to 1993.**

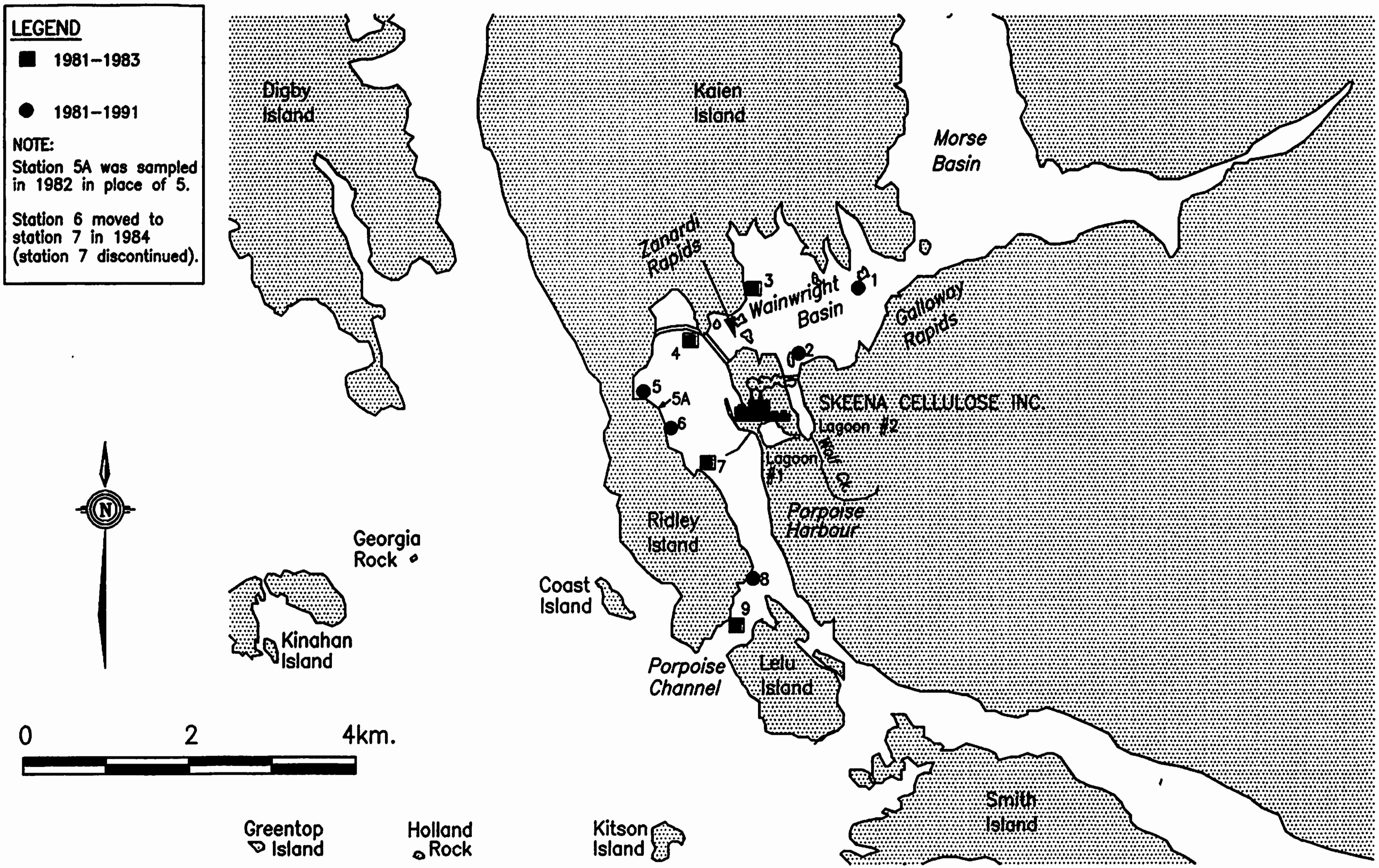


Source: Dwernychuk, 1989b; Dwernychuk *et al.*, 1992a,b, 1993a,b.

ND = not detected

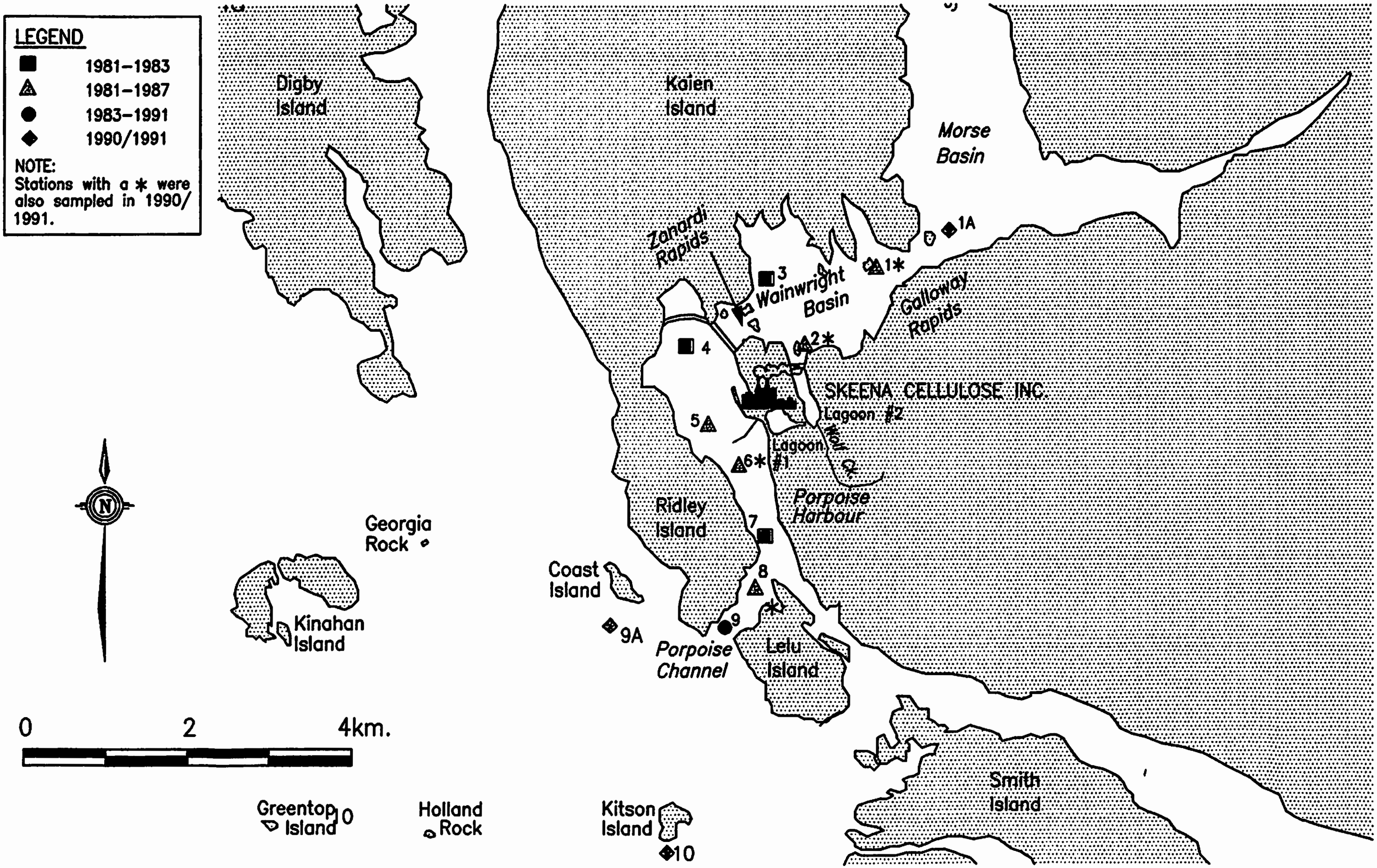
NT = not tested

Figure 5.13 Intertidal Macroalgae Sampling Stations at Skeena Cellulose Inc., Prince Rupert, B.C., 1981 to 1991.



Source: Beak Consultants Ltd., 1983, 1985; Dwernychuk, 1989b; Dwernychuk et al., 1992a.

Figure 5.14 Subtidal Benthic Invertebrate Sampling Stations at Skeena Cellulose Inc., Prince Rupert B.C., 1981 to 1991.



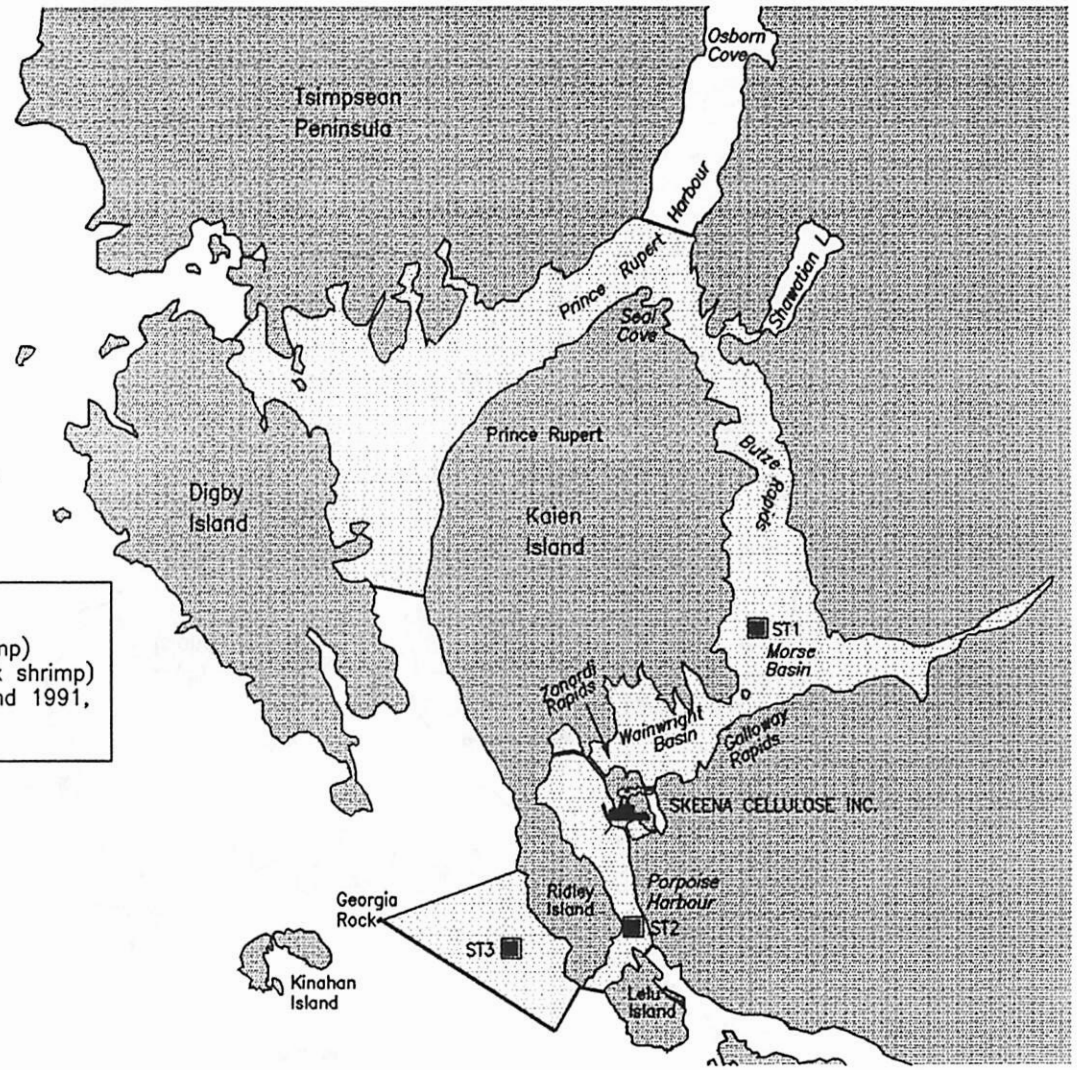
Source: [illegible] 1983 Owen et al.

hcl

Figure 5.15 Prince Rupert Shrimp; 2,3,7,8-TCDD, 1989 to 1993.

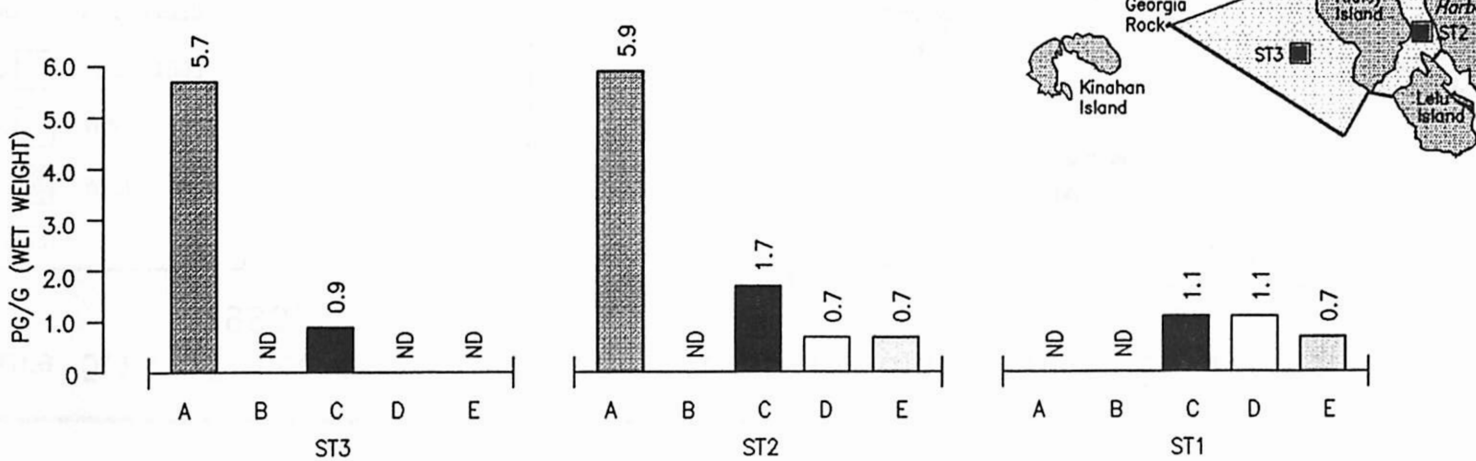
LEGEND

A		JANUARY 1989
B		JUNE 1990
C		MARCH 1991
D		MARCH 1992
E		APRIL 1993
ND		NOT DETECTED



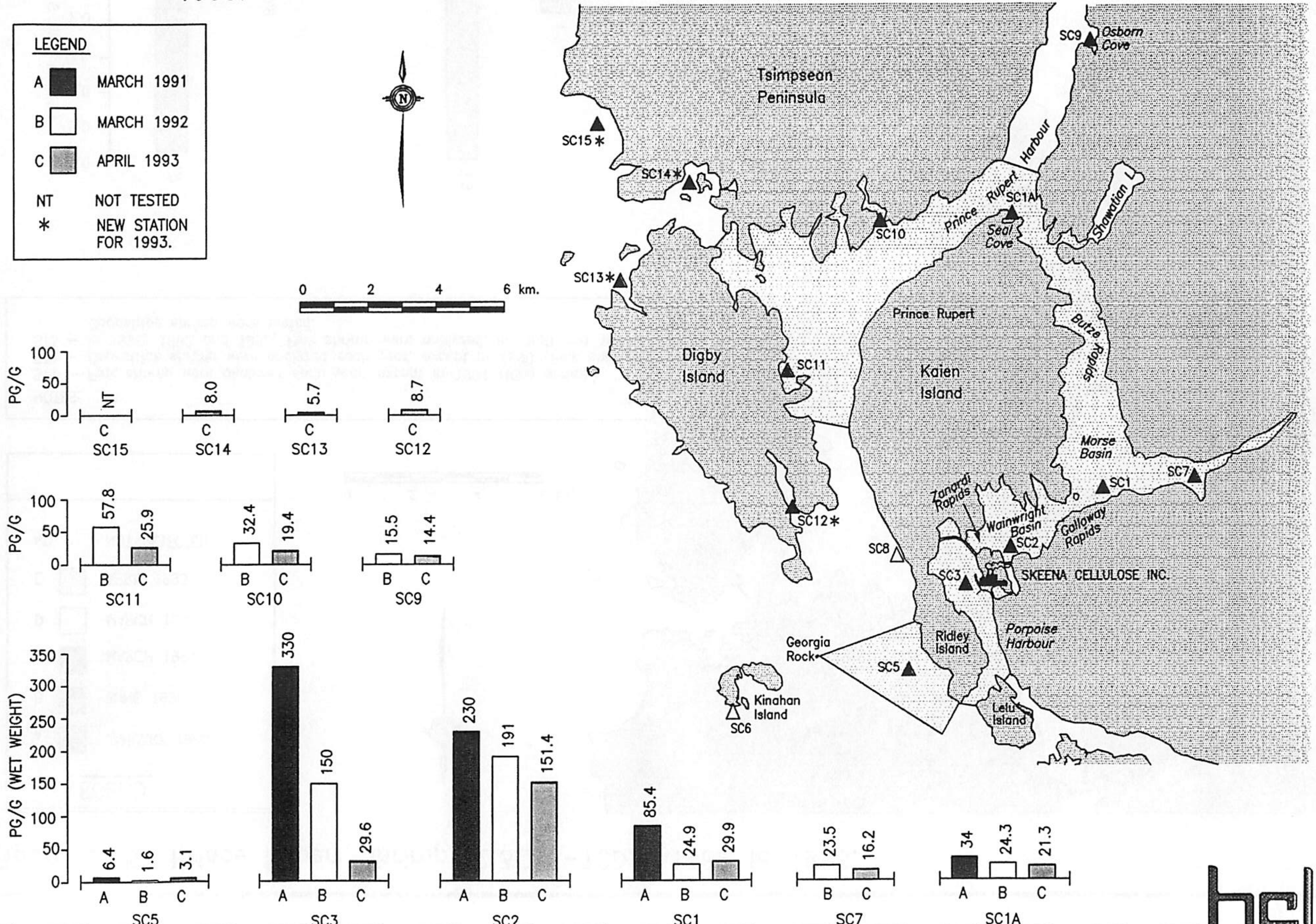
NOTES:

ST1 – Pink shrimp were analyzed each year, except in 1991 (King shrimp)
ST2 – Coonstripe shrimp were analyzed each year, except in 1990 (Pink shrimp)
ST3 – In 1990, 1992 and 1993, Pink shrimp were analyzed. In 1989 and 1991, Coonstripe shrimp were tested.



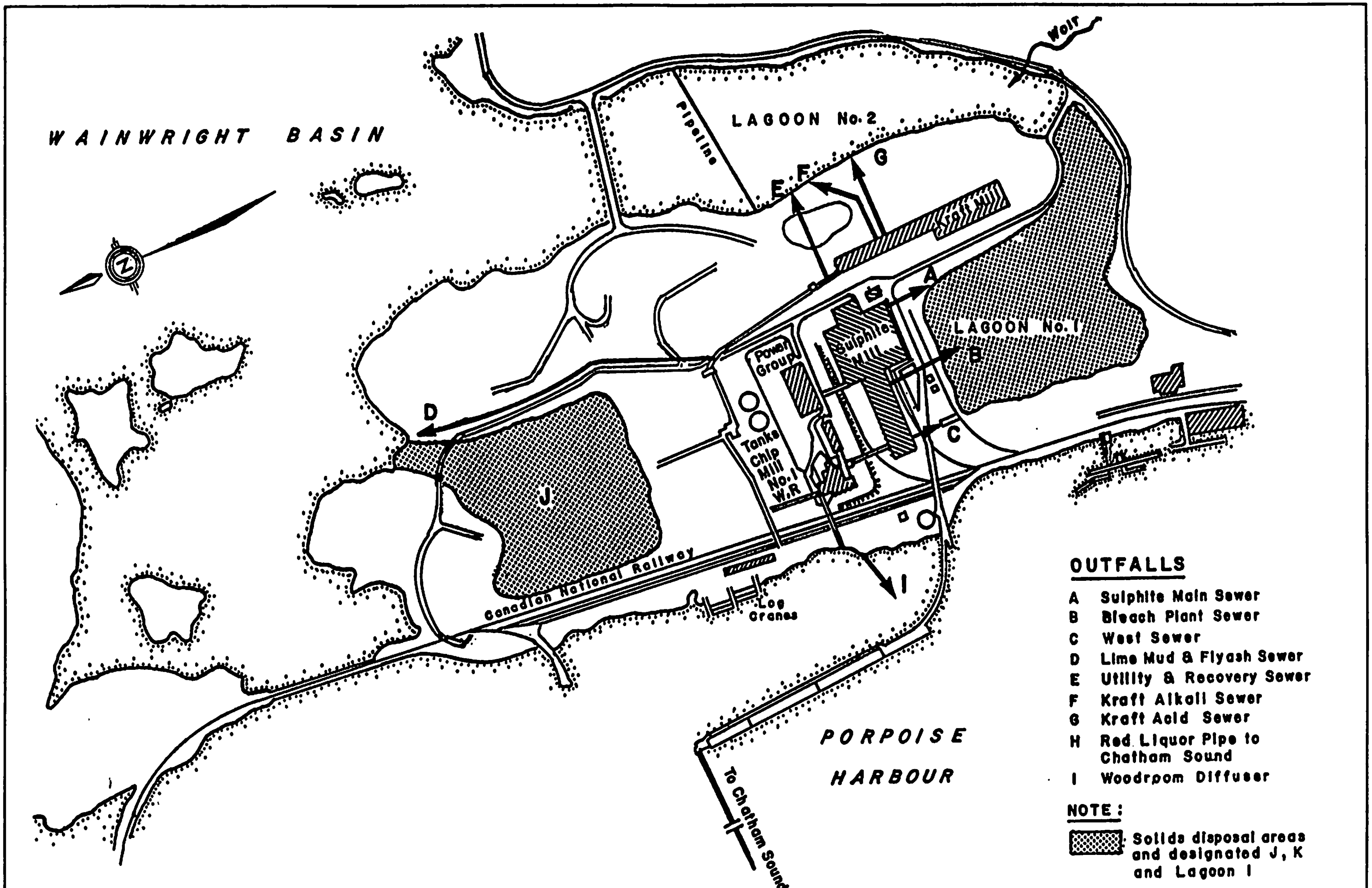
Source: Dwernychuk et al., 1993b.

Figure 5.16 Prince Rupert Dungeness Crab Hepatopancreas, Environment Canada TEQs, 1991 to 1993.



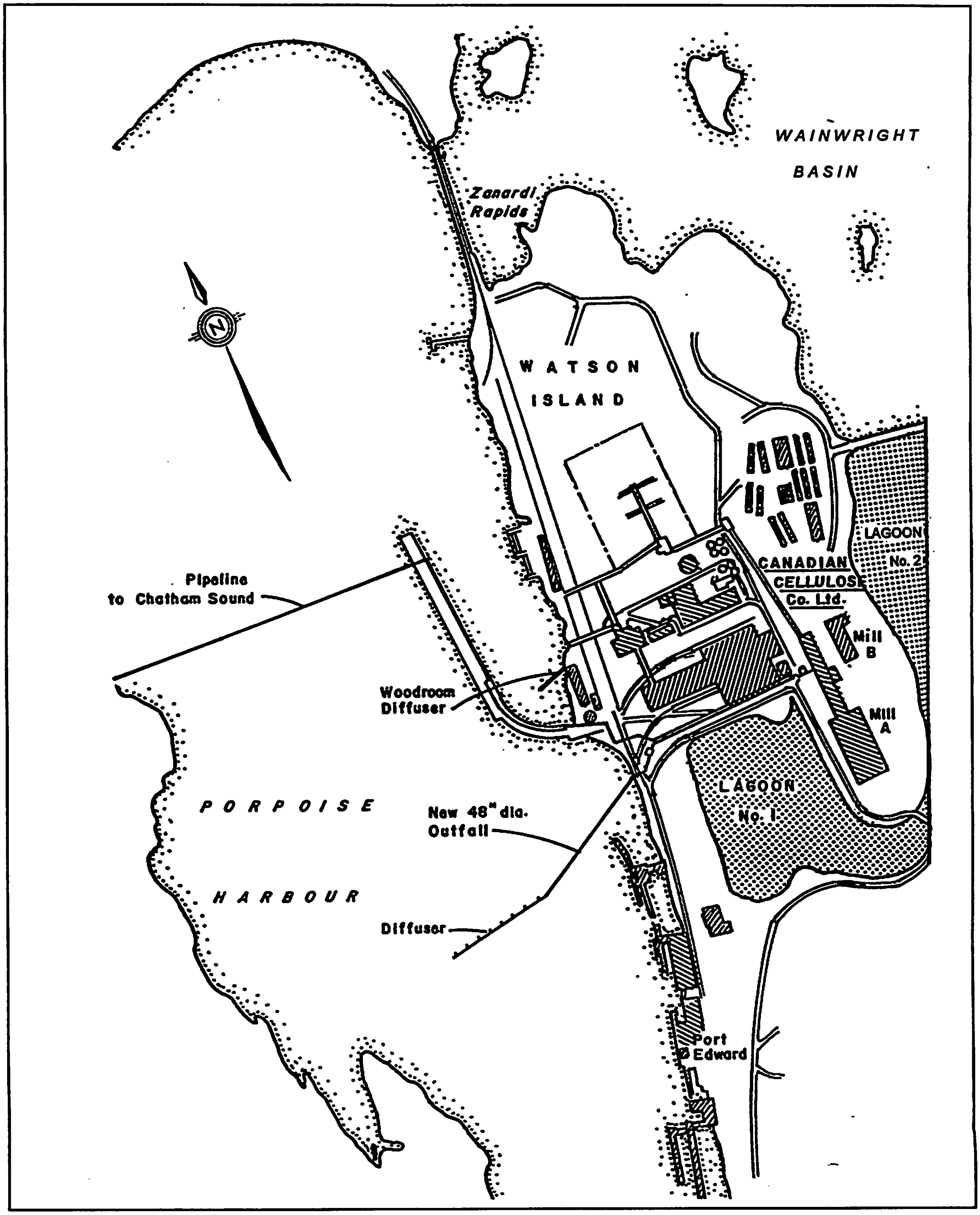
rce Dw[redacted]k et c[redacted]3b.

Figure 6.1 Skeena Cellulose Inc. site map and discharges prior to 1978.



Source: Packman, 1979.

Figure 6.2 Skeena Cellulose Inc. site map, October 1978.



Source: Packman, 1979.

Figure 6.3 Skeena Cellulose Inc. mill layout as of 1993, including discharge points.

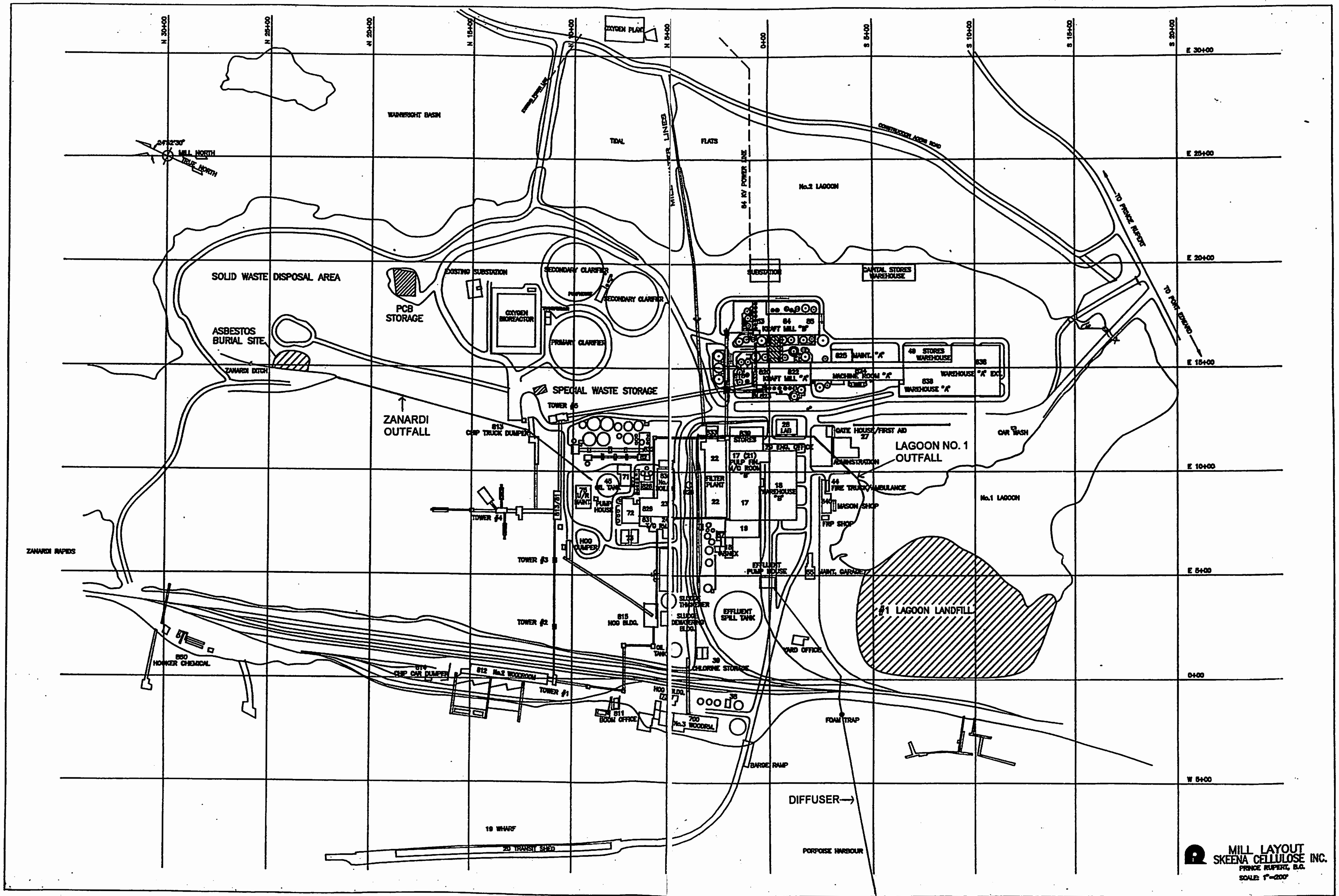
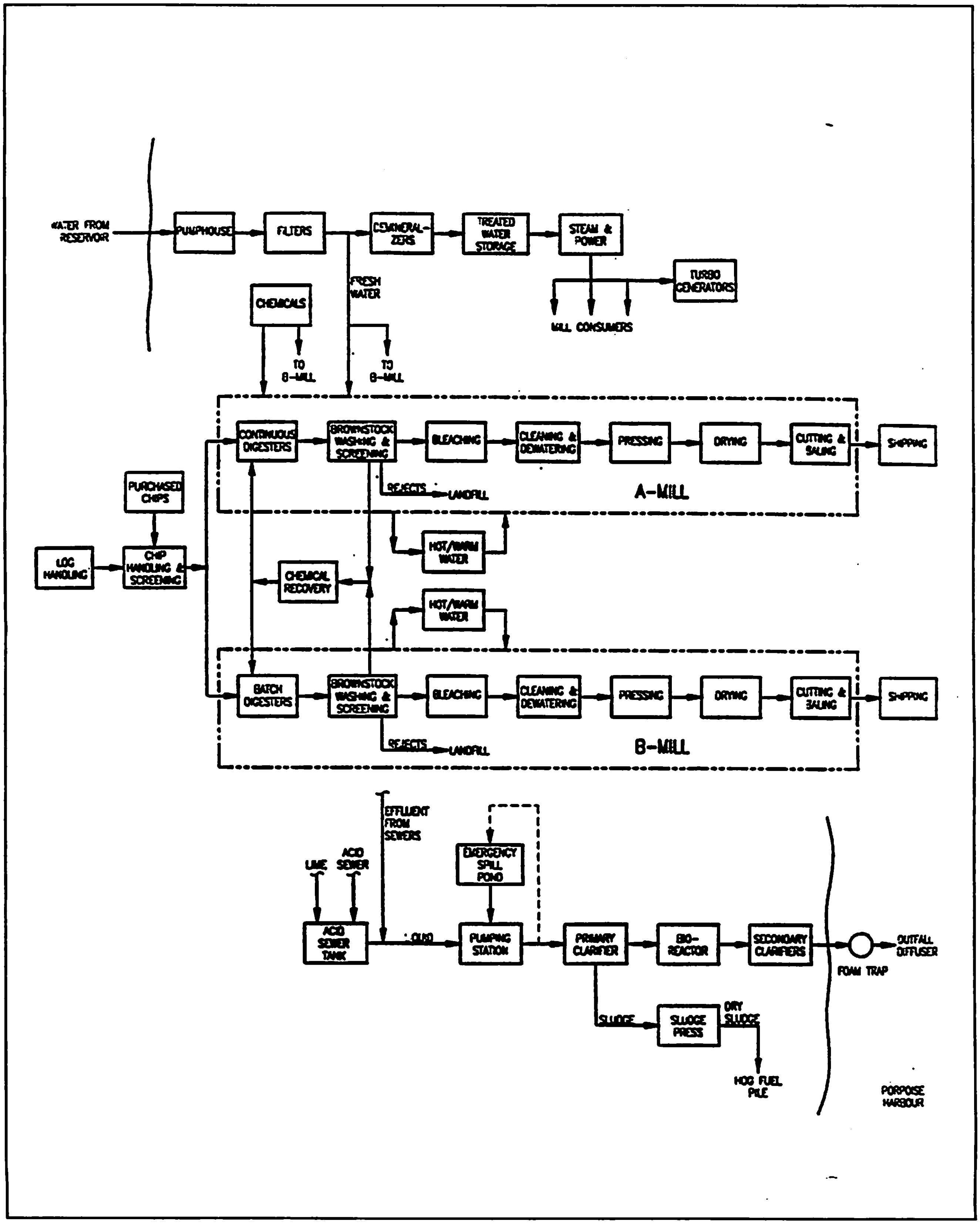
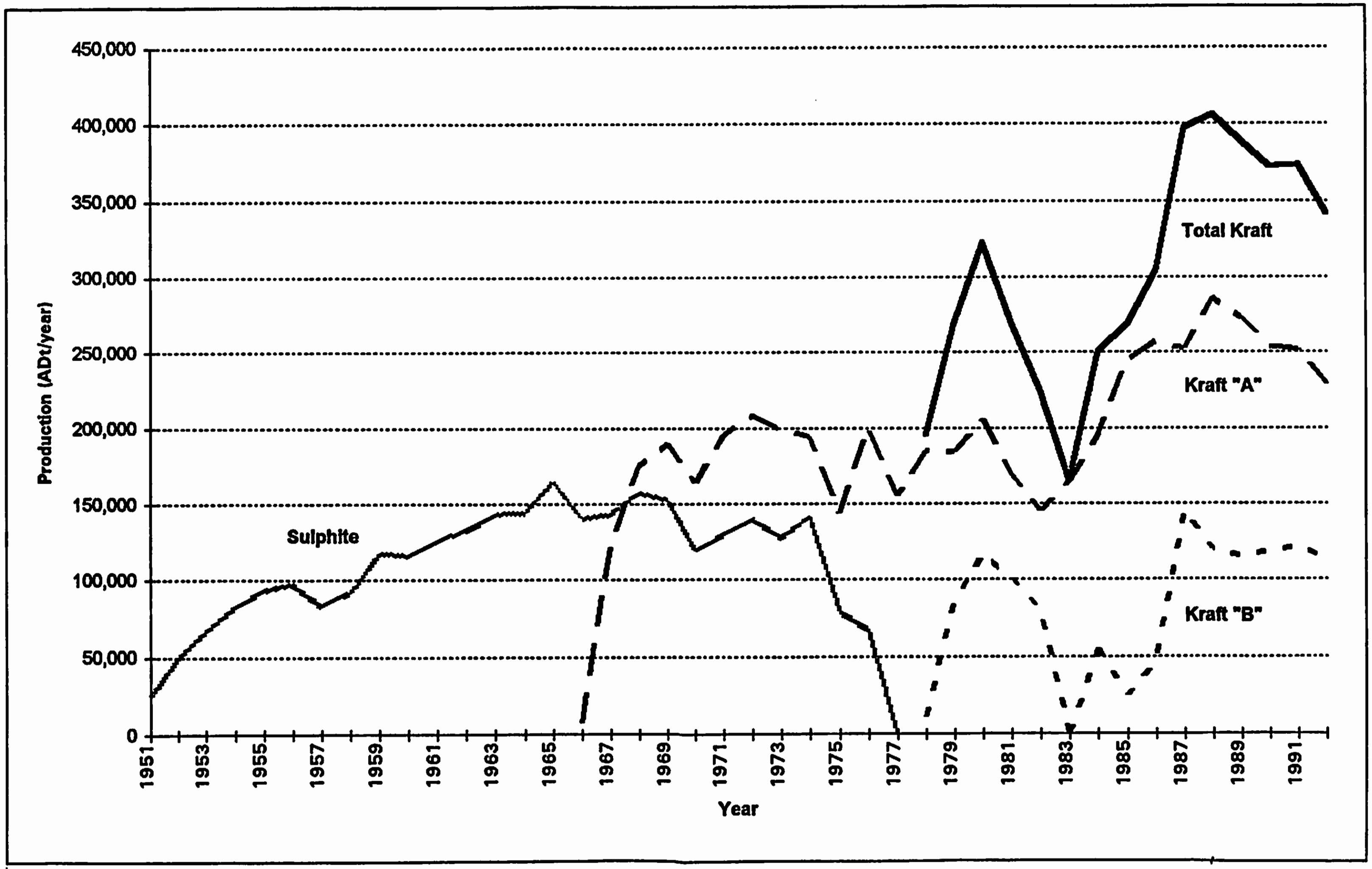


Figure 6.4 Skeena Cellulose Inc. mill process overview.



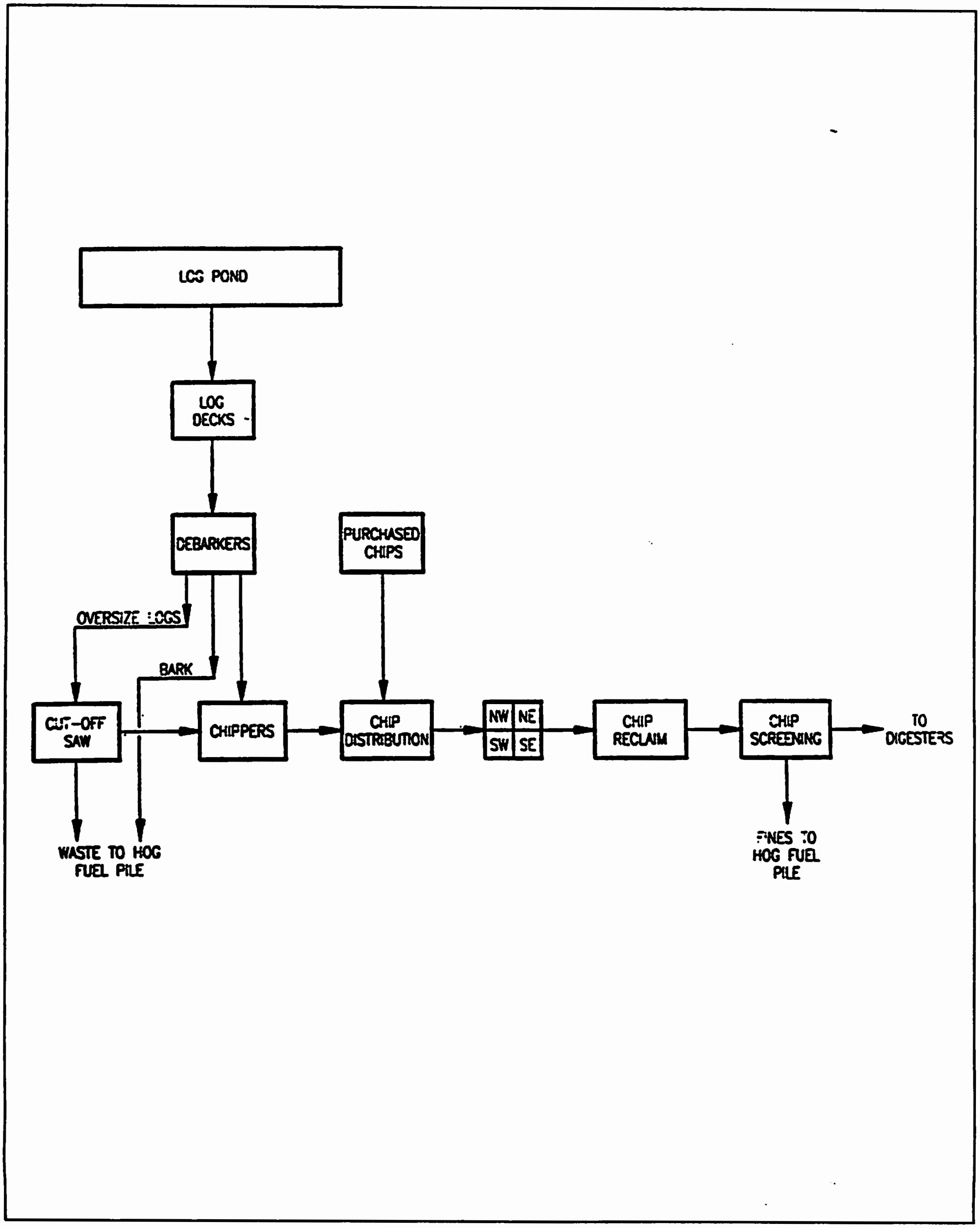
Source: Skeena Cellulose Inc., revision 3 May, 1991.

Figure 6.5 Pulp production at Skeena Cellulose Inc., 1951 to 1992.



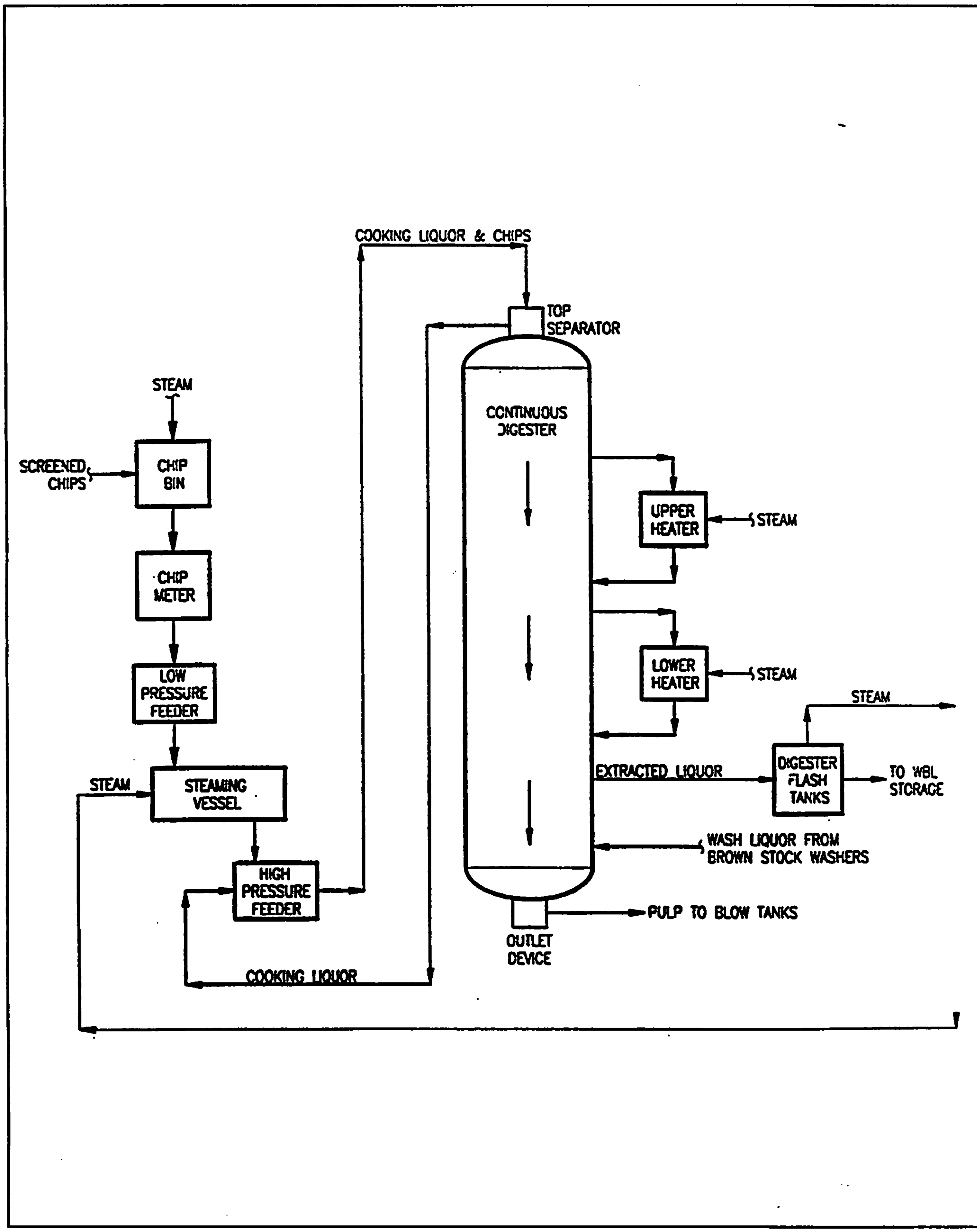
hcl

Figure 6.6 Log and chip handling, Skeena Cellulose Inc.



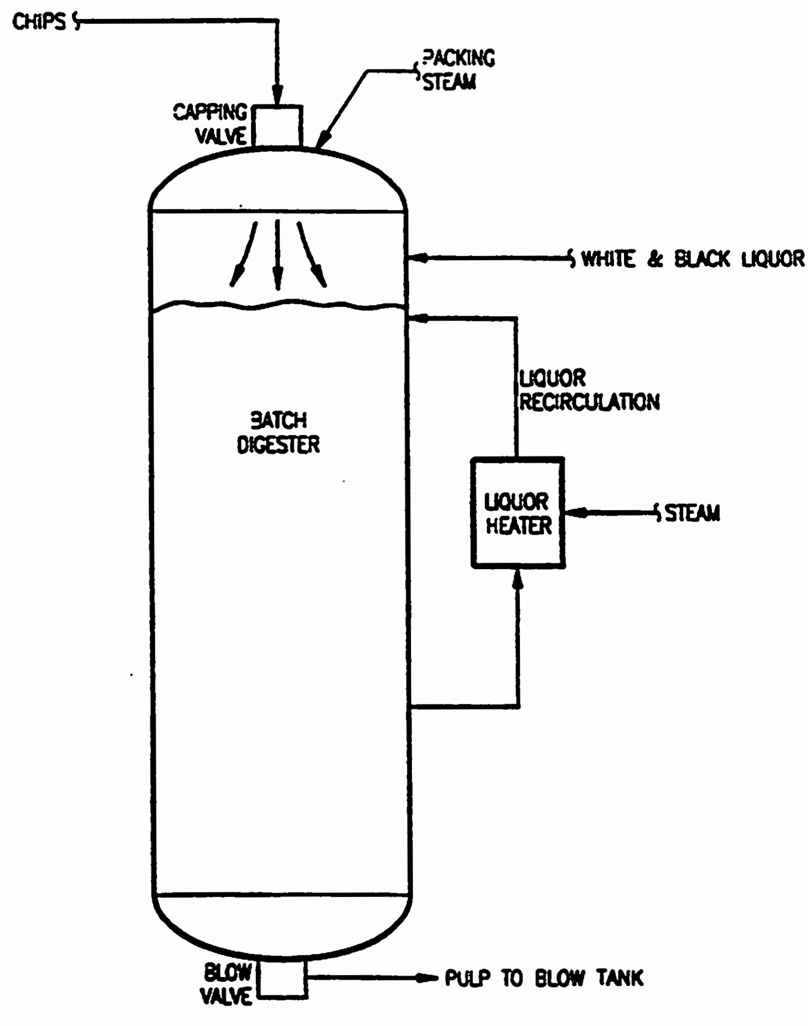
Source: Skeena Cellulose Inc., revision 3 May, 1991.

Figure 6.7 Continuous digester, Skeena Cellulose Inc.



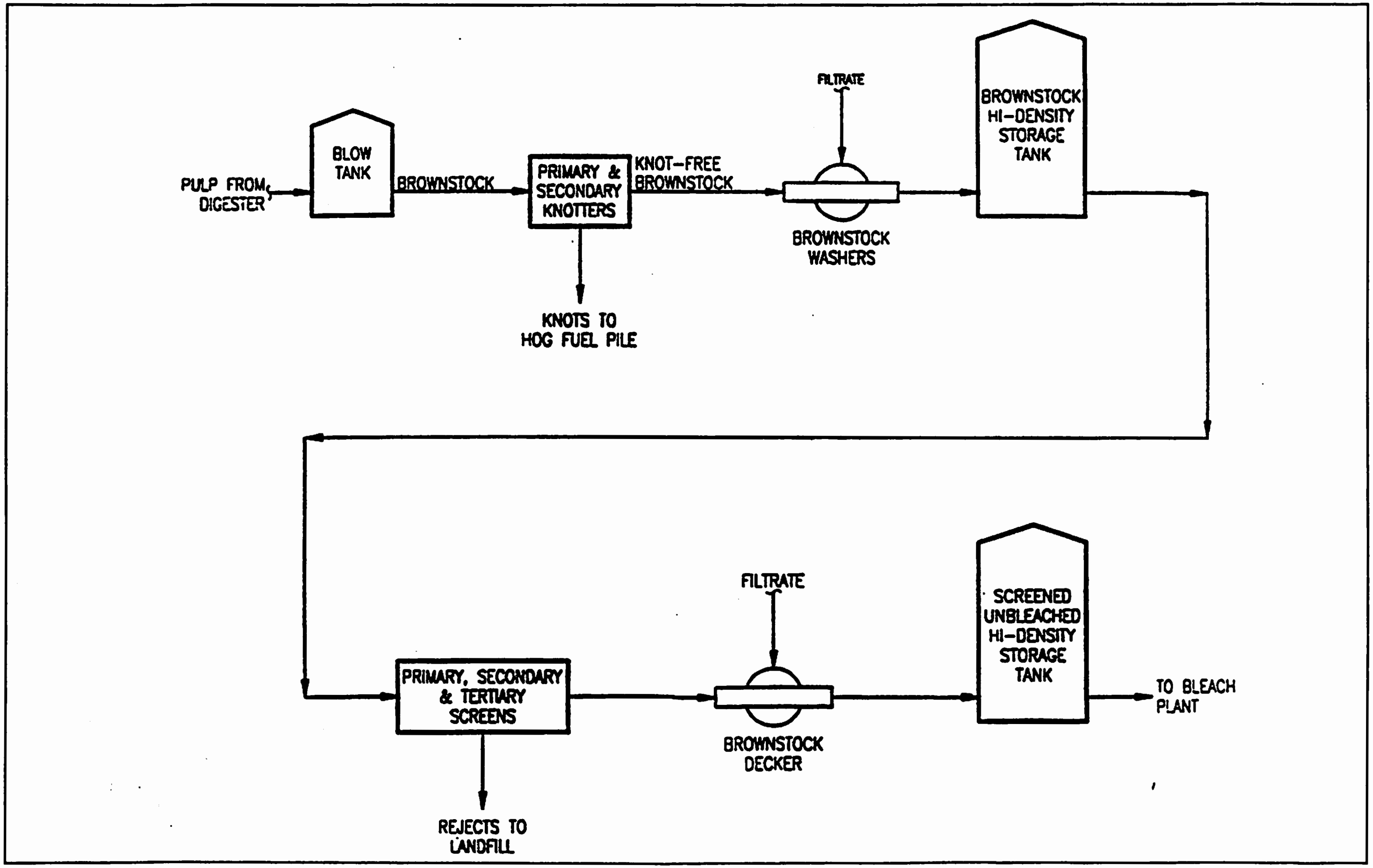
Source: Skeena Cellulose Inc., revision 3 May, 1991.

Figure 6.8 Batch digester, Skeena Cellulose Inc.



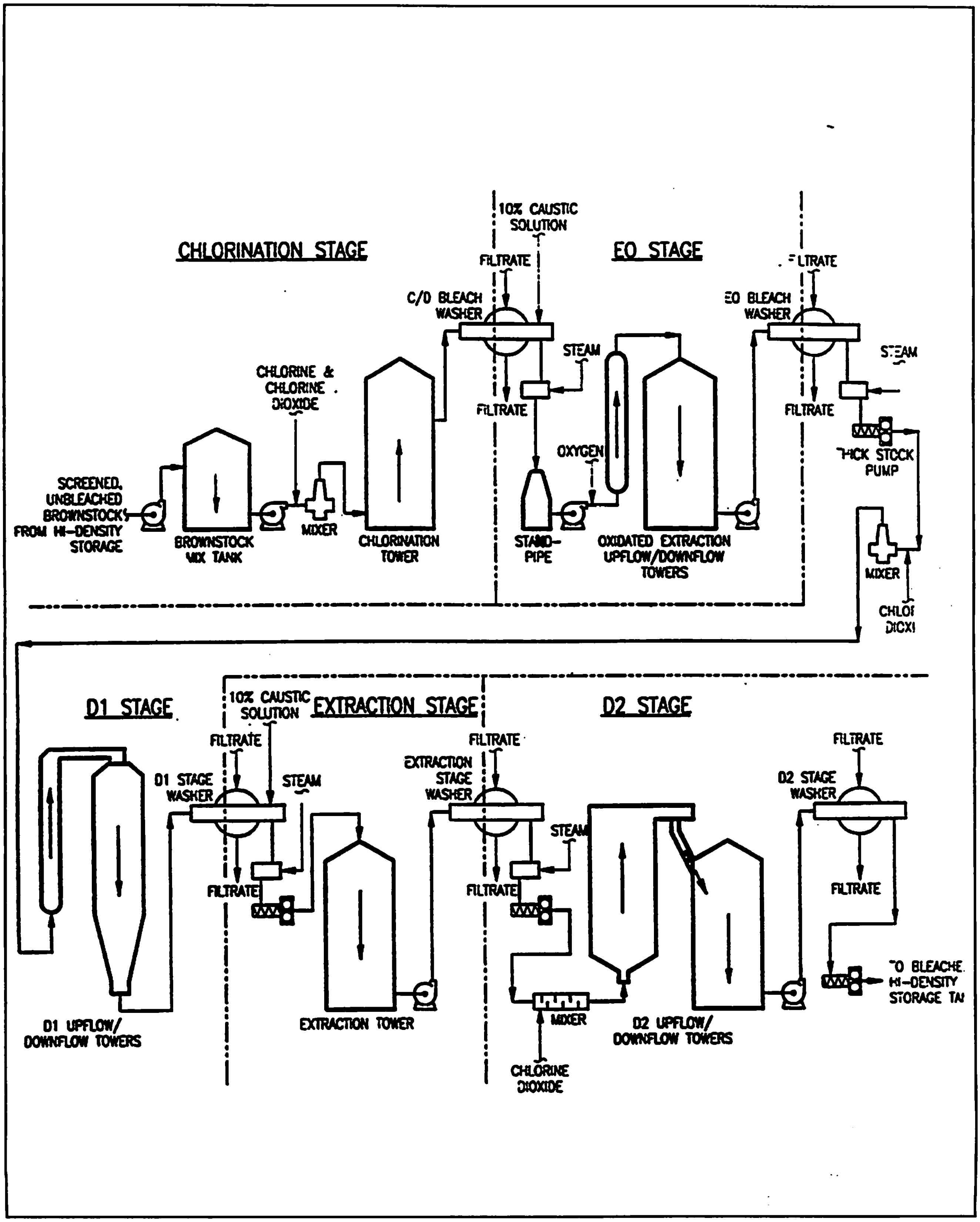
Source: Skeena Cellulose Inc., revision 3 May, 1991.

Figure 6.9 Brownstock, Skeena Cellulose Inc.



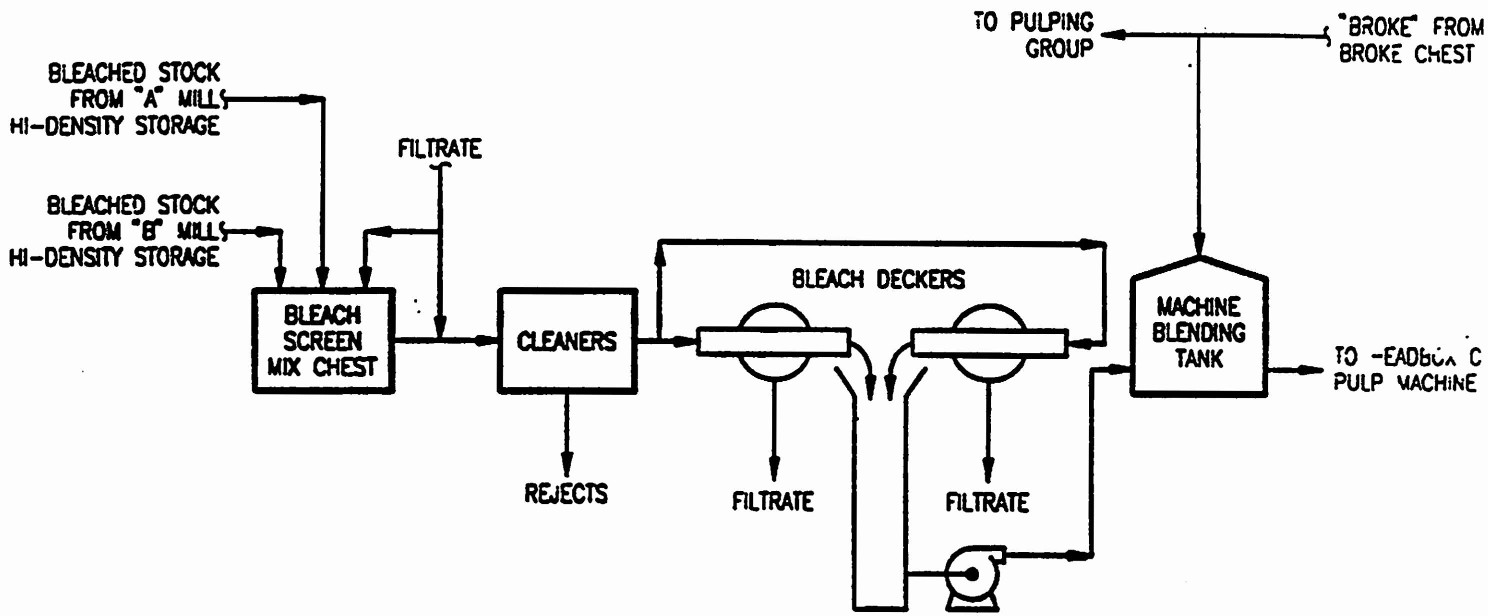
Source: Skeena Cellulose Inc., revision 3 May, 1991.

Figure 6.10 Bleaching process, Skeena Cellulose Inc.



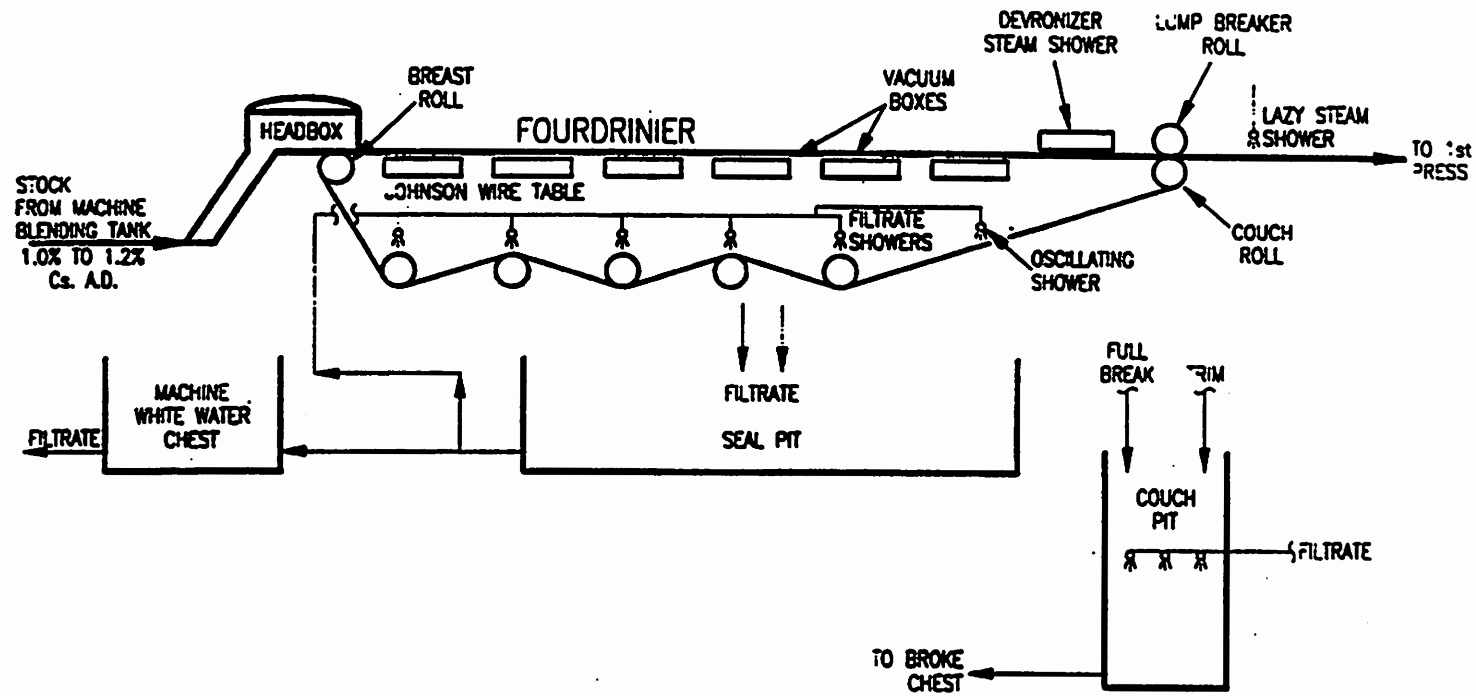
Source: Skeena Cellulose Inc., revision 3 May, 1991.

Figure 6.11 Stock preparation, Skeena Cellulose Inc.



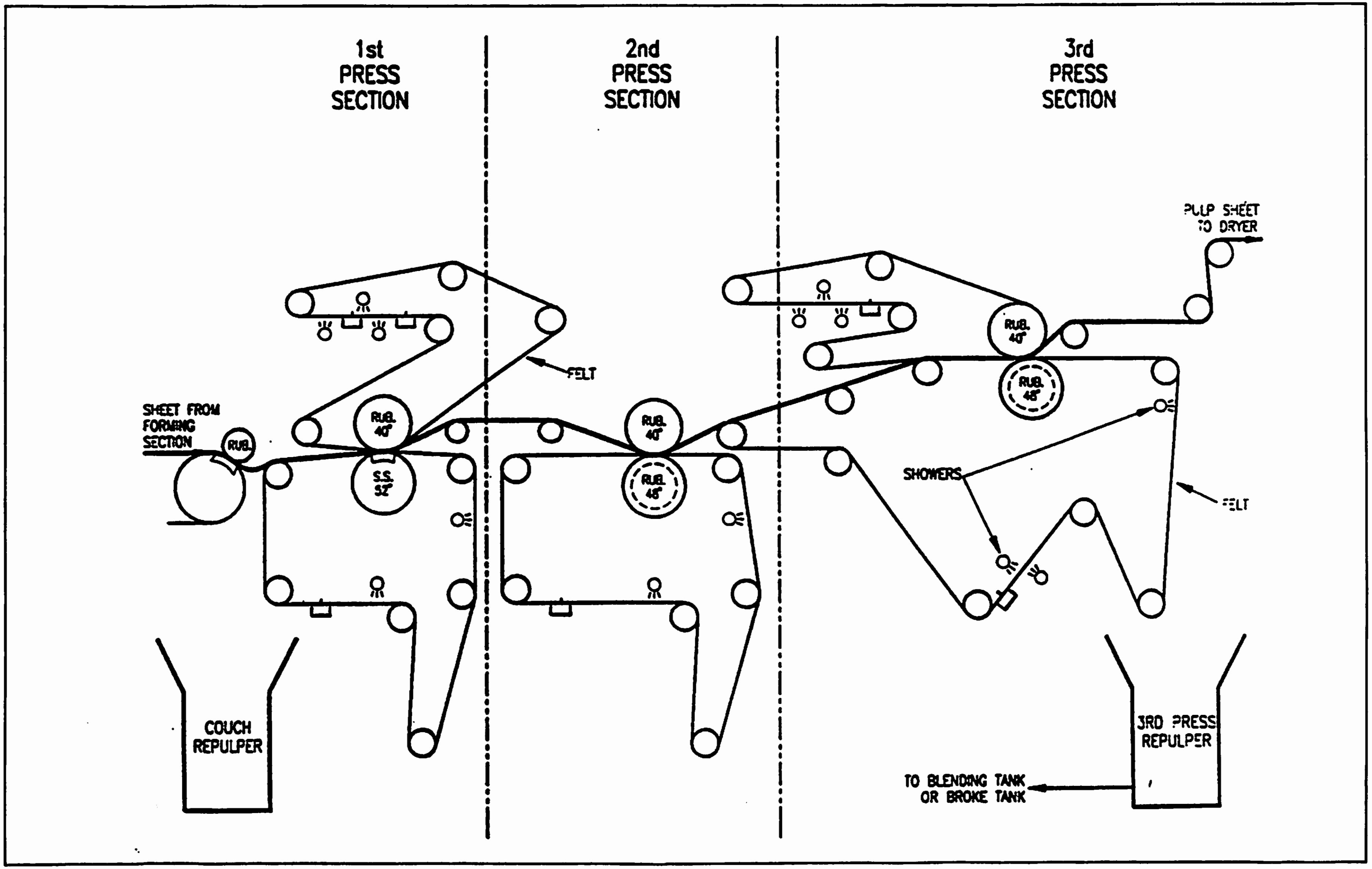
Source: Skeena Cellulose Inc., revision 3 May, 1991.

Figure 6.12 Sheet formation (machine room), Skeena Cellulose Inc.



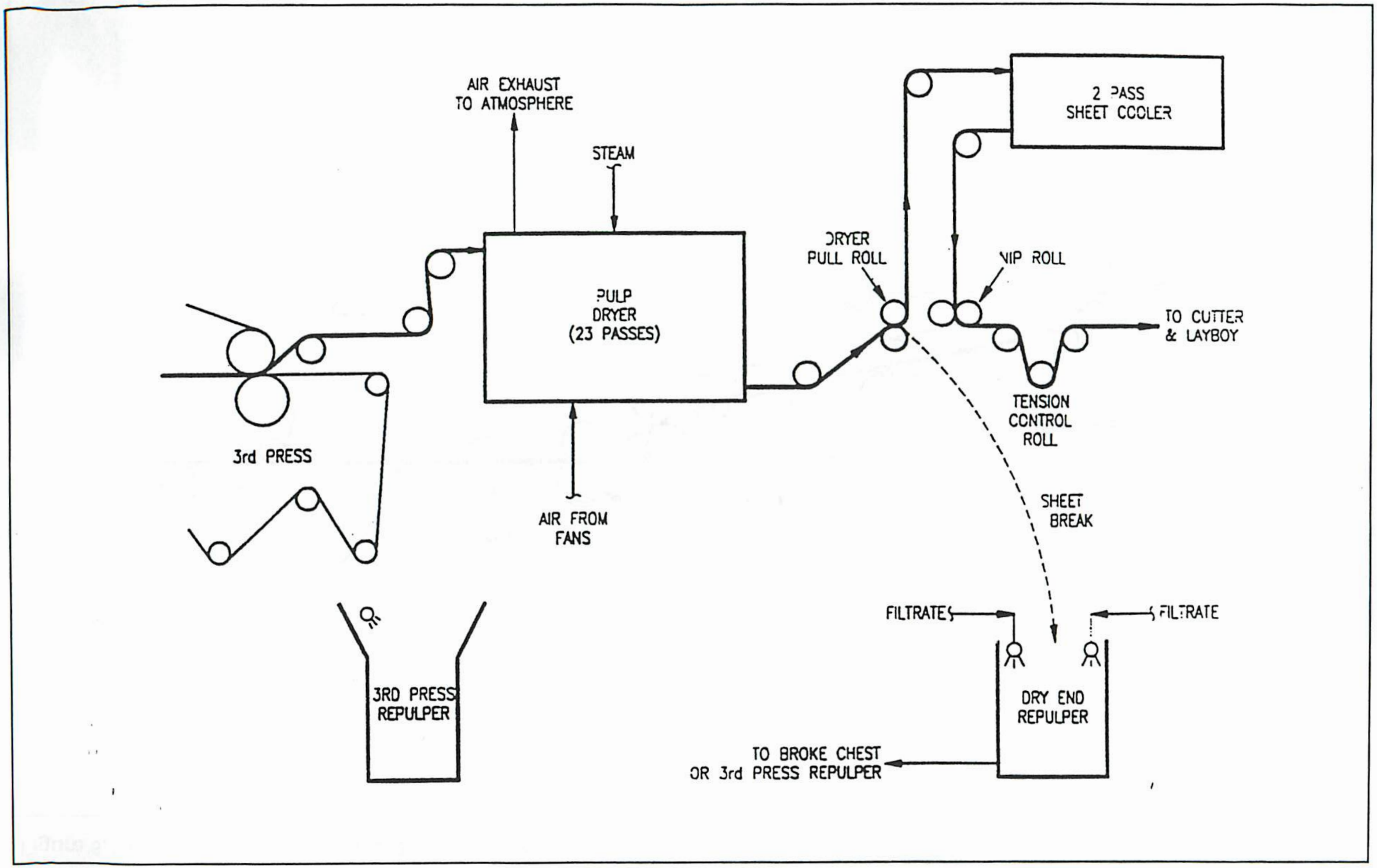
Source: Skeena Cellulose Inc., revision 3 May, 1991.

Figure 6.13 Press (machine room), Skeena Cellulose Inc.



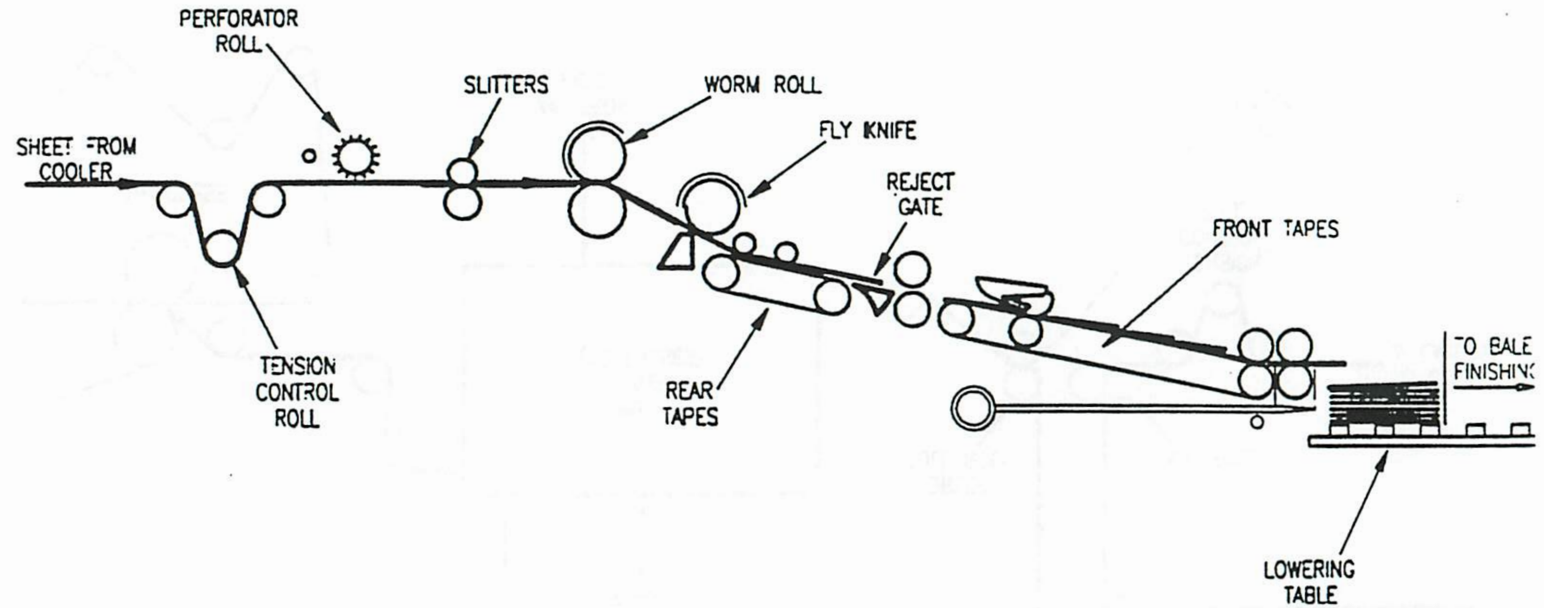
Source: Skeena Cellulose Inc., revision 3 May, 1991.

Figure 6.14 "A" mill dryer (machine room), Skeena Cellulose Inc.



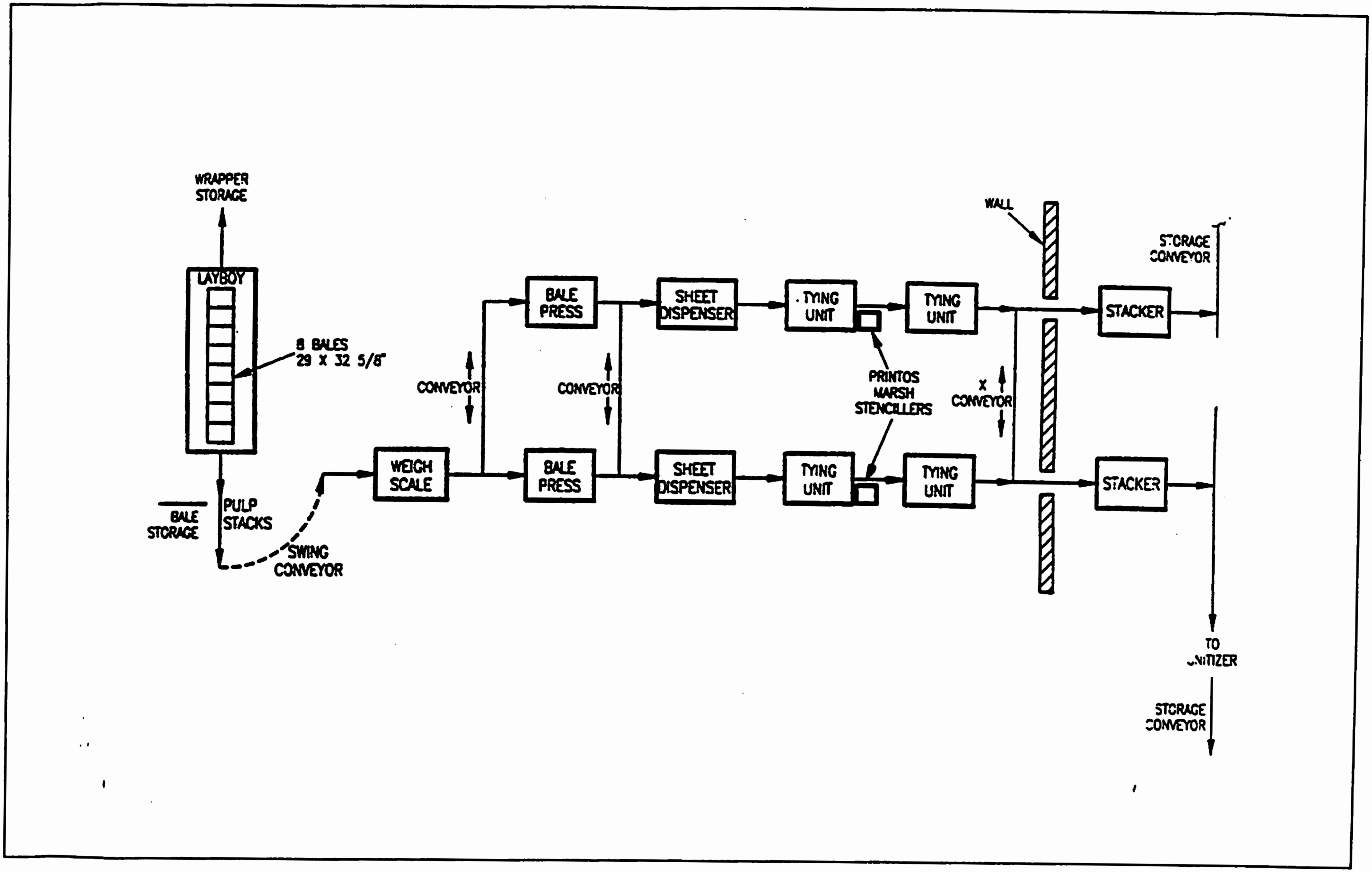
Source: Skeena Cellulose Inc., revision 3 May, 1991.

Figure 6.15 Cutter and layboy (machine room), Skeena Cellulose Inc.



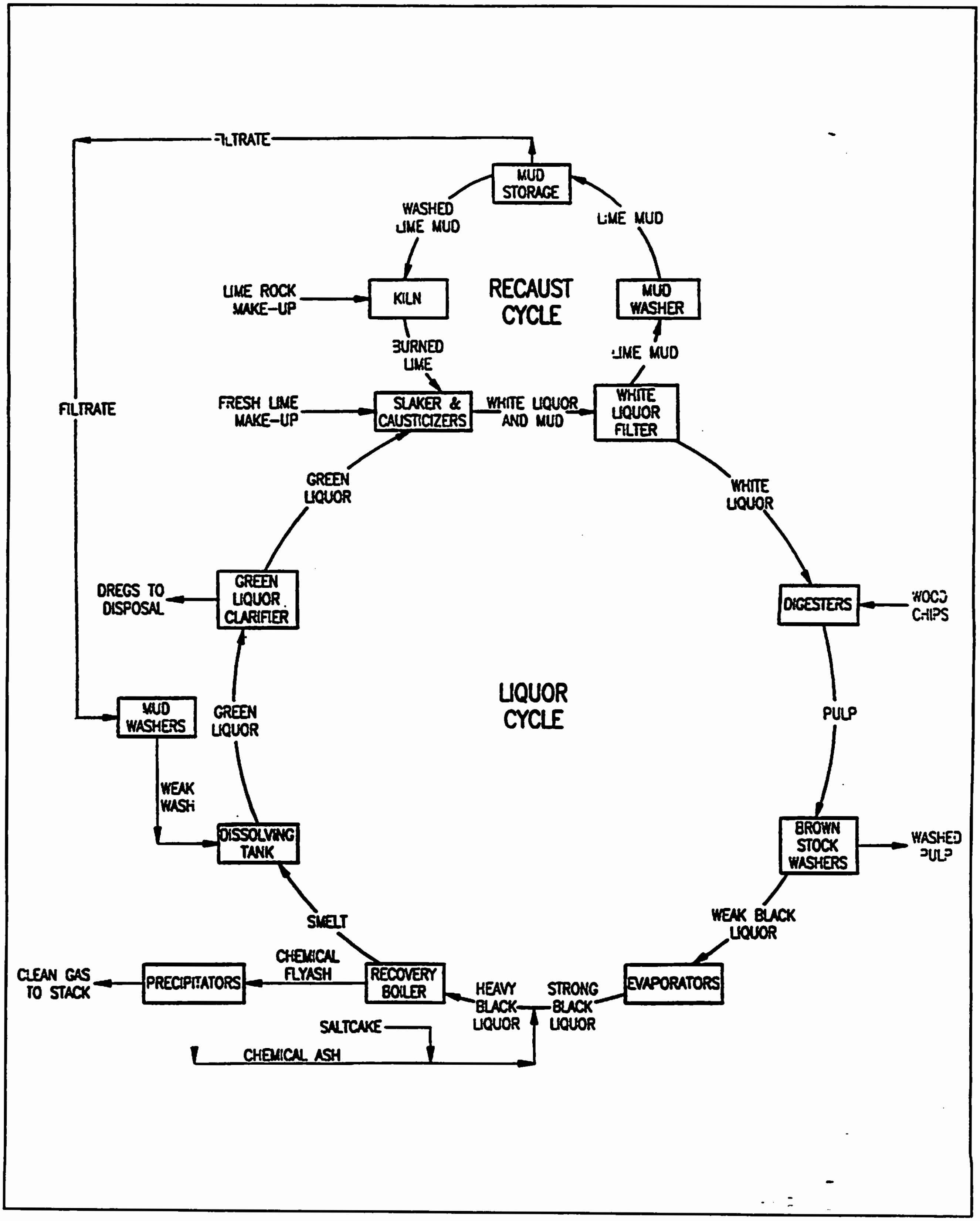
Source: Skeena Cellulose Inc., revision 3 May, 1991.

Figure 6.16 Bale finishing (machine room), Skeena Cellulose Inc.



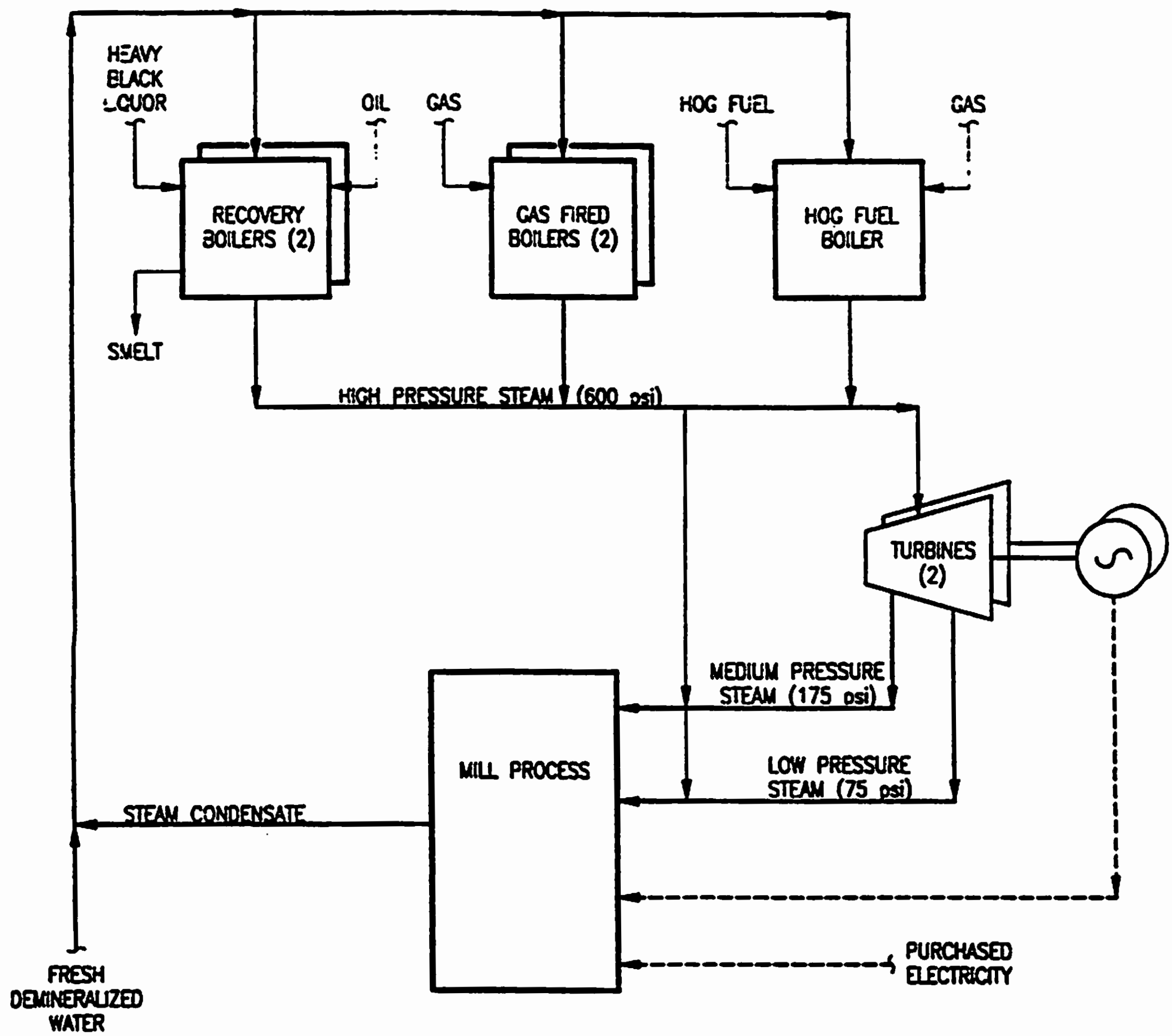
Source: Skeena Cellulose Inc., revision 3 May, 1991.

Figure 6.17 Recovery and recaust cycles, Skeena Cellulose Inc.



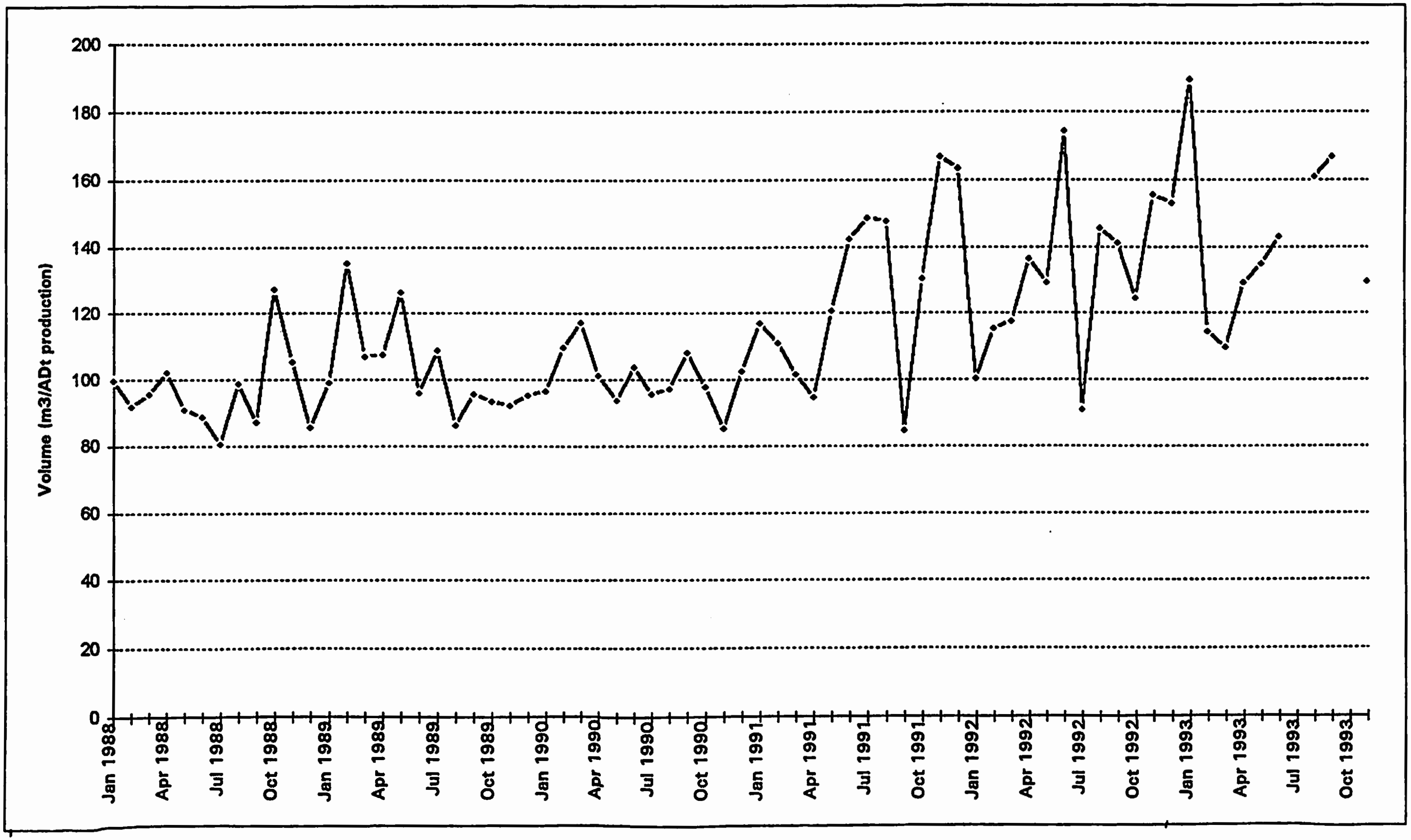
Source: Skeena Cellulose Inc., revision 3 May, 1991.

Figure 6.18 Energy system, Skeena Cellulose Inc.



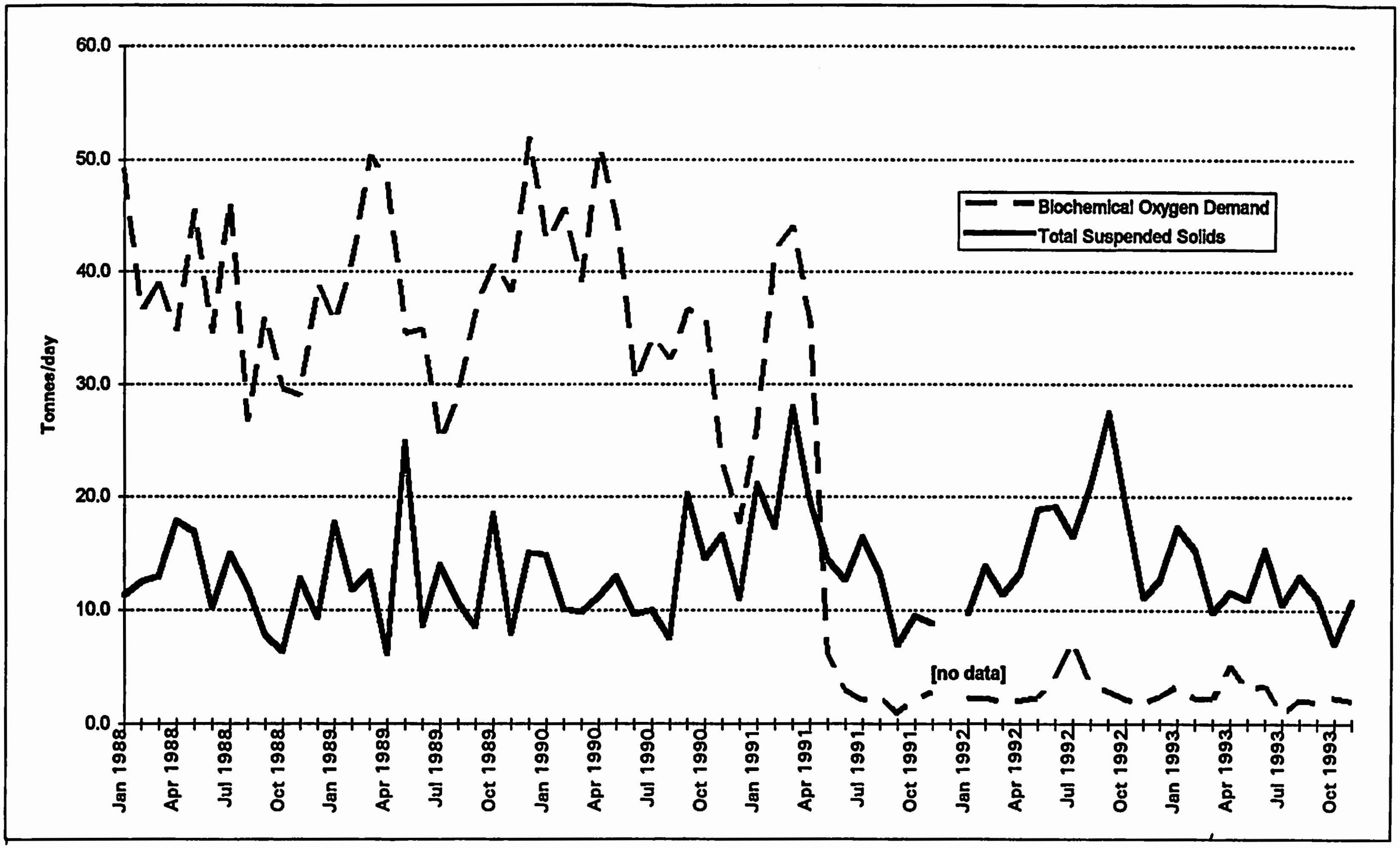
Source: Skeena Cellulose Inc., revision 3 May, 1991.

Figure 6.19 Volume of effluent discharged from Skeena Cellulose Inc., 1988 to 1993.



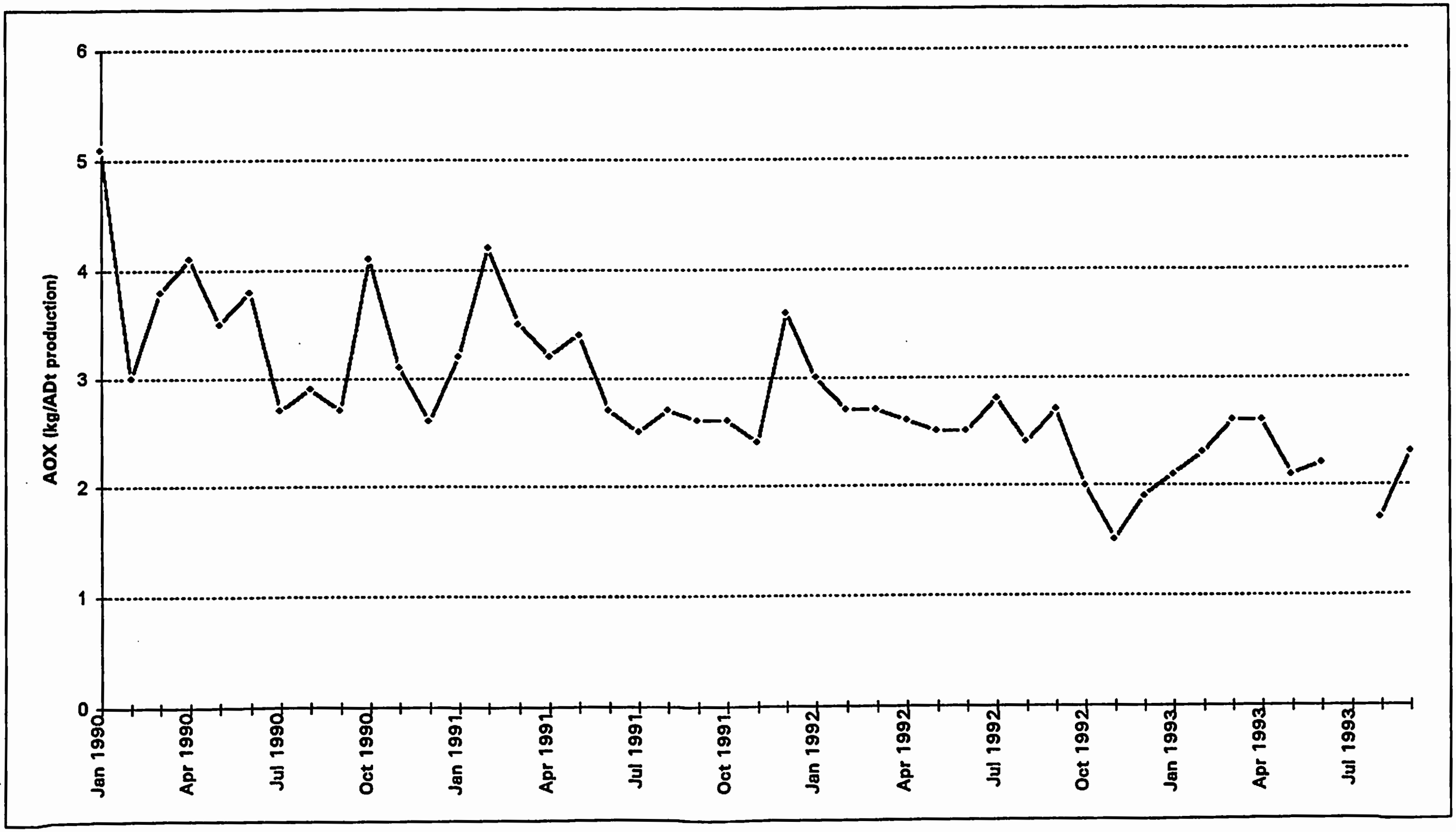
hcl

Figure 6.20 **Effluent quality at Skeena Cellulose Inc.: Biochemical oxygen demand and total suspended solids, 1988 to 1993.**



hcl

Figure 6.21 Adsorbable organic halides (AOX) discharged from Skeena Cellulose Inc., 1990 to 1993.



hcl

Figure 6.22 2,3,7,8-T4CDD concentrations in effluent from Skeena Cellulose Inc., 1988 to 1993.

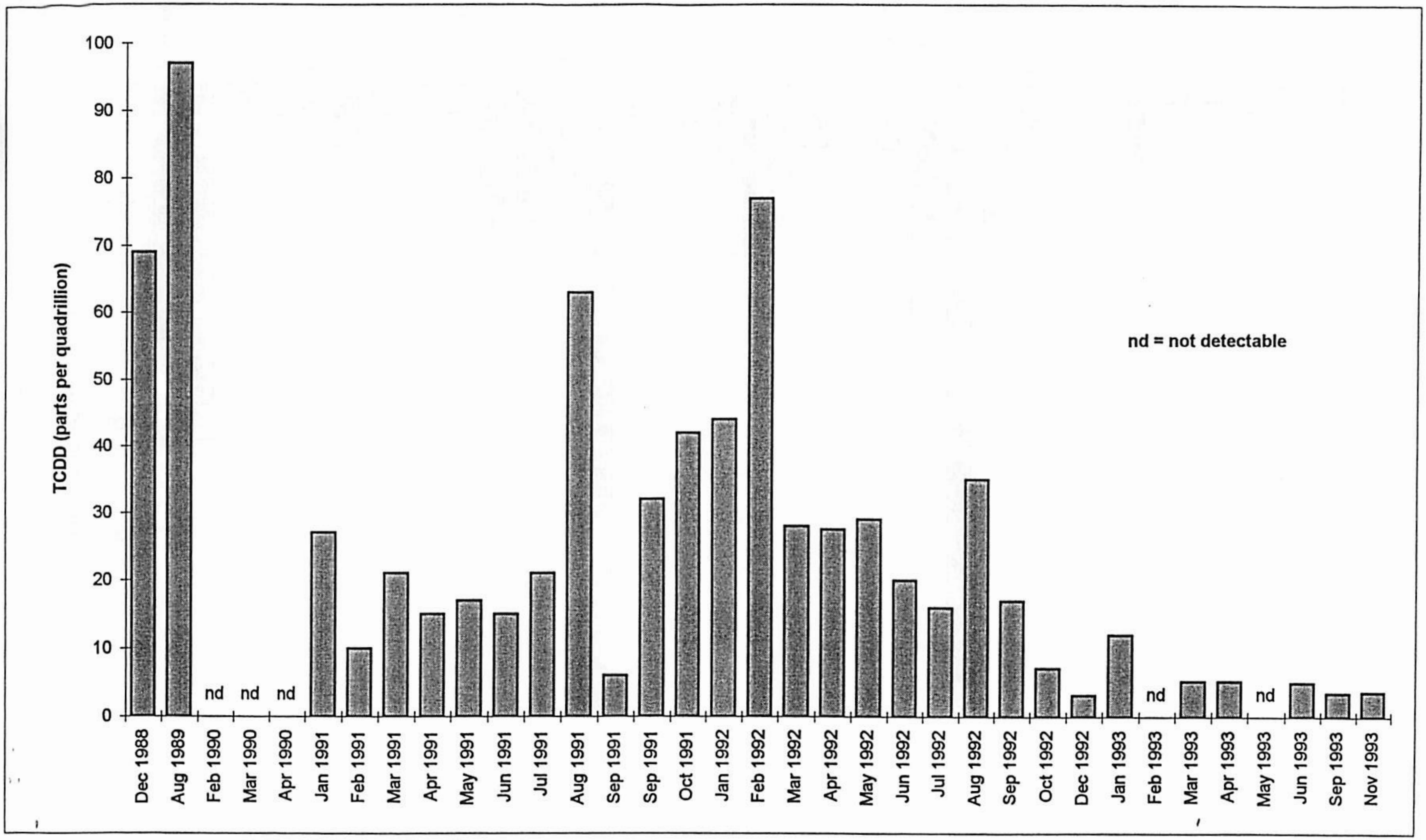


Figure 6.23 2,3,7,8-T4CDF concentrations in effluent from Skeena Cellulose Inc., 1988 to 1993.

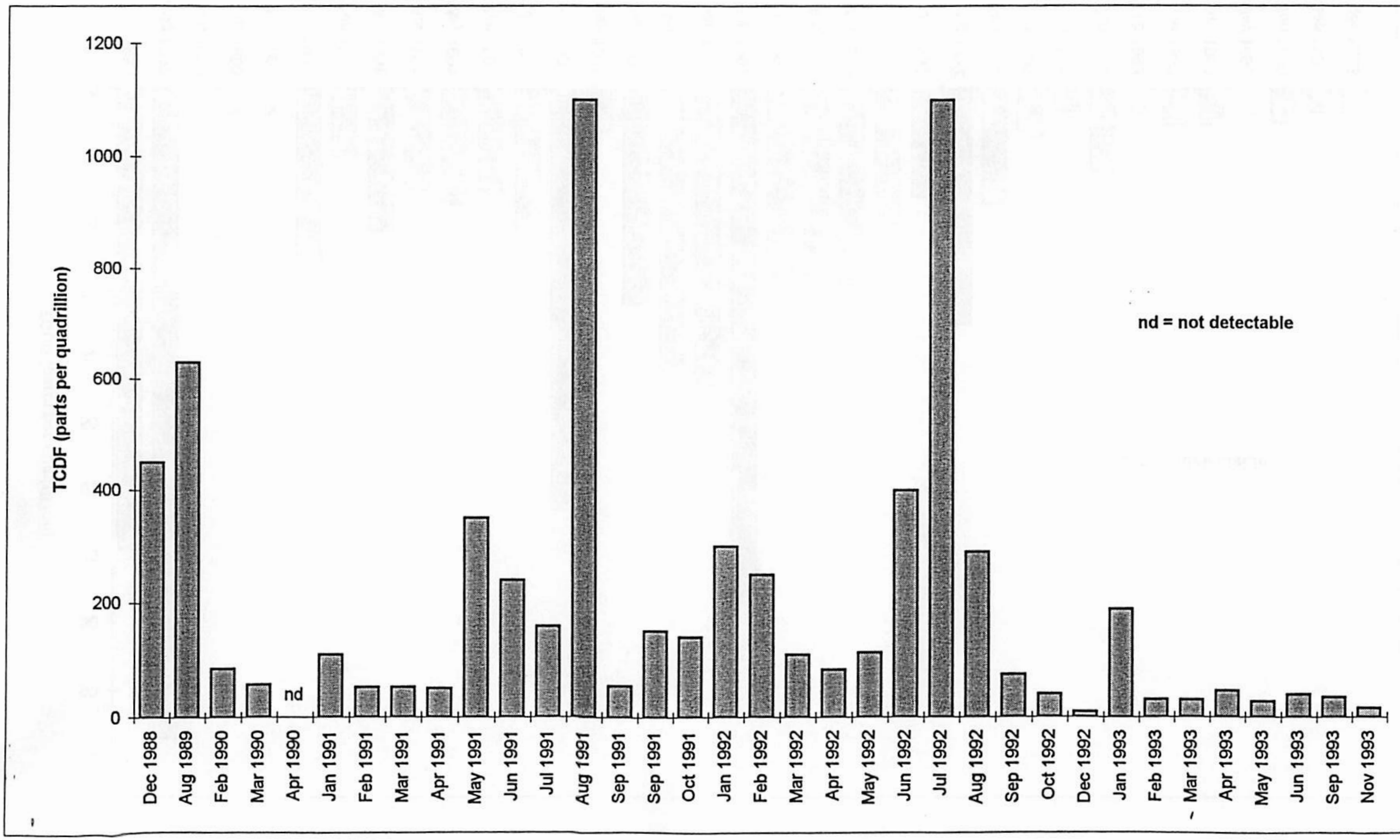
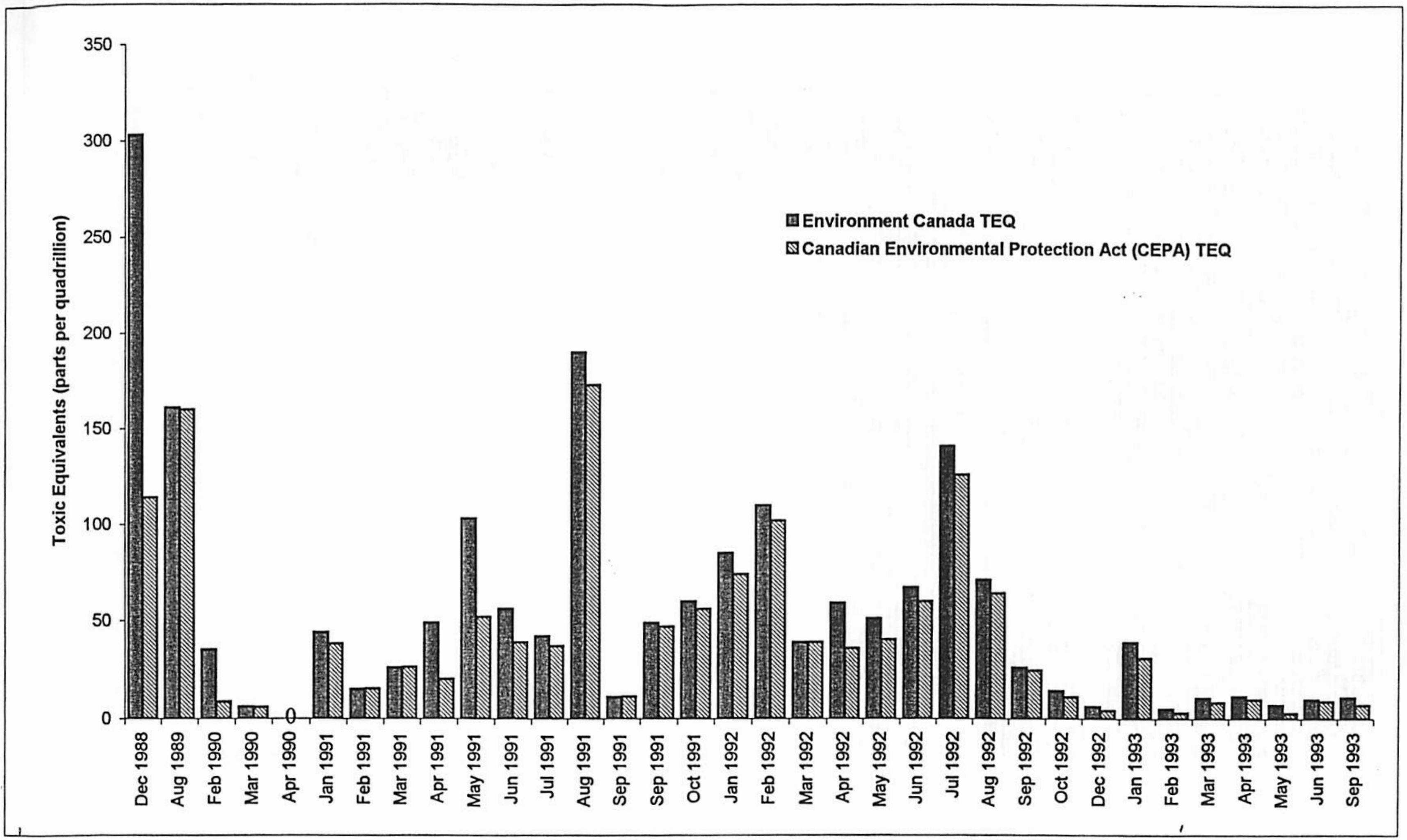
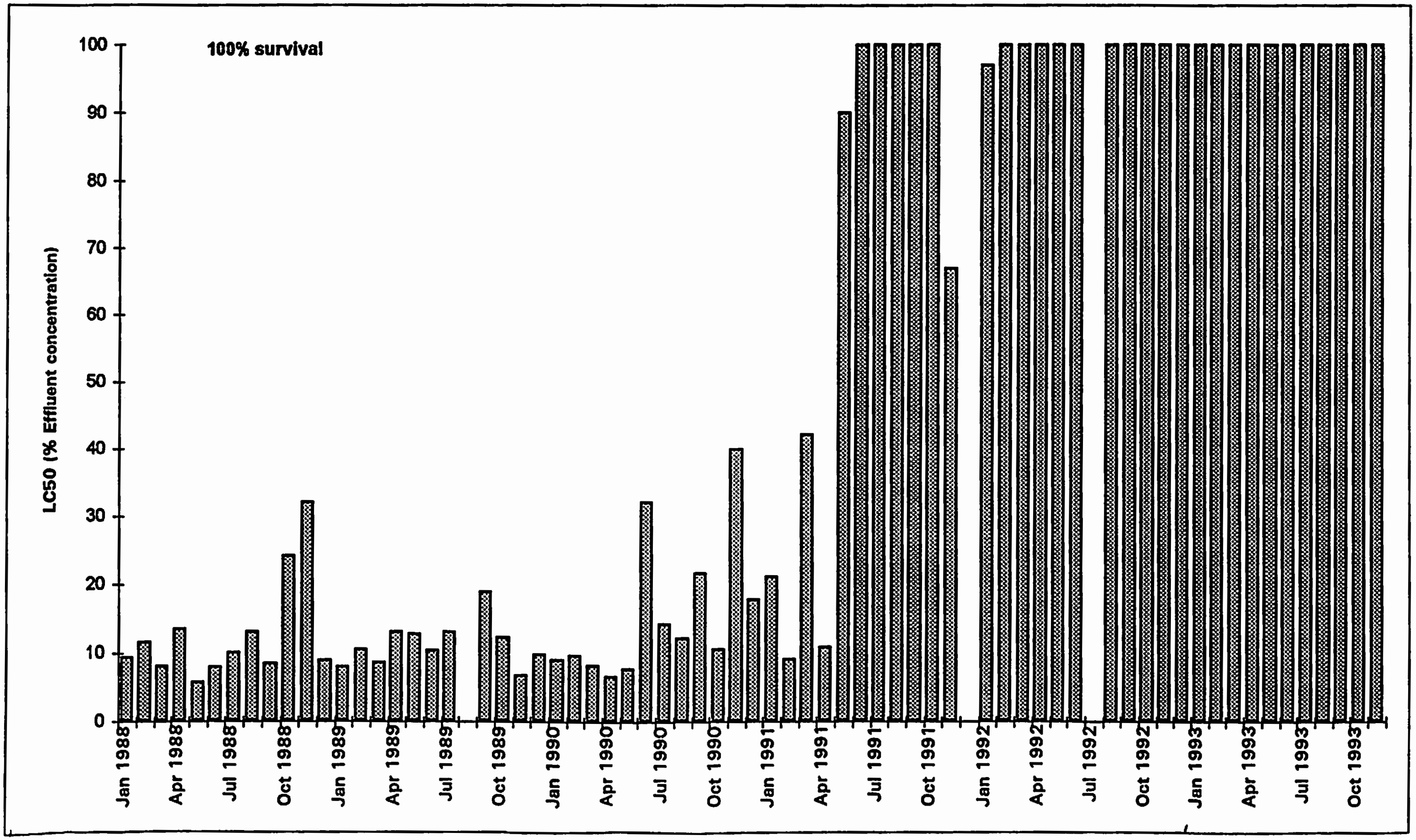


Figure 6.24 Total 2,3,7,8-T4CDD-TEQs and CEPA-TEQs for Skeena Cellulose Inc. effluent, 1988 to 1993.



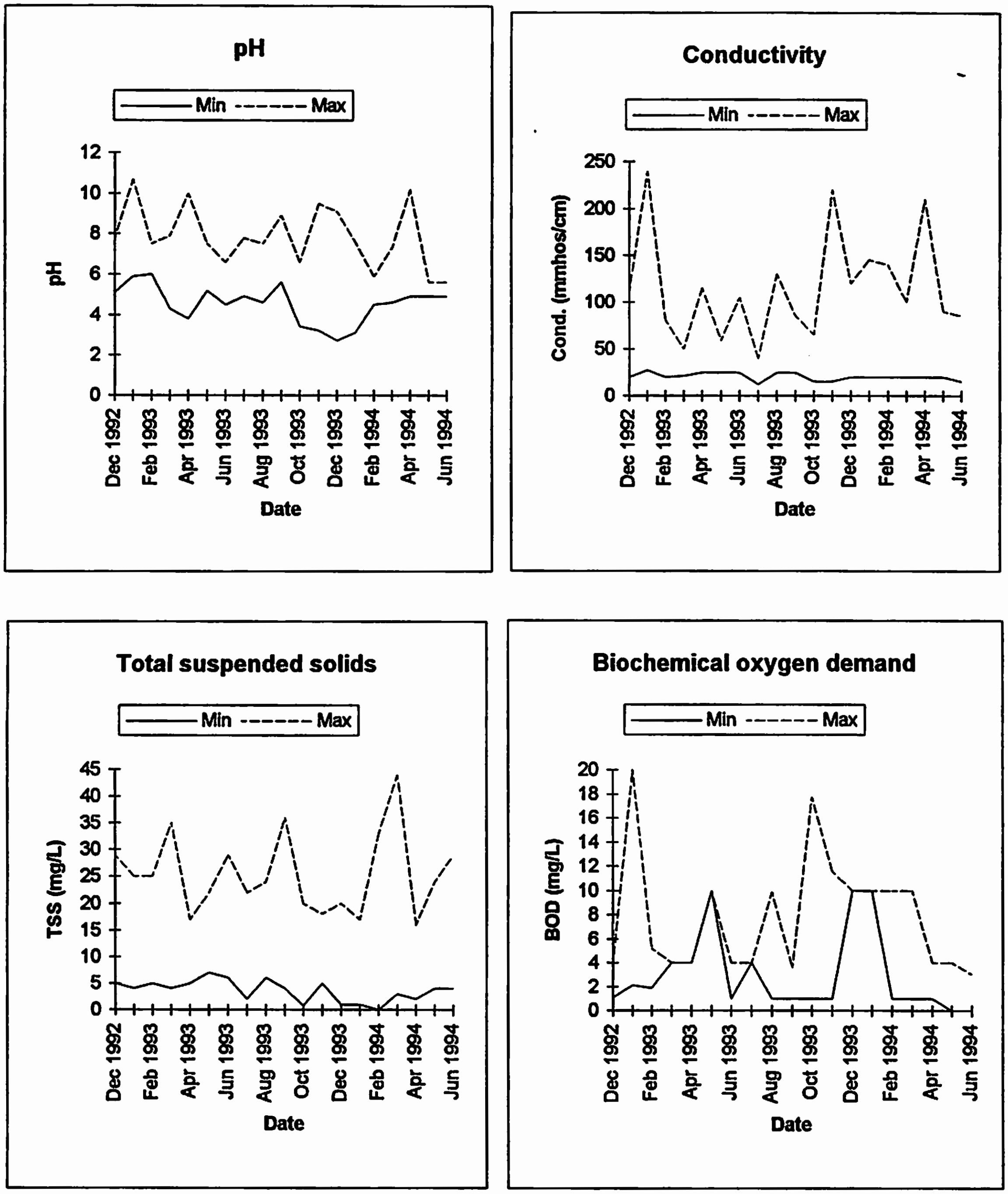
hcl

Figure 6.25 Acute toxicity of effluent discharged from Skeena Cellulose Inc., 1988 to 1993.



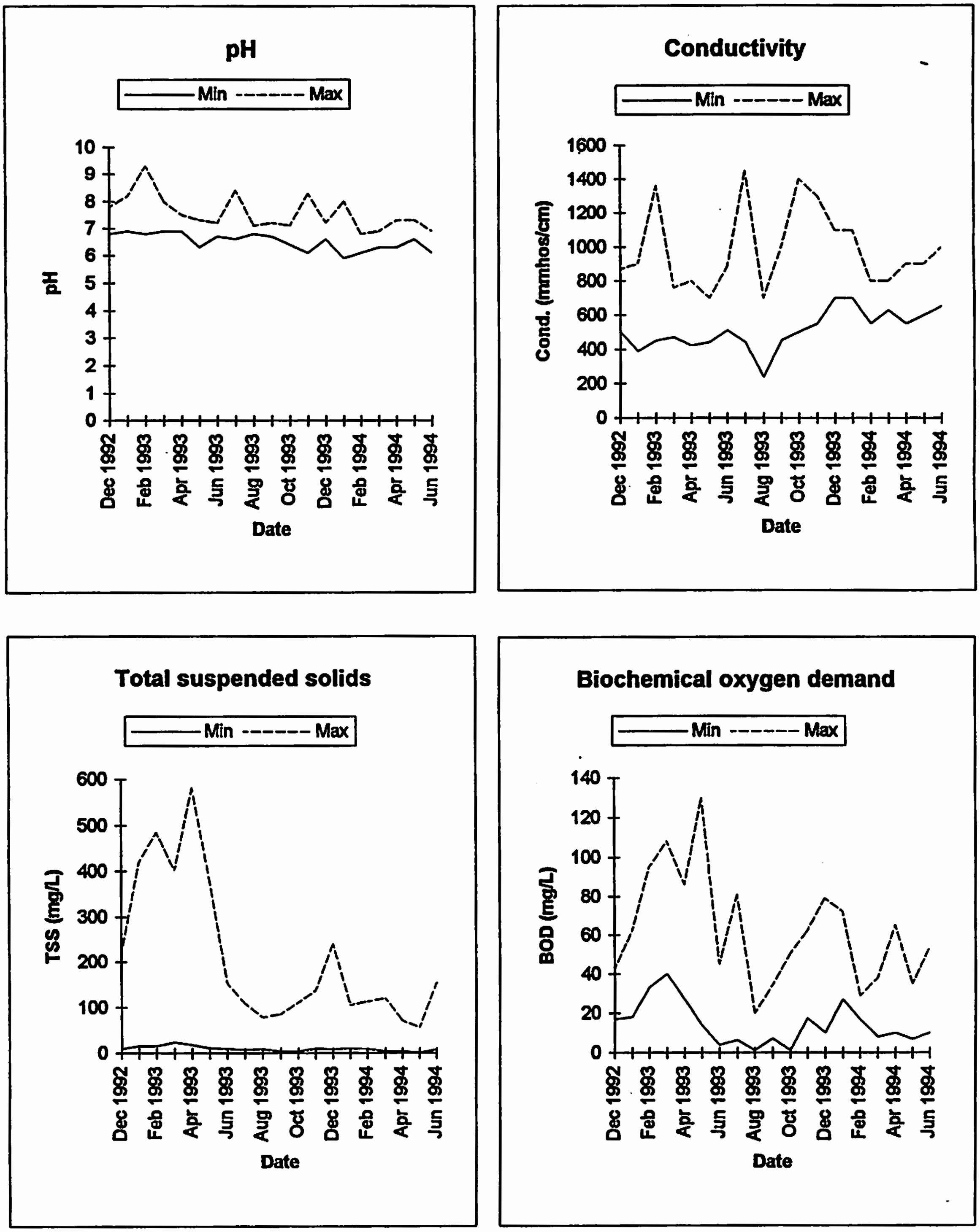
hcl

Figure 6.26 Lagoon No. 1 outfall characteristics, Skeena Cellulose Inc., December 1992 to June 1994 (outlying data not included).



hcl

Figure 6.27 **Zanardi outfall characteristics, Skeena Cellulose Inc., December 1992 to June 1994 (outlying data not included).**



hcl