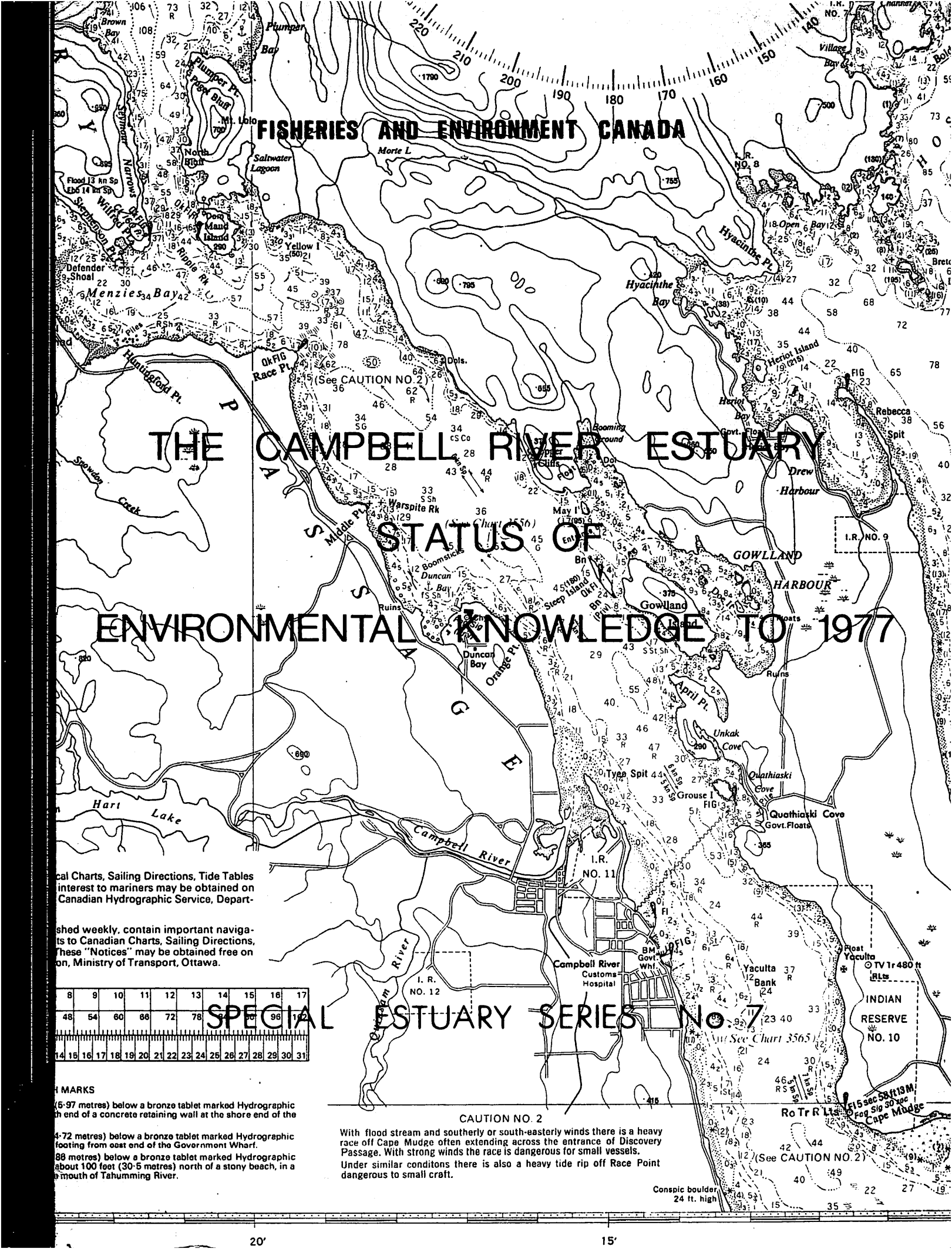

FISHERIES AND ENVIRONMENT CANADA
THE CAMPBELL RIVER ESTUARY
STATUS OF
ENVIRONMENTAL KNOWLEDGE TO 1977
SPECIAL ESTUARY SERIES NO. 7
Plumper Bay
Plumper Pt.
Mt. Lolo
Morte L
Saltwater Lagoon
Menzies Bay
Yellow I
Defender Shoal
Ripple Rk
Hunuttgford Pt.
Race Pt.
Middle Pt.
Warspite Rk
Duncan Bay
Orange Pt.
Hyacinthe Bay
Hyacinthe Pt.
Heriot Bay
Heriot Island
Booming Ground
Drew Harbour
Rebecca Spit
I.R. NO. 9
GOWLLAND HARBOUR
Gowlland Island
Ruins
April Pt.
Unkak Cove
Quathiaski Cove
Quathiaski Cove Govt. Floats
Tyee Spit
Grouse I
Hart Lake
Campbell River
I.R. NO. 11
I.R. NO. 12
Campbell River Customs Hospital
Yaculta Bank
Float Yaculta
INDIAN RESERVE NO. 10
See Chart 3565
Cape Mudge
(See CAUTION NO. 2)
Conspic boulder 24 ft. high
CAUTION NO. 2
With flood stream and southerly or south-easterly winds there is a heavy race off Cape Mudge often extending across the entrance of Discovery Passage. With strong winds the race is dangerous for small vessels.
Under similar conditons there is also a heavy tide rip off Race Point dangerous to small craft.
cal Charts, Sailing Directions, Tide Tables
interest to mariners may be obtained on
Canadian Hydrographic Service, Depart-
shed weekly, contain important naviga-
ts to Canadian Charts, Sailing Directions,
These "Notices" may be obtained free on
on, Ministry of Transport, Ottawa.
H MARKS
(5·97 metres) below a bronze tablet marked Hydrographic
h end of a concrete retaining wall at the shore end of the
4·72 metres) below a bronze tablet marked Hydrographic
footing from east end of the Government Wharf.
88 metres) below a bronze tablet marked Hydrographic
about 100 feet (30·5 metres) north of a stony beach, in a
mouth of Tahumming River.
20'
15'

FISHERIES AND ENVIRONMENT CANADA

THE CAMPBELL RIVER ESTUARY

STATUS OF

ENVIRONMENTAL KNOWLEDGE TO 1977

REPORT OF THE ESTUARY WORKING GROUP
DEPARTMENT OF FISHERIES AND THE ENVIRONMENT
REGIONAL BOARD PACIFIC REGION

By
LEONARD M. BELL and JAMES M. THOMPSON

Under the Direction of Dr. M. Waldichuk

Fisheries and Marine Service

Pacific Environment Institute

West Vancouver, B.C.

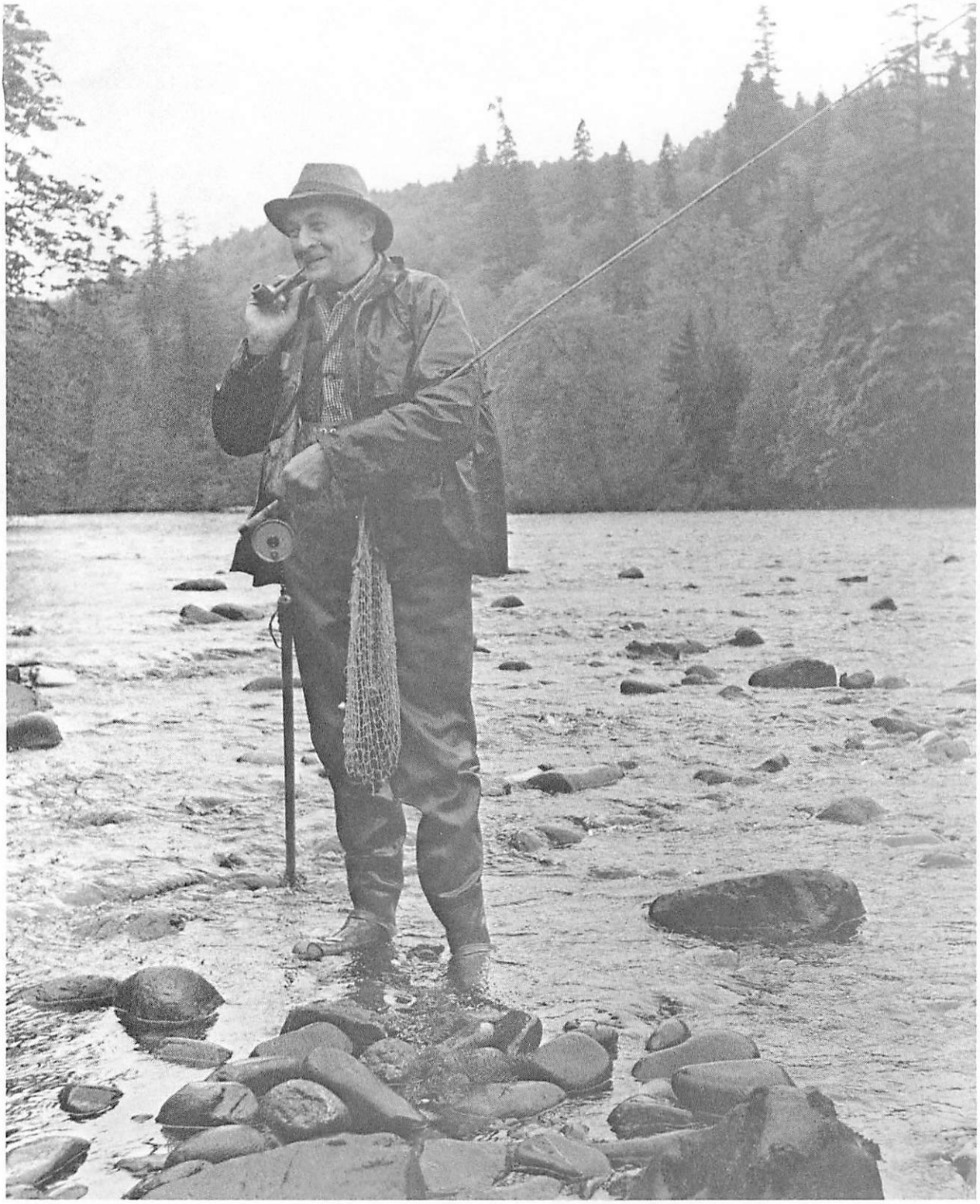
SPECIAL ESTUARY SERIES No. 7

JULY 1, 1977

IN MEMORIAM

RODERICK LANGMERE HAIG-BROWN

1908 - 1976



RODERICK L. HAIG-BROWN
1908 - 1976
writer, university chancellor, angler,
conservationist, Provincial Court Judge, father.

PACIFIC SALMON

River-born fugitives, red muscled under sheathing silver,
Alive with lights of ocean's changing colors,
The range of deeps and distances through wild salt years
Has gathered the sea's plenty into your perfection.
Fullness is the long return from dark depths
Rendering toll of itself to the searching nets
Surging on to strife on brilliant gravel shallows
That opened long ago behind the failing ice.
In violence over the gravel, under the burn of fall,
Fullness spends itself, thrusting forth new life
To nurse in the stream's flow. The old life,
Used utterly, yields itself among the river rocks of home.

Roderick Haig-Brown

ON ESTUARIES :-

"In general it is true that river mouths are not spectacular; one has to know and understand something of them to appreciate them. Even the youngest and wildest rivers tend to cushion their approach to immolation by building deltas of gravel and sand and mud. This then, is likely to be the way of estuaries. Only when one has walked the flat places and heard the wind in the grasses, explored the sloughs and side channels, watched the tides and faced the storms, does a river mouth take on character and substance and reveal its dramatic power."

(From Fisherman's Fall, Roderick Haig-Brown, p.105)

IN MEMORIAM

RODERICK LANGMERE HAIG-BROWN
1908-1976

Born on February 21, 1908, in Lancing, Sussex, England, Roderick Langmere Haig-Brown was brought into a family with both a literary and outdoor tradition. His father, A.R. Haig-Brown published in 1913 a volume entitled "My Game Book". After his father, a keen sportsman, was killed during the First World War, Roderick's uncles took over his outdoor education. Some of his early experiences with nature in the woods and on the streams in England are reflected in his numerous books.

Young Roderick went to Charterhouse at Godalming until he was seventeen. Then he came to the State of Washington, where he had relatives. He immediately started working in a logging camp, taking every opportunity to become acquainted with the lakes and streams of the United States Pacific Northwest. When his American residence permit expired, Roderick moved to Vancouver Island, where he worked in the woods at Nimpkish Lake, Beaver Cove and Menzies Bay, and also had a trapline. He took every opportunity to observe life in the wild and how the creatures adapted to live in harmony with their environment. He returned to England in 1929, where his first book "Silver" was published. In 1931, he came back to the Nimpkish to continue his writing and work at a variety of outdoor jobs - logging, fishing, guiding and trapping.

Roderick Haig-Brown finally settled down in 1934, when he married Ann Elmore of Seattle and took up residence in Campbell River. At that time, Campbell River consisted of little more than a cluster of houses served by Laver's store, with the Willow's Hotel and Painters' Lodge serving visitors. The wilderness of Vancouver Island was still at his back door. There was clean water in streams, lakes and in the sea, bountifully supplied with

fish, almost in any direction he turned. In Campbell River, Haig-Brown continued his writing, on angling and on the streams and estuaries with which he was now intimately familiar.

Professionally, next to his writing, Roderick Haig-Brown was best known on Vancouver Island as the understanding and sympathetic magistrate. He was a lay judge who had learned his law by extensive reading. It all started when the only police constable in Campbell River asked him in 1939 to submit his name for the magistrate's position. Haig-Brown did so, and in 1942 he was appointed magistrate, sometimes modestly stating that he "became a judge because there was nobody else to become one". Magistrate Haig-Brown became well known for the way in which he handled criminal cases that came before him. He was generally known as a lenient judge but firm in dealing with certain cases. Many a young offender was "penalized" by being told to write an essay on some subject of conservation and to submit it to the magistrate by a given deadline. Haig-Brown only gave jail sentences as a last resort, having remarked that "any deprivation of liberty is pretty horrible, but sometimes it can help by giving a person time to think or helping those who believed they couldn't do anything to make a success of themselves". He served as a stipendiary magistrate and judge of the juvenile court for Campbell River over a period of 33 years. Many of the people who faced Haig-Brown in magistrate's court undoubtedly gained a great deal from his kindly and thoughtful reprimands. If there was ever any doubt in his mind about a case, he always ruled in favour of those charged with an offence. A quotation from Judge Hugh Campbell: "the only piece of advice he ever gave me was that if I erred in the court in favour of the accused, at least I would sleep at night".

Roderick Haig-Brown served on a host of naturalist, conservation and sportsmen's bodies, being a National Director of Trout Unlimited, National Director of the United States Federation of Fly Fishers and Honorary Director of the Theodore

Gordon Fly Fishers of New York. He was a patron of the Vancouver Public Aquarium, a director of the National and Provincial Parks Association, a trustee of the Nature Conservancy of Canada, adviser to the B.C. Wildlife Federation, member of the Federal Saltwater Sports Fishing Advisory Committee and the Federal Fisheries Development Council. In 1970, he was appointed to the International Pacific Salmon Fisheries Commission.

Haig-Brown quietly, and in his own way, fought on the side of conservation long before it became fashionable to become involved in protests on various issues concerning the environment. He led the battle against the B.C. Power Commission's plan to build a dam on Buttle Lake in Strathcona Park, and he was vocal in his protest against dams on the Fraser River. He expressed concern about pulp mills being developed in many valuable fisheries areas, especially near his beloved Campbell River.

Haig-Brown was a gifted writer. Professor George Woodcock, noted writer, critic and English professor, of the University of British Columbia, paid tribute to him as an author in a half-hour radio broadcast on CBC radio, Vancouver, on January 10, 1977. Quoting from Judge Campbell again, "He was gifted far beyond anyone else I've known. He wasn't a writer, he just wrote as he spoke and thought, clearly, lucidly and fluently. It was easy for him while the rest of us struggled for journalistic language. To him it just flowed."

Writing recently in Esquire Magazine (reprinted in the Vancouver Sun, March 11, 1977), Russell Chatham stated: "Happily absent from his writing is that boorish, tiresome stance of the 'expert' giving his boring advice on how we might catch more fish or kill more game. Instead, Haig-Brown observes for the sake of observing, and he informs with astounding clarity, a complete lack of hysteria and no sense whatsoever of personal gain. He invites you to enter his world, and it is not so much the rather specific world of the fisherman as it is the broader,

richer one of natural cycles, of wonder, gratitude and most of all, hope."

For his literary excellence, Haig-Brown received the Governor General's Citation in 1948, the University of Alberta National Award for letters in 1956, the Burien Guild Library and the Vicky Metcalfe awards in 1964, and the Canadian Library Association Medal in both 1946 and 1964. Haig-Brown received an honorary degree from the University of British Columbia in 1952 and was elected chancellor of the University of Victoria in 1970.

The lack of formal advanced education did not prevent Haig-Brown from becoming a scholar in his own right. He was an avid reader. His library was replete with many books on varied subjects. He had learned comments on many issues of the day, particularly those with a conservation bent. His counsel was sought by many, including sportsmen, conservationists and politicians. In spite of all this, he was a quiet, humble and modest man who never imposed his opinions on anyone. He was available to provide advice if anyone needed it. His wisdom and clarity of thought often rescued deliberations from what seemed like inextricable tangles, and led to positive action.

Roderick Haig-Brown, logger, guide, trapper, fisherman, farmer, sportsman, magistrate, university chancellor and author, passed away quietly of a heart attack on October 9, 1976, at the age of 68. He left behind a loving wife, three daughters and a son. He will be missed deeply not only by his family, but by the thousands of others who read his books and reaped a profit from his dedication toward making this a better land to live in through his efforts in conservation.

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3 From Canada by land
4 Seeds of settlement
5 Beginnings of government

Vol. 2, Part 6 British Columbia drama
7 Gold
8 Towards the Cariboo
9 Overland route

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13 What manner of people

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2250 CAMPBELL RIVER ROAD. CAMPBELL RIVER. BRITISH COLUMBIA V9W 4N7
TEL. (604) 287-6646

June 7th, 1976

Dr. M. Waldichuk
Fisheries Research Board of Canada
Pacific Environment Institute
4160 Marine Drive
West Vancouver, B.C.

Dear Dr. Waldichuk:

Thank you very much for your letter of June 1st and I am sorry I confused you about the estuary report series, but I did already have copies of these provided by Rod Hourston's office.

Both the Nature Conservancy of Canada and the National Second Century Fund of B. C., of which I am also a director and trustee, are constantly on the watch for areas of ecological significance which might be available for purchase at a reasonable price. Needless to say, the question of estuaries frequently comes up and at present, the National Second Century Fund is considering the estuary at the head of Nanoose Bay. It is also hoping for some proposal on parts of the Salmon River estuary and, has previously considered (unfortunately without success) such estuaries as Trout Creek and Cook Creek. The National Second Century Fund does have money available, though not in vast quantities. The Nature Conservancy of Canada has to raise funds for each individual project.

I should be most happy if you would present my letter at the next meeting of the estuary working group. I should be most interested to hear their reactions, as I have promised to advise Aird Lewis of the Nature Conservancy of Canada, in more detail, on my original proposal of an inventory of estuaries made to him last year.

It was a pleasure to hear from you.

With all personal good wishes,

Very sincerely,

Rod. Haig. Brown

Roderick Haig-Brown

RHB:rs

M.W.

JUN - 9 1976

9-8-1

2250 CAMPBELL RIVER ROAD, CAMPBELL RIVER, BRITISH COLUMBIA V9W 4N7
TEL. (604) 287-6646

September 28, 1976

Dr. M. Waldichuk
Pacific Environment Institute
4160 Marine Drive
West Vancouver, B.C. V7V 1N6

Dear Dr. Waldichuk:

Thank you very much indeed for your letter of September 8th. I will be forwarding copies of this to Aird Lewis, of the Nature Conservancy of Canada and to Bert Hoffmeister of the National Second Century Fund. I know that both organisations will be interested in the future reports you are planning and, in the meanwhile, I will suggest to Aird Lewis that the Nature Conservancy of Canada look further into the possibility of making some sort of an inventory of estuaries with special attention to the possibilities of protection by purchase.

The thought has occurred to me that the majority of estuaries in British Columbia, especially the smaller ones, perhaps are backed by Indian reserved lands, or actually in Indian Reserves themselves. This point seems to me worth some examination with a view to discussion with Indian groups on the possible development of some policy of protection.

Thank you again for your interest and my thanks also to the estuary working group. Perhaps we can develop something of value to assist them.

Very sincerely,

Roderick Haig-Brown

Roderick Haig-Brown

RHB:rs

CC: Mr. F. Aird Lewis
Mr. B. M. Hoffmeister

OCT - 5 1976

M.W.



Campbell River Estuary and Discovery Passage - September 20, 1976

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ABBREVIATIONS AND SYMBOLS

asl	above sea level
ac.	acre(s)
A.L.R.	Agricultural Land Reserve
A.R.D.A.	Agricultural and Rural Development Act
ADT; Adt	air dry ton, air dry tonne (metric)
et al.	and others
Atmos. Environ. Serv. (AES)	Atmospheric Environment Service
av.	average
BOD	biochemical oxygen demand
fbm	board feet
B.C.	British Columbia
B.C.L.I.	British Columbia Land Inventory
BKME	bleached kraft mill effluent
BP	Before Present (geologic time scale)
C.L.I.	Canada Land Inventory
CPR	Canadian Pacific Railway
cm	centimetre(s)
cm/s (cm/sec)	centimetres per second
cont'd	continued
cfs	cubic feet per second
m^3 (cu.m)	cubic metre(s)
m^3/s (cms)	cubic metres per second
dm^3	cubic decimetre(s)
^oC	degrees Celsius (centigrade)
^oF	degrees Fahrenheit
σ_τ	density (sigma-t)
E	east
ed.	editor or edition
EEB	Environmental Emergency Board
ELUCS	Environment and Land Use Committee Secretariat
EPS	Environmental Protection Service

Abbreviations and Symbols (cont'd)

pH	expression for acidity or alkalinity of a solution
fm	fathom(s)
ft.	foot (feet)
e.g.	for example
gal.	gallon(s)
g	gram(s)
g/m^2	grams per square metre
gpd	gallons per day
GSC	Geological Survey of Canada
>	greater than
ha	hectare(s)
h. (hr.)	hour(s)
Igpd	Imperial gallons per day
in.	inch(s)
Ibid.	in the same place
IOUBC	Institute of Oceanography, University of British Columbia
km	kilometre(s)
km/hr.	kilometre(s) per hour
Lat.	latitude
<	less than
l	litre(s)
Long.	longitude
MS	manuscript
max.	maximum
mem.	memoir
m	metre(s)
µg	microgram(s)
mi.	mile(s)
m.p.h.	miles per hour
meq/l	milliequivalents per litre
mg/l	milligrams per litre
mm	millimetre(s)
MMfbm	million board feet

Abbreviations and Symbols (cont'd)

Mm^3	million cubic metres
min.	minimum
m. (')	minute
misc.	miscellaneous
n.mi.	nautical mile(s)
N	north
No. (#)	number
oz.	ounce
PBS	Pacific Biological Station
PEI	Pacific Environment Institute
p.	page or pages
pp.	pages
ppm	parts per million
$^o/oo$	parts per thousand
%	percent
PCB	Pollution Control Branch
lb(s)	pound(s)
Reg. Bd.	Regional Board
rept.	report
sat.	saturated
ser.	series
S	south
spec.	special
sp.	species (singular)
spp.	species (plural)
cm^2	square centimetres
sq.ft.	square feet
m^2	square metre(s)
sq.mi.	square mile(s)
STD(std.)	standard
SCF	standard cubic foot (air pollution)
SCFM	Standard cubic foot per minute (air pollution)
SS	suspended solids

Abbreviations and Symbols (cont'd)

temp.	temperature
i.e.	that is
Mfbm	thousand board feet
TDS	total dissolved solids
TIC	total inorganic carbon
TOC	total organic carbon
TS	total solids
TSS	total suspended solids
UBC	University of British Columbia
U.S. (USA)	United States (of America)
U.Vic	University of Victoria
var.	variety (biology), variance (statistics), variation (navigation)
vol.	volume
W	west
yr.	year

PREFACE

This is the seventh report in the Special Estuary Series, reviewing all environmental information available for the Campbell River estuary. Eighteen estuaries along the British Columbia coast are considered critical from the point of view of threat of development and preservation of renewable resources. Environmental information for seven of these has been compiled, collated and summarized in the six previous reports: (1) Fraser, (2) Squamish, (3) Skeena, (4) Cowichan and Chemainus, (5) Nanaimo and (6) Kitimat. There are ten estuaries remaining in this series, including those of the Indian, Homathko, and Bella Coola rivers on the British Columbia mainland coast, and the Courtenay-Puntledge, Somass, Quatse, Salmon, Gold, Wannock and Nimpkish rivers on Vancouver Island. The next reports in the series will review the Courtenay-Puntledge river estuary, followed by the Somass River estuary, as priority systems for consideration, because of activities already underway there and the possibility of instituting environmental improvements.

The reports in this series are intended to bring together a wide range of environmental material on the selected estuaries, to summarize it, to pinpoint the sources of existing and upcoming information and to identify the gaps in knowledge. The audience for which these reports are written consists of government agencies, the academic community, consulting firms and interested lay persons. Our goal is to have the reports available in as many libraries as possible at least in the Pacific region, so that they can receive maximum use by interested persons and institutions.

Campbell River, draining into Discovery Passage, is world renowned for its famous Tyee salmon (large Chinook or Springs, as they are still known to many anglers) prized by sports fishermen. Fishing for these king-sized salmon has been sought by celebrities from places like Hollywood for many years.

The late Roderick Haig-Brown, the magistrate/author from Campbell River gave the area world-wide reputation through his writings on angling. The town of Campbell River becomes a flourishing tourist resort in the latter part of summer and early autumn when fishermen from many parts congregate there.

Elk Falls, a few kilometres upstream from the mouth of Campbell River, is an attractive waterfall in a forest glen, preserved for some time as a provincial park. It provides viewing, picnicking and camping recreation for many tourists and local visitors during the summer months. Not too far away, south of Campbell River, on the shores of the northwestern part of the Strait of Georgia, is Miracle Beach, one of the other well-known recreational havens, with a nature centre and a large area set aside for camping and picnicking under its provincial park status.

However, Campbell River is not without its environmental problems. The need for electrical power in this part of Vancouver Island was recognized almost as early as white man settled there. Because electrical power sources are very limited on Vancouver Island, any stream with a significant gradient was examined with covetous eyes by the hydro-electric power people, nearly from the beginning of the century. Campbell River and the complex of lakes behind it happen to be one of the water systems with a substantial gradient and a good potential for hydro-electric power development. In 1945 construction was commenced on the John Hart Dam on Campbell River, above Elk Falls. It was completed in 1947, forming an impoundment behind the dam, later named John Hart Lake. By December 1947, the John Hart Development was producing 40,000 kilowatts of electricity from the first two units installed at the Generating Station. Now comprising three dams and generating stations (John Hart, Ladore Falls and Strathcona), the Campbell River Hydroelectric Development has a combined generating capacity of more than 200,000 kilowatts, the largest hydro-electric power source on Vancouver Island.

Salmon could not ascend Elk Falls even before the John Hart Dam was built, so that the direct effects of the hydro-electric power development on Campbell River salmon runs were considered rather minimal. However, flows had to be regulated not only for power generation, but also for flood control. To accommodate the upstream salmon migrants, destined for spawning grounds below the falls in the late summer and early autumn, flows had to be maintained above a certain prescribed level. To achieve the flow required for power generation and for protection of salmon, the Heber River was diverted into Upper Campbell Lake, the reservoir behind Strathcona Dam, and the Salmon and Quinsam Rivers were partly diverted into Lower Campbell Lake, the reservoir formed behind Ladore Falls Dam. These diversions required considerable engineering skill to achieve the goal established for power generation. However, these developments necessitated environmental change in the lake and river systems of this area, and even at that time, there was considerable resistance to these modifications from conservationists.

Because Campbell River water is naturally comparatively low in sedimentary materials, except during heavy local runoff, the effects of the dams on the river delta have been probably minimal. However, this has never been fully ascertained. Certainly, because of flow control, the extreme seasonal fluctuations in river water volume that once occurred in the estuary are no longer experienced.

More recently, the B.C. Hydro and Power Authority has considered another possibility in its hydro-electric power development on the Campbell River. This involves a diversion of part of the Campbell River flow through pipelines and penstocks leading to a generating station discharging into Duncan Bay. The environmental consequences of such a diversion are unknown, but are now being examined by engineers and biologists in the Fisheries and Marine Service of Fisheries and Environment Canada. A report issued in 1976 reviews the various options for further power

development and prognosticates on the environmental consequences.

In the early 1950's, a pulp mill was installed at Duncan Bay, on Discovery Passage, just north of Campbell River. Although the ecological impact of pulp mills on receiving waters was beginning to be appreciated by this time, there was little work actually conducted in relation to pulp mill waste disposal and its effects on the ecosystem prior to the installation of the pulp mill. Some studies were conducted, however, when the pulp mill expanded during the mid-1950's and the environmental consequences of waste disposal in this area began to be better understood. Perhaps more by accident than design, this pulp mill happened to be located at a preferred site from the point of view of environment. The prevailing winds transport the rather mal-odorous atmospheric emissions from the kraft mill toward relatively uninhabited areas and away from population centres. The turbulent, tide-swept waters of Discovery Passage rapidly dilute and disperse the effluents that are injected into this coastal system. Even temporary discharge of black liquor into Discovery Passage following an accident in the recovery system in October 1963 appeared to cause little more than foam near shore in the initial mixing zone. Therefore, the Elk Falls pulp mill is often cited as a model for good siting, in that natural conditions are such that environmental degradation during the quarter century of pulp mill operation appears to have been minimal.

Recently, there has been a number of proposals for development within the Campbell River estuary itself. One of these involves a marina. Because an Indian Reserve is associated with this proposal, there is a jurisdictional issue as well as an environmental one to resolve. A recent study by the Fisheries and Marine Service Habitat Protection Directorate indicates that any development in the estuary would remove valuable and scarce habitat used as a nursery area by juvenile salmonids. Log booming continues to be carried on in the protected waters of the inner

estuary, and this has resulted in a certain amount of estuarine degradation. There are other pressures on this ecosystem from existing activities and proposed developments. A Task Force, comprised of representatives of agencies of all levels of government, has been examining the various environmental problems and will issue a report soon. There is also an Environmental Council in the Campbell River area, with a membership made up of various interested and concerned groups.

The foregoing comments indicate that certain developments have already affected the Campbell River system and its estuary. It is hoped that these effects have not all been adverse and irreversible. Campbell River and its salmon runs have already received a great deal of recreational use, and one can only fervently hope that such use will continue. They have much more potential in this regard. The waters of this river system and its estuary also support substantial living resources that can be harvested commercially. It is obvious that they merit consideration for a high degree of protection to preserve their contribution to commercial fisheries, as well as their recreational and aesthetic values. However, as in many of the other estuaries of the province, little is known about the impact of various types of development, whether they be small marinas or large superports. It is clear that intensive studies are still required in these areas, before we can clearly state what the limits of development are to avoid destruction of estuarine ecosystems or encroachment on irreplaceable habitats. Studies conducted thus far merely indicate the potential threat that development poses in these vulnerable estuarine waters.

Once again, I wish to extend my sincere appreciation to the Directors-General and Directors of Fisheries and Environment Canada in the Pacific region for their moral and financial support in the production of this series of reports on British Columbia estuaries. My thanks also go to members of the Estuary Working Group (see attached list) of the Regional Board Pacific Region for their unflagging efforts on the estuary

project, particularly in promptly reviewing drafts of the reports in this series and in assisting with revisions when needed. I also wish to thank the contractors, Messrs. Bell, Kallman and Thompson who have dedicated themselves to the task of collating and synthesizing the large amount of scattered information on these estuaries and finalizing the reports in good time. Many people, too numerous to name them all here, took time to discuss various aspects of the Campbell River Estuary and made available a great deal of unpublished information.

While we were collecting information on the Campbell River estuary we were saddened to hear of the passing of Roderick Haig-Brown, with whom we had developed a good rapport on conservation of estuaries generally, and whom we were planning to visit to discuss some aspects of the Campbell River estuary with which he was intimately familiar. It seemed appropriate that we should dedicate this volume to the memory of Roderick Haig-Brown, outstanding conservationist, author and sportsman. We include here a brief biography of Dr. Haig-Brown, a bibliography of his many published works and unpublished manuscripts, along with two of his last letters to us indicating his interest in preservation of estuaries. Mrs. Ann Haig-Brown, his widow, has been extremely helpful in providing some of the biographical and bibliographic data on Dr. Haig-Brown.

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Acknowledgements

The authors are grateful to the many who energetically gave of their time and experience. We wish to thank the management of the Crown Zellerbach Elk Falls Pulp Mill, the Comox-Strathcona Regional Board planners, and the staff of the District of Campbell River for their interest and participation.

The members of the Estuary Working Group were asked to review the draft manuscript in a particularly busy season and we wish to thank them for their constructive criticisms. Various agencies of the provincial government deserve mention, including the Fish and Wildlife Branch and the Services Section of the Pollution Control Branch.

Acting on the consensus of the Estuary Working Group, Dr. M. Waldichuk wrote the Oceanography chapter and directed our work with enthusiasm--we were pleased to have his guidance.

We wish to acknowledge the hospitality and sense of perspective given us by the so-called "amateur" environmentalists whose concern for natural ecosystems in the Campbell River area has been a driving force behind many of the institutionalized studies discussed in this report. The ornithological data contributed by naturalist H. Telosky is indicative of their patient dedication.

And finally, we once again wish to thank our typist, Mrs. Rose Dawson, for her patience in deciphering our hieroglyphics while typing the manuscript.

SUMMARY

1. INTRODUCTION

The Campbell River estuary and surrounding waters were first surveyed by Captain George Vancouver in 1792. In the eighteenth century the lands adjacent to the estuary were occupied by native people of the southern Kwakiutl tribes. By 1900, white settlers from the United Kingdom of Great Britain and Ireland were occupying land from Oyster River to the Campbell River. Logging was a primary occupation of the early white settlers. A lumber industry was soon established, with the estuary providing an ideal location for log storage and the associated lumber mills. The estuary is still being used by the forest industry for log booming, but with an increased awareness of its impact on the abundant fisheries resources of the area.

2. GEOLOGY

Prior to 1960, geological investigations of the region delineated by the boundaries of the Campbell River study area were confined mainly to exploration for ore bodies. The occurrence of magnetite (iron ore) near Upper Quinsam Lake was documented as early as 1902. By 1952, monthly production of concentrate from ore bodies from the Iron Hill deposit had reached 65,000 tons. Production of copper, lead and zinc from mines at the southern end of Buttle Lake commenced in the early 1960s, with the concentrate currently exported to Japan and the United States.

The regional geology of the Upper Campbell Lake and Buttle Lake area has been mapped at a scale of one inch to two miles, and is currently being updated by the Geological Survey of Canada. Two major groups of rocks are found in the study area: Upper Cretaceous sediments (sandstones, conglomerates, shales and coal), which underlie the surficial deposits in the estuary,

and volcanic rocks of the Sicker Group which predominate in the Buttle Lake, Upper Campbell Lake and Upper Quinsam Lake areas.

Surficial sediments, well exposed along the shoreline from Willow Point to Campbell River, have been identified as either Pleistocene and Recent sediments related to present sea, river and lake levels, or post-glacial deposits of marine and fluvial origin related to former (higher) sea, river and lake levels, or till associated with the last period of regional glaciation of southwestern British Columbia.

Soils in the study area have been mapped at a scale of one inch to one mile. While soil cover is generally sparse, soils in the Campbell River watershed provide suitable conditions for forest cover and provide a high quality timber resource for the forest industry. Only a few small areas of soils suitable for general agriculture are found in the study area, mainly in the Quinsam Valley.

3. CLIMATOLOGY

The climate of the Campbell River estuary may be generally classified as predominantly maritime west coast. It is generally cooler, cloudier and wetter than the more southerly estuaries on the east coast of Vancouver Island. Maximum precipitation usually occurs during the months of November, December and January, with 270 mm in December being the greatest. While it has no distinctly dry summer season, rainfall averages about 50 mm in May, June and August and about 40 mm in July. It has an appreciable amount of summer sunshine (annual average 1,751 hours). Mean monthly temperatures range from a low of $1.3^{o}C$ in January to a high of $17.4^{o}C$ in July. Temperature and precipitation are recorded at five stations within a radius of 10 km from the town of Campbell River. Non-continuous records of wind speed and direction are available from the Campbell River Airport. However, the nearest source of continuous records of wind data is at Comox Airport, 48 km south of the estuary.

4. HYDROLOGY

The Campbell and Quinsam rivers drain a combined area of 1,741 sq.km (672 sq.mi.) and provide the main source of freshwater inflow to the Campbell River estuary. Nunns Creek, Willow Creek and Simms Creek which discharge into the estuary and Discovery Passage on the south side of Campbell River, contribute significantly less amounts of fresh water but are none the less biologically significant to the fisheries resource. North of Campbell River, Menzies Creek, Mohun Creek and Welch Creek discharge into Menzies Bay providing an additional source of estuarine and freshwater fish habitats.

Flows in the lower reaches of the Campbell River are controlled by regulated discharge through the John Hart Power generating station, located below Elk Falls approximately 5 kilometres (3 miles) upstream of the river mouth. The combined mean annual discharge of the Campbell and Quinsam rivers at the mouth of the estuary, based on river flow measurements made since 1950, is 108 cms (3,816 cfs). Flood control downstream of the John Hart power station, especially in the Campbellton area, has been greatly facilitated by regulation of maximum water levels and the use of storage reservoirs to route flood flows through the Campbell River power system.

Recommended maximum and minimum discharges from power developments on the Campbell River have been made by Environment Canada and B.C. Hydro based on field studies of the effects of modified hydrology on the Campbell River salmonids.

5. OCEANOGRAPHY

The Campbell River estuary system is characterized oceanographically by the swift and turbulent waters of Discovery Passage into which the river discharges. This means that the apparent influence of the river water is confined to the inner

estuary behind Tyee Spit, where sea water probably intrudes along the bottom, forming a typically stratified estuary for only a short distance.

Tides are of the mixed type, mainly diurnal, and are influenced more from the north (Queen Charlotte Sound) than from the south (Strait of Georgia). The mean and large tidal ranges at Campbell River are 2.9 m (9.6 ft.) and 4.6 m (15.0 ft.), respectively.

Discovery Passage is vertically mixed, giving respective ranges of salinity, temperature and dissolved oxygen from about 29.7^{o}/oo, 9.8^{o}C and 8.5 mg/1 at the surface to 29.9^{o}/oo, 9.6^{o}C, and 8.0 mg/1 at the bottom for a survey in October 1961. Water clarity is relatively high, with Secchi disc readings of 10 m (32 ft.) or more. Tidal currents are nearly uniform from top to bottom, and the southward setting flood may reach 300 cm/sec (6 kn) during spring tides, with an ebb slightly less at 250 cm/sec (5 kn).

Wave action is most severe at the southern entrance to Discovery Passage around Cape Mudge. Treacherous races and tide rips form here when a flooding current from the north opposes a strong southeast wind. These conditions can be especially dangerous for small craft. Waves in the vicinity of Campbell River probably do not exceed 1.5 m (5 ft.), although there are no measurements to verify this. Developments at the Campbell River estuary, whether they are a marina or log holding pond, would have to take into account the severe oceanographic conditions in Discovery Passage, especially the strong tidal currents. Any structures into this passage would alter the flow pattern, erosion and depositional characteristics along the shoreline.

6. FISH

The existence of the Quinsam River Salmon Hatchery since 1974, and the presence of natural spawning populations of chinook, coho, chum and pink salmon (*Oncorhynchus* spp.) and steelhead (*Salmo gairdneri*) in the Quinsam and Campbell Rivers has prompted considerable research into the ecology of the lower Campbell River and estuary. Federal biologists have determined that juvenile coho, chinook, and chum salmon utilize the estuary's invertebrate fauna extensively for food while migrating from the river to the ocean, and have suggested an ideal regime of discharge rates for the John Hart Generating Station, which regulates flow patterns in the lower Campbell River spawning grounds. Two-thirds of the Quinsam River is available to salmonids for spawning, but only that portion of the Campbell River below the powerhouse can be reached by anadromous fish. The lower Campbell River is preferred by chinook and chums, while most of the coho and pinks continue up the Quinsam to spawn.

Nose-tagging data indicate that sea-going adults from these populations enter the commercial fishery all over the British Columbia coastline and join with concentrations of salmon from home streams in the Strait of Georgia to support the Discovery Passage sport salmon fishery: the second largest in B.C. Sport fishermen visit Campbell River from around the world to fish for the consistent, local run of Tyee, which are chinook (*O. tshawytscha*) salmon over 30 pounds (13.6 kg) in weight. During the 1975-76 season the catch of steelhead from the Campbell River was twelfth highest among the province's rivers.

Discovery Passage supports a typically marine ichthyofauna, but commercial fishing in the southern portion is limited to lingcod and salmon trolling. Nets are not permitted south of Seymour Narrows owing to the importance of the Passage as a migration route for salmon: up to 80% of the salmon swimming

through the north end of the Strait of Georgia to and from the open Pacific appear to utilize Discovery Passage. Herring migrate through the Passage, but spawning is infrequent and limited to small deposits in Quathiaski Cove.

7. INVERTEBRATES

Terrestrial invertebrates in the watershed have not been studied. Freshwater invertebrate fauna drifting in the Lower Campbell River during September 1973 were found to be largely zooplankton (63-78%), terrestrial species and benthos contributing to the remainder. The composition of the drift fauna changed under varying generating station discharge rates. Invertebrates in the major lakes were predominantly chironomids, cladocerans, oligochaetes and pisidians. Estuarine fauna accounted for 76-84% of the biomass of the stomach contents of juvenile salmon caught inside the estuary: *Anisogammarus*, *Corophium*, harpacticoid copepods, *Exosphaeroma oregonensis*, cumaceans and mysids comprised the majority of the salmon food. The invertebrate fauna of Discovery Passage is typical of the marine coastal fauna elsewhere in British Columbia, although it is noted for its diversity and abundance. No commercial invertebrate fishery operates in Discovery Passage south of Seymour Narrows. Crabs are taken in small quantities by sports fishermen on the mud flats off the mouth of the river, and clams are harvested from Cape Mudge.

8. FLORA

Most of the Campbell River watershed was logged early in the twentieth century, and two major fires destroyed 39,100 ha (96,500 acres) of timber. Much of the present forest is consequently second growth. Logging is in progress throughout the upper watershed. Increased water level fluctuation in Upper and Lower Campbell Lakes as a result of operating the hydroelectric installations resulted in a loss of rooted vegetation. Urban and industrial development surrounds the estuary. The

vascular, "amphibious" vegetation of the estuarine intertidal zone has been studied, and eight floral communities of the intertidal zone and terrestrial fringe were identified and mapped. *Carex lyngbyei* (sedge) is a major presence, as is typical of many B.C. estuaries. The intertidal zone at the mouth of Nunns Creek is the only large, vegetated wet-land in the estuary, and a preliminary analysis of its production is in progress. Benthic algae in the estuary was not examined. The aquatic flora of Discovery Passage is typically marine, comprised of algal phytoplankton and attached macrophytes (seaweed). Kelp growths are abundant throughout the Passage. *Iridaea* beds are extensive south of the estuary and on Cape Mudge. Eelgrass is not common.

9. WILDLIFE

On January 2, 1977, 84 species of 8,151 birds were counted within the area bounded by Duncan Bay, the Oyster River, McIvor Lake and Sutil Channel. Over several years, 140 species of birds have been observed in the Campbell River estuary which, along with the heads of Duncan Bay, Menzies Bay and the north arm of Gowlland Harbour, is a locally important source of food for migrating birds in the Discovery Passage Region. Most of the rest of the watershed has extreme limitations to waterfowl production. Of the 140 species that use the estuary, 69 are considered to be resident and 24 are common residents, hence the estuary supports a large assemblage of both migratory and resident bird species. In the winter of 1974-75 gulls were the most common inhabitants, followed by diving ducks, loons, grebes, cormorants and alcids. The annual appearance of 8-10 trumpeter swans (*Olor buccinator*) for a winter of feeding has been noted frequently.

The biology of mammals present in the Campbell River watershed has not been reported in the scientific literature. As many as 25 terrestrial and marine species might live in and near the estuary and a speculative species list has been prepared. The kill of deer, black bear, elk and cougar has been monitored,

since the region supports hunting as a form of recreation. A variety of marine mammals utilizes Discovery Passage. Harbour seals have been seen in the Campbell River estuary, but industrial development on the banks of the estuary inhibits its use by most terrestrial and marine mammals.

10. LAND AND WATER USE

The use of land for residential and urban development is confined mainly to a narrow belt of land along the western shore of Discovery Passage extending from Oyster Bay in the south to Duncan Bay in the north. Industrial development of land and water in the area of the estuary adjacent to the Campbell River mouth is dominated by the timber industry for log storage and handling, and the production of lumber. The economic significance and physical impact of this primary use of the estuary on the fisheries resource is presently under investigation.

The Campbell River system provides the largest source of hydroelectric power on Vancouver Island. Development of the system by the B.C. Hydro and Power Authority was carried out in three successive stages over a period of 13 years and at a cost of $75 million. The combined John Hart, Ladore Falls and Strathcona generating stations produce more than 200,000 kilowatts of power that is fed into the Vancouver Island distribution system.

Land capability for the production of merchantable timber in the western and northern areas of the Campbell River drainage basin is high. The economy of the Campbell River area is dominated by the forest industry, with logging, lumber manufacturing and the production of pulp and paper at the Elk Falls Mill (Crown Zellerbach) providing the main source of employment for the district residents.

The rivers, lakes and undeveloped lands of the Campbell River area are used extensively for fishing, hiking, camping and

other outdoor activities. Three Provincial Parks--Strathcona, Elk Falls and Morton Lake in the western and northern sectors of the study area--provide many recreational facilities within 60 km (38 mi.) of the town of Campbell River.

11. POLLUTION AND WATER QUALITY

Considerable water quality (chemical and bacteriological) data exists for the Campbell River-Discovery Passage aquatic network. The freshwaters are soft (16.5 - 55 mg $CaCO_3$/1) well oxygenated (7.8 - 13.7 mg/1 in Quinsam River and Nunns Creek), and the temperature of the Campbell River at the John Hart Generating Station seasonally varies from 3 to 17°C. Discovery Passage is a marine water body where tidal forces cause vertical mixing and rapidly integrate freshwater input from either streams or pollution sources. Water quality in the estuary is a function of the quality of water in both the Campbell River and Discovery Passage, of sources of pollution that input directly to the estuary and of biological activity in the estuary.

Sources of pollution in the upper watershed include the Western Mines Limited copper, lead and zinc mine, which discharges tailings slurry into Buttle Lake. Studies since 1966 have been unable to determine the impact of this pollution on natural flora and fauna in the watershed, but impairment of Campbell River's domestic water supply has not occurred. Pollution directly affecting the inner estuary includes: disturbance of the flow and sedimentation regime by hydroelectric facilities; log handling; chronic but small petroleum spills from marinas and the seaplane terminal; nutrients from treated and untreated (septic tanks) sewage; and turbidity and hydrogen sulphide from periodic dredging in marinas and under the log sorting and storing areas. Pollution in Discovery Passage includes 3.16 cms (60 million Imperial gallons per day) of effluent from the Elk Falls Pulp Mill on Duncan Bay, which produces groundwood and bleached kraft pulp; discharge from the Campbell River District sewage treatment plant;

sewage from urban areas not on sewers; petroleum spills from shipping; and log debris from log transport and handling in Duncan and Menzies bays. The British Columbia government (Pollution Control Branch) has placed these polluting industries under permits which dictate effluent standards and monitoring programs. The federal government has permitted dredge spoil to be dumped at a site south of Cape Mudge, under permits issued through the Regulations of the Ocean Dumping Control Act. Air quality in the Campbell River region is good, but air polluters (under PCB permit) include Western Mines Ltd. on Buttle Lake, Tayco Paving, Island Redi-mix, sawmills in the estuary (Raven Lumber and Ocean Cedar) and Crown Zellerbach's pulp mill.

12. EFFECTS OF DEVELOPMENT

The development of the forest, tourist and hydro-electric industries has paralleled urban development in Campbell River, placing stress on the natural communities of fish, birds, invertebrates and flora that existed there before the arrival of Europeans in the early nineteenth century. Commercial use of the estuary has involved an area of 65 ha (89%) in terms of foreshore leases. About 83% is utilized by the forest industry for log handling (since the turn of the centry). Not all of that area fails to support some form of natural biota, however shade and organic fallout from logs, and changes in the shape of the estuary's basin, due to the construction of marinas and development of shore facilities for industry, have eliminated vegetated zones known to produce invertebrate food supplies of the kind presently exploited by juvenile salmonids preparing to migrate to sea from the Campbell River. The salt marsh at the mouth of Nunns Creek on the Indian Reservation is the only large area of salmonid food chain habitat left undisturbed in the estuary. Nearly all of Discovery Passage remains free of known contamination, except parts of Duncan Bay, Menzies Bay and Gowlland Harbour affected by log handling. The benthic community, within 200 m of the Elk Falls Pulp Mill outfall, showed obvious signs of stress

measured as a decrease in diversity and abundance before the new effluent diffuser system commenced operations in January, 1977.

1. INTRODUCTION

1 (i) GENERAL

The Campbell River estuary is located on the eastern shore of Vancouver Island, mid-way between the northern and southern extremities of the Island, at latitude 50° 03' north and longitude 125° 15' west.

For the purpose of this report the limits of the study area have been defined as follows: the northern limit is marked by Brown Bay at the northwestern end of Seymour Narrows; the Campbell River District Municipality boundary and Oyster Bay mark the southern limit, while the west shore of Quadra Island, from Cape Mudge to Plumper Bay, delineates the eastern limit (Figure 1.1). The central and western sectors of the study area are defined by the limits of the Campbell River and Quinsam River watersheds.

The Campbell River and its main tributary, the Quinsam River, with a combined total average annual flow of 108 cms (3,816 cfs), provide the main freshwater discharge to the estuary. Since 1947, when the construction of the John Hart Generating Station was completed, the river flow has been carefully controlled to minimize the effect of discharge through the station on the important salmon fisheries resource that utilizes the lower reaches of the river for spawning.

The estuary, situated at the southern end of Discovery Passage, is protected from the open waters of the Strait of Georgia by Quadra Island. It can be classified as both tide dominated and freshwater dominated, depending on the location. For example, the outer estuary, with its water circulation modified by the submarine topography of Discovery Passage and the presence of Quadra Island, may be regarded as tide dominated (Stommel, 1951). The inner estuary, however, supports a brackish water flora and invertebrate

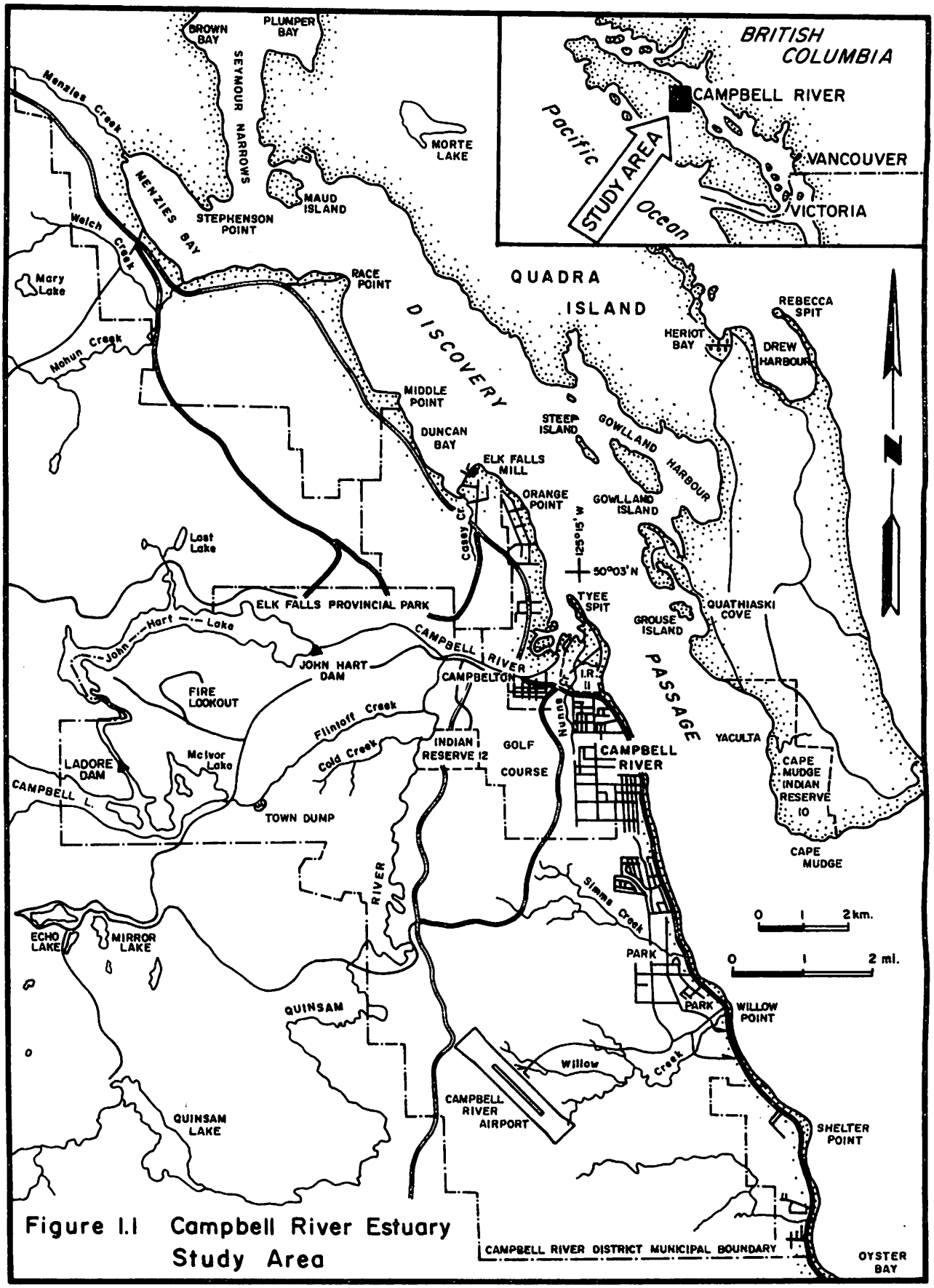


Figure 1.1 Campbell River Estuary Study Area

fauna characteristic of a fresh water dominated environment (Levings, et al., 1975).

The logging industry, the primary supporter of the local economy, has utilized the estuary since the early 1900's for the storage and transportation of logs to the local sawmills. This use of the estuary is currently the focus of a joint federal, provincial, regional and local government agency task force, convened to review the social and economic impact of industrial development on the environmental quality of the estuary.

A prominent morphological feature of the estuary is Tyee Spit. The Spit provides good protection for the Island Airlines sea-plane base, which was established in 1959 to service the forest industry on northern Vancouver Island. The base is alleged to be one of the most heavily used in the world. An ore loading dock was constructed on the seaward side of the Spit in 1951, to handle iron concentrates mined at Iron Hill near the Quinsam River for shipment to Japan and the United States of America. The last shipment of ore was made in 1957, and the dock remained unused until 1965, at which time it was rebuilt by Western Mines to ship copper and zinc concentrates to an international market from their mines at the southwestern end of Buttle Lake.

Two of the highest mountains on Vancouver Island, Golden Hinde 2,200 m (7,219 ft.) and Elkhorn Mountain 2,195 m (7,200 ft.), are found west of Buttle Lake. They are located in Strathcona Park, the oldest provincial park in British Columbia, which was created in 1911 by a special Act of the Provincial Legislature. Three roadless tracts within the park, with a total area of more than 122,000 ha (302, 000 ac) have been designated as nature conservancy areas. Two of these are situated in the study area: (1) the big Den nature area is located at the north end of the park, east of Upper Campbell Lake, and (2) the Central nature area, the largest of the three areas, extends westward from Buttle

Lake from the Heber River in the north to the southern boundary of the park. The third area, the Comox Glacier nature area, is in the southeast corner of the park and contains the headwaters of Ralph River and several creeks, flowing into the southern end of Buttle Lake.

1 (ii) HISTORICAL PERSPECTIVE

The early history of Campbell River from the late eighteenth century to the mid-1960's has been described by Helen Mitchell (1966), a long time resident of Campbell River, whose book "Diamond in the Rough" provided much information for the following historical narrative.

The first settlers on the east coast of Vancouver Island, in the Campbell River area, were Indians of the Southern Kwakiutl tribes, Weewiakay and Weewiakum, whose descendants are known today as members of the Cape Mudge and Campbell River Bands (Duff, 1964). These early inhabitants lived in an Indian Village situated at the mouth of the Campbell River. During the summer months they moved to the Quinsam River flats where they fished for salmon, which was smoked and preserved for winter use.

In 1972, after an extensive survey of the mainland coast, Captain George Vancouver, in his ship the *Discovery* (after which Discovery Passage is named), arrived at Cape Mudge (which he named after his first lieutenant). A report on the existence of a passage to the north prompted a survey of the local waters, during which time the *Discovery* was forced to anchor in what is now known as Menzies Bay, while awaiting a favourable tide to navigate the treacherous waters of Seymour Narrows.

The man for whom the Campbell River and the town were named appears to have been Dr. Samuel Campbell, a surgeon aboard HMS Plumper, a survey ship that occupied a station off the mouth of the river during the period 1857 to 1861. The name Campbell River appeared as early as 1860 on a Great Britain Admiralty

hydrographic chart. The first land survey of the area around Campbell River was made in 1887, and in the following year (1888) a survey of the Campbell Indian Band village was made while the Band was away at the Quinsam River flats. In 1865, John Buttle, a botanist, naturalist and geologist with the Vancouver Island Exploration Expedition, first sighted the largest of the lakes in the Campbell River system, which lake now bears his name.

The first white man to settle within the limits of the village of Campbell River was Frederick L. Nunns, an immigrant from Ireland, and after whom the creek which flows through Indian Reserve No. 11 is named. Among other early settlers described by Mitchell was a man named Edward B. Hill, who moved into the area in 1890. He is listed in the Land Registry Office as the original purchaser from the Crown, in 1890, of District Lot 160, the 64.8 hectare (160 acre) lot on which most of the present business section of Campbell River is situated. By 1900, settlers occupied lands from Oyster River north to the Campbell River. As the demand for timber increased, logging camps were established and the first industrial activity began. A store and hotel were erected in 1904 and Campbell River was established as a settlement.

The lumber industry, still the prime industry in the Campbell River area, was established as early as 1898, when the McLarens, eastern Canadian lumbermen, purchased extensive holdings in the Campbell River area to supply their mill in Vancouver.

In 1904, the International Timber Company, now Elk River Timber Company, commenced operations from the mouth of the Campbell River. In 1905, the Vancouver Timber and Trading Company purchased 932 hectares (2,300 acres) in the vicinity of Campbell River. Large camps were established to cut timber for export to a lumber mill in Blaine, across the American border.

By the early 1920's, there were three major logging camps operating north of Campbell River. Logs were transported by railroad to booming grounds in Menzies Bay. The first sawmill in

6. Introduction

Campbell River was built in 1922, on a site near Campbellton. In 1942, Baikie Brothers commenced logging operations in the Mount Menzies district (northwest of Menzies Bay). Their operation was subsequently bought by two of the company's employees, who changed its name to the Raven Lumber Company. The Elk River Timber Company and Raven Lumber presently operate sawmills at the mouth of the Campbell River, and are the major users of the estuary for log storage and handling.

The hydro-electric potential of the Campbell River and its integrated systems of lakes and tributary rivers was realized as early as 1903, when the Island Power Company held the first power licence. A second licence was granted, in 1910, to the Campbell River Power Company. A report on the commercial aspect and power market of the Campbell River Power Company's project includes a detailed description of the Campbell River district and the industry located there at the time. Extracts from this report are contained in the history recorded by Mitchell (1966).

In the early 1920's, the Water Rights Branch, of the British Columbia government, made a detailed survey of the river from Buttle Lake to Discovery Passage (Knewstubb, 1925, 1927). However, debate on the use of the Campbell River system for power development continued until 1945, in which year the British Columbia Power Commission was established, and plans were prepared to develop the power potential of the river.

The John Hart generating station, the first of a series of power projects to be built on the river was officially opened in 1947, and at the same time the Campbell River district power system was converted to 60-cycles from the 25-cycle power supplied since 1935 from the Puntledge River development.

2. GEOLOGY AND SOILS

2 (i) GENERAL GEOLOGIC HISTORY

Prior to 1930, geological work relating to the northern portion of Vancouver Island was limited almost entirely to investigations of the strip of Upper Cretaceous coal-bearing rock along the east coast by Richardson (1872, 1873 and 1878), and a coastal reconnaissance by Dawson (1887; 1890). Their work provided a considerable amount of general information for Clapp (1912) and MacKenzie (1922), who carried out detailed explorations of the coal-bearing strata in the Comox Basin area, lying between Comox and Campbell River.

In 1930, the general geology of the Buttle Lake map-area was first investigated by Gunning (1930), who made a geological reconnaissance of the area and examined the local mineral deposits, other than coal. In 1963, Muller undertook a systematic reconnaissance mapping of Vancouver Island in conjunction with a geological investigation of a large number of representative mineral deposits by Carson, including Western Mines zinc and copper deposits at the southern end of Buttle Lake (Muller and Carson, 1969). The regional mapping started by Muller in 1963 is still continuing, and resulted in a key paper on the stratigraphy and biochronology of the Upper Cretaceous, Nanaimo Group, (Muller and Jeletzky, 1970). Reconnaissance geological mapping of Vancouver Island is now complete, and has been described in many reports by Muller and others. It is synthetized on a geological map of Vancouver Island at a scale of 1:250,000 (Muller, 1977a).

Northcote (1973) has described the geologic history of Vancouver Island as largely one of volcanism recorded in three cycles.

8. Geology and Soils

The oldest rocks on Vancouver Island are the Mid-Paleozoic volcanics and Late Paleozoic Carboniferous sediments of the Sicker Group, deposited during the first volcanic cycle (see Appendix 2.1 for Geologic Time Scale). Rocks of the Sicker Group have been described by Muller and Carson (1969), as volcanic tuff and breccia of intermediate composition, with argillite and chert overlain by Buttle Lake limestone. Northcote (1973), points out that because of the long history of Sicker rocks being subjected to various geological processes, the Sicker Group contains some of the most intensely deformed and metamorphosed rocks on the island.

The second cycle of volcanism is represented by rocks of the Vancouver Group, ranging in age from early Triassic to late Triassic (Table 2.1). Two periods of volcanism were associated with the second cycle. The first has been identified with the basaltic lavas of the Karmutsen Formation. This period was followed by a period of quiescence during which 91 m to 610 m (300 ft. to 2,000 ft.) of massive gray to thin bedded black limestone (Quatsino Formation) was deposited in the late Triassic. This in turn was followed by a resurgence of volcanism, during the lower to Mid-Jurassic time, which resulted in the deposition of 1825 m to 2438 m (6,000 ft. to 8,000 ft.) of lavas, tuffs and breccias. The rocks of the Vancouver Group associated with this period of volcanism have been named by Muller and Carson (1969) as the Bonanza Subgroup.

The later stages of the Bonanza volcanism were accompanied by an intensive period of plutonic activity, during which time the Island Intrusives were formed, resulting in large batholiths (bodies of intrusive rock) of granitic rocks. The second cycle of volcanism was then terminated by a period of uplift erosion and deposition of a series of sedimentary rocks of late Jurassic to Upper Cretaceous age, named by Dawson (1890) as the Nanaimo Group. This succession of rocks contained extensive coal seams, which for more than one hundred years (1852-1967) made coal mining

Table 2.1. Partial Table of Formations, Vancouver Island (after Muller, 1977).

ROCK UNIT	AGE	DESCRIPTION
Tertiary Volcanics	Early Tertiary	Basaltic volcanics - southern Vancouver Island
Nanaimo Group	Upper Cretaceous	Greywacke, sandstone, conglomerate, shale and coal
Island Intrusions	Middle to Upper Jurassic	Large batholiths of granodiorite
Bonanza Group	Lower Jurassic	Tuff, andesitic volcanic breccia and lava
Vancouver Group		
Parson Bay Formation	Upper Triassic	Calcareous black argillite, calcareous greywacke and limestone
Quatsino Limestone	Upper Triassic	Limestone
Karmutsen Formation	Middle to Upper Triassic	Volcanic rocks, pillow, lava, breccia and tuff
Sicker Group	Pennsylvannian and/or Permian	Volcanic tuff and breccia, with argillite and chert overlain by Buttle Lake Formation limestone

a major industry of Vancouver Island (Buckham, 1947; James, 1969; Muller and Jeletzky, 1970). The distribution, lithology, and economic importance of the Nanaimo Group is discussed in the subsequent sections of this chapter.

The third cycle of volcanism on Vancouver Island is associated with the Tertiary geologic history of the southern portion of Vancouver Island, and thus has no relevance to this report.

2 (ii) BEDROCK GEOLOGY

The bedrock geology of the study area described in this report can be conveniently divided into two major groups of rock types. Underlying the surficial deposits of the estuary area are the Upper Cretaceous sediments of the Comox Basin (a narrow coastal strip, about 5 kilometres wide, ranging from Campbell River in the north to Bowser in the south). Composed of sandstones, conglomerates, shales and coal, the geology of the Comox Basin has been described in detail by Muller and Jeletzky (1970).

The Geology and mineral deposits of the Upper Campbell Lake and Buttle Lake areas have been described by Muller and Carson (1969), and are included on the Alberni map sheet (GSC Map 17 - 1968) at a scale of 1:250,000. A more recent description of the geology of Vancouver Island is contained in the Guidebook: Field Trip 7 (Muller, 1977), prepared for the 1977 joint annual meeting of the Geological Association of Canada and the Mineralogical Association of Canada.

In the Buttle Lake, Upper Campbell Lake and Upper Quinsam Lake areas, volcanic rocks of the Sicker Group predominate, overlain by white to grey crystalline limestone (Buttle Lake Formation) and minor amounts of argillite and quartzite. Dating of fossils found in the limestone around the headwaters of Marble

Creek (west-centre Buttle Lake) has placed the age of this formation in the Permian (Gunning, 1930; Yole, 1969). This limestone is also exposed in the vicinity of the south fork of the Wolf River and along the road on the east shore of Buttle Lake. Unconformably overlying the Buttle Lake limestone is a great thickness of pillow lavas and breccias (submarine) and amygdaloidal basalt flows (subaereal) named Karmutsen Formation, to a maximum thickness of about 18,000 ft. (6,000 m). Fossils in sediments above and below the volcanic sequence indicate that their age is Late Triassic. Upper Triassic limestone (Quatsino Formation) and argillaceous sediments (Parson Bay Formation) generally overlie the volcanics, and are exposed in Iron River.

Cutting the Paleozoic and Vancouver group rocks are the Coast Range intrusives occurring as dykes, stocks and batholiths. A large body of these granitic intrusives is exposed in the vicinity of Upper Campbell and Upper Quinsam lakes and termed Quinsam granodiorite by Gunning (1930).

2 (iii) SURFICIAL GEOLOGY

The surficial geology of the eastern coastal lowland of Vancouver Island has been mapped and described in detail by Fyles (1963). While mapping has not been completed north of latitude 50° 00' N, the surficial geology of the area extending from Willow Point on the coast to middle Quinsam Lake, has been included on the Oyster River map sheet (GSC Map 49-1959), at a scale of one inch to one mile.

The principal surficial materials of the coastal lowland comprise two groups of glacial deposits, a thick intervening succession of non-glacial and proglacial sediments, and post-glacial marine and fluvial deposits. Part of the "standard" succession proposed by Fyles (1963) as the basis for the stratigraphic subdivision of the surficial deposits of the study area is shown in

Table 2.2.

Salish sediments have been described by Fyles (1963), as related to present sea, river and lake levels, and represented by channel, flood-plain and alluvial-fan deposits along the rivers, and deltaic deposits where the rivers enter the sea and lakes. They have been identified along the shoreline north of Willow Point, including Tyee Spit, and in areas adjacent to the Quinsam River in the vicinity of Quinsam Lake (Fyles, 1959b). Marine deposits (including glacio-marine) of the Capilano succession have been identified in the area between the coast and Quinsam Lake, while west of the Lake, Vashon Drift deposits interspersed with large areas of bedrock outcrops are predominant.

Fyles (1963) has described the Capilano sediments south of Campbell River as marine, glaciomarine, lacustrine and fluvial deposits related to former sea, river and lake levels, significantly higher or lower (± 6 m) than the present levels. Deltaic sediments found above present sea level were deposited where streams and rivers flowing across the coastal lowland entered the sea. Capilano sediments consist of varied gravels, sands, silts and clays, and provide a record of the events that occurred during the retreat of the Vashon ice during the last period of glaciation in the lowland area, about 10,000 years to 14,000 years ago (Armstrong, et al., 1965). Marine and glaciomarine deposits formed during the melting of the glaciers on Vancouver Island are found at elevations up to 183 m (600 ft.) at Campbell River (Fyles, 1959a).

The tills of the Vashon Drift have been described by Fyles (1963) as extremely varied in texture, thickness and surface topography. Dry till near the surface is pale grey and hard and commonly referred to by local residents as "hardpan", by way of comparison to the "blue clay" or moist, darker grey and softer till found at greater depths. Ground moraine deposits in the coastal lowland are composed of sandy till and may reach a thickness of

Table 2.2 Stratigraphic sub-divisions of surficial deposits found in the study area (based on Fyles, 1963).

Stratigraphic Unit	Composition	Max. Thickness Metres (Feet)
Salish Sediments (Pleistocene and Recent)	-gravel, sand, silt, clay and peat related to present sea, river and lake levels	-
Capilano Sediments (Post-glacial deposits)	-gravel, sand, silt and clay of marine and fluvial origin, related to former (higher) sea, river and lake levels	24 (80)
Vashon Drift (associated with the last period of regional glaciation of south-western British Columbia)	-till, grey and sand; glacio-fluvial deposits of gravel, sand and lenses of till	30 (100)
Pre-Vashon stratified sediments (non-glacial strata)	-white sand, horizontally stratified, current bedded;	75 (250)
	-local beds of gravel and plant-bearing silts; silt, fine gravel, sand peat, and wood;	8 (25)
	-clayey silt containing stones and marine shells	24 (80)

30 m (100 ft.). Such deposits may be observed on the west side of the Island Highway, as one approaches the centre of Campbell River from the south. Glacio-fluvial deposits of gravel and sand with lenses of till, in the form of conical hills (kames) and depressions (kettles), have been mapped by Fyles (1959b), in the vicinity of Quinsam Lake.

Pre-Vashon stratified sediments are also found in the Campbell River area. Originally named Quadra sediments, they have been desribed by Fyles (1963) as non-glacial strata lying below the Vashon Drift and separated by an erosional unconformity (surface of erosion or non-deposition). A sample of wood, collected by Fyles from stratified grit, sand and silt overlying marine clay, in an excavation behind the John Hart Power Station, was age dated at >37,200 BP (Dyck and Fyles, 1962).

2 (iv) ECONOMIC GEOLOGY

The economic geology in the Campbell River study area is closely associated with the production of lode metals. Reports on the occurrence of magnetite (iron ore) on Iron Hill near Upper Quinsam Lake were published as early as 1902 (B.C. Minister of Mines).

Magnetite deposits have been explored near the mouth of the Iron River, a small stream that joins the Quinsam River, and at Iron Hill, about 20 km southwest of Campbell River on the east shore of Upper Quinsam Lake. The location, geology and economic development of these deposits have been described by Young and Uglow (1926), who estimated the ore content of the Iron Hill deposit as 1,700,000 tons of iron ore. In 1952, monthly production of concentrates was approximately 65,000 tons. A small amount of these was shipped to Baltimore, U.S.A., while the remainder was sent to Japan.

15. Geology and Soils

The Iron River deposits have been described in the B.C. Minister of Mines annual reports (Bacon and Black, 1952; Bacon, 1956). These deposits are located in the Esquimalt and Nanaimo Railway Belt Land Grant. The property owned by Canadian Colleries (Dunsmuir) Limited was originally leased to the Argonaut Co. Ltd. whose parent organization (Utah Co. of the Americas) took over the lease in 1956. The Argonaut Company during their period of operation from 1951 to 1957, mined 4,027,337 tons of ore and shipped 2,193,917 tons of concentrate (B.C. Minster of Mines, 1958).

Present-day mining of mineral deposits found in the study area is limited to the development of two massive zinc-copper sulphide deposits at the southern end of Buttle Lake.

The regional setting of these deposits has been described by Gunning (1930), and in the B.C. Minister of Mines and Petroleum Resources annual reports for 1962 and 1963 (McKechnie and Merrett, 1963; Jeffrey and Merrett, 1964 and Jeffrey, 1965). In 1962, Western Mines Limited, together with the wholly owned subsidiaries, Myra Falls Mines Ltd. and Price Creek Mines Ltd., held a total of 23 Crown grants, 2 claims held by mineral leases, and 123 claims by record. These covered an area approximately 3.2 km wide (2 mi.) and nearly 8 km long (5 mi.) at the south end of Buttle Lake in Strathcona Provincial Park.

Most of the early exploratory work was done on the Lynx property, where the ore bodies are enclosed by a variety of volcanic rocks. The ore itself occurs as massive sulphide bodies containing zinc, copper, lead, silver and gold. The geology, shape and size of the ore bodies, mineral composition, classification and origin of the ore bodies has been described in detail by Jeffrey (1965).

The Lynx mine on the north side of Myra Creek and the Myra mine on the south side are operated as one mine. During

the initial development of the mine (1966), tailings were discharged into a small tailings pond close to the plant area. In 1967, the B.C. Pollution Control Branch, granted permission to the Company to discharge tailings from the concentrator, through a submerged outfall, to the bottom of the south end of Buttle Lake. The effect of the disposal of the tailings on the water quality of Buttle Lake has been investigated by the Pollution Control Branch (B.C. Research, 1974). The results are discussed in the Water Quality Section of this report.

Production from the mine in 1974, was 297,290 tons of ore with gross content: 25,485 ounces of gold, 1,151,509 ounces of silver, 8,669,995 pounds of copper, 5,995,424 pounds of lead, 47,360,963 pounds of zinc, and 189,481 pounds of cadmium. At the end of 1974, total ore reserves were 1,887,900 tons (B.C. Minister of Mines and Petroleum Resources, 1976a).

The concentrator is located near the portal of the Lynx mine, and in 1974 with a capacity of 900 tons per day, produced copper, lead and zinc concentrates which were trucked to storage at a ship-loading dock in Campbell River. Copper concentrate was loaded directly into ships for delivery to Japanese smelters. Zinc concentrate was either shipped to Japan or barged to Seattle for shipment to smelters in the United States. The lead concentrate was shipped by rail through Courtenay and Vancouver to the smelter at Trail.

Gravel and sand suitable for concrete aggregate and road building is available from several pits near the highway between Campbell River and Quinsam. According to Fyles (1963) the principal sources are the ice-contact deposits of the Vashon drift and the terraced delta deposits of the Capilano sediments. Gravel and sand have also been obtained from the channel deposits of the Campbell River near the river mouth. From 1964 to 1974, Island Redi-mix Company Limited removed and processed over a quarter of

a million cubic yards of sand and gravel from the estuary at the southern end of Tyee Spit. Following the closure of the operation in 1974, the company (Island Ready Mix) established a gravel plant on General Hill, near the town dump, approximately 8 km west of Campbell River. The processed materials are then trucked to Tyee Spit for storing and use in the "Ready-Mix" cement plant. Additional information on the entire operation is contained in the Land and Water Use Section of this report.

2 (v) SOILS

For a description of the soils in the estuary area and the Campbell River drainage basin, the reader is referred to the British Columbia soil survey of southeast Vancouver Island (Day, Farstad and Laird, 1959).

The survey was carried out by the Research Branch, Canada Department of Agriculture in co-operation with the University of British Columbia and the British Columbia Department of Agriculture, and includes a detailed map sheet of the Courtenay-Campbell River area, at a scale of one inch to one mile. It is presently the most comprehensive reference available on soils in the study area, and with a compendium of soils of Vancouver Island compiled by the Research Division, British Columbia Forest Service (Keser and St. Pierre, 1973), forms the basis for the following summary.

Soils predominant in the immediate vicinity of the river mouth are the gravelly loamy sands and sandy loams of the Cassidy Series. Tyee Spit is classified as coastal beach and is composed of shore-washed sand, gravel and stone. Much of this sand and gravel has been exploited commercially. This use is discussed further in the Land and Water Use Section of this report.

South of Campbell River on the eastern shore of Discovery

Passage, gravelly loamy sand of the Dashwood Soils Series extends almost to Willow Point, where it merges with the loamy sand of the Bowser Series. Though relatively free of gravel and stones, only a small percentage of this soil is cultivated, and it is used mainly for hay and pasture.

Southwest of the town of Campbell River soils of the Fairbridge Series, extend east and west of the Quinsam River providing land suitable for general agricultural purposes. East of Hart Lake a north-south trending band of soils of the Qualicum and Kye Series follows the Sayward Valley. The soils provide conditions suitable for a vegetation composed principally of lodgepole pine with Douglas fir, hemlock, red alder and occasionally arbutus. Associated with the Kye and Bowser Series are soils of the Sayward Series, which cover 1,172 ha (2,895 acres) in the Campbell River and Sayward areas. This soil is used entirely for forestry purposes.

West of the John Hart dam, rough mountainous land, with sparse soil coverage, comprises the western regions of the Campbell River drainage basin. However, on the south side of Campbell Lake, Quinsam soils composed of gravelly sandy loam comprises about 3,627 ha (8,955 acres). The native vegetation is mainly second growth Douglas fir, hemlock, balsam and red cedar, and with a site index for forestry ranging from medium to high, these soils produce high quality timber.

3. CLIMATOLOGY

3 (i) GENERAL

The Campbell River estuary and adjacent coastal areas are generally cooler, cloudier and wetter than the more southerly estuaries of the east coast of Vancouver Island. These factors, combined with a more abundant summer rainfall, provide a cool humid environment favoured by the coastal Douglas fir and western hemlock grown commercially within the study area. Cool temperatures limit the amount of heat available for crop growth. The annual accumulation of degree days as expressed by the amount and duration of temperature above the daily average of 5.6°C (42°F), averages about 2,000 to 2,500 compared with 2,500 to 3,500 for most of the southern areas of the east coast of Vancouver Island. Parameters determining the climate capability classification for agriculture are documented in a British Columbia Land Inventory Climatology report (B.C. Dept. Agric., 1972).

The climate of the study area is predominantly marine west coast based on the Koppen classification system (Chapman, 1952; Trewartha, 1968). However, some variations occur between the climate at the estuary and the upper regions of the Campbell River drainage basin, owing to changes in topography and increases in elevation. For example, the mountainous topography of the upper reaches of the Campbell River contributes to a marked variation of precipitation within the area, with the amount of precipitation decreasing rapidly towards the coastal plateau.

Campbell River has a moderate climate with an appreciable amount of summer sunshine, annual average 1,751 hours, and a mean daily annual temperature of 8.9°C, ranging from 1.3°C in January to 17.4°C in July. While the area has no distinctly dry summer season, average rainfall during the summer months is relatively low, reaching a minimum of 39 mm in July and not exceeding 52 mm in the May to August period. November and December are usually the wettest months with averages of 231 mm and 270 mm of

precipitation, respectively. Maximum snowfalls occur in the months of December and January, with long-term averages of 30 cm and 44 cm, respectively.

Five climatological stations are presently active in the study area. A sixth, Comox Airport, although well to the south, has been considered in order to obtain wind summaries indicative of conditions at Campbell River. No meteorological data is available from the estuary itself, although data from the former Campbell River climatological station on the Quinsam Indian Reserve date back to 1936. Observations estimating wind speeds and directions at the southern end of Quadra Island are made by the keeper of the Cape Mudge light.

A summary of publications containing meteorological data from climatological stations in the Campbell River area is contained in Table 3.1.

3 (ii) CLIMATOLOGICAL STATIONS

Five active and one inactive weather recording stations in the study area are all located within a radius of 10 km of the town of Campbell River (Figure 3.1). Temperature and precipitation have been recorded at the Campbell River Airport since January 1965 and at the British Columbia Forest Service station north of Elk Falls since June 1969. This station also records rate of rainfall. Precipitation records have been kept since 1957 at the Duncan Bay station near the Elk Falls Pulp and Paper Company. Observations began in 1972 and 1975, respectively, at the B.C. Hydro and Power Authority John Hart generating station and at the Quinsam River Hatchery.

Historical data including temperature, precipitation and hours of sunshine are available from the records of the meteorological observations made at the Campbell River station between 1936 and 1965. The available weather data and periods of record for this

Table 3.1. Campbell River climatological stations - meteorological data and reference source.

DATA	PUBLICATION	SOURCE
Temperature and Precipitation	British Columbia means for the period 1941-1970 and extremes up to 1970.	Can. Dept. Env., 1971 Atmos. Env. Serv.
Temperature and Precipitation	Climate normals 1941-1970 Extremes of record.	B.C. Dept. of Agric., 1971 (compiled from Atmos. Env. Serv. data)
Temperature, Precipitation and Sunshine	Summary of monthly and annual means.	B.C. Dept. of Agric. (published annually)
Temperature, Precipitation, wind, atmospheric pressure, vapour pressure, cloud cover, visibility and sunshine	Monthly record of meteorological observations in Canada includes daily observations and monthly summaries	Can. Dept. Env. Atmos. Env. Serv. (Downsview, Ontario)
Temperature, Precipitation and Wind	Canadian normals Vol. 1 Temp. (1941-1970) Vol. 2 Precip. (1941-1970) Vol. 3 Wind (1955-1972)	Can. Dept. Env. Atmos. Env. Serv. (Downsview, Ontario)

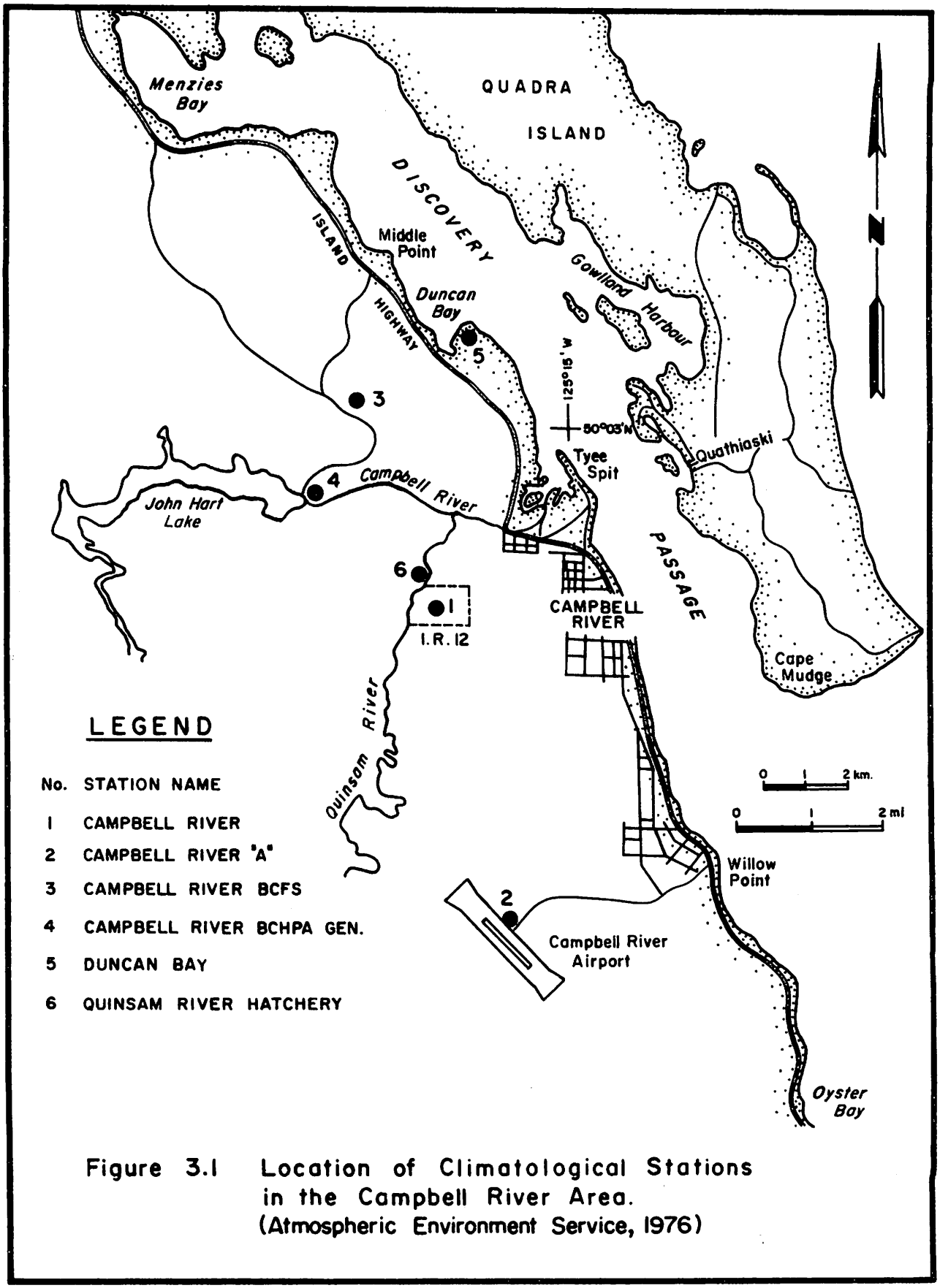


Figure 3.1 Location of Climatological Stations in the Campbell River Area. (Atmospheric Environment Service, 1976)

station and the currently active ones are shown in Table 3.2.

No weather records are available for the estuary area itself, on either a short term or long term basis. No wind data are available from any of the stations within the study area. The nearest station reporting wind speed and direction is at the Comox Airport 48 kilometres to the south. Observations of atmospheric pressure, temperature, vapour pressure, cloud cover and visibility are also taken at Comox Airport. A summary of general climatic conditions for Campbell River is shown in Table 3.3.

3 (iii) PRECIPITATION

The mean annual precipitation for Campbell River based on a 29 year average between 1941 and 1970 is 1540 mm. Measurements made at Duncan Bay, from 1957 to 1970, show a similar mean annual total precipitation of 1595 mm (Can. Dept. Env., 1971).

A comparison of the annual rainfall and snowfall at Campbell River Airport, the Campbell River BCFS Station and Duncan Bay, for the years 1973, 1974 and 1975, is shown in Table 3.4. These data, based on figures published by the B.C. Dept. of Agriculture from Atmospheric Environment Service records, show an interesting contrast between the Duncan Bay station and the other two. For the three years in question rainfall is higher and snowfall is lower at the coastal station (Duncan Bay) than at the two stations further inland. This may be related to the local topography and height of stations above sea level (see Table 3.2).

Precipitation in the interior areas of the Campbell River drainage basin is generally considerably higher than in the coastal areas. An estimate of precipitation in the mountain watersheds, prepared for a water supply survey for the Greater Campbell River Water District (Dayton and Knight Ltd., 1972), showed areas in the Buttle Lake - Upper Campbell Lake region receiving from 1,778 mm (70 in.) to 2,286 mm (90 in.) per year. These figures were based on a plot of the average precipitation

Table 3.2. Available weather data from climatological stations serving the Campbell River area (Canada Department of the Environment, 1977).

1. Campbell River	50°01'N 125°18'W	79 m asl
Precipitation		February 1936 - June 1958
Temperature & Precipitation		July 1958 - May 1969
Sunshine		April 1956 - April 1967
		July 1958 - March 1967
2. Campbell River "A"	49°57'N 125°16'W	98 m asl
Temperature & Precipitation		January 1965 - Continuing
3. Campbell River BCFS	50°04'N 125°19'W	128 m asl
Temperature & Precipitation		June 1969 - Continuing
Rate of Rainfall		September 1969 - Continuing
4. Campbell River BCHPA Gen.	50°03'N 125°19'W	31 m asl
Temperature & Precipitation		November 1972 - Continuing
Rate of Rainfall		November 1972 - Continuing
5. Duncan Bay	50°04'N 125°17'W	7 m asl
Precipitation		September 1957 - Continuing
6. Quinsam River Hatchery	50°01'N 125°18'W	46 m asl
Temperature & Precipitation		September 1975 - Continuing
7. Comox Airport	49°43'N 124°54'W	23 m asl
Wind mileage (Recorder)		September 1944 - September 1959
Hourly wind reports		October 1959 - Continuing
Temperature	)	
Atmospheric pressure	)	January 1944 - Continuing
Cloud cover	)	(from hourly reports)
Visibility	)	

Table 3.3. Campbell River Estuary - climate summary (Canada Department of the Environment - Atmospheric Environment Service, 1975).

CAMPBELL RIVER	
Temperature	
Mean temperature - Annual	8.9°C
Mean temperature - January	1.3°C
Mean temperature - July	17.4°C
Extreme maximum temperature	37.2°C
Extreme minimum temperature	-17.8°C
Precipitation	
Mean annual total precipitation	1538 mm
Mean annual rainfall	1436 mm
Mean annual snowfall	104 cm
Annual Number of Days with:	
Frost	85 days
Measurable precipitation	137 days
Average Annual Hours of Bright Sunshine	1,751 hours
Frost Free Period	
April 29 - October 27	180 days
COMOX AIRPORT	
Wind	
Prevailing wind direction by hours	southeast
Prevailing wind direction by miles	southeast
Mean annual wind speed	11.9 km/hr.

for the whole of Vancouver Island for the period 1960 to 1966 and the interpolation of the isoheyts thus obtained.

Table 3.4 Comparison of annual rainfall (mm) and snowfall (cm) for years 1973, 1974 and 1975 from records kept at climatological stations in the Campbell River area (B.C. Dept. of Agriculture, 1975; 1976a; 1976b).

	CAMPBELL RIVER A			CAMPBELL RIVER BCFS			DUNCAN BAY		
	Rain	Snow	Total	Rain	Snow	Total	Rain	Snow	Total
1973	1290	53.3	1343	1452	56.9	1509	1559	32.5	1591
1974	1298	192.8	1491	1543	159.5	1702	1852	25.1	1877
1975	1320	177.0	1497	1698	265.7	1964	1964	101.9	1949

3 (iv) TEMPERATURE

Temperature records for the discontinued Campbell River station are available for the period July 1958 to May 1969. Campbell River Airport and Campbell River BCFS have been recording air temperatures since January 1965 and June 1969 respectively. Observations began in November 1972 at the B.C. Hydro site, and in September 1975 at the Quinsam fish hatchery.

The 30 year (1941-1970) average (Can. Dept. Env., 1971) shows a mean annual temperature of 8.9°C for Campbell River. January is generally the coldest month with a mean temperature of 1.3°C, while July is usually the warmest month with a mean temperature of 17.4°C. The maximum temperature recorded to date (37.2°C) occurred in July, while the minimum temperature recorded (-17.8°C) occurred in January.

A comparison of the winter, summer and annual temperature in the Campbell River area for the years 1973, 1974 and 1975 is shown in Table 3.5. These records indicate very small monthly and annual differences in temperature between the airport and the B.C. Forest Service sites.

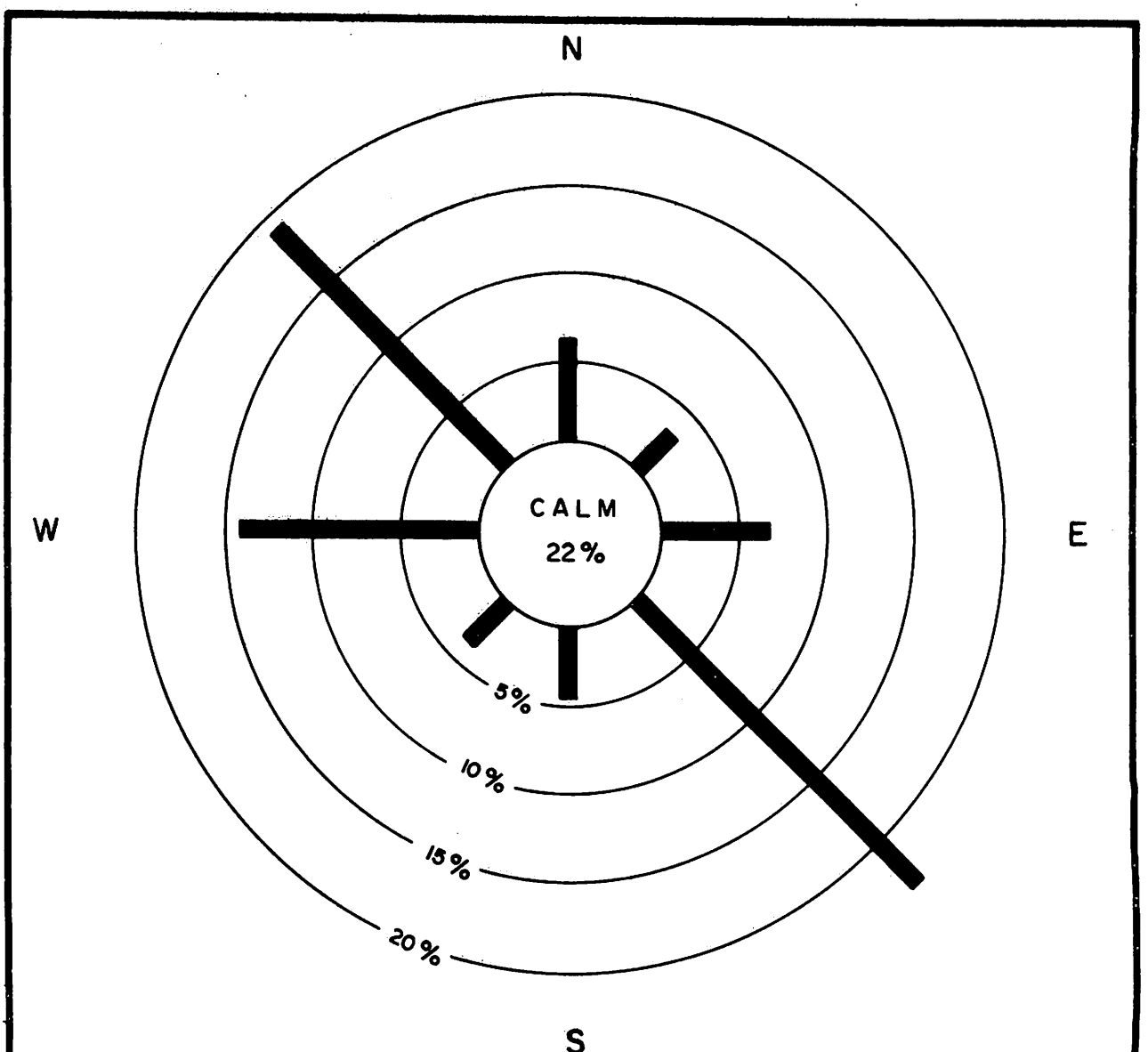
Table 3.5. Winter, summer and annual temperature (^{o}C) at Campbell River for 1973, 1974 and 1975 (B.C. Dept. of Agriculture, 1975; 1976a; 1976b).

	Campbell River "A"			Campbell River BCFS		
	Jan.	Jul.	Annual	Jan.	Jul.	Annual
1973	$0^{o}C$	$16.1^{o}C$	$7.8^{o}C$	$1.1^{o}C$	$15.6^{o}C$	$8.3^{o}C$
1974	$0.6^{o}C$	$15^{o}C$	$8.3^{o}C$	$0.6^{o}C$	$14.4^{o}C$	$8.9^{o}C$
1975	$-0.6^{o}C$	$17.2^{o}C$	$7.2^{o}C$	$0^{o}C$	$17.2^{o}C$	$7.8^{o}C$
Average (since Jan.1965)	$0^{o}C$	$17.2^{o}C$	$7.8^{o}C$	Not available		

3 (v) WIND

No continuous wind recording stations are located in the study area. Intermittent hourly observations are made at the Campbell River Airport. The closest continuous recording station is at Comox Airport, 48 km south of the estuary, where hourly observations are made of both wind speed and direction. The percentage frequency by direction of winds recorded at Comox Airport is shown in Figures 3.2 and 3.3. Prevailing winds during the period 1955 to 1966 were mainly southeast and northwest. The mean wind speed was 11.9 km/hr. with a maximum hourly wind speed of 93.4 km/hr. recorded from the southeast. The maximum observed gust was 128.8 km/hr.

Hourly wind observations are also made at Chatham Point at the northern end of Discovery Passage. Extrapolation of wind data from the Comox and Chatham Point records may give an approximation of wind conditions experienced in the vicinity of the Campbell River estuary.



0 10 20 %

SCALE : 1 INCH = 10 PERCENT

MEAN WIND SPEED = 11.9 km/hr

MAX. HOURLY SPEED = 93.3 km/hr (SE)

MAX. OBSERVED GUST SPEED = 128.7 km/hr

Figure 3·2 Comox (A) Wind Rose 1955 - 1972 Percentage Frequency by Direction (Atmospheric Environment Service 1975).

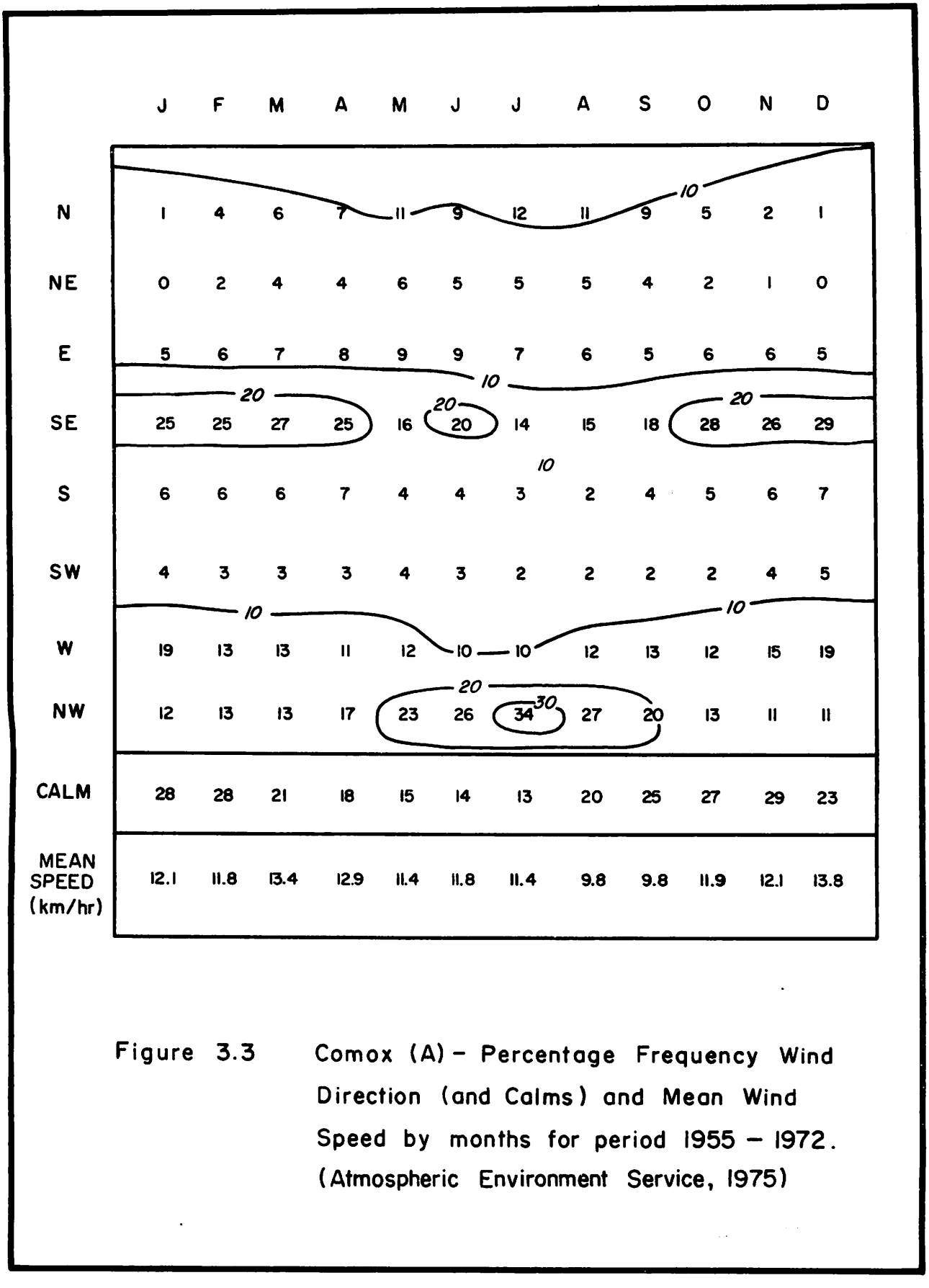


Figure 3.3 Comox (A) - Percentage Frequency Wind Direction (and Calms) and Mean Wind Speed by months for period 1955 – 1972. (Atmospheric Environment Service, 1975)

3 (vi) OTHER PARAMETERS

For other parameters such as atmospheric pressure, vapour pressure, cloud cover, and visibility, the closest observations to the Campbell River estuary are those made at Comox Airport, 28 km to the south. Detailed data summaries of daily and hourly records are available from the Atmospheric Environment Service (Can. Dept. Env., 1975).

Hours of bright sunshine were recorded at the Campbell River climatological station from April 1956 to April 1967, and July 1958 to March 1965. The average annual hours of sunshine recorded for Campbell River is 1,751 hours. At the present time sunshine records are not being kept at any of the climatological stations in the study area.

Temperature records from the Campbell River climatological station showed that frost occurred on 85 days a year (1941-1970 normals), with a frost-free period of 180 days between April 29 and October 27.

3 (vii) AIR POLLUTION POTENTIAL

Although site specific data relating to winds and inversions are lacking for the Campbell River Estuary, a qualitative description of the wind regime can be provided based upon records collected at Comox Airport to the south, Chatham Point to the north and Cape Lazo and Cape Mudge in the Strait of Georgia. Approximate inversion frequencies can be estimated by extrapolation of regional information (J. Emslie, pers. comm., Atmospheric Environment Service).

The surface wind flow over Georgia Strait is channelled by the mountains of Vancouver Island and the mainland in such a way that southeast and northwest directions prevail. South-easterlies prevail in late fall, winter and early spring, and northwesterlies prevail at other times. Calm winds are quite

frequent (i.e., greater than 20 percent of hours), except from May to July, and occur principally overnight. Greatest mean wind speeds occur with southeasterly winds, with peak speeds in late fall, winter and early spring associated with the passage of Pacific storms.

With adjacent ridges of high ground and the relatively cold water of Georgia Strait close by, Campbell River is an area where overnight and early morning surface-based inversions are very frequent. Occurrences during the day are fairly uniform through the year, being the result of overrunning warmer air in fall and winter and the cooling of the surface air layer by the sea in spring and summer. The following table shows the percentage frequency of ground-based inversions in the late afternoon and early moring:

(Percent Frequency)

	Winter	Spring	Summer	Fall
P.M.	35	25	30	40
A.M.	70	75	88	80

During winter, with measurable precipitation falling on about half the days, rainout and washout of airborne pollutants should be quite effective. Under daylight conditions, there appears to be little problem with the dispersion of airborne pollutants, except for brief periods in fall and winter during calm winds, when ground-based inversions are fairly frequent.

4. HYDROLOGY

4 (i) GENERAL

The Campbell River, the third largest on Vancouver Island in terms of recorded mean annual discharge and second largest based on size of drainage basin (Table 4.1), drains an area of 1461 sq. km (564 sq. mi.) of mountainous topography to the west and south of the town of Campbell River (Figure 4.1).

It flows northwards for about 64 km (40 mi.) from its source at Buttle Lake, then turns eastward for 26 km (16 mi.) before discharging into Discovery Passage south of Seymour Narrows. Three kilometres upstream of the river mouth, the river is joined by its largest tributary, the Quinsam River, which originates in Upper Quinsam Lake and drains an additional area of 280 sq. km (108 sq. mi.) The Quinsam River and several other tributaries in the Buttle Lake area, namely Elk River, Wolf River, Myra, Thelwood, Price and Ralph Creeks are key contributors to the fishery resource of the Campbell River system. Their ecological significance to the aquatic resources of the study area is described later in this report under the sections on Fish and Invertebrates.

Three biologically significant creeks, Nunns creek, Willow creek and Simms creek flow through the residential areas on the southern side of Campbell River, and discharge into the estuary. Nunns creek (also known as Camp creek) flows through the Indian Reserve Number 11 adjacent to Tyee Spit. During times of flood, it contributes a considerable inflow of fresh water to the highly productive marshes in the mouth of the Campbell River; however, no records are available of streamflows.

Willow creek and Simms creek (also referred to as Erickson and Swansky creeks) discharge into Discovery Passage near the southern boundary of the District of Campbell River.

Table 4.1. Comparison of sizes of the major rivers on Vancouver Island. Historical streamflow summary, British Columbia 1914 to 1973 (Can. Dept. Env., 1974).

	MEAN ANNUAL DISCHARGE CMS (CFS)	DRAINAGE AREA SQ.KM (SQ.MI)	PERIOD OF RECORD	STATION NO.
COWICHAN	53 (1890)	834 (322)	1960-1973	08HA011
CHEMAINUS	19 (670)	378 (146)	1914-17,1952-73	08HA001
NANAIMO	41 (1460)	684 (264)	1965-1973	08HB034
PUNTLEDGE	43 (1510)	583 (225)	1914-17,1955-57 1964-1973	08HB006
CAMPBELL	99 (3490)	1461 (564)	1949-1970	08HD003
SALMON	66 (2320)	1210 (467)	1956-1973	08HD006
NIMPKISH	129 (4560)	1761 (680)	1926-1938	08HF002
GOLD	88 (3110)	1036 (400)	1956-1973	08HC001
SOMASS	130 (4580)	1311 (506)	1957-1973	08HB017
QUINSAM	9 (326)	280 (108)	1956-1973	08HD005

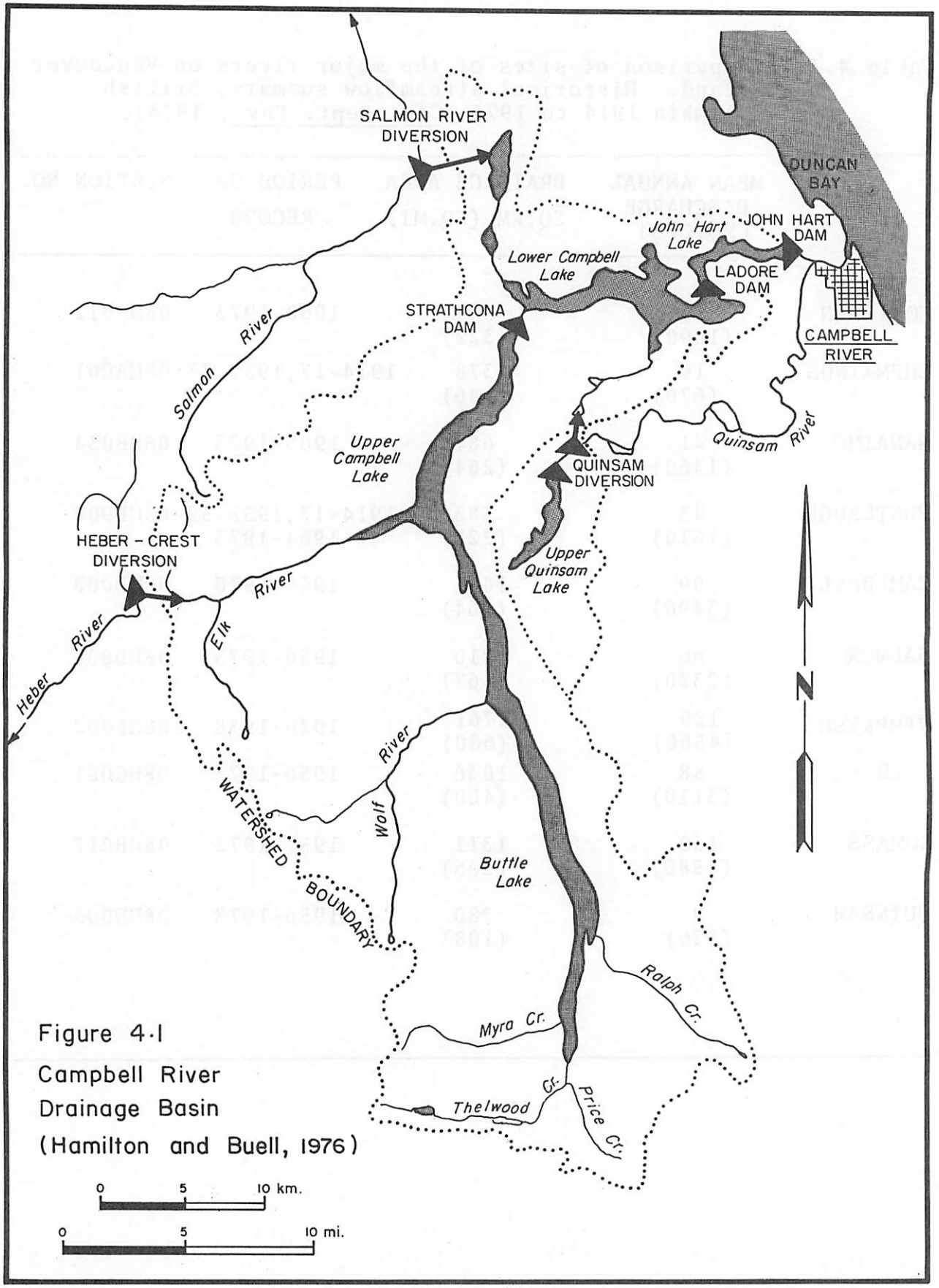


Figure 4.1
Campbell River
Drainage Basin
(Hamilton and Buell, 1976)

Their significance to the local fisheries resource, and the relative importance of Nunns creek to the ecology of the Campbell River estuary is discussed further in the biological sections of this report.

The flow in Campbell River at the estuary is the sum of the combined flows of the Campbell River and the Quinsam River, which together have an average annual flow of 108 cms (3,816 cfs) (Can. Dept. Env., 1976a). Tidal influence extends up the river to a point about 457 m (1500 ft.) upstream of the Highway 19 bridge crossing. The tidal state in the river mouth is of particular significance when routing floods past the John Hart powerplant and down the Campbell River. This aspect of flood control is discussed further in Sub-section 4 (iii).

4 (ii) STREAMFLOW GAUGING STATIONS

Streamflow data are available from three stations on the Campbell River and two on the Quinsam River. Continuous measurements of the natural flow on the Campbell River were made from 1910 to 1949 at Station 08HD001 (Campbell River at outlet of Campbell Lake), and at Station 08HD004 (near Quinsam River) from 1953 to 1956. Measurements of regulated flow downstream of the John Hart generating station were made between 1949 and 1970 at Station 08HD003 (Campbell River near Campbell River).

Continuous streamflow measurements have been made on the Quinsam River near Campbell River (Station 08HD005) since 1949, with miscellaneous measurements available for the years 1914 and 1915. Unpublished data are available from records maintained by Canada Department of Fisheries and Environment from a station on the Quinsam River below Quinsam (Station 08HD010). A summary of streamflow gauging stations, their locations, drainage areas and period of record is shown in Appendix 4.1.

Below the John Hart generating station, the Campbell

River is a shallow, swift-moving stream about 61 m (200 ft.) wide with an average annual flow of 99 cms (3490 cfs), measured at Station 08HD003 for 19 complete years between 1950 and 1970 (Can. Dept. Env., 1974). River flow downstream of the John Hart powerplant has been regulated since 1947. B.C. Hydro's Operation Order No. 412 for the plant requires an absolute minimum river flow of 13 cms (450 cfs) but, at the request of Fisheries Management, the flow is not reduced below about 28 cms (1000 cfs) (IPEC, 1973). The maximum discharge from the powerplant based on the hydraulic capacity of the turbines, 6 units at 20.7 cms (730 cfs) per unit, is 124 cms (4,380 cfs). Therefore, except during periods of flood, the river flow varies between 28 cms (1,000 cfs) and 124 cms (4,380 cfs).

The maximum daily discharge observed on the Campbell River, since records were started (1910), was 857 cms (30,300 cfs). It was recorded at Station 08HD001, at the outlet of Campbell Lake, on November 16, 1939. The lowest daily flow ever recorded for the Campbell River was 7.9 cms (280 cfs). It occurred on October 18, 1925 and was measured at the same station.

The mean annual flow in the Quinsam River, based on streamflow records from Station 08HD005, for the period 1956 to 1973, was 9.2 cms (326 cfs). The minimum daily discharge recorded during this period was 0.9 cms (31.4 cfs), recorded on September 21, 1956. The maximum daily discharge for the same period was 218 cms (7,700 cfs), and occurred on January 19, 1968.

A summary of other record-flow data for the Campbell and Quinsam rivers is shown in Tables 4.4 and 4.5. In 19 years of record (1950 to 1970), peak flows in the Campbell River occurred between May 22 and June 24 and October 19 and February 24 (Can. Dept. Env., 1973a). A discharge hydrograph for the Campbell River near Campbell River for a typical year (1965) is shown in Figure 4.2.

Table 4.2. Record-flow data for the Campbell River. Historical streamflow summary, British Columbia to 1973 (Can. Dept. Env. 1974).

CAMPBELL RIVER (STN. 08HD003)	cms	cfs	date
Maximum daily flow	798	28,200	Nov. 15, 1953
Minimum daily flow	16	562	Sept. 4, 1957
Largest mean annual flow	125	4,410	1968
Smallest mean annual flow	44	1,540	1957
Maximum mean monthly flow	278	9,840	Jan. 1968
Minimum mean monthly flow	21	729	June 1957

Table 4.3. Record-flow data for the Quinsam River. Historical streamflow summary, British Columbia to 1973 (Can. Dept. Env. 1974).

QUINSAM RIVER (STN. 08HD005)	cms	cfs	date
Maximum daily flow	218	7,700	Jan. 19, 1968
Minimum daily flow	0.9	31.4	Sept. 21, 1956
Largest mean annual flow	13.5	476	1968
Smallest mean annual flow	6	213	1970
Maximum mean monthly flow	48	1,710	Jan. 1968
Minimum mean monthly flow	1.2	41.8	Aug. 1973

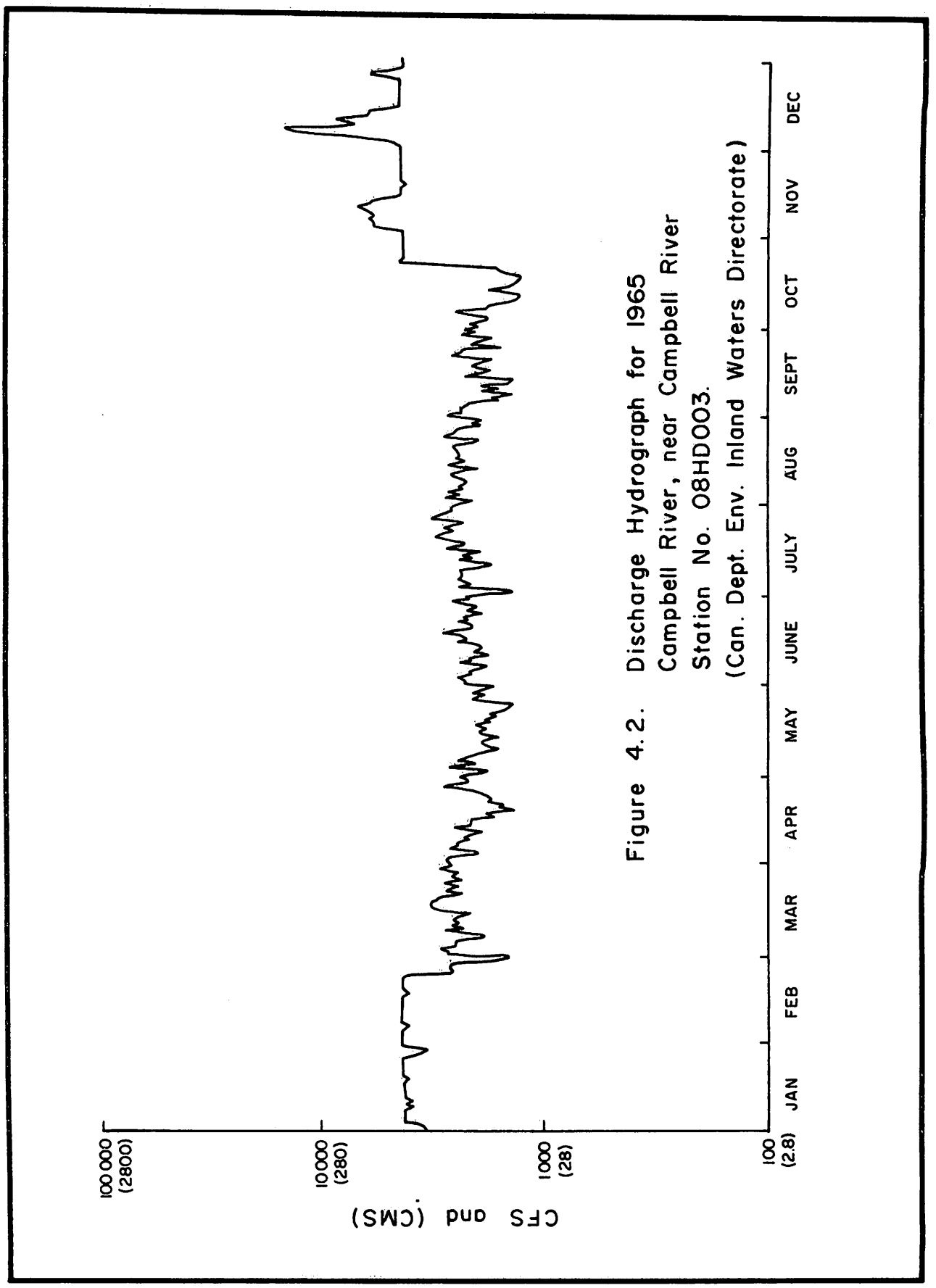


Figure 4.2. Discharge Hydrograph for 1965
Campbell River, near Campbell River
Station No. 08HD003.
(Can. Dept. Env. Inland Waters Directorate)

4 (iii) FLOODS AND FLOOD CONTROL

For data on maximum daily mean flows and plots of flood probability for the Campbell River, the reader is referred to a report on the magnitude of floods in British Columbia prepared by the Water Survey of Canada, Vancouver, B.C. (Can. Dept. Env., 1972). Figure 4.3 shows a flood probability curve for the Campbell River, based on maximum daily mean flows for the period 1950 to 1970, measured at Station 08HD003 near Campbell River.

Water level gauges installed by B.C. Hydro in the tidal and non-tidal reaches of the river are used as references for regulating maximum water levels to prevent flooding in Campbellton and other low-lying areas adjacent to the river. Flood peaks downstream of the John Hart powerhouse are reduced considerably by using the storage reservoirs of the Campbell River power developments to route flood flows through the system (IPEC, 1973).

Tidal influence in the lower Campbell River, and the routing of floods, is discussed in a report on flow conditions downstream of the John Hart powerplant (IPEC, 1973). This report, prepared in conjunction with preliminary design studies for the proposed John Hart II project, describes the mathematical models developed to assist in the determination of steady state and transient flow conditions, which could exist downstream of the power plants.

Combinations of extreme high tide at the mouth of the Campbell River, and flood flow on the Quinsam, could restrict power output from the combined plants, by limiting the discharge through the plant to minimize flooding. Figure 4.4 shows maximum daily mean flows for the Quinsam River from 1957 to 1971, plotted against frequency of occurrence. The mean annual flood of 62 cms (2,200 cfs) has been exceeded seven times during this 15-year period, and the maximum recorded flood is 218 cms (7,700 cfs).

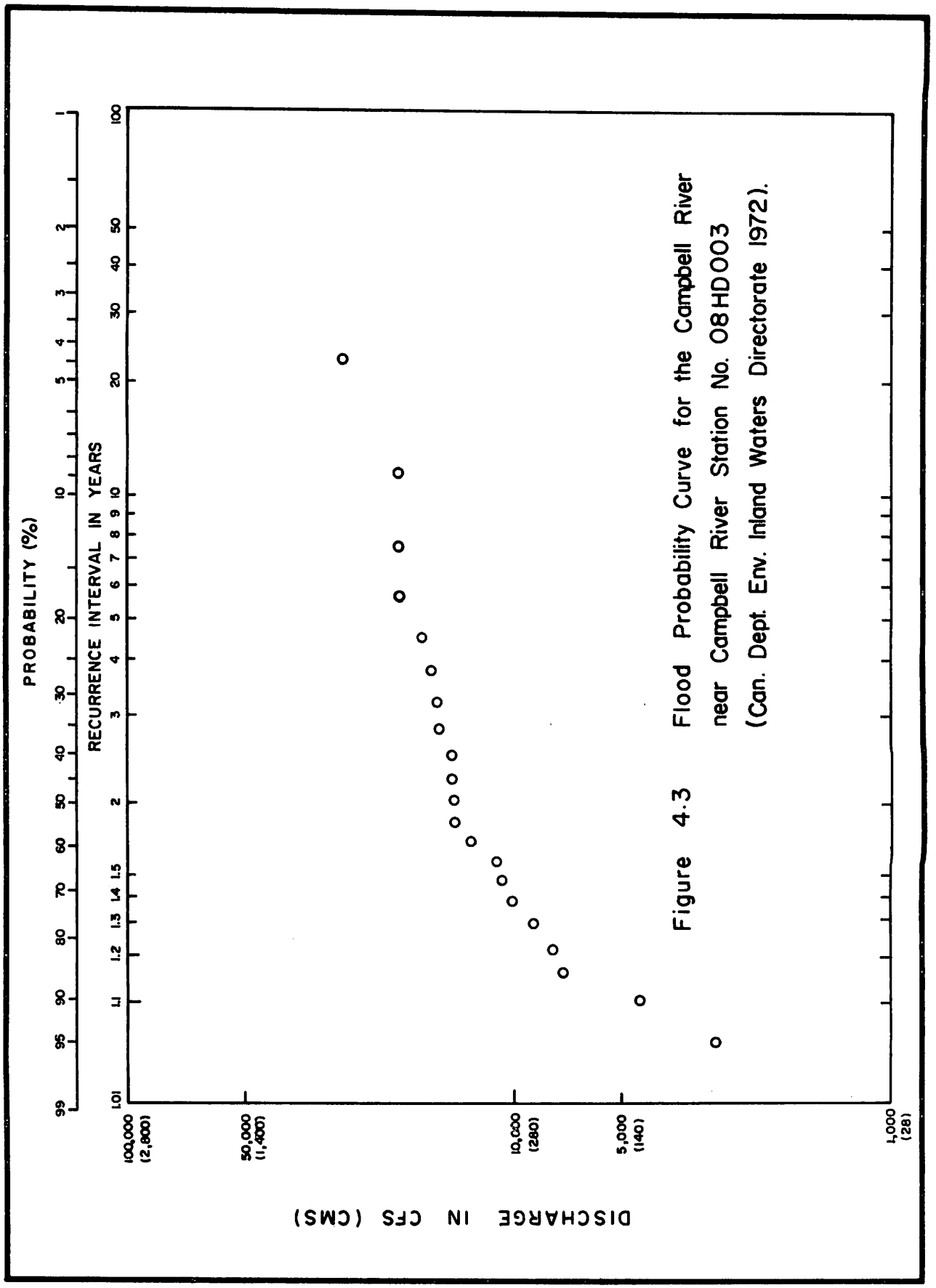


Figure 4.3 Flood Probability Curve for the Campbell River near Campbell River Station No. 08HD003 (Can. Dept. Env. Inland Waters Directorate 1972).

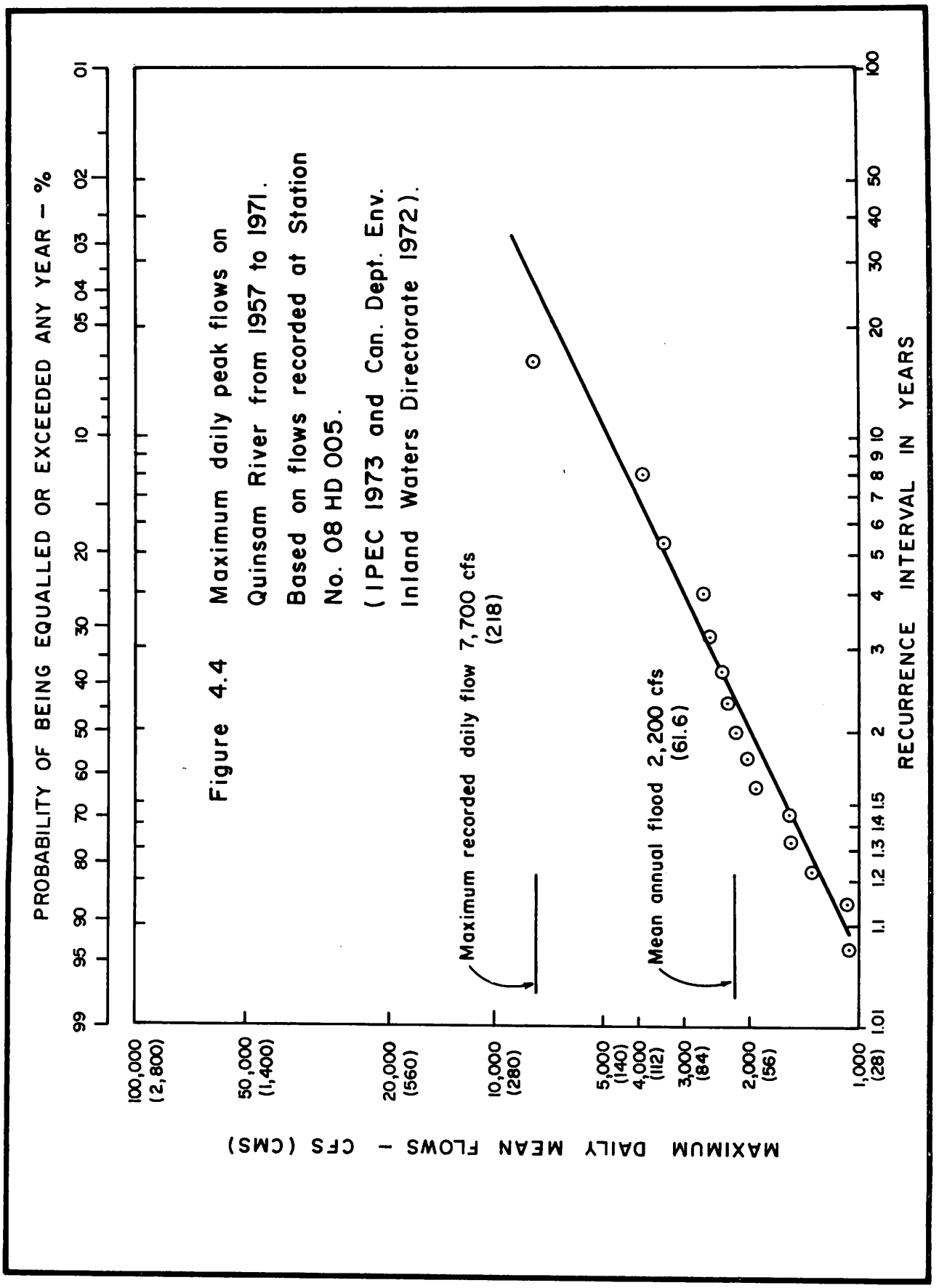


Figure 4.4 Maximum daily peak flows on Quinsam River from 1957 to 1971. Based on flows recorded at Station No. 08 HD 005. (IPEC 1973 and Can. Dept. Env. Inland Waters Directorate 1972).

Tide records for Campbell River were analyzed by IPEC (1973), to determine the expected frequency of occurrence of extreme high tides. These were found to occur during the months of November, December and January. "High high water" for Campbell River is listed in the regional tide tables (Can. Dept. Env., 1977), as 4.1 m (13.5 ft.) for the mean tide, 4.6 m (15.1 ft.) for a large tide, with the maximum recorded tide height being 5.3 (17.6 ft.). The low-lying areas in the flood plain are subject to inundation at high tides, even with low flows in the Campbell River.

4 (iv) HYDROELECTRIC POWER DEVELOPMENTS

Three hydroelectric power developments utilize the 213 m (700 ft.) drop in elevation between Buttle Lake and the lower reaches of the Campbell River. The John Hart power development, when the first stage was completed in 1947, dammed the river above Elk Falls and raised the water level in the catchment area to 140 m (458 ft.) above sea level. The new lake formed, named John Hart Lake, is 8 km (5 mi.) long and covers an area of 255 ha (630 ac.). The main dam has a spillway discharge capacity of 1557 cms (55,000 cfs) (Ballantyne, 1960).

The Ladore Falls storage dam at the outlet of Lower Campbell Lake above Ladore Falls, was completed in 1949. It controls 321 x 10^6 cu.m (260,000 acre feet) of water in Lower Campbell Lake to an extreme flood water level of 178 m (585 ft.). The reservoir covers an area of 2,430 ha (6,000 ac.), almost ten times the area of John Hart Lake.

The Strathcona dam and generating station, completed in 1958, was the third and most recent power development on the Campbell River system. It is located approximately 22.5 km (14 mi.) upstream from the Ladore Falls generating station. The reservoir created by the Strathcona dam brought the level of Buttle Lake and Upper Campbell Lake to one common elevation of

221 m (725 ft.), for the maximum storage water level. The extreme flood water level of the reservoir is 225 m (737 ft.). The reservoir which is 56 km (35 mi.) long, has an area of 6,683 ha (16,500 ac.) and provides live storage of 762 x 10^6 cu. m (618,000 ac. ft.) for the benefit of the three power stations now on the river. An additional flood storage capacity of 241 x 10^6 cu. m (195,000 ac. ft.) is also available.

To help meet the load put on the Campbell River power developments by even increasing energy demands, three river diversions were constructed on the Salmon, Quinsam and Heber Rivers (Table 4.4).

Table 4.4. River diversions associated with hydroelectric power development on the Campbell River (Ballantyne, 1960).

Location of Discharge	Salmon Lower Campbell Lake	Quinsam Lower Campbell Lake	Heber Upper Campbell Lake
Average flow diverted	11.3 cms (400 cfs)	2.8 cms (100 cfs)	3.0 cms (105 cfs)
Maximum works capacity	42.5 cms (1,500 cfs)	8.5 cms (300 cfs)	22.6 cms (800 cfs)

The Salmon River diversion added approximately 259 sq. km (100 sq. mi.) to the system, and diverts an average flow of 11.3 cms (400 cfs) into Lower Campbell Lake. The Quinsam diversion was designed to divert a flow of 2.8 cms (100 cfs) into the Campbell River system, and added another 78 sq. km (30 sq. mi.). The last of the three diversions was the Heber River diversion, constructed in 1958. Similar in size to the Quinsam diversion, it too added approximately 78 sq. km (30 sq. mi.) of drainage basin to the Campbell River, and diverted an average flow of 3.2 cms (113 cfs) into Upper Campbell Lake.

The morphometry of the lakes of the Campbell River system, before and after flooding has been described by McMynn and Larkin (1953), following an investigation of the effects on fisheries of water utilization in the Campbell River drainage area. The main characteristics are summarized in the following table.

Table 4.5. Summary of main characteristics of Buttle Lake, Upper Campbell Lake and Lower Campbell Lake morphometry.

	Length km(mi.)	Average Width km(mi.)	Area sq.km (sq.mi.)	Depth Max. m (ft.)	Depth Mean m (ft.)	Total * Volume cu. m (cu. ft.)
Buttle Lake	29.9 (18.6)	1.0 (0.6)	29.9 (11.2)	121 (396)	61 (201)	19×10^8 (6.7×10^{10})
Upper Campbell Lake	7.1 (4.4)	0.9 (0.55)	6.3 (2.4)	40 (130)	12 (40)	8×10^7 (2.97×10^9)
Lower Campbell Lake	8 (5)	1.3 (0.8)	10.4 (4.0)	60 198	17 (55)	18×10^7 (6.4×10^9)

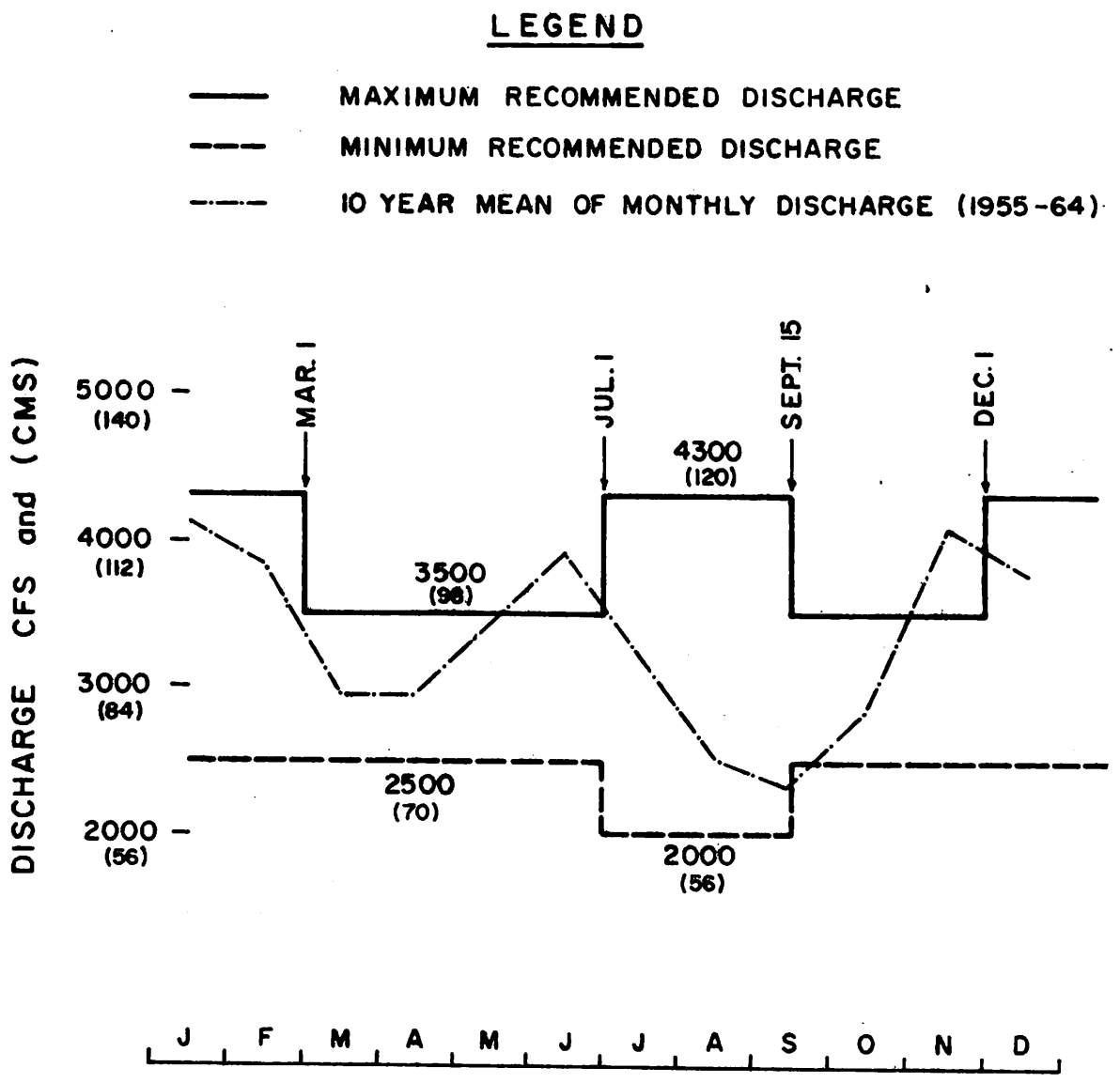
* Before flooding for power development

4 (v) RIVER DISCHARGE CONTROL FACTORS

Recommendations for maximum and minimum discharges from power developments on the Campbell River, based on the results of field studies, are outlined in a report on the effect of modified hydrology on Campbell River salmonids (Hamilton and Buell, 1976). A minimum discharge of 57 cms (2,000 cfs), and a maximum of 122 cms (4,300 cfs) have been recommended. Figure 4.5 shows a graph of the maximum and minimum discharges plotted on a year basis and compared with a 10-year (1955-1964) mean of actual monthly discharge.

Relationships among river hydrology, food organisms and

Figure 4.5 Recommended discharge limits to the Campbell River at John Hart I Power Plant.
(Hamilton and Buell, 1976)



dietary requirements of rearing anadromous fishes in the river and estuary are discussed in Chapter 6 (Fish) of this report. The effects of power development on the natural resources of the Campbell River system are reviewed in Chapter 12.

5. OCEANOGRAPHY

5 (i) INTRODUCTION

As in most of the estuaries in British Columbia, little oceanographic work has been done on the inner estuary of Campbell River, but oceanographic surveys have been conducted in waters of Discovery Passage adjacent to the Campbell River estuary proper. Some of these surveys have been associated with general oceanographic studies in the Strait of Georgia and its contiguous waters; others have been related to investigations of the effects of the pulp mill at Duncan Bay, just north of Campbell River. More recently, ecological studies have been conducted in the Campbell River estuary with respect to possible effects of a proposed marina development on the fisheries resources of this estuarine system (Goodman and Vroom, 1974). Another study near Campbell River involved, among others, a proposal to divert water from the John Hart Dam through a tunnel to an underground generating station and thence discharging into Duncan Bay (Hamilton and Buell, 1976).

Channels connecting the Strait of Georgia to Johnstone Strait were examined, as part of the study of the physical oceanography of the Strait of Georgia in the early 1950's (Waldichuk, 1957). These observations included not only oceanographic stations for vertical distribution of water properties, but also current observations in Discovery Passage (Pacific Oceanographic Group, 1954; Waldichuk, unpublished manuscript). In connection with environmental effects of the pulp mill at Duncan Bay, observations were conducted in the bay and in Discovery Passage adjacent to Duncan Bay during a number of oceanographic surveys from July 1957 to September 1968 (Waldichuk et al. 1968; Waldichuk et al., unpublished data).

Some of the early observations on water movements in Duncan Bay, initiated because of the proposed expansion of the Elk

Falls Company Pulp Mill, were reported by Waldichuk (MS, 1956). Mill staff and consultants (Beak Consultants Limited, 1974, 1976) continued observations at the outfall and in Duncan Bay and Discovery Passage for the mill (nowCrown Zellerbach Canada Ltd.) in more recent times. The effects of a number of expansions in pulp and paper production and alterations in the outfall since 1956 have been monitored in accordance with requirements of the B.C. Pollution Control Branch.

Because Discovery Passage is the only reasonably safe channel for navigation between the Strait of Georgia and Johnstone Strait for virtually all sizes of vessels, there has been a substantial amount of hydrographic work in this passage. This involved not only charting of the bottom topography to precisely pin-point shoals, but also measurement of currents in various channels. Seymour Narrows is world famous, of course, for its treacherous eddies, intensive turbulence and strong tidal currents, which may exceed 750 cm/sec (15 kn.). The removal of Ripple Rock in the middle of the southern end of Seymour Narrows in April 1958 was heralded as the largest non-nuclear blast ever observed up until that time. It made navigation considerably safer, especially for the larger, deeper-draught vessels, through this tide-swept channel. Seymour Narrows has been the subject of study not only for practical navigational purposes, but also for scientific reasons, because of certain anomalies in sea level that are exhibited as a result of the extreme flows (LaCroix and Tully, 1954). Although the strong currents in Seymour Narrows and in Discovery Passage generally make navigation hazardous, they have the positive attributes of providing a natural system for rapid dilution and dispersion of waste discharged into these waters.

The problems of navigation, and the currents to be expected in Discovery Passage and Seymour Narrows, are well described in the British Columbia Pilot (Canada Department of Mines and Technical Surveys, 1959). Current predictions for Seymour

Narrows are given in the Canadian Tide and Current Tables (Canada Department of the Environment, 1977). The main chart for the channels north of the Strait of Georgia is No. 3594 DISCOVERY PASSAGE, TOBA INLET and Connecting Channels on a natural scale of 1:75,000, with the latest edition corrected and reprinted in 1973. A larger scale chart for DISCOVERY PASSAGE (No. 3565) includes the Campbell River estuary, SEYMOUR NARROWS and the northern channels on a scale of 1:38,000, with the 1970 edition corrected and reprinted in 1973. This chart also has an enlarged insert of SEYMOUR NARROWS on a natural scale of 1:18,247 surveyed in 1944 and again in 1958. Harbour chart No. 3556 gives larger-scale charts for a number of harbours along Discovery Passage, including Quathiaski Cove, Gowlland Harbour and Duncan Bay. Because there is no special boat facility at the mouth of Campbell River, no large-scale chart of this area has been prepared by the Canadian Hydrographic Service. It should be noted, however, that the topography in this region changes from year to year as a result of siltation from the river and the log booming activities that take place behind Tyee Spit. Campbell River itself is navigable for a few miles upstream by smaller boats and river craft.

(ii) GENERAL OCEANOGRAPHIC CHARACTERISTICS

The Campbell River estuary has perhaps the most unique characteristics of all the estuaries considered in this series in that there is an abrupt termination of its seaward influence by the swift and turbulent waters of Discovery Passage. Fresh water from the river mixes quickly into the sea water of the Passage, where there is intensive stirring from top to bottom, and the usual two-layered estuarine system does not exist far beyond the mouth of the river itself. Thus the true estuary is rather small and confined by the physical processes in Discovery Passage. No oceanographic studies have been done directly in the river mouth or in Discovery Passage, immediately outside the river entrance to document this transition zone. However, oceanographic observations in Duncan Bay and Discovery Passage, about 4 km (2 n.mi.) to the

northwest, provide a good indication of what the conditions are like in the part of the passage receiving the Campbell River water.

There is little evidence of fresh water in the surface layer of Discovery Passage beyond the immediate vicinity of the river inflow. Vertical mixing creates a homogeneous water column in salinity, temperature and dissolved oxygen at only a short distance from the shoreline in all parts of Discovery Passage. It is anticipated, that a "salt wedge" penetrates a short distance into the lower Campbell River. However, it would be expected that the salt wedge and the overlying fresh water undergo a sharp transition into the vertically homogeneous water column of Discovery Passage, probably at the eastern end of Tyee Spit. A surface sample taken just outside of Tyee Spit on August 13, 1955, had a temperature of 12.5°C and a salinity of 25.8$^{0}/_{00}$ (Bousfield, 1956). Salinities of surface samples at a station due west of the north end of Tyee Spit, taken during a shellfish sanitary survey February 3-10, ranged from 0.2-6.0$^{0}/_{00}$ (Arney and Kay, 1976). Any wastes released into the surface or bottom waters of Campbell River or along the shore in Discovery Passage would be quickly mixed into the whole water column and rapidly spread by currents and eddy diffusion throughout the whole breadth and depth of Discovery Passage, and then quickly transported out of the area by the strong tidal currents.

Except during heavy local runoff, when there is discharge of muddy fresh water from local streams, the waters of Discovery Passage are comparatively clear. Some of the largest Secchi discs values, obtained anywhere in B.C. coastal waters, have been noted in this area. Even the bloom of phytoplankton has to be short-lived because of the turbulence, and large populations of phytoplankton can probably not be established in Discovery Passage, except in the more quiescent embayments, especially on the Quadra Island side. Bottom scouring by the

swift tidal currents is too great to allow deposition of sedimentary materials, judging by the rocky and cobbly bottom materials. Any suspended material introduced appears to be generally transported out of Discovery Passage or deposited along the shores where currents and turbulence are weaker.

Discovery Passage has ecological importance, being a major migration route for salmonids, as well as for other species, such as killer whales. The special oceanographic characteristics of Discovery Passage provide a rather unique habitat for flora and fauna. The Pacific kelp *Nereocystis* is generally found on the reefs near shore where it can benefit from the nutrients provided by an ample flow of water with the strong currents and deep penetration of sunlight through the clear water for photosynthesis. Certain current-loving invertebrates find this area a suitable place for attachment and growth because of the nourishment available from the food organism carried with the strong tidal currents. For example, in bottom sampling of Discovery Passage, cobbles were usually collected, and occasionally attached to a rock, a giant barnacle, *Balanus nubilus*, was picked up.

(iii) TIDES

Although the waters of Discovery Passage in the vicinity of the Campbell River estuary can be considered to have tides typical of the coast of British Columbia, they tend to be rather unique in certain respects. The tide is influenced more from the north than it is from the south even though the southern end of Discovery Passage is connected to the Strait of Georgia. Therefore, rising water at Campbell River is accompanied by a tidal current setting to the south rather than to the north. Because of the importance for navigation of this section of the coastal waters of British Columbia, Campbell River has been selected as a reference port where tides are recorded continuously.

Typical of the British Columbia coast, tides at Campbell River are of the mixed type, but designated as mainly diurnal (MD). This means that usually, but especially when the moon has a low declination, there are two complete tidal oscillations daily. Inequalities in heights of successive high or low waters and their corresponding time intervals are very marked. The mean tidal range at Campbell River is 2.9 m (9.6 ft), while the large tidal range is 4.6 m (15.0 ft). To illustrate how rapidly the tidal characteristics in Discovery Passage change, Owen Bay, on Okisollo Channel north of Quadra Island, only about 37 km (20 n.mi.) to the north of Campbell River, is also a reference port. Seymour Narrows is the barrier between tides referred to Campbell River in the south and those referred to Owen Bay to the north. Secondary ports for the tides in the southern section of Discovery Passage south of Seymour Narrows, referred to Campbell River, are Quathiaski Cove, Gowlland Harbour, Duncan Bay and Bloedel. The tidal characteristics of Campbell River and Owen Bay, as well as the southerly secondary ports are given in Table 5.1. Time and height differences of the secondary ports in relation to the reference ports are given in Table 5.2.

It should be noted that while time differences are not large for higher high water and lower low water between secondary ports in the southern part of Discovery Passage and Campbell River, there are substantial differences in the heights of mean and large tides. The tide differences for ports north of Seymour Narrows are very large relative to Campbell River, so that one should never anticipate the stage of the tide on the other side of the Narrows based on the observations in the waters being left behind.

(iv) WATER PROPERTIES

There have been no oceanographic observations in Discovery Passage directly in front of and extending into the lower Campbell River. However, oceanographic data from Discovery Passage in the vicinity of Duncan Bay should be reasonably

Table 5.1 Tidal characteristics at the reference and secondary ports in Discovery Passage, Cape Mudge to Seymour Narrows. (From Canada Department of Environment, 1977)

PORT	POSITION	DURATION OF TIDAL RECORDS	MEAN TIDAL RANGE m	MEAN TIDAL RANGE ft	LARGE TIDAL RANGE m	LARGE TIDAL RANGE ft
Reference Ports						
Campbell River	50°01'N 125°14'W	1965-1968 1972-Present	2.9	9.6	4.6	15.0
Owen Bay	50°19'N 125°13'W	1954-1955	2.8	9.1	4.4	14.3
Secondary Ports		on Campbell River				
Quathiaski Cove	50°03'N 125°13'W	8 May 1899 - 4 June 1899 8 August 1923 - 7 March 1924 28 April 1950 - 26 May 1950	2.7	8.9	4.3	14.0
Gowlland Harbour	50°04'N 125°14'W	1 June 1951 - 6 August 1951	2.3	7.4	3.8	12.5
Duncan Bay	50°05'N 125°18'W	9 August 1958 - 6 Sept. 1958	2.2	7.2	3.8	12.5
Bloedel	50°07'N 125°23'W		2.1	6.9	3.7	12.3
		on Owen Bay				
Seymour Narrows	50°08'N 125°21'W	1943-1950 1958 (3 months)	3.0	9.9	4.8	15.7

Table 5.2 Time and height differences for tides at secondary ports in Discovery Passage relative to the reference ports. (From Canada Department of the Environment, 1977)

Port	Higher High Water					Lower Low Water				
	Time h.m.	Mean Tide m	Mean Tide ft	Large Tide m	Large Tide ft	Time h.m.	Mean Tide m	Mean Tide ft	Large Tide m	Large Tide ft
				On Campbell River						
Quathiaski Cove	0 00	-0.5	-1.5	-0.5	-1.6	-0 01	-0.2	-0.8	-0.2	-0.6
Gowlland Harbour	-0 09	-0.8	-2.6	-0.9	-3.1	-0 05	-0.3	-1.1	-0.2	-0.6
Duncan Bay	0 00	-1.0	-3.3	-1.1	-3.6	-0 01	-0.5	-1.6	-0.3	-1.1
Bloedel	-0 49	-0.7	-2.4	-0.7	-2.4	-0 38	-0.1	-0.4	+0.4	+0.3
				On Owen Bay						
Seymour Narrows	+0 04	+0.5	+1.5	+0.5	+1.7	-0 01	+0.2	+0.07	+0.1	+0.3

representative of conditions that prevail near Campbell River. From July 1957 to August 1966 a number of surveys have been conducted in the vicinity of Duncan Bay, as well as in Duncan Bay itself, to examine the effects of the pulp mill there.

The changes in physical and chemical properties, as one proceeds from the Strait of Georgia into Discovery Passage and further northward, were observed in a survey conducted during March 1953 (Pacific Oceanographic Group, 1954). Stations were occupied in the Strait of Georgia and in channels to the north, as shown in Figure 5.1. It is clear in the distribution of salinity that the vertically stratified conditions observed in the Strait of Georgia diappear when one enters Discovery Passage. Station F occupied near Campbell River showed virtually homogeneous water from top to bottom. It was not until station 45 was occupied in the section of Discovery Passage north of Seymour Narrows that some semblance of salinity difference between the top and bottom water could be observed. The same general pattern of dissolved oxygen distribution can be seen in the right-hand panel of Figure 5.1. While there was a fairly marked stratification in vertical distribution of dissolved oxygen in the Strait of Georgia, it varied only between 8.0 and 8.5 mg/l in Discovery Passage even at the northern station (45). Clearly, with a variation of only 0.5 mg/l in dissolved oxygen from top to bottom, there is little likelihood of stagnation and depletion of oxygen from the bottom water by organic decomposition.

One of the surveys related to study of the effect of the pulp mill effluent discharges in Duncan Bay and Discovery Passage was conducted in October 1961 (Waldichuk et al., 1968) (Figure 5.2). Vertical distributions of properties in a section from Duncan Bay across Discovery Passage are shown in Figure 5.3. At this time of the year, there was still some effect of local summer heating on the surface water. This is represented in a rather thin surface layer of water warmer than 9.7°C. The water in Duncan Bay generally exceeded this temperature and actually reached 10.0°C at

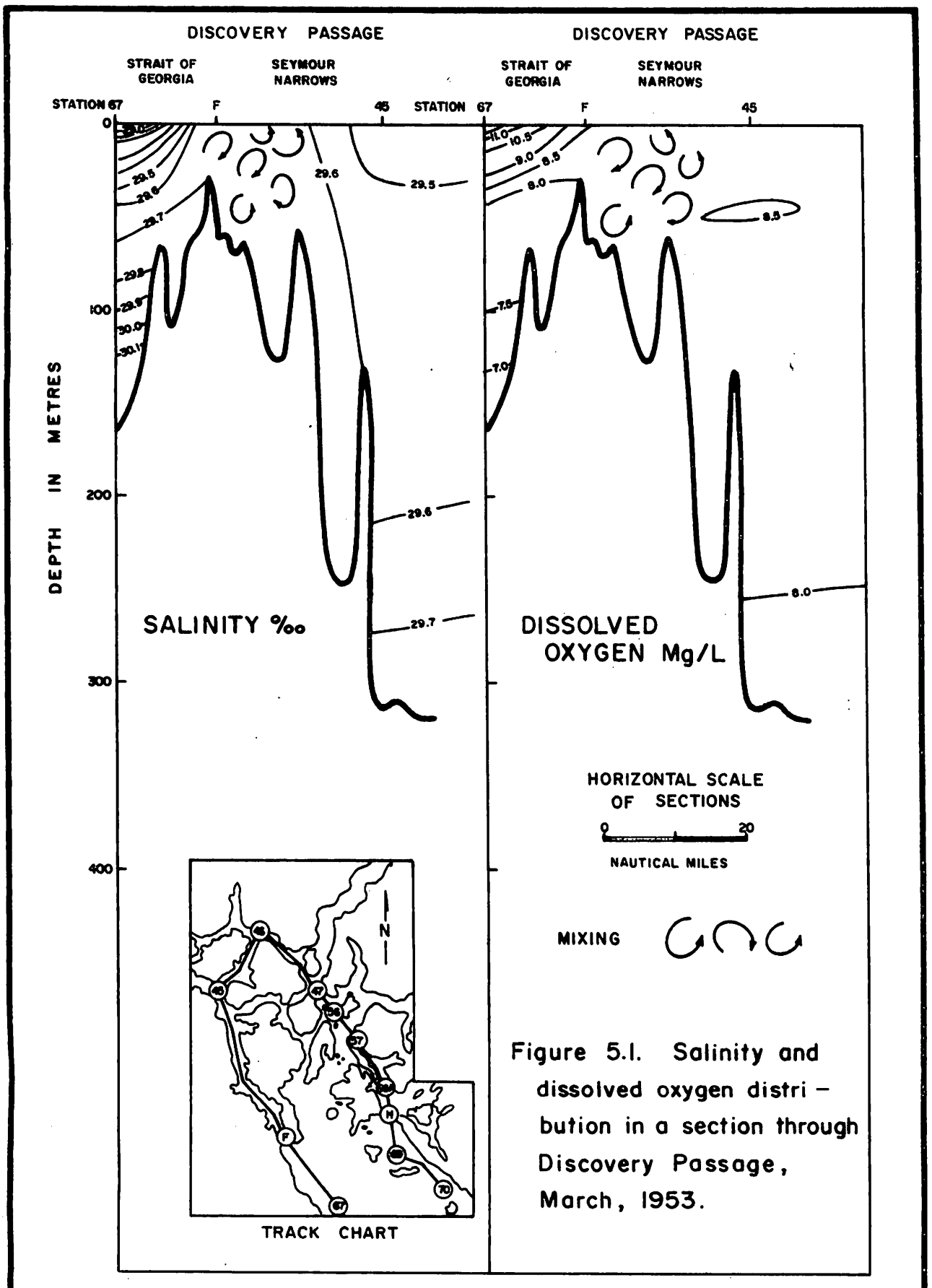


Figure 5.1. Salinity and dissolved oxygen distribution in a section through Discovery Passage, March, 1953.

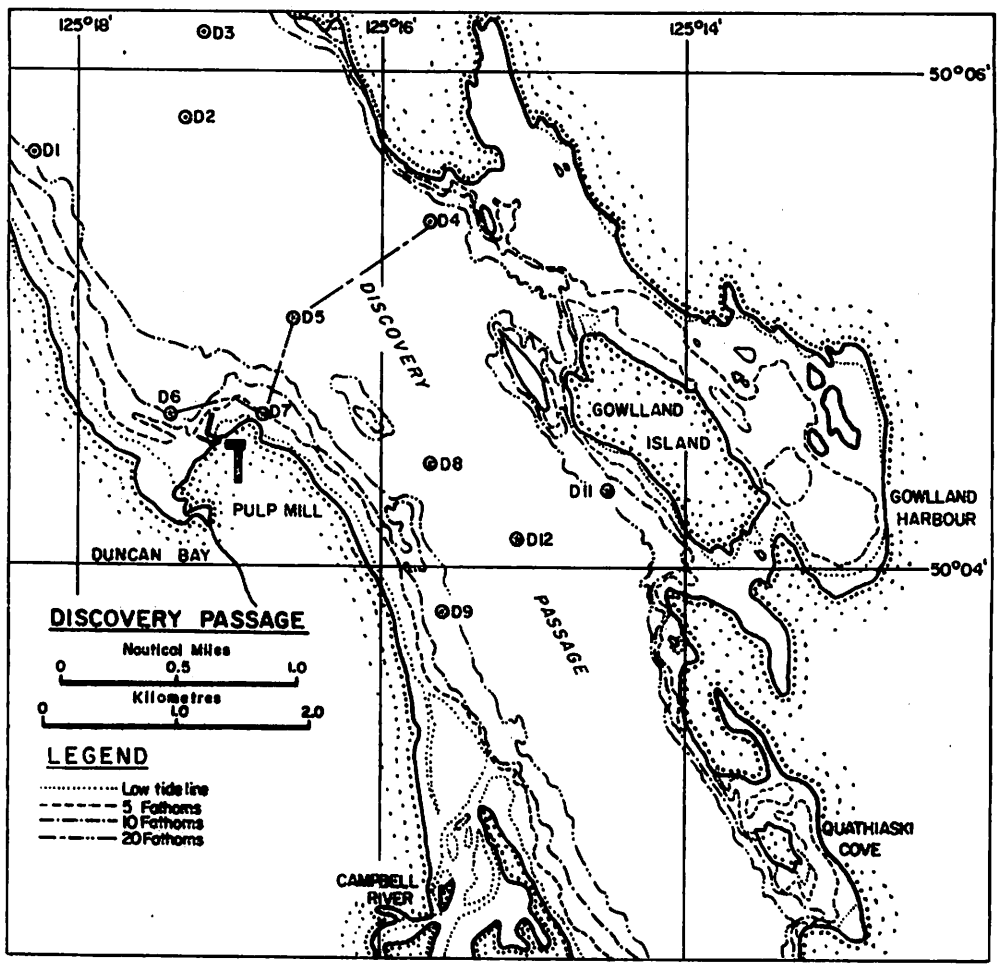


Figure 5·2 Chart of Discovery Passage showing stations occupied in a survey, 12 October, 1961.
(D6 —·—· D4 is the section shown in Fig. 5·3).

the surface. However, as shown in the upper left-hand panel of Figure 5.3, the temperature range from top to bottom of Discovery Passage was very small indeed, from about 9.8 to 9.6°C. Likewise, salinity varied by as little as $0.2^0/_{00}$ from top to bottom with a range of about $29.65^0/_{00}$ at the surface to $29.85^0/_{00}$ at the bottom. Once again, there was a slightly thicker layer of lower-salinity water in Duncan Bay, where the apparent effect of Casey Creek can be noted. However, even here the range in salinity is comparatively small from $29.3^0/_{00}$ at the surface to $29.7^0/_{00}$ at the bottom. The density anomaly (σ_t) shown in the lower left-hand panel of Figure 5.3 is essentially a reflection of the temperature and salinity effect. It is noteworthy that even with some surface heating and freshwater input from Casey Creek, the variation in density from top to bottom in relatively sheltered Duncan Bay is comparatively small, from 22.6 to 22.95σ_t units.

The right-hand panels of Figure 5.3 show the non-conservative properties observed in this survey. Dissolved oxygen in the upper right-hand panel did exhibit a slightly higher dissolved oxygen concentration at the surface than in the deeper water. However, compared to the vertical distribution of dissolved oxygen in inlets at this time of year, the range in dissolved oxygen was remarkably small, from about 6.1 mg/l in the bottom water to about 6.9 mg/l at the surface. Hydrogen-ion concentration (pH) and total alkalinity values, likewise, were quite uniform from top to bottom, corresponding fairly closely to the dissolved oxygen distribution.

Secchi disc readings, as a measure of the transparency of the water, were quite large and generally uniform at all stations occupied in Discovery Passage during this period, ranging from 10 m (32 ft) to about 11 m (35 ft). As noted earlier, bottom samples were taken with a clam-shell-type bottom sampler during the surveys. However, bottom sampling is difficult,

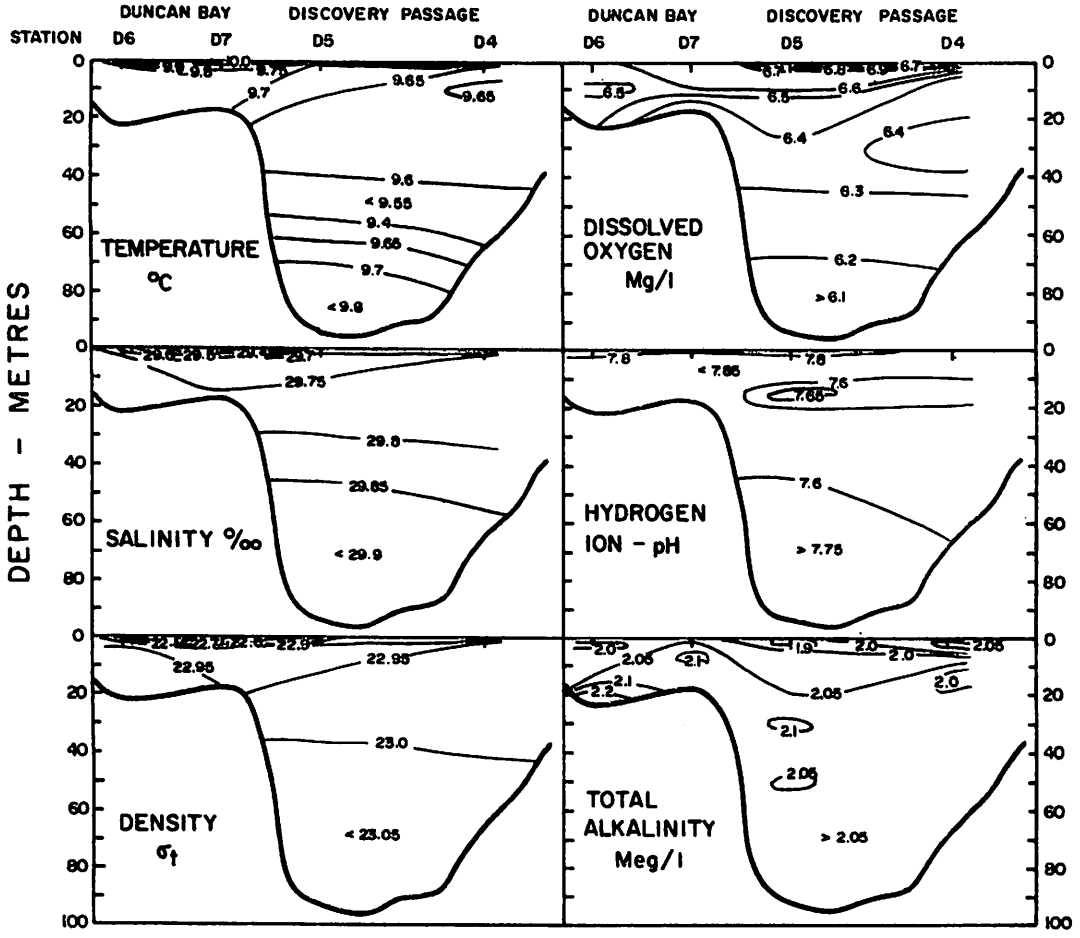


Figure 5.3. Distributions of various properties in a vertical section across Discovery Passage into Duncan Bay, October, 1961.
(See Fig. 5-2 for locations of stations)

because the substrate is rocky with large boulders and course gravel swept clean by the intensive turbulence and strong currents in the passage. Even at a station adjacent to the outfall from the pulp mill,it was impossible to pick up any deposited fibres or other wood materials with the type of sampling equipment used in this survey. Some wood fibre and other wood solids apparently accumulate in the quieter and less scoured waters near shore, especially in small embayments.

(v) CURRENTS

Currents in Discovery Passage are dominated by the tidal effect. They are extremely swift, especially during the spring tides, and are generally a challenge for navigation. Vessels plying Discovery Passage and navigating through Seymour Narrows must either have good local knowledge or study the B.C. Coast Pilot (Canada Department of Mines and Technical Surveys, 1959) and carefully follow the current tables for Seymour Narrows (Canada Department of the Environment, 1977). Currents in mid-Channel of Discovery Passage are quite predictable, based on the tidal characteristics at reference ports or on tidal predictions for Seymour Narrows (Canada Department of the Environment, 1977). The surface current can be slightly modified by the winds. For example, an ebbing current setting to the northwest may be amplified slightly by a southeast wind of gale force and somewhat retarded by strong northwest winds. Likewise, a flooding current may be amplified by northwest winds and retarded by southeast winds. In the vicinity of the mouth of the Campbell River, drift-pole current observations have indicated that a flooding current setting to the southeast can have a speed of 300 cm/sec (6 kn.) during spring tides. The ebbing current under similar tides, setting to the northwest, is only slightly weaker at about 250 cm/sec (5 kn.).

Like the distribution of properties of the water in Discovery Passage, the currents are almost uniform in speed from

top to bottom. However, they do diminish as one proceeds to the shores. Any points that jut into the current will create eddies, and these may be quite dangerous in certain areas, such as those off Cape Mudge at the entrance to Discovery Passage and at Race Point near the southern entrance to Seymour Narrows. Weaker eddy systems occur in some of the embayments as a result of the force of water flowing through Discovery Passage. For example, such currents have been observed in Duncan Bay, and no doubt occur in the lee of Tyee Spit at the mouth of the Campbell River.

Currents observed for a brief period in March 1953, in mid-channel of Discovery Passage just off Campbell River (Pacific Oceanograhic Group, 1954), are shown in Figure 5.4. The observed currents followed quite closely the predicted tides plotted on the same figure. Maximum ebb and flood occurred during the mid-periods between low and high waters, characteristic of the current associated with a progressive wave, which is the form of the advancing tidal wave in Discovery Passage. Currents were observed in the wharf area for the Duncan Bay pulp mill during 1955 and these are represented in Figures 5.5 and 5.6 for the flood and ebb stages of the tide. The eddy effect in Duncan Bay is clearly shown in these figures with a clockwise circulation generally occupying the bay during a flooding tide from the northwest, and a counter-clockwise circulation during an ebbing tide. One might anticipate that a similar condition would prevail in the inner Campbell River estuary behind Tyee Spit, although there have been no actual current measurements there to confirm such a hypothesis.

(vi) WAVE ACTION

Wind waves themselves may not be as important as wind waves combined with a tidal current in Discovery Passage and in the Campbell River estuary. The longest fetch for winds to develop in southern Discovery Passage exists toward the southeast. From this direction, winds have virtually the whole length of the Strait of Georgia to develop a big sea. It is these strong

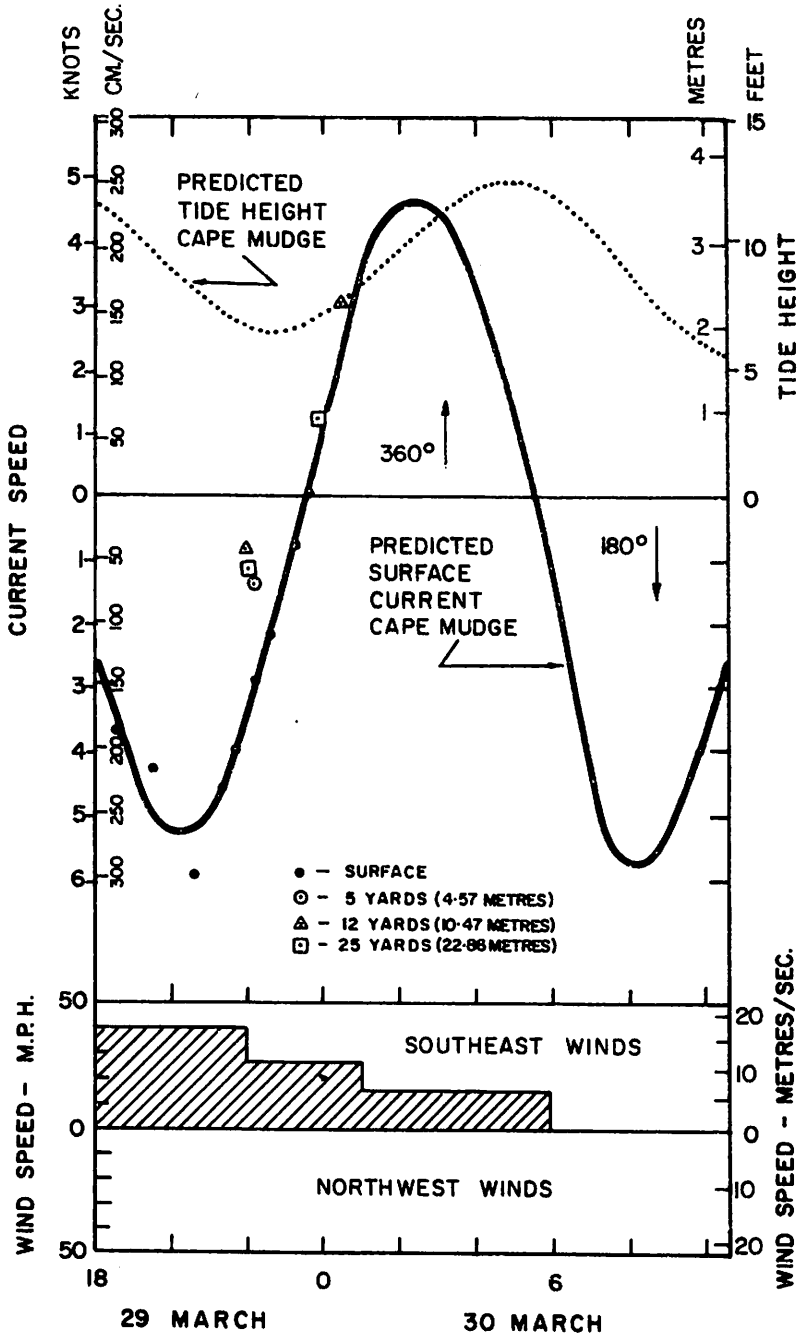


Figure 5.4. Variation of currents at Station F, in Discovery Passage (50°0·7' N., 125°12·8' W. - See Fig. 5·1) 29 - 30 March, 1953.

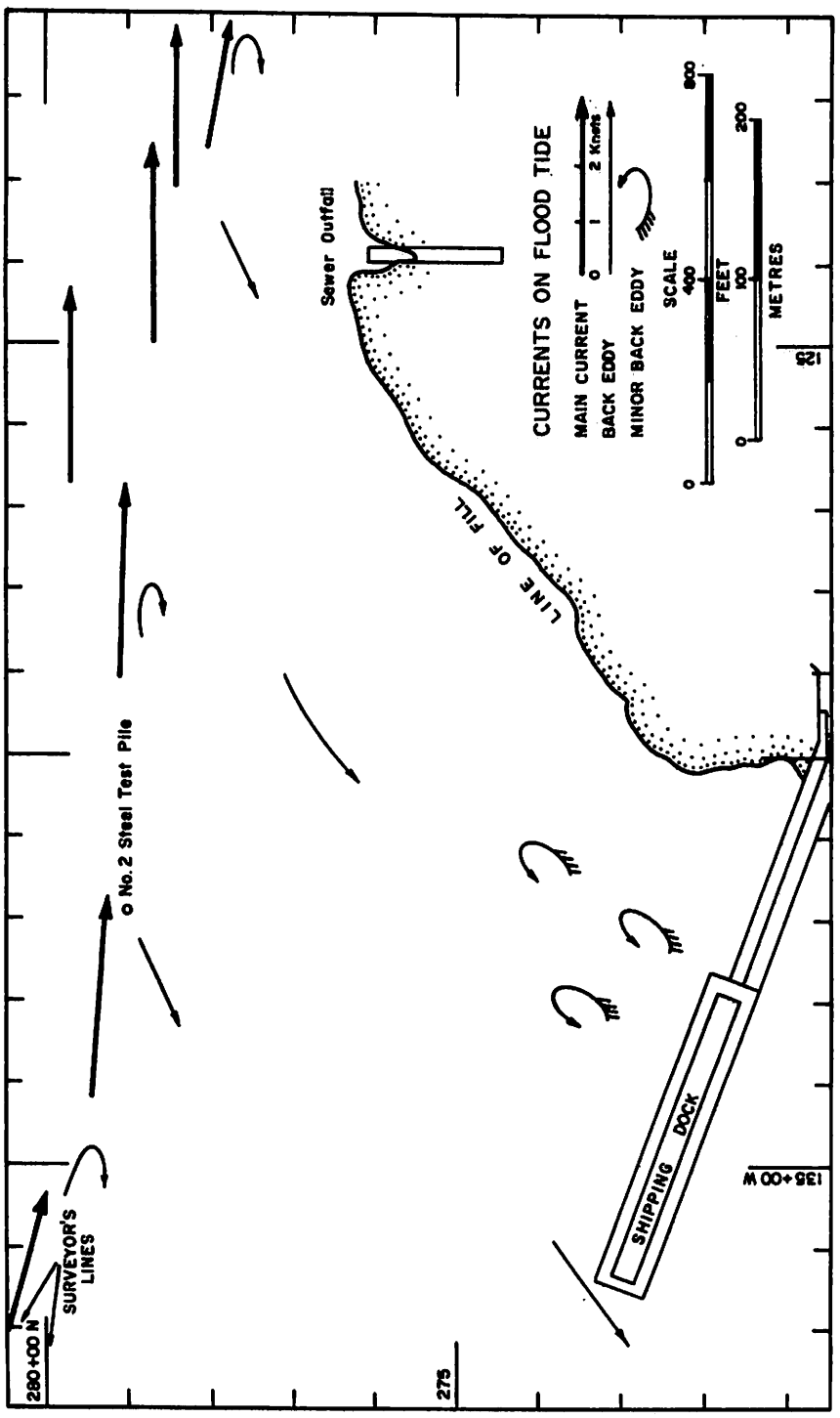


Figure 5.5. Surface circulation in Duncan Bay on flood tide (from data by Mackay, 1955).

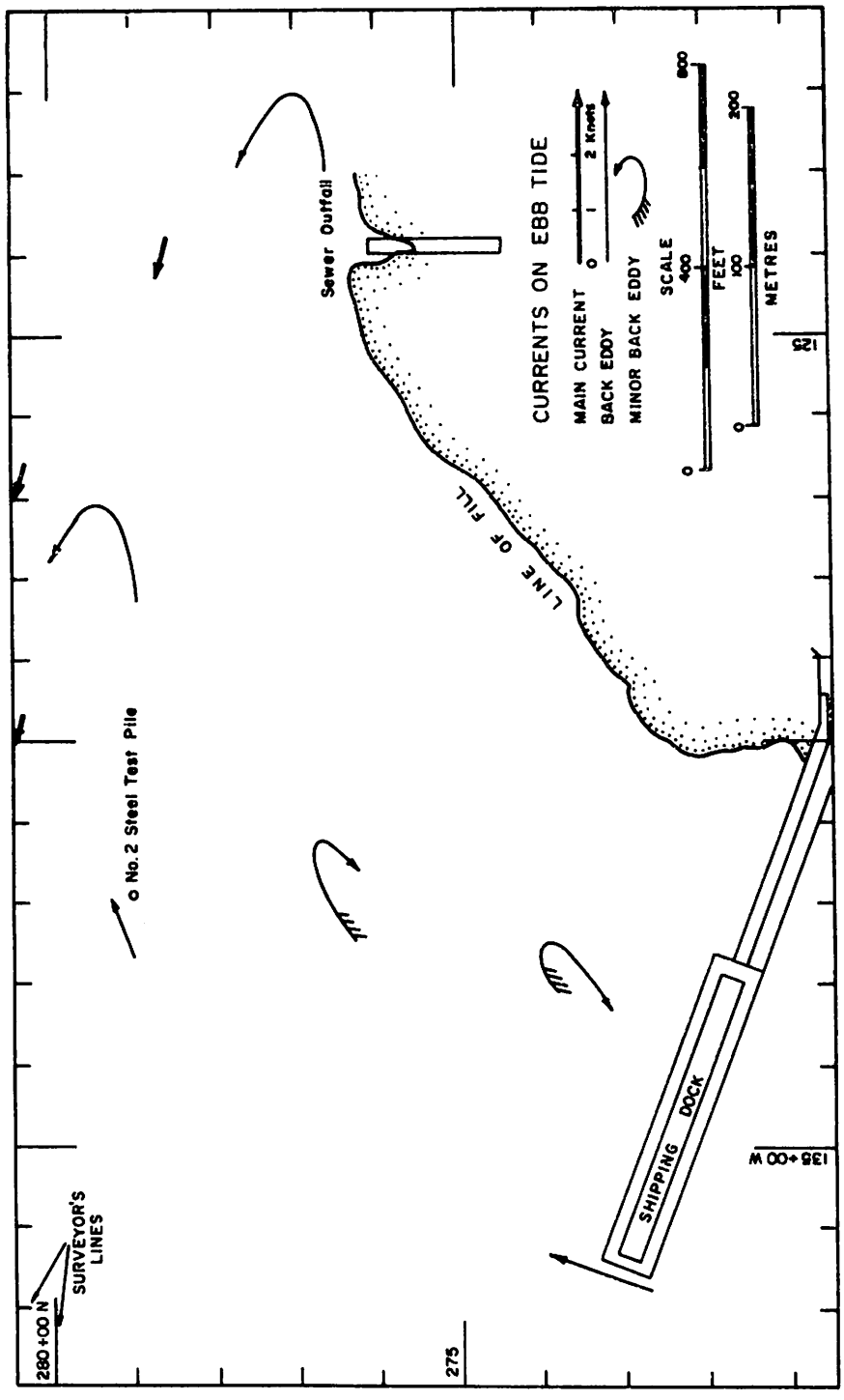


Figure 5.6 Surface circulation in Duncan Bay on ebb tide (from data by Mackay, 1955).

southeast winds, combined with a flooding current from the north, that can make navigation in the vicinity of Cape Mudge extraordinarily treacherous. Under these conditions, small vessels are cautioned to be extremely careful in entering Discovery Passage to seek shelter. Many vessels, some of substantial size, have been lost in this area.

A cautionary note on chart No. 3594 states: "With flood stream and southerly or south-easterly winds there is a heavy race off Cape Mudge often extending across the entrance of Discovery Passage. With strong winds the race is dangerous for small vessels. Under similar conditions there is also a heavy tide rip off Race Point dangerous to small craft." A similar precautionary note is given on chart No. 3565, noting that the heavy race off Cape Mudge often extends across to Willow Point.

No doubt this kind of wave action can have a certain ecological impact on shore flora and fauna along the southern end of Discovery Passage and possibly even in the inner Campbell River estuary. Certainly winds opposing the current in the vicinity of Tyee Spit will create sharp-crested waves on the bank in this area, which can disrupt the substrate for both flora and fauna. Because northwest winds cannot develop too strongly in Discovery Passage, it is not anticipated that the effect of a northwest wind opposing an ebbing tide would be too devastating on the delta of the Campbell River area, although it is exposed more to the northwest than it is to the southeast.

No actual observations have been made on waves in the area of the Campbell River estuary, but it is anticipated that they would seldom exceed 1.5 m (5 ft) in height at the delta. In the entrance to Discovery Passage, with extremely strong southeast winds over a sustained period, it is conceivable that waves of 2 m (6.5 ft) could develop. These could be dangerous for small craft, especially when opposing a flooding current and resulting in extremely choppy, steep-crested waves.

(vii) DEVELOPMENTS AND EFFECTS OF OCEANOGRAPHY

It is quite obvious that because of the dynamic oceanographic characteristics of Discovery Passage, any developments along the waterfront have to take these carefully into account. In some instances, it is possible that the swift currents will be responsible for the need to install certain protective facilities. For example, it would be impossible to put a marina on the exposed shores of Discovery Passage without a breakwater for protection from currents. However, although breakwaters and jetties will impede the currents and provide some measure of protection for vessels, they will also change the current patterns and littoral drift of sediments in the nearby waters. Therefore, one must be careful in making such installations, first of all, to be sure that erosion by currents will not undermine the protective structure; and secondly, that the depositional pattern of sedimentary materials will not be altered in such a way as to create problems for nearby users of the waterfront, or indeed, problems for the developer installing the breakwater or other protective structure. Needless to say, there would also be an impact on habitats for fish and wildlife, and this is likely to be even more difficult to predict than the changes in physical characteristics.

In the immediate vicinity of the Campbell River delta, the deposition of sedimentary materials carried down by the river could be substantially modified by jetties, training walls and breakwaters which alter the flow of water. Tyee Spit was obviously a manifestation of reduced nearshore current and deposition of sedimentary materials transported by the ebbing current along the west side of Discovery Passage adjacent to Campbell River. The extent of the delta could probably be increased by jetties extending into Discovery Passage on either side of the mouth of Campbell River to reduce the scouring action of the currents and to allow sedimentary deposition.

However, any modifications in the delta will obviously affect the estuarine ecosystem, and careful studies must be made of all factors involved before embarking on such a program.

6. FISH

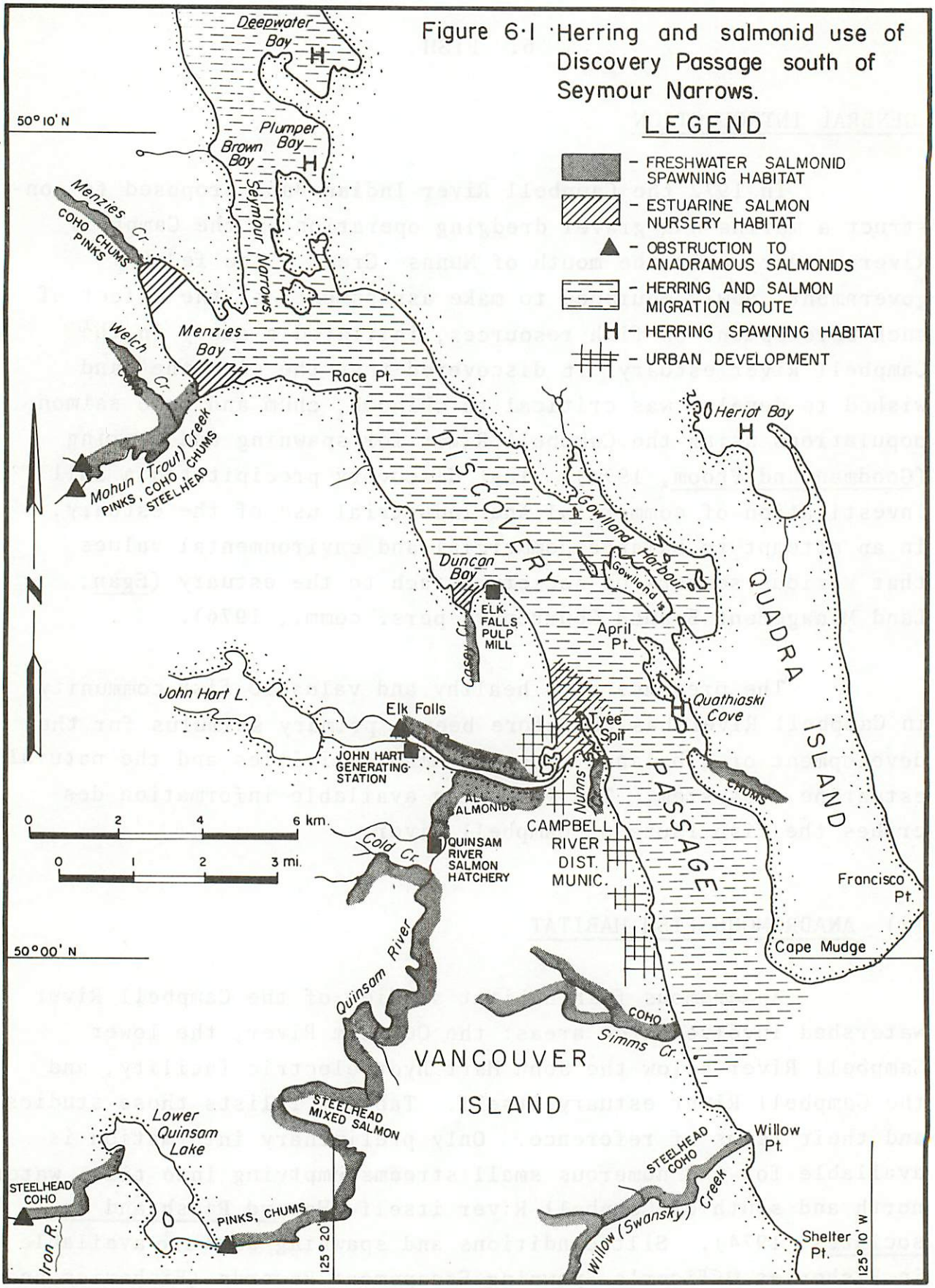
6 GENERAL INTRODUCTION

In 1972 the Campbell River Indian Band proposed to construct a marina and gravel dredging operation in the Campbell River estuary near the mouth of Nunns Creek. The federal government, newly equipped to make assessments of the effect of such development on fish resources, initiated a study in the Campbell River estuary. It discovered that the site the Band wished to develop was critical to chinook, chum and coho salmon populations using the Campbell River for spawning and rearing (Goodman and Vroom, 1974). That discovery precipitated a full investigation of commercial and industrial use of the estuary, in an attempt to balance commercial and environmental values that various sectors of society attach to the estuary (Egan, Land Management Branch Courtenay, pers. comm., 1976).

The presence of a healthy and valuable fish community in Campbell River has therefore been a primary stimulus for the development of a balance between human activities and the natural estuarine ecosystem. The following available information describes the fish fauna of Campbell River.

6 (i) ANADROMOUS FISH HABITAT

Anadromous fish habitat studies of the Campbell River watershed involve three areas: the Quinsam River, the lower Campbell River below the John Hart hydroelectric facility, and the Campbell River estuary itself. Table 6.1 lists those studies and their terms of reference. Only preliminary information is available for the numerous small streams emptying into tidal water north and south of Campbell River itself (Howard Paish and Associates, 1974). Silt conditions and spawning data are available in Fisheries Officer's Spawning Escapement Records (Fisheries and


Deepwater Bay
H
50° 10' N
Plumper Bay
Brown Bay
H
Seymour Narrows
Menzies Cr
COHO CHUMS PINKS
Welch Cr
Menzies Bay
Race Pt.
Mohun (Trout) Creek
PINKS, COHO CHUMS STEELHEAD
DISCOVERY PASSAGE
Heriot Bay
H
Gowlland Harbour
Duncan Bay
ELK FALLS PULP MILL
Casey Cr
April Pt.
QUADRA ISLAND
John Hart L.
Elk Falls
JOHN HART GENERATING STATION
Tyee Spit
Quathiaski Cove
Nunns Cr
CHUMS
ALL ALMONDS
CAMPBELL RIVER DIST. MUNIC.
QUINSAM RIVER SALMON HATCHERY
Cold Cr
0 2 4 6 km.
0 1 2 3 mi.
Francisco Pt.
50° 00' N
Cape Mudge
Quinsam River
COHO
Simms Cr
VANCOUVER ISLAND
STEELHEAD MIXED SALMON
Lower Quinsam Lake
STEELHEAD COHO
Iron R.
PINKS, CHUMS
125° 20' W
STEELHEAD COHO
Willow Pt.
Willow (Swansky) Creek
Shelter Pt.
125° 10' W
N
Figure 6·1 Herring and salmonid use of Discovery Passage south of Seymour Narrows.
LEGEND
- FRESHWATER SALMONID SPAWNING HABITAT
- ESTUARINE SALMON NURSERY HABITAT
- OBSTRUCTION TO ANADRAMOUS SALMONIDS
- HERRING AND SALMON MIGRATION ROUTE
H - HERRING SPAWNING HABITAT
- URBAN DEVELOPMENT

Marine Service, Vancouver).

1. QUINSAM RIVER:

Although the Quinsam River flows 38.6 km (24 mi.) from Upper Quinsam Lake to its union with the Campbell River, 3.2 km (2 mi) upstream of the Campbell estuary, only a portion is available to anadromous fish because of natural obstructions (Figure 6.1). The uppermost is a rock cascade just above the confluence of the Quinsam and Iron Rivers, 25.7 km (16 mi.) from the mouth and impassable to any fish moving upstream. Further down, 21.7 km (14 mi.) from the Campbell River, a second rock cascade can be crossed only by steelhead and coho, while pinks and chums remain below (Van Tine, unpubl., 1973).

British Columbia Power Commission facilities on the Quinsam are described elsewhere in this report. They are above the present natural obstructions and, aside from regulating flow patterns in the river (except during flood crises), present no direct obstacle to anadromous fish.

Officials of the B.C. Fish and Wildlife Branch have surveyed the Quinsam River from lower Campbell Lake to the federal hatchery (B.C. Dept. Rec. Cons., 1975). Their report details physical and biological characteristics of this length of the river, including substrate distribution, river bed morphology, aquatic and terrestrial vegetation present in the river and on its banks, abundance of aquatic invertebrates and a general discussion of the river's suitability as a habitat for salmonids at all stages of their life cycle.

The Quinsam River supports steelhead trout and the five species of Pacific salmon: details are provided in the section on Species Biology [6(ii)].

Table 6.1. Publications providing information on the fish habitat of the Campbell River watershed. See bibliography for details of references.

Report	Period of Study	Location	Habitat Information Yield
Carl (1937)	1930's	Campbell Lake	limnology.
McMynn and Larkin (1953)	1951	lakes in upper watershed	vertebrate, invertebrate and floral biota, water chemistry, lake bathymetry.
Sinclair (1965)	early 1960's	same	same.
B.C.Research (1974)	1966-1973	Buttle Lake	water chemistry.
Van Tine (1973,unpub.)	1973	Quinsam River, lower Campbell River	abiotic features, spawning site, history of hydro development.
Van Tine (1974,unpub.)	1974	Quinsam River, Campbell River, Cold Creek	current velocities.
Marshall, et al. (in press)		Quinsam River Campbell River	predators, abiotic features, (general survey).
B.C.Dept. Rec. and Cons. (1975)	1975	Quinsam River	land use, physical features, vegetation, food sources.
International Power (1973)	1972-3	lower Campbell River	current patterns, river basin morphology, flooding.
Galbraith (1973)	1972	lower Campbell River	current velocities, substrates.

Table 6.1 (cont'd).

Hamilton and Buell (1976)	1972-3	lower Campbell River	spawning, holding, rearing sites, current velocities, dates of occupation by fish, food sources.
Mundie and Mounce (1976)	1973	lower Campbell River	food sources.
Yeomans (1976)	1975-6	lower Campbell River; estuary	land use and recreational potential.
Kennedy and Waters (1974)	1974	estuary	vegetation analysis.
Goodman and Vroom (1974)	1972-3	estuary	food chains, fish distribution.
Bond (1975)	1975	estuary	areas of sensitivity, log handling fallout.
Burns (1976)	1975	estuary	land use, abiotic features.
Lawseth (unpub.)	1976	estuary	fish distribution over area and time.
Conlan (M.Sc. in prog.)		estuary	effects of log handling.
Kennedy (M.Sc. in prog.)	1975-6	estuary	vegetation.
Pollution Control Branch Permits	current	entire watershed, contiguous marine waters	point sources of pollution. (Appendix 11.1).
Fisheries Marine Service	annual	same	variety of comments re biota and habitat

2. CAMPBELL RIVER:

Campbell River, 90 km in length, discharges to Discovery Passage from a watershed of 146,000 hectares including the Quinsam system. In 1947 the John Hart Dam and Generating Station were constructed, with the effect of reducing available habitat for anadromous fish in the Campbell from 5.6 km, the distance Elk Falls lies above the estuary, to 5.0 km (Figure 6.1). Water flow over Elk Falls is nearly negligible now that the hydroelectric facility is operating, its flow being mainly leakage from the dam.

Extensive descriptions of this lower portion of the Campbell River are available in Van Tine (1973), International Power (1973), Galbraith (1973) and Hamilton and Buell (1976).

The last three reports summarize information obtained from studies determining the effect of modifying the lower Campbell River salmonid habitat by increasing discharge from the John Hart Dam. They contain a wealth of detail on substrate distribution, river morphology, current velocities, fish distribution and invertebrate food sources for this section of the river.

Hamilton and Buell (1976) felt that the lower Campbell River presented a limited rearing habitat for chinook, coho and steelhead, all of which require a freshwater rearing stage in their life cycle Circumstantial evidence suggests that coho and chinook have very large populations of early emigrants that leave the river and depend on the estuary for freshwater rearing. Possible reasons for this precocious downstream migration are the short reach of river available, augmented by a possibly suboptimal food supply, a lack of riparian vegetation due to frequent flow fluctuations and the relative lack of quiet pools in which juveniles can rest.

Spawning habitat is also limited, in part because of the short reach available, but also because when the river was diverted

around Campbell River Canyon, the lower reach was cut off from a source of spawning gravel, needed to replenish beds scoured by the river's current.

The entire reach of the lower river from John Hart down to the bend just before Baikie's slough is utilized for spawning, rearing and holding by the five species of Pacific salmon (detailed maps in Hamilton and Buell, 1976).

Yeomans (1973) reports briefly on effects of human presence along the shores of the lower river but points to a lack of comprehensive literature describing this critical aspect of the Campbell River habitat.

Mundie and Mounce (1976) studied the effect of changing discharge rates from John Hart on the composition and density of food organisms floating in the river that could be utilized by salmonids. Their work is discussed in the chapter on invertebrates.

3. CAMPBELL RIVER ESTUARY:

The inner estuary has been intensively studied in recent years (Table 6.1). Salinity distributions have not yet been determined for the estuary, making it difficult to set its boundaries by classical oceanography (see Glossary). Tidal influence is known to extend upstream as far as 457 m above the Island Highway Bridge (International Power, 1973), and the intertidal biota 700 m north of the estuary is apparently stressed by Campbell River's freshwater outflow (Beak Consultants Ltd., 1974). Burns (1976) has defined the estuary in Bauer's terms of "process zones".

The importance of the estuary to salmonids was demonstrated by Goodman and Vroom (1974; see section 2 in Effects of Development). While the authors were able to prove that estuarine organisms are major components of the stomach contents of juvenile salmonids caught both inside and just outside Tyee Spit, no

investigation of fauna other than fish and birds in the estuary has been reported. The emergent, vascular flora of the estuary was examined by Kennedy (see Flora). Bond (1975) has surveyed the distribution of log handling fallout on the bottom of the estuary. He reported that 89% of the 73 hectare (180 acre) estuary has been occupied by industry. Burns (1976) collected information regarding foreshore leases in the estuary and made subjective assessments of their impact.

6 (ii) SPECIES BIOLOGY

1. FRESHWATER SPECIES:

Fish resources in the Campbell River watershed upstream of the anadromous fish habitat are outside the terms of reference for this report and will not be discussed beyond the following comments.

Six species of fish comprise the total species list for Campbell River's upper watershed: coastal cutthroat trout (*Salmo clarki clarki*), Dolly Varden char (*Salvelinus malma*), kokanee (*Oncorhynchus nerka*), prickly sculpin (*Cottus asper*), rainbow trout (*Salmo gairdneri*) and threespine stickleback (*Gasterosteus aculeatus*) (Sjolund, pers. comm., 1977). Sinclair (1965, 1968) and McMynn and Larkin (1953) have studied various aspects of the limnology of the watershed. Sjolund (1976) is investigating in depth the fish resource of Sayward forest lakes. Fisheries and Marine Service personnel are studying the feasibility of releasing salmon fry into the inaccessible reaches of the Quinsam River for rearing (Rhinehart, pers. comm., 1977).

2. ANADROMOUS SPECIES:

(a) Quinsam River Salmon Hatchery. The first chinook (*Oncorhynchus tshawytscha*) salmon fry were released from the Quinsam River Salmon Hatchery in June, 1975, in an effort to enhance salmon production

in the Quinsam-Campbell system. Those fry were hatched from eggs collected in 1974 by trapping adults that were part of the natural watershed stocks, in keeping with the policy of preventing "genetic dilution" by introducing spawn from other rivers. The hatchery now raises coho (*Oncorhynchus kisutch*) and steelhead (*Salmo gairdneri*) fry from donor stock in the Quinsam, as well as chinook from the Campbell, and by 1978 will have reached production capacity in all three species. The first returns are expected in 1977 (Table 6.2).

Table 6.2. Production of coho, chinook and steelhead by the Quinsam River Salmon Hatchery since inception of operations in 1974. Date and number released are tabulated, together with an indication of full hatchery capacity and date of first expected returns. (From hatchery information sheet, August 13, 1976).

Juveniles Released and Year of Release	Number released and % of full capacity	First expected adult return	Potential adult production (at 100%)
Coho smolts (1976)	1,400,000 (75%)	1977	275,000
Chinook fingerlings (1975)	179,000 (6%)	1977	2,000
" (1976)	425,000 (14%)	1978	4,000
Steelhead smolts (1976)	20,000(100%)	1977	2,000

Salmon and trout produced at this hatchery are expected to contribute to the commercial troll fishery of Vancouver Island's west coast, to the Johnstone Strait net fishery, and to the sports fishery in Discovery Passage, northern Strait of Georgia and the freshwaters of Campbell and Quinsam Rivers. Nose-tagging experiments

are discussed on pages 79 - 83.

Juveniles are released at a stage in their life cycle when they are least likely to remain in the river or estuary for any length of time, in order to prevent them from competing for food and space with wild juveniles hatched on natural spawning grounds in the river. Observations by hatchery personnel (Van Tine and Lawseth, unpub. data) confirm that hatchery coho clear the estuary quickly,but that chinook might spend up to six weeks in the river mouth before finally heading to sea.

G. Hoskins, of the Pacific Biological Station in Nanaimo, has been isolating and identifying disease agents from wild and hatchery populations of salmonids in the Quinsam watershed (unpublished data).

The hatchery facility consists of a water supply diversion dam on Cold Creek, three concrete adult holding ponds, fifteen concrete rearing ponds, a fish diversion fence and fishway on the Quinsam River, and the hatchery building, which contains egg incubators and laboratory facilities.

(b) Salmon - General Comments. Campbell River's Pacific salmon populations have done more to stimulate interest in maintaining the health of the estuary's natural ecosystem than any other single factor. The famous and consistent run of big Tyee salmon (chinook over 30 lbs.) has international attention, although the Campbell and Quinsam Rivers also support spawning populations of cutthroat and steelhead trout, and coho, chum, pink and a few sockeye salmon, thereby contributing fish to several commercial and sport fisheries along North America's Pacific coast.

Annual spawning escapement data, tabulated in Appendix 6.3,were examined for trends by Goodman and Vroom (1974) and Hamilton and Buell (1976). Chum salmon have returned to the

Campbell with decreasing frequency since about 1949 although five-year averages indicate an increase in recent years (Table 6.3). The strength of the chinook run has increased since 1935, perhaps accounting to some extent for the consistency of the Tyee sport catch (Tyee Club data, 1974), in the face of increasing sport fishing effort. Coho and pink escapements have been consistent since 1957, when hydroelectric facilities began to regulate flow in the Campbell River at more or less stable discharge rates (see the section on Hydrology). Even-year runs of pink salmon dominate odd-year runs. The run of sockeye to Campbell River is very small; the average from 1970 to 1975 was only 141 spawners.

Table 6.3. Five-year average salmon and steelhead trout escapements to the Campbell River, compiled by Bond (1975). Figures combine estimated escapements to both Quinsam and Campbell Rivers. (u.d. = undetermined, n.o. = non-observed.)

5-YEAR PERIOD	CHINOOK	COHO	PINK	CHUM	SOCKEYE	STEELHEAD
1935 to 1939	2,400	3,500	2,800	6,700	n.o.	460
1940 to 1944	3,813	20,875	4,125	14,375	n.o.	1,263
1945 to 1949	2,125	1,450	3,900	8,375	n.o.	1,313
1950 to 1954	2,300	1,300	3,395	3,900	n.o.	1,050
1955 to 1959	2,175	3,835	3,420	2,020	n.o.	1,056
1960 to 1964	3,805	5,175	2,955	1,800	n.o.	u.d.
1965 to 1969	4,900	6,110	3,430	1,660	95	u.d.
1970 to 1975	4,670	3,625	8,925	3,958	141	u.d.

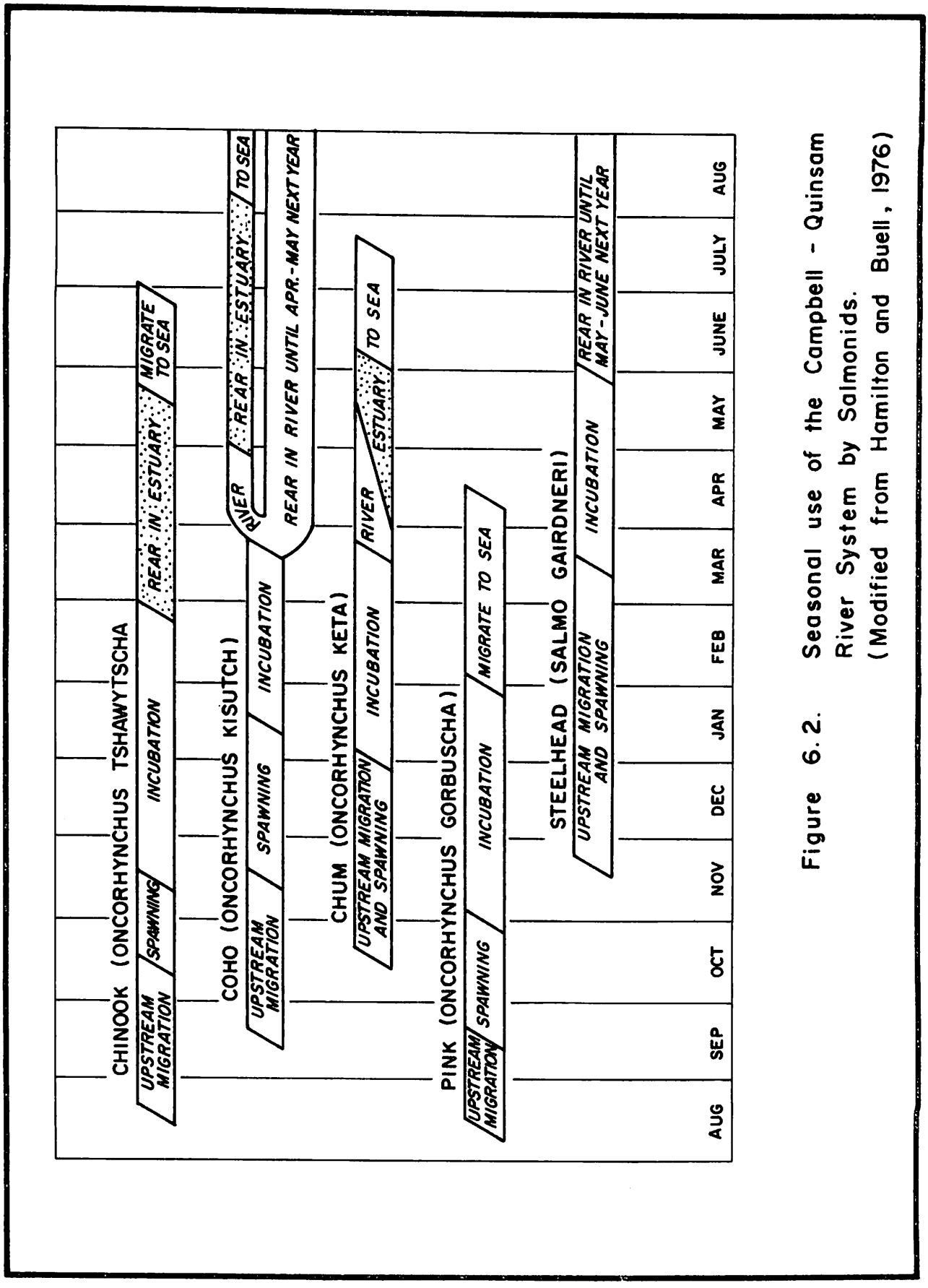


Figure 6.2. Seasonal use of the Campbell - Quinsam River System by Salmonids. (Modified from Hamilton and Buell, 1976)

Hamilton and Buell (1976) report on the freshwater biology of lower Campbell River salmon in considerable detail, documenting spawning, holding and rearing sites, periods of migration and specific dates for various stages of the life cycle (Figure 6.2).

(c) Chinook Salmon (*Oncorhynchus tshawytscha*). Other common names for the chinook include spring (commercial fishermen), king (American) and Tyee (local fish over 30 lbs.).

Chinook returning to spawn hold in three major sites in and near the estuary: Frenchman's Pool, Tyee Pool and the site of the disused Island Redi-mix gravel operation near the mouth of Nunns Creek. Once in the river, they may hold prior to spawning in any of several locations (Hamilton and Buell, 1976; Van Tine, 1973).

They begin the run upstream during mid-August, and spawning begins about mid-October. Chinook spawn mainly in the Campbell, only about one in 170 using the Quinsam. Most of the spawn is deposited in redds between the powerhouse and the confluence of the Quinsam. Their fry are free-swimming by early March, spend three months in the river and migrate into the estuary, where they spend another three months increasing in size and physiologically adjusting to sea water before heading at last to the sea in the autumn. Chum and coho also rear for some time in the estuary, but data are not available for pinks on this question.

Of the 179,000 chinook fry released from the Quinsam hatchery in 1975, 79,517 were nose-tagged and had their adipose fins removed for participation in the coast-wide head recovery program being run by the federal Department of Fisheries and the Environment. By July, 1976, 25 heads were recovered, largely from commercial fisheries from Johnstone Strait north to the Queen Charlotte Islands (Figure 6.3; Harris, Bulletin 25).

Studies in the estuary revealed that 76.3% of the stomach contents of juvenile chinook caught inside Tyee Spit was made up of estuarine benthic fauna. The remainder was freshwater and terrestrial invertebrate fauna (16.5%) and marine zooplankton. Juvenile chinook caught just outside the estuary, along the seaward beach of Tyee Spit, contained mainly *Anisogammarus* sp., *Parathemisto pacifica*, herring, insect larvae and ostracods: 67.7% estuarine benthos. The estuary therefore appears to be a major food source for young chinook. Both chinook and chum salmon grew considerably during their residence time in the estuary (Goodman and Vroom, 1974).

Mundie and Mounce (1976) point out that drift organisms carried into the estuary from the river can be an important supplementary source of food for young salmon. These two scientists assessed the effects of changing discharge from John Hart on the food organisms of chinook fry (see chapter on Invertebrates).

During the 1972-3 study by federal fisheries biologists (Goodman and Vroom, 1974), juvenile chinook comprised 42% of the total catch of fish in and around the estuary, by far the dominant species. Threespine stickleback (*Gasterosteus aculeatus*) followed at 23% (see Appendix 6.1). Chinook were present in the estuary from February through November, the peak falling in late June (Figure 6.2).

Adult chinook tagged in the estuary were later found spawning in streams further up and down the coast of Vancouver Island (Van Tine, pers. comm., 1977), indicating that the estuary is of some value to stocks from areas other than Campbell River. In fact, the opinion that Discovery Passage is a major migration route for Pacific salmon travelling between the Strait of Georgia and the open Pacific is widespread among fisheries officials. Tagging data collected over the past 40 years seems to bear this out. Chinook tagged in Deepwater Bay (Figure 6.1) were recovered

from the Big Bank (continental shelf southwest of Ucluelet, B.C.), off Victoria in the Strait of Juan de Fuca, and in the Strait of Georgia (Argue and Heizer, 1974).

(d) Coho Salmon (*Oncorhynchus kisutch*). Coho move up the Campbell to spawn later than chinooks. The run starts in mid-September and spawning lasts until January. Most deposit their eggs in the Quinsam River, the ratio being 4:1. Their fry emerge near the end of March, and in early May a portion migrates down to the estuary to follow a pattern of rearing similar to chinook. Most stay in the river, however, and migrate directly to the sea a little over a year after emerging, during April and May.

Coho evidently depend heavily on estuarine benthos for food: 84.2% of the stomach contents of coho juveniles caught inside the estuary in 1972-3 were organisms from the estuary. Juveniles caught on the seaward beach of Tyee Spit contained 20.2% estuarine fauna, while most of the remainder was composed of fish (herring, salmon and unidentified larvae), *Euphausia pacifica* and harpacticoid copepods. Coho caught in the intertidal flood channels adjacent to Nunns Creek grew 23% from May to June 1973 (Goodman and Vroom, 1974).

Nose tags have been planted in samples of wild (since the 1972 brood year) and hatchery-raised Quinsam River coho (since 1974). Returns from the Georgia Strait sport fishery indicate that Quinsam stocks contribute to recreational fishing as far south in the Strait of Georgia as Nanoose Bay and as far north in Johnstone Strait as Hardwicke Island (Figure 6.3). Commercial net and troll operators have caught these fish throughout the B.C. Coast, including the waters off Washington State. The great majority of tags were returned from the southern half of Discovery Passage and the waters off Cape Mudge. However, that finding should be regarded with caution since the numbers have not been weighted to take into account regional differences in fishing effort (Harris, pers. comm., 1977).

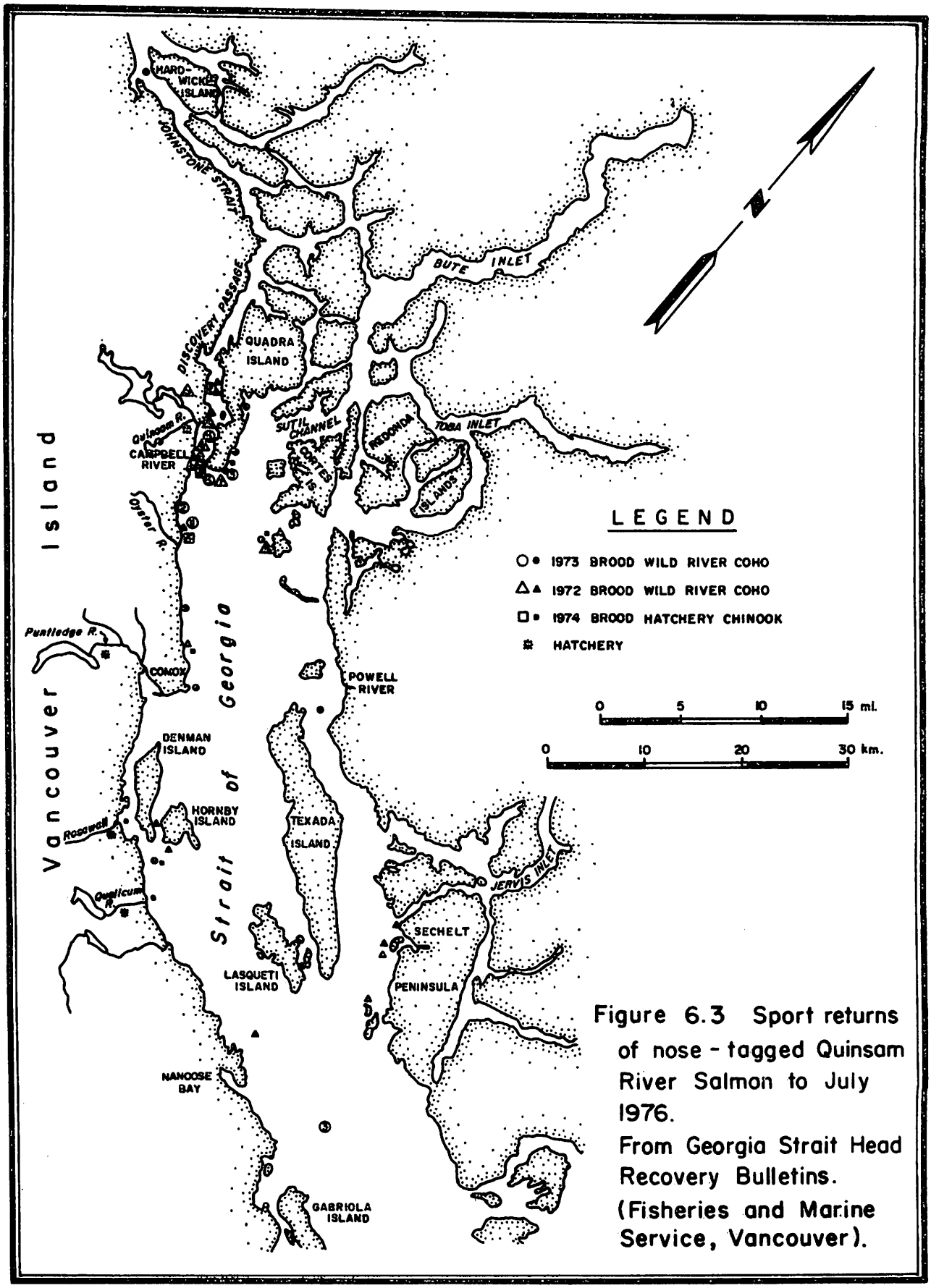


Figure 6.3 Sport returns of nose - tagged Quinsam River Salmon to July 1976.
From Georgia Strait Head Recovery Bulletins. (Fisheries and Marine Service, Vancouver).

Table 6.4. History of Quinsam River nose-tagging of coho and chinook juveniles, indicating number of fish tagged and number of tags returned by Sept., 1976 from all fisheries on the B.C. Coast. Data compiled from Georgia Strait Head Recovery Bulletins 18-27 (Fish. Mar. Serv., Vancouver).

Species	Brood Year	No. tagged	Source	No. tags returned by July, 1976
Coho	1972	2,384	river (wild)	42
Coho	1973	8,505	river (wild)	170
Coho	1974	196,437	hatchery	147
Chinook	1974	79,517	hatchery	25
Chinook	1975	?	hatchery	0
Steelhead	1975	?	hatchery	0

The head recovery data also show that a considerable proportion of the coho and chinook caught by sport fishermen near Campbell River are migrants from hatcheries and streams tributary to Strait of Georgia and to coastal U.S. waters, further evidence that this "outer estuary" of the Campbell River is an important habitat for Pacific salmon on the British Columbia Coast.

(e) Chum Salmon (*Oncorhynchus keta*). Average escapements of chum salmon to the Campbell-Quinsam system in the period 1970-74 (4,010) rank this species fourth behind pink (5,930), chinook (5,076) and coho (4,720). Two-thirds of the chum escapement remain in the lower Campbell to spawn, one-third use the Quinsam (Hamilton and Buell, 1976).

In the Campbell-Quinsam system, chum migrate upstream to

spawn between mid-October and the end of December. Their fry emerge in March and April, whereupon the young migrate immediately to the estuary for a period of about three months, as they increase in size (Hamilton and Buefl, 1976).

The young occupy shallow regions throughout the estuary and Baikie's Slough during their early weeks of estuarine residence, sharing that environment with coho and chinook in nearly equal numbers (26.3%, 38.2% and 35.4%, respectively). Juvenile chum in the estuary grew 50% between May and July 1973, feeding extensively on estuarine benthos (Goodman and Vroom, 1974).

Tagging studies of chum salmon were carried out on populations in Deepwater Bay. The results of tagging 3,413 chums in the fall of 1962 suggest once again that Discovery Passage is a major migration route for Pacific salmon, since 851 of those tags were recovered from a variety of rivers in the Strait of Georgia (see Walker et al.,1962; Manzer,1954,1956,1969; Chatwin,1953).

(f) Pink Salmon (*Oncorhynchus gorbuscha*). Pinks can be found in the river as early as July, but they migrate into the Campbell to spawn in August and September, building their redds and laying eggs from mid-September to early November. Even-year adults are distributed evenly between the Quinsam and Campbell Rivers for spawning, but six times more pinks use the Quinsam than the Campbell in odd years. Even-year escapements have been the largest.

Their fry begin to emerge in late January and migrate downstream to the estuary almost immediately, the migration peaking in March. No data are available to describe the estuarine rearing of pink salmon in the Campbell River.

Tagging studies of adults include those by Pritchard (1932), Pritchard and Delacy (1944), Delacy and Neave (1947), and Manzer

(1954, 1956 and 1969). These operations were carried out to study the migrations of pink salmon in Johnstone Strait, southern British Columbia and the Pacific off Washington.

(g) Sockeye Salmon (*Oncorhynchus nerka*). The first record of a sockeye presence in the Campbell River system was the Fisheries Officer's Annual Spawning Report for 1943, recording an escapement to the river of an undetermined number of adults. The largest escapement on record was 275 (1968 and 1972). Hamilton and Buell (1976) reported some redd digging in the lower Campbell but spawning activities were not accurately documented. Sockeye were seen in the river between mid-August and mid-October, apparently utilizing both the Quinsam and Campbell Rivers. The small population of fry appears to migrate to sea within its first year of life, after a brief freshwater rearing period.

(h) Steelhead Trout (*Salmo gairdneri*). Steelhead, even though they migrate to sea for their adult lives, are the responsiblity of the provincial government. Provincial biologists are taking advantage of the federal hatchery to enhance winter steelhead stocks in the Campbell River system and in 1976 effected the first release of 20,000 smolts. An estimated 2,000 adult steelhead will be produced from this brood year. Eggs for the brood were taken from the November-December and March-April runs, in equal amounts (Hooton, 1976a).

Steelhead enter the Campbell in mid-November and spawn from January to the middle of March. Their young emerge from the gravel in late May and early June, spend almost a year in the river, and then migrate directly to sea without spending much time in the estuary (Hamilton and Buell, 1976). Lawseth (unpub. data, 1976) has surveyed the estuary for young salmonids, as part of the hatchery program, and recorded juvenile steelhead in the estuary during only one weeek (2 fish, early June) during the March-September period in 1976.

Table 6.5. Weekly totals of steelhead and cutthroat trout trapped at the Quinsam hatchery diversion fence while migrating downstream between April 3, 1976 and June 28, 1976 (Carswell, unpub. data, 1976).

Date	Number of Fish		
	Steelhead Smolts	Cutthroat Smolts	Both spp. Presmolts
April 3-9	5	0	0
10-16	1	0	0
17-23	11	0	0
24-30	93	38	51
May 1-7	173	4	270
8-14	350	10	442
15-22	358	8	293
22-28	118	6	193
29-June 4	80	17	385
June 5-11	54	32	518
12-18	10	11	155
19-25	3	12	135
26-28	0	2	20

(i) Cutthroat Trout *(Salmo clarki clarki)*. Aside from the downstream data in Table 6.5, virtually no information is available on the coastal cutthroat trout populations of Campbell River in those regions accessible by fish from the sea. Their presence in the estuary has been established by Lawseth (Quinsam hatchery, unpub. data, 1976). Yeomans (1973) discovered that cutthroat are sought by local sport fishermen. In other systems, they are known to spend considerable time in estuaries and to feed extensively on young salmon (Scott and Crossman, 1973; Hart, 1973).

(j) Lamprey. Quinsam Hatchery personnel have observed lamprey in the Campbell River estuary and watershed (pers. comm., 1977). Hamilton and Buell (1976) reported the presence of Pacific lamprey (*Lampetra tridentatus*), but considerable work remains to be done in the field of lamprey biology before any of these reports can be accepted with confidence in British Columbia.

There appear to be two forms of lamprey in this province: the freshwater brook lamprey and the anadromous Pacific and river lampreys. Lamprey spend years in the beds of streams and rivers before emerging to spend their shorter adult lives as parasites of fish. If salmonids are to be enhanced in the Campbell-Quinsam system, some study of these predators and their use of the river for spawning should be undertaken.

(k) Threespine Stickleback *(Gasterosteus aculeatus)*. Sticklebacks comprised 23% of the catch reported by Goodman and Vroom (1974) taken in and very near the estuary. Nothing is known about the origin or biology of this local population.

3. MARINE SPECIES:

A survey carried out by Lawseth (Quinsam hatchery, unpub. data, 1976) revealed the presence of several species of marine fish in the estuary, including unidentified sculpins, gunnels, blennies, needlefish, herring, and perch. No information is available regarding the exact distribution of marine fish in the estuary except the observation in Goodman and Vroom (1974) to the effect that more herring *(Clupea harengus pallasi)* were caught seaward of Tyee Spit than inside.

A diving team from the Provincial Museum in Victoria surveyed both Gowlland Island in 1976, using rotenone and underwater photography, and Willow Point reef in 1974 (Peden, pers. comm., 1977). Their files contain unpublished observations of the fish life in those two localities. Unpublished data also

exist in Nanaimo from surface seining by the Fisheries and Marine Service off Mittlenatch Island, south of Discovery Passage (Beamish, pers. comm., 1976).

Annual Narratives and Annual Histories prepared by federal fisheries officers are on file at Fisheries Operations in Vancouver. Campbell River lies in federal statistical area 13 and federal conservation district 5, and these documents provide some indication of the state of commercially valuable fish populations from those administrative perspectives.

(a) Herring *(Clupea harengus pallasi)*. A small resident population of herring occupies Discovery Passage south of Seymour Narrows. One hundred metres of spawn was deposited in Quathiaski Cove during March and April of 1976 (Campbell River fisheries officers, pers. comm., 1977 - Fig. 6.1). There are several locations in the Passage that appear to be good spawning habitats, including Menzies Bay (Webb, pers. comm. 1977), but for some reason they are not used by herring. Heavy spawning takes place each year in Kanish Bay at the north end of Discovery Passage and along the east coast of Quadra Island from Hyacinthe Bay south of Drew Harbour (Webb, 1975).

Fisheries and Marine Service personnel feel that the food fish concentrations of herring in Kanish and Deepwater Bays, fished during the winter, migrate south through Discovery Passage to spawning grounds as far south as Nanoose Bay in the Strait of Georgia (Webb, pers. comm., 1977).

Lawseth (Quinsam Hatchery, unpublished data, 1976) netted herring during May, June, July and September, 1976 (no records for other months) in Menzies Bay, Quathiaski Cove, around Gowlland Island and along the Campbell River townsite foreshore. Goodman and Vroom (1974) caught herring inside the spit only in July, 1973, although they were present along the outside of the

spit in June and December, 1972 and in February, May, July and August, 1973 - in larger numbers than inside the spit.

(b) Other Marine Species. "Needlefish" (unidentified), along with crustacean zooplankton and herring, were important as a source of food for predatory fish throughout federal fisheries Statistical Area 13 during 1974 (Can. Dept. of the Environment, 1975). Few data are available on the biology of members of the fish assemblage in the southern half of Discovery Passage. The species list in Appendix 6.1 is based on sampling in the estuary throughout the year between 1972 and 1973 (Goodman and Vroom, 1974).

A commercial fishery for lingcod *(Ophiodon elongatus)* exists in Discovery Passage.

6 (iii) THE FISHERY RESOURCE

Both commercial and sport fishing are important activities with respect to Campbell River, and both have been instrumental in generating environmental concern for the river, its estuary and Discovery Passage. Salmon are the most important species. Their contribution to the sport and commercial fisheries of Statistical Area 13 is given in Table 6.6.

A wealth of information on the tidal fisheries of Discovery Passage is available in Annual Narratives and Salmon Histories for Area 13, and in Conservation District 5 Annual Narrative Reports, on file with the Fisheries and Marine Service in Vancouver. These unpublished documents describe sport and commercial landings, salmon spawning conditions, enforcement activities, pollution problems, fishing methods and other activities of federal fisheries offices in the region.

1. SPORT FISHING:

The Campbell River sport fishery was worth an estimated $5.5 million in 1972 over a 100-day tourist season (Yeomans, 1973). In a sample of 244 fishing parties questioned by Yeomans

in the Campbell River area, 40% indicated a preference for tidal waters, 24% for the lower Campbell River and 25% for the upper watershed. The value of Campbell River's aquatic ecosystem is indicated in social terms by the fact that 85% of all tourists questioned said that water-oriented activities were the major attraction for them. About 56% came to Campbell River for its sport fishing and 76% of those felt that their success justified the trip.

In 1975, the Campbell River (Area 13) sport catch of salmon amounted to 69,977 pieces (Table 6.6), amounting to 16% of the whole sport catch for the province and 11% of the total Area 13 salmon catch, including commercial landings. Comox-Courtenay (Area 14) ranked highest in the province at 91,469 pieces - and Campbell River placed second.

Table 6.6. Comparison of sport and commercial salmon catches in Campbell River Statistical Area 13 for the period 1971-75. Catches are shown in pieces. Note: the sport catch is mostly chinook and coho, while the commercial catch is largely pink, chum and sockeye (Argue, pers. comm. 1977). Data from Underwood, McLellan and Associates (1975), Canada Dept. of Fisheries and the Environment (Salmon Sport Fishing Catch Statistics - annual) and Can. Dept. Env. Area 13 Annual History (1975).

	Area 13 Salmon Catch (in pieces)		
Year	Total	Sport	Net & Troll
1971	1,192,920	64,529	1,128,391
1972	908,024	53,141	854,883
1973	1,818,590	67,872	1,750,718
1974	674,272	73,671	600,641
1975	634,871	69,977	564,894

Campbell River's success ratio of 1.5 fish per boat per day was the highest in the province in 1975. Campbell River ranked second behind the Comox-Courtenay area among British Columbia's statistical areas in terms of sport fishing effort (Sport Fishing Catch Statistics, Fisheries and Marine Service, Vancouver).

(a) Pacific Salmon (*Oncorhynchus* spp.). While 67% of the 1975 sport salmon catch in Campbell River Area 13 was coho, the river is famous for its run of big Tyee salmon (chinook heavier than 30 pounds). Tyee Club of British Columbia membership rules (1974) state that a Tyee must be fought and landed from a rowboat, and since its inception in 1924 more than 700 fishermen have earned their membership. Club members have annually landed between 41 (in 1961) and 298 (in 1955) Tyee since 1933.

The number of Tyee taken by all sport methods in Discovery Passage between Seymour Narrows and Cape Mudge annually ranges between 200 and 300. Nearly all are red-fleshed (Murphy, pers. comm., 1977), as opposed to the white varieties generally considered inferior by commercial markets.

(b) Trout (*Salmo* spp.). Steelhead trout (*Salmo gairdneri*) is being managed as a fishery resource by the Fish and Wildlife Branch of B.C. Ministry of Recreation and Conservation. The Branch has run two analyses of Campbell River's steelhead: (1) a mail-in survey of licenced anglers (Steelhead Harvest Analysis, B.C. Ministry of Recreation and Conservation); and (2) an on-site interview and creel check program, carried out on the banks of the Quinsam and Campbell Rivers (Hooton, 1976b).

According to licence surveys, anglers on the Campbell River (Quinsam excluded) landed an estimated 1,264 steelhead during the 1975-76 season (Appendix 6.3). That figure represents 6% of the total catch from all of Vancouver Island's 145 steelhead

streams, bringing Campbell River to rank twelfth in British Columbia. The Quinsam that season yielded 656 additional steelhead and 70 were caught in Trout Creek. There are no steelhead data for any of the other streams between Seymour Narrows and Oyster Bay.

Although more than half of those fish were released, the observation by R.C. Bryan (quoted in Underwood, McLellan Associates, 1975) that 80% of fishermen don't fish to catch fish implies that the presence of fish in a stream is by itself sufficient to support a sport fishery. The success ratio for the Quinsam stood at 0.432 fish per day during the 1975-76 season, significantly higher than the provincial average of 0.292, an indication that the Campbell-Quinsam steelhead resource has considerable recreational value.

Data from the mail-in surveys indicate that in 1974-75 85% of the steelhead caught in Campbell River were landed by residents of Vancouver Island, 11% by residents of the lower mainland, 1% by Canadians from outside B.C. and 4% by American anglers. Even though most of the catch was taken by residents of Vancouver Island, 33% of the anglers who tried for fish were visitors to the region. Between 748 and 1210 anglers have visited the Campbell watershed to fish steelhead each season since 1966. On-site surveys have recently questioned the accuracy of some of these data (Hooton, 1976b) and, in conjunction with the B.C. Fish and Wildlife Branch, Hooton (M.Sc. in progress) is examining the value of various survey methods.

(c) Other Species: Non-salmonid species of fish accounted for 10% of the total Area 13 1974 sport catch, if herring (12,350 pounds) is excluded. The majority of these other species were lingcod *(Ophiodon elongatus)* and rockfish *(Sebastes* spp.), catch of the former being 3,273 pieces and of the latter, 5,080 pieces (Canada Department of the Environment, 1975).

2. COMMERCIAL FISHING:

Information on commercial fishing in the Campbell River area can be obtained from Area 13 salmon histories and annual narrative reports (Canada Department of Fisheries and the Environment), and Conservation District 5 annual narrative reports also on file with the Fisheries and Marine Service in Vancouver. Appendix 6.4 is a table summarizing Area 13 landed values for the past several years. Information of an economic nature can be obtained from a B.C. Dept. of Economic Development report (1976). Underwood, McLelland and Associates (1975) examined the impact of marine resources on the region and their data were used in the preparation of this latter report.

Areas 12 and 13 are managed by the federal government as a single unit for numerous pink, chum and sockeye stocks on spawning migrations to local and southern Strait of Georgia rivers. These three species form the bulk of the more than one million pieces harvested annually by seines, gillnets and troll gear in the Johnstone Strait management unit. Recent management strategies and salmon stock analyses are summarized in annual reports by Anderson (1973, 1975, 1975a, 1976, 1976a) and Anderson and Bailey (1974).

Commercial fishing activity in Discovery Passage south of Seymour Narrows is not heavy. Lingcod, some salmon and bait herring are taken, but the 287 vessels stationed in Campbell River and Courtenay in 1973 (5.2% of the B.C. fleet) generally worked the intensive Johnstone Strait salmon and northern Discovery Passage herring fisheries. Their catches, as determined by the Interim Planning Agreement staff (B.C. Department of Economic Development, 1976) amounted in 1973 to $5.8 million, about half of the landings from that area reported by all B.C. fishermen, and 3.9% of the total landings for the province of British Columbia. The catch was 91.4% salmon, 1.1% herring and 7.5% other species. Three fish camp barges are moored in

Campbell River every season to receive salmon caught locally by trollers.

Indian bands on the Cape Mudge and Campbell River reserves have traditionally fished for food. Permits are issued regularly to enable them to purse seine migrating chum and sockeye salmon stocks in northern Discovery Passage and southern Johnstone Strait. Fishing with nets is prohibited south of Seymour Narrows to Cape Mudge, and trolling is prohibited within one half mile of the estuary, to protect salmon holding there prior to upstream migration (Fisheries Officers, Campbell River, pers. comm., 1977). The total Indian food fishery catch for Area 13 in 1974 amounted to 8,198 pieces (Canada Department of the Environment, 1975).

7. INVERTEBRATES

7 (i) TERRESTRIAL INVERTEBRATES

There is virtually no information in the available scientific literature regarding terrestrial invertebrates in the Campbell River watershed (Carcasson, Provincial Museum, pers. comm., 1976). Forest pests have not been present in epidemic proportions, although endemic populations do exist in some localities (Wood, pers. comm., 1977; Canadian Forestry Service, 1975). Mundie and Mounce (1976) discovered that 2-6% of the drift (food of salmon fry) in Lower Campbell River was of terrestrial origin (Table 7.1). Some unpublished information regarding insects is available at the Miracle Beach Provincial Park Nature House in Black Creek, south of Campbell River.

7 (ii) FRESHWATER INVERTEBRATES

Although freshwater invertebrates are known to be an important food source for fish, there is not an abundance of site-specific knowledge pertaining to this group of fauna as it exists in the Campbell River system.

McMynn and Larkin (1953), and Sinclair (1965) have studied the invertebrate, fish and floral biota of Buttle, Upper Campbell, Lower Campbell lakes and the John Hart Head Pond. Sinclair compared his findings to those of McMynn and Larkin, because in the intervening years Strathcona Dam had been constructed, flooding the river valley and extending Buttle and Upper Campbell lakes, and he wanted to assess the effects of that impoundment.

McMynn and Larkin (1953) reported Buttle Lake's benthic fauna to be typical of an oligotrophic lake, the majority of its biomass being attributed to profundal (deep) regions since 80% of the lake bottom before impoundment was deeper than 23 m (75 ft).

They also provided data describing the composition of both the benthos and the plankton of all four lakes.

Sinclair (1965) found that impoundment had effected no change in Buttle Lake's physical or chemical properties, other than causing an increase in water level fluctuation. Lower Campbell Lake experienced a large increase in the extent of shallow waters, but not enough of that new portion was shallow enough to generate a detectable increase in productivity.

The four dominant groups of invertebrate fauna before impoundment - chironomids, cladocerans, oligochaetes and pisidians - remained dominant in the two lakes but shifted in relative importance among themselves. The loss of rooted and vascular plants in both lakes, due to water fluctuation, resulted in the decimation of associated *Hyalella knickerbockeri* (amphipod) and large insect larvae, forcing trout to compete among themselves for food. Sinclair also measured an increased production of planktonic cladocera in Lower Campbell Lake.

Mundie and Mounce (1976) studied the Lower Campbell River drift fauna during September 1973 under varying rates of discharge from the John Hart hydroelectric facility. When the discharge rate increased from 31.4 m^3/s (1110 cfs) to 83.5 m^3/s (2950 cfs), a five-fold increase in zooplankton, six-fold increase in benthic organisms and 12-fold increase in floating terrestrial insects was initiated. They assumed that this would result in an increase in availability of food for salmon fry but felt that frequent and higher changes in discharge rates would eventually deplete the freshwater fauna (see Section 1 of "Effects of Development"). The composition of the drift fauna in the lower Campbell River during September 1973 is described by Table 7.1.

Provincial fisheries personnel carried out a biological and physical survey of the Quinsam River in the summer of 1975

Table 7.1. Invertebrates in the lower Campbell River drift during September, 1973. Zooplankton from the John Hart Head Pond comprised 63%-78% of the drift; benthos from the river bed was 17%-31% and terrestrial items accounted for 2%-6% (from Mundie and Mounce, 1976). Most abundant are marked (*).

ZOOPLANKTON: (63-78%)		TERRESTRIAL ITEMS: (2-6%)	
Cladocera	*Bosmina coregoni* *	Diptera	Mycetophilidae
	Alona affinis		Empididae
	Daphnia		Chironomidae *
	Holopedium gibberum		
Copepoda	*Cyclops* *	Hemiptera	Aphididae *
	Diaptomus oregonensis *		miscellaneous families
	Harpacticoida		
Ostracoda		Hymenoptera	Mymaridae
		Psocoptera	
		Thysanoptera	

BENTHOS: (17-31%)		
Diptera	Tanypodinae	
	Orthocladiinae *	
	Chironomini	
	Tanytarsini	
	Simulium	
	Antocha	
Trichoptera	*Hydropsyche* *	
	Dicosmoecus	
	Glossosoma	
	Oxyethira	
	Rhyacophila	
	Brachycentridae	
Ephemeroptera	*Baetis* *	
Plecoptera	*Nemoura*	
Collembola	*Isotoma*	
	Smynthuridae	

(B.C. Ministry of Recreation and Conservation, 1975), making general observations on the aquatic invertebrate fauna in the river between Lower Quinsam Lake and the federal hatchery. Future surveyors might find useful a guide to Vancouver Island stream insects written by Mounce (1973).

7 (iii) MARINE INVERTEBRATES

An immediate distinction should logically be made between the stenohaline fauna adapted to living in the relatively high salinities of Discovery Passage and the estuarine fauna found in the more brackish estuarine waters.

The invertebrates of Discovery Passage are truly "marine" fauna, existing in salinities that remain above 25% (see "Oceanography") except very near the effluents of the Campbell River, Mohun (Trout) Creek, Menzies Creek, Willow Creek, and the outfalls of the Campbell River sewage treatment plant and Crown Zellerbach's pulp mill in Duncan Bay. These animals are taxonomically and ecologically distinct from the fauna of the estuary, although flood tides might carry them inside its boundaries.

1. INVERTEBRATA OF THE ESTUARY:

The estuary's invertebrate fauna is known only from juvenile salmon stomach contents. The small crustacean *Anisogammarus confervicolus* -- an amphipod adapted to living in estuarine conditions (Levings, McDaniel and Black, 1976) -- made up a third of the stomach contents of all juvenile coho caught in the estuary between May 1972 and August 1973 (Goodman and Vroom, 1974). The critical point to note is that this species is not likely to be found in large numbers anywhere else in Discovery Passage (Levings, pers. comm., 1977), and since Goodman and Vroom (1974) felt that the maintenance of *A. confervicolus* habitats in the estuary was essential to young salmon hatched in the river, they recommended that the vegetated intertidal areas of the estuary be left undeveloped. This amphipod, like other food organisms of fish,

Table 7.2. Estuarine, benthic organisms found in the stomach contents of Coho, chinook, and chum salmon caught in the inner estuary between May 1972 and August 1973. Figures indicate the percent biomass representation of each organism in the total stomach contents for each species of salmon (compiled from Goodman and Vroom, 1974).

	Percent of Total Stomach Content (by weight)		
FOOD ORGANISM	Coho	Chinook	Chum
Amphipods:			
Anisogammarus sp.	34.5	20.4	13.8
Corophium sp.	4.9	10.1	3.7
unid. Caprellid	0	0.2	0
unidentified sp.	0.1	0	0
Copepods:			
unid. harpacticoid	19.9	11.6	42.7
Decapods:			
Shrimp-like Crab	0	0	0.1
Shrimp	0.4	0.1	0
Isopods:			
Gnorimosphaeroma oregonensis	6.9	5.6	0
Cumacea (unid.)	8.3	8.8	20.0
Mysidacea (unid.)	8.2	10.0	2.0
Ostracoda (unid.)	0	9.3	0
Annelids			
unid. polychaete	0.8	0	0
Molluscs:			
unid. gastropod	0.2	0	0
unid. pelecypod	0	0.2	0
Totals	84.2	76.3	82.4
No. Stomachs examined	208	144	67

lives among the roots of such vegetation and depends to some extent on nutrient input from sedge detritus.

Goodman and Vroom (1974) reported that estuarine benthic fauna accounted for the major biomass component of stomach contents of juvenile coho (84.2%), chinook (76.3%) and chum salon (82.4%) caught inside the estuary (Table 7.2). Freshwater and terrestrial invertebrates accounted for 7.0% (coho), 16.5% (chinook) and 10.5% (chum) of the total stomach content biomass, while the remainder was mostly marine and nearshore zooplankton.

Estuarine benthos was also the major food source of juvenile chinook and chums caught outside the estuary along Tyee Spit, however the authors were unable to determine whether this was because the fish moved out of the estuary with full stomachs or whether the benthos was transported out to them. It has also been suggested that freshwater seepage through Tyee Spit might support an estuarine fauna on the seaward beach.

Juvenile coho outside the estuary showed more dependence on truly marine food sources: fishes (larval herring, salmon and unidentified larval fish) and *Euphausia pacifica* (a marine crustacean of the zooplankton known as "shrimpfeed" or "krill") formed 75.6% of the biomass stomach contents of young coho caught outside the Spit.

2. INVERTEBRATA OF DISCOVERY PASSAGE:

Discovery Passage, like turbulent marine channels elsewhere in the Strait of Georgia, is famous for the abundance and diversity of its benthic invertebrate fauna. In fact, the Passage is rapidly becoming a favourite recreational site for scuba divers who brave its exceptionally strong tidal currents in order to explore its rocky shores for such unusually abundant animals as the

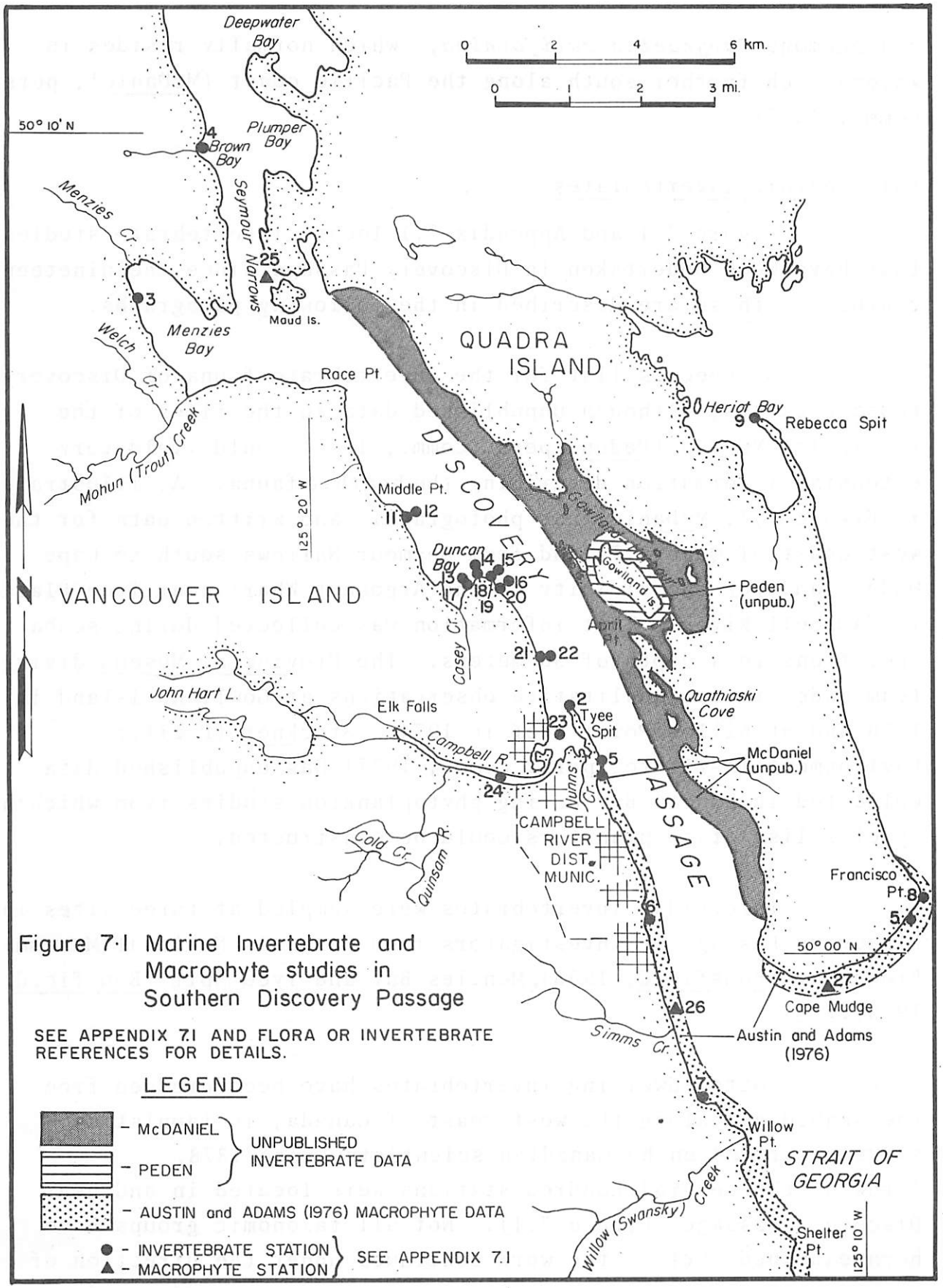


Figure 7.1 Marine Invertebrate and Macrophyte studies in Southern Discovery Passage

SEE APPENDIX 7.1 AND FLORA OR INVERTEBRATE REFERENCES FOR DETAILS.

sea anemone *Corynactis californica,* which normally resides in waters much farther south along the Pacific coast (McDaniel, pers. comm., 1977).

(a) Benthic invertebrates

Figure 7.1 and Appendix 7.1 locate invertebrate studies that have been undertaken in Discovery Passage since the nineteenth century -- these are described in the following paragraphs.

No species list for the invertebrate fauna of Discovery Passage exists, although unpublished data in the files of the Provincial Museum (Peden, pers. comm., 1977) could yield very extensive information describing the benthic fauna. As illustrated in Figure 7.1, McDaniel has photographic and written data for the west coast of Quadra Island from Seymour Narrows south to Cape Mudge, and for the vicinity of the Argonaut Wharf near Tyee Plaza in Campbell River. That information was collected during scuba operations to a depth of 30 meters. The Provincial Museum diving team made similar qualitative observations at Gowlland Island in 1976 and at Willow Point Reef in 1974. Stockner (Pacific Environment Institute, pers. comm., 1977) has unpublished data collected in Duncan Bay during phytoplankton studies from which a species list of zooplankters could be constructed.

Intertidal invertebrates were sampled at three sites in Discovery Passage by investigators from Canada's National Museum: Brown Bay (Bousfield, 1963), Menzies Bay and Tyee Spit (Bousfield, 1956).

Bottom-dwelling invertebrates have been dredged from the seabed all along the west coast of Canada, in faunistic surveys carried on by Canadian scientists since 1878.
A few of the several hundred stations were located in and near Discovery Passage (Figure 7.1). Not all taxonomic groups have been examined yet: the work continues under the direction of

F. Bernard, Pacific Biological Station, Nanaimo. Austin and Haylock (1973) identified the ophiuroids (brittle stars) present at some of these stations.

Cockbain (1963) was unable to report on the foraminiferal fauna of the Passage itself, although his survey included several sea-bottom stations south of Cape Mudge and east of Quadra Island: These data provide useful baseline information for comparing northern Strait of Georgia and Discovery Passage biota in future.

Beak Consultants Limited (1974, 1976) was retained by Crown Zellerbach of Canada Ltd. to conduct a biological and chemical monitoring program on effluents released to Discovery Passage from the Elk Falls pulp and paper mill on Duncan Bay. Beak's biologists surveyed the invertebrate fauna at 4 shoreline and 5 sea-bottom locations in front of the mill, and at two "control" stations some distance up and down the coast (Middle Point to the north and Tyee Camp to the south -- Figure 7.1). Their data are discussed fully in the chapter on Pollution and Water Quality. Beak have retained the samples in their museum for more detailed study, if the need should arise.

The two Beak reports provide information on the habitats and major macroinvertebrate groups in Duncan Bay. The authors found that the intertidal shores distant from the mill were characterized by a *Mytilus-Balanus* (mussel-barnacle) community, and were sparse in plant life owing to the unstable nature of the substrate. They felt that the shoreline as a whole was not especially rich compared to intertidal habitats elsewhere in British Columbia. The shore near Tyee Camp, 700 m (766 yds.) north of the estuary, is swept by low salinity river water at times, "causing estuarine conditions on the shoreline which (were) probably responsible for somewhat less luxuriant intertidal shore in that area" (Beak Consultants Ltd., 1974). Low salinities

were not discovered in the bottom waters at any of the stations, and surface waters to a depth of 10 m were characterized by salinities between 25°/oo and 30°/oo. Only the top 1.5 m at the station near the estuary was periodically low in salinity. This information accounts for the general presence of a characteristically marine biota revealed by the Beak surveys from 700 m north of the estuary to Middle Point. In 1975, arthropods (amphipods, tanaids, isopods and cirripeds) and annelids (primarily polychaetes) were the most numerous invertebrates at all stations but one, where epiphytic bryozoans dominated.

Coates is studying enchytraeid oligochaetes -- common aquatic relatives of the earthworm -- along the Discovery Passage shoreline north of the estuary (M.Sc. in prog., U. Victoria).

Howard Paish and Associates Ltd. (1972) published a collection of maps indicating that southern Discovery Passage is a "major invertebrate area", "crab area", and a "principal clam beach area" (west bank near Campbell River), but the report fails to document sources of information. Their study was commissioned by Environment Canada to survey the coast for sensitivity to oil spills. A similar inventory of marine resources by the federal Environmental Protection Service (Canada Department of the Environment, 1976) indicates only that crabs and an estuarine environment (Campbell River) are present in Discovery Passage.

The exceedingly rich sponge fauna (phylum Porifera) in Discovery Passage has been sampled by N. McDaniel and R. Harbo, and some of their collection is being studied by W.Austin and B.Ott (Austin, pers. comm., 1977).

(b) Zooplankton

Heavy tidal flushing through the Passage prevents stratification and probably inhibits the development of indigenous zooplankton assemblages in Discovery Passage, the fauna there

being contributed from populations in Johnstone Strait or the Strait of Georgia (Lewis, pers. comm., 1977). Stockner (pers. comm., 1977) can provide a species list from his data files on Duncan Bay, but no direct studies on the zooplankton of Discovery Passage have been undertaken.

7 (iv) INVERTEBRATE FISHERY

Invertebrates do not contribute much to the area's commercial fishery. Prawns, shrimps, crabs, oysters and clams are fished in Statistical Area 13 (Table 7.3), although local fisheries officers report only recreational activity in Discovery Passage south of Seymour Narrows. Crabs were once fished commercially from mud flats off the Campbell River estuary, where there is still a recreational rake fishery for crab in operation. Cape Mudge is important for recreational clam fishing but parts of the Campbell River shoreline from Middle Point south to Shelter Point have been closed to the taking of bivalves for any purposes, owing to the fear of sewage contamination (Canada Department of the Environment, 1975 ; see Chapter 11, Section [v]4).

In 1974 the Area 13 recreational catch reportedly included: 259 kg of shrimp and prawns, 371 dozen crabs, 12,372 round kg of oysters, 114 l. of shucked oysters and 9,090 kg of clams (Canada Dept. of the Environment, 1975b). Landed values for 1971 to 1975 are broken down in Table 7.3. Oysters are taken by sportsmen from provincially stocked reserves on the east side of Quadra Island, at Heriot Bay and Francisco Point, and are not present in quantity in Discovery Passage (Smith, pers. comm., 1976). Octopus has been taken along the west coast of Quadra Island.

Table 7.3. Landed value in thousands of dollars of invertebrates taken by commercial fishermen from federal Statistical Area 13, which includes Campbell River and Discovery Passage. Three clam species were taken: butter (*Saxidomus giganteus*), Japanese littleneck (*Venerupis japonica*) and native littleneck (*Protothaca staminea*). (Data compiled from Area 13 1A worksheets, Fisheries and Marine Service, Vancouver, B.C.)

	Landed Value in $000			
Year	prawns	shrimps	clams	crabs
1975	5	0	21	9
1974	3	0	123	10
1973	15	1	23	20
1972	1	0	73	0
1971	2	0	34	0

8. FLORA

8 (i) TERRESTRIAL FLORA

Dry land vegetation is important to the biology of a watershed because of the shade it provides young salmonids, its nutrient and detrital input to aquatic ecosystems, and the soil stabilization effected by its root formation in surface soils, but little information regarding forest or stream-bank vegetation is available in a comprehensive form for Campbell River's watershed.

1. BIOGEOCLIMATIC DESCRIPTION OF WATERSHED:

Krajina (1965, 1970) has proposed a method for dividing British Columbia into eleven biogeoclimatic zones, based on the idea that forest climax communities are a function of a specific combination of climatic, soil and topographic conditions. The type of forest then indicates the long term growing (biogeoclimatic) conditions of a particular environment. Packee (1974a, b) selected Krajina's approach as being the most applicable to Vancouver Island from among four proposals and produced a map of the Island delineating seven biogeoclimatic subzones, modified from Krajina (1970) only slightly.

The estuary, most of Campbell River's watershed and the shores of Discovery Passage are occupied by a "wet Douglas-fir" subzone characterized (Packee, 1974b) by low summer rainfall, even though annual precipitation is high. Soil moisture deficits are moderate to high (60 to 150 mm). Douglas-fir *(Pseudotsuga menziesii)* dominates this subzone.

Three more minor subzones contribute to our study area: "dry Douglas-fir" along the coast from Willow Point south to Comox, "dry western hemlock" on the shores of Buttle Lake and a "wet western hemlock" fringe among the high altitude headwater creeks. Characteristics of their soils and climatic regime are found in Packee (1974b), and details of local climatic and soil conditions

are discussed elsewhere in this report. Detailed descriptions of the plant associations found in each subzone are provided by Krajina and Spilsbury (1953).

2. FOREST COVER:

The Campbell River watershed was logged intensively in the early twentieth century, bull teams first skidding logs down to Elk Falls in 1889 (see the Land Use chapter). A spectacular fire broke out 12 miles west of Campbell River in 1938 and burned out of control as far south as Courtenay, destroying 30,300 ha (75,000 acres) of prime and immature timber. The Elk River fire destroyed another 8,900 ha (22,000 acres) of forest in 1951. Because of these fires and the logging activity, most of the present forest cover is secondary growth.

Current biological literature on the forest cover is either outdated or fragmentary (Wormald, 1976). The B.C. Forest Service is preparing to manage the 100,000 ha (0.25 million acre) Sayward Provincial Forest with a multidisciplinary approach involving expertise from the British Columbia Ministry of Recreation and Travel Industry. The co-ordinating committee is having a report prepared summarizing current information for that region (Diggle, pers. comm., 1977) but it was not available as this volume in the Special Estuary Series went to press.

A team under Dr. Paul Barker (the B.C. Forest Service Productivity Committee) has been providing research support for the Managed Yield Table Program in Sayward Forest by examining the effects of fertilization and thinning in small stands of Douglas fir, balsam and hemlock since the early 1960's. If fertilization of forest stands becomes operational, urea (which is 46% nitrogen, will not leach through the soil as quickly as other fertilizers and is easy to handle) will probably be the preferred chemical for enhancing Douglas fir growth (Barker, pers. comm., 1977). Much of the watershed's forest is private

land in the Esquimalt and Nanaimo Land Grant belt, except for Strathcona Provincial Park property around the upper end of Buttle Lake.

Forest Cover maps are available for parts of the watershed (B.C. Forest Service, 1967) but they are rapidly becoming outdated. More recent Unit Survey Reports can be obtained for Sayward Forest and the Crown portions of the E & N belt (B.C. Forest Service, 1971). These documents detail available maps and present a summary of land area in terms of forest type, water coverage, rock area and so forth, and broadly indicate the age and species structure of the forests in each region. The problem with this information is that it refers to too large an area to be of use in understanding forest cover in the Campbell watershed.

In 1940, the Campbell River Forest Nursery was established on the Quinsam River one mile west of Campbell River to provide two-year, root-pruned Douglas fir seedlings for reforestation projects. By 1962, 53 million young trees had been shipped from the nursery (B.C. Forest Service, 1962).

3. STREAMBANK VEGETATION

The only available reference to streambank vegetation in the Campbell River watershed is an inventory report on the Quinsam River (B.C. Ministry of Recreation and Conservation, 1975). Its authors briefly mention that the Quinsam banks from Lower Quinsam Lake to the old Elk River Timber bridge crossing are lined with deciduous and coniferous vegetation -- an immature Douglas fir *(Pseudotsuga menziesii)* association -- providing only about 5-10% cover, since the branches don't overhang the banks. The upper end of the next reach, from the bridge crossing down to the power transmission lines, harbours a mature alder *(Alnus* sp.) canopy with cow parsnip, devil's club and salmonberry understory that provides 20% cover. Mature hemlock *(Tsuga* sp.), spruce

(*Picea* sp.) and cedar (*Chamaecyparis* sp.) overgrow a thick salmonberry (*Rubus spectabilis*) understory to provide 20-30% cover in the lower end.

8 (ii) FRESHWATER FLORA

The Quinsam River anadromous fish habitat was surveyed in some detail in 1975 (British Columbia Ministry of Recreation and Conservation, 1975), but only passing observations on the aquatic flora were recorded. From Lower Quinsam Lake down to the old Elk River Timber bridge crossing, vascular plants were virtually non-existent, although algal production was high in some areas. From the bridge down to the power transmission lines, green algae were present in low quantities and bull rushes and lily pads were common in deep pools (December 8).

Hamilton and Buell (1976) reported a lack of riparian vegetation in the Lower Campbell River, probably as a result of frequent flow fluctuations caused by manipulations of the John Hart hydroelectric dam flow rate.

Carl (1937), McMynn and Larkin (1953) and Sinclair (1965), have produced a series of reports documenting to some extent the limnology of the large lakes on Campbell River: Buttle, Upper Campbell, Lower Campbell and John Hart. Some of their data pertain to the benthic flora. Aquatic vegetation plays an important role in the aquatic ecosystem by providing detrital nutrients and physical habitat for the support of food chains that sustain salmonid populations, a fact that concerned Sinclair (1965) when he observed that rooted plants were lost from both Campbell and Lower Campbell Lakes owing to water level fluctuations generated by hydroelectric energy production. That loss probably instigated a reduction of dependent invertebrates like the large amphipod *Hyalella knickerbockeri* and large insect larvae, forcing trout into an undesirable competition for food. Before the third dam flooded Buttle and Upper Campbell Lakes from

1957 onwards, Buttle Lake supported growths of sedge grass (*Carex* sp.), water milfoil and some *Chara* sp. down to a depth of 4 m (12 feet). McMynn and Larkin,(1953) and Carl (1937) reported pond weeds in Lower Campbell Lake to a depth of 4.5 m (14 feet).

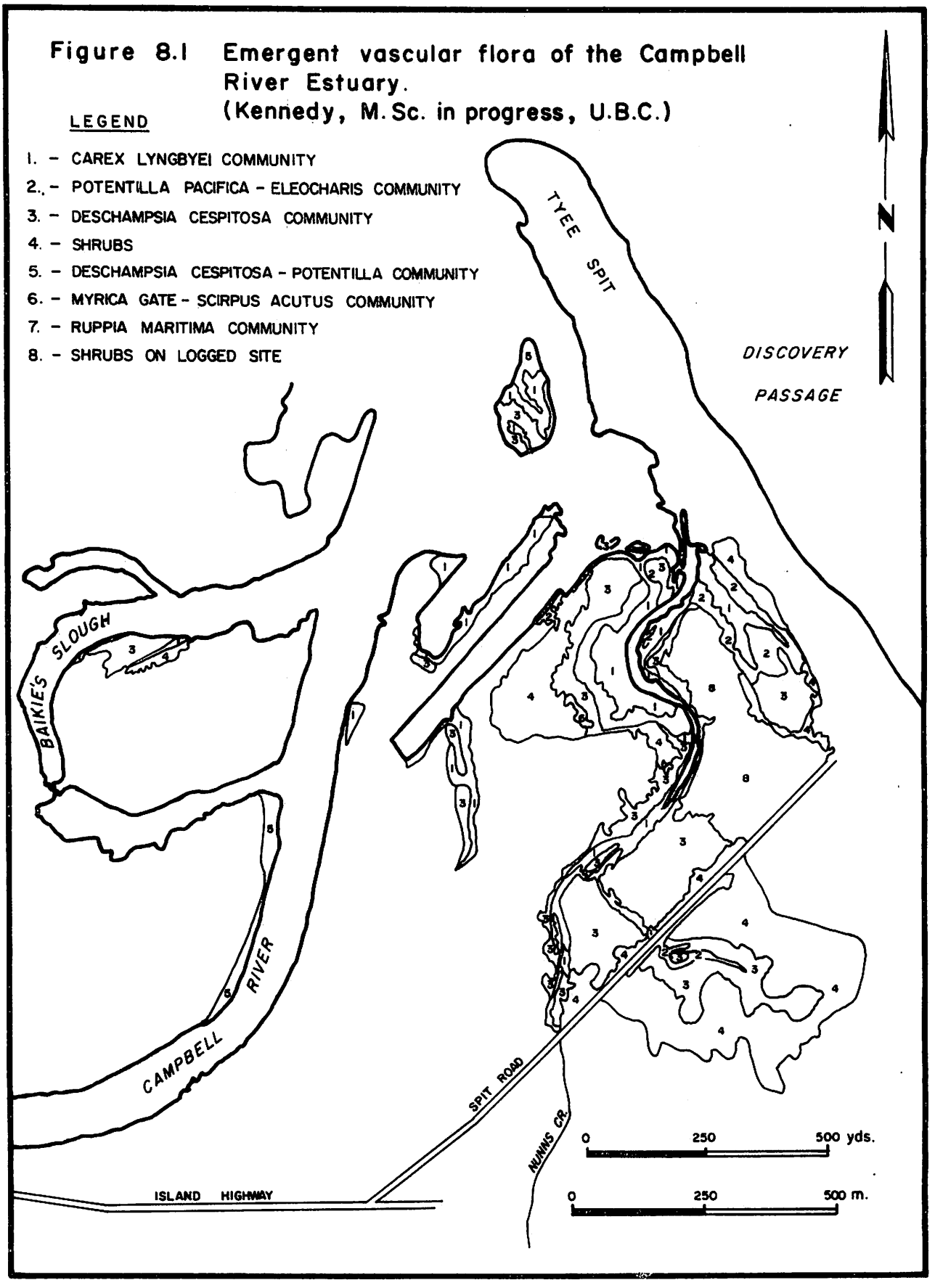
Although these three papers discuss the chemical and physical limnology of Campbell River's lakes, no information is available on the phytoplankton, which are important because they constitute a vector for the transport of nutrients from the watershed into the estuary.

8 (iii) ESTUARINE FLORA

Vegetative cover plays a key role in the natural functioning of the ecosystem of the Campbell River estuary (e.g. Goodman and Vroom, 1974). Kennedy (M.Sc. in prog., Univ. of B.C.) has carried out an intensive study of the estuary's emergent vascular flora. Her data is the only available floral information for the estuary; it contributes to both the species list in Appendix 8.1 and the floral map in Figure 8.1. Kennedy identified eight communities in the intertidal zone of the estuary, each with characteristic dominants:

1. *Carex lyngbyei* (Lyngby's sedge)
2. *Potentilla pacifica* (Pacific silverweed), and *Eleocharis palustris* (spike-rush)
3. *Deschampsia cespitosa* (tufted hairgrass)
4. *Alnus rubra* (red alder), *Rubus laciniatus* (evergreen blackberry), *Cytisus scoparius* (broom), *Rosa nutkana* (Nootka rose), and *Rubus spectabilis* (salmonberry)
5. *P. pacifica* and *D. cespitosa*
6. *Myrica gale* (sweet gale) and *Scirpus acutus* (hardstem bulrush)
7. *Ruppia maritima* (ditchgrass)
8. *Alnus rubra* (red alder), *Rosa nutkana* (Nootka rose), and *Symphoricarpos albus* (snowberry)

Figure 8.1 Emergent vascular flora of the Campbell River Estuary. (Kennedy, M.Sc. in progress, U.B.C.)



Sedge (*Cyperaceae*), particularly *Carex lyngbyei* is an important family in estuaries because its roots and rhizomes provide cover for the amphipod *Anisogammarus*, and for harpacticoid copepods, all distant relatives of shrimp and major components of stomach contents taken from juvenile coho (*Oncorhynchus kisutch*) and chinook (*O.Tshawytscha*) salmon caught in the estuary (Goodman and Vroom, 1974). Kennedy's thesis, to be completed in the summer of 1977, includes an estimation of the primary production of these amphibious vascular plants. Investigations in the Squamish estuary, at the head of Howe Sound, revealed that 10% of the estuary's primary organic production took place in the phytoplankton, 45% in the benthic algae and 45% in the sedge stands (Waldichuk, 1977), and it is possible that extensive sedge growths on the south shore of the Campbell River estuary may make a similar major contribution to the estuary's primary production. Confirmation will have to await publication of the thesis report. Analysis of the fish fauna in the estuary has already indicated the importance of the vegetated intertidal areas surrounding the mouth of Nunns Creek to the Campbell River's salmonid populations (Goodman and Vroom, 1974).

8 (iv) MARINE FLORA

The aquatic vegetation seaward of Tyee Spit is influenced by the characteristically well-mixed, saline waters of Discovery Passage (see Oceanography chapter), therefore marine algal species dominate both plankton and benthos, and aquatic vascular plants are represented by only a very few species.

1. PHYTOPLANKTON:

The phytoplankton of Discovery Passage has not been studied, but the Strait of Georgia has had considerable attention. It is reasonable to assume that tidal currents effect exchanges of planktonic flora between the Strait and Discovery Passage, hence the extensive bibliography on phytoplankton in Stockner and Cliff (1976) might be useful to researchers working near the Campbell River estuary.

Unpublished data collected in the course of plankton studies in Duncan Bay could yield a species list of phytoplankters (Stockner, pers. comm., 1977) although the final report (Stockner et al., 1975) was concerned with the effect of Crown Zellerbach's pulp mill effluent on phytoplankton production in those waters. Their results are discussed in Chapter 11 and detailed in Table 11.6. Primary production on October 3, 1973 was measured at 357 mg C/m ^{2}/day and on September 26, 1974 at 1269 mg Cm^{2}/day, using C^{14}. Controls run in uncontaminated water were not much different, suggesting that rapid tidal mixing dilutes the mill's effluent before it can have an impact on phytoplankton carbon production. Waldichuk (see chapter on Oceanography) presumes that this violent mixing inhibits the development of large phytoplankton associations.

Cruises in the Strait of Georgia near Discovery Passage during 1966-67 yielded information on surface concentrations of chlorophyll 'a', salts, silicate, nitrate, and suspended solids, and on temperature distribution (Stephens, 1968).

2. BENTHIC VEGETATION:

Foreman and Root (1975), in a major review of macrophyte research in the Strait of Georgia, indicated that of the 52,000 specimens installed at the University of British Columbia Phycological Herbarium, several were collected at four sites in southern Discovery Passage and Cape Mudge. Ecological information for these specimens is summarized in computer files at U.B.C. Druehl (1965, 1967) investigated the distribution of *Laminaria* sp. in relation to environmental factors at Cape Mudge, and Widdowson (1964) investigated the morphology of *Alaria* sp. in the vicinity of Seymour Narrows and on Vancouver Island's shore south of the Campbell River estuary. Norris and Abbott (1972) described 28 new species of algae from Duncan Bay to Hope Island on the north end of Vancouver Island.

Austin and Adams (1974, 1975) have prepared detailed charts of the distribution of *Iridaea cordata*, Japweed (*Sargassum muticum*), kelp (*Nereocystis luetkeana*), eelgrass (*Zostera marina*), and five less conspicuous seaweeds on the south tip of Quadra Island, the west coast of Hernando Island and on Vancouver Island from Campbell River south to Denman Island, at a scale of 1:10,000. Their maps were prepared from ground surveys during 1972-74 and infrared and natural colour aerial photography during 1972 and 1974. Detailed ground surveys complement these photographic data. Their information provides an excellent baseline from which to measure the effects of human activity in the near-shore marine environment (Austin, pers. comm., 1976). *Iridaea cordata* is a potential source of the colloidal suspensor carageenan, used in a variety of pharmaceuticals and food products.

Their charts indicate the presence of 21 hectares (52 acres) of *Iridaea* beds along the shoreline between Campbell River's government wharf and Oyster Bay. Another 24 ha (52 ac.) of this commercially significant seaweed and its associated

species lies on Quadra Island's foreshore between Francisco Point and Cape Mudge. Permanent sampling sites were established at Cape Mudge and Willow Point in 1975 and 1976.

The foreshore between Campbell River and Oyster Bay consists of bedrock outcropping and mounds of glacial cobbles and boulders on sand in a band 100-200 m seaward from the high tide line. Beds of seaweed lie offshore from this substrate, *Iridaea* forming a strip between the low tide line and the kelp (*Nereocystis luetkena*) beds, which occupy water deeper than 3-5 meters (10-16 feet). Where sand replaces rock along the shore, eelgrass (*Zostera marina*) beds replace kelp and *Iridaea* offshore. One of the 12 species of vascular plants (Tracheophyta) adapted to life in the sea, eelgrass is frequently an important component of coastal zone ecosystems and is often a substrate for spawning herring. Harris (1953) reported that eelgrass was scarce between Oyster Bay and Campbell River, as appears to be the case today.

Booth (1969) has sampled marine fungi from halomorphic (salt-laden) soils along Vancouver Island's shoreline south of Campbell River, at Oyster Bay, Shelter Point Creek, Shelter Point Settlement, Oyster Pond and the Oyster River. His paper describes several monocentric chytrids and Chytridiaceous species from those stations.

Beak Consultants Ltd. (1974, 1976) was retained by Crown Zellerbach's Elk Falls pulp and paper mill to survey the impact of the mill's effluent on the biota of Duncan Bay. Six of the stations were sampled by intertidal transect methods which yielded tabular and photographic information on the floral cover between high and low tide marks. Grab samples obtained offshore from these beach stations were also examined for macrophytic content. All six stations were surveyed on four dates:

October 15, 1973; April 28, 1974, April 22, 1975 and October 27-28, 1975. Algal genera common to marine intertidal rock and mud habitats were present, including *Ulva, Chondrus, Fucus, Enteromorpha, Porphyra, Nereocystis, Endocladia, Petrocelis, Zostera* (offshore), diatom films and filamentous green alga. These results are discussed in a pollution context in Chapter 11.

9. WILDLIFE

9 (i) BIRDS

Birds rely heavily on natural resources of the Campbell River estuary. Provincial Fish and Wildlife Branch biologists in Nanaimo are charged with managing non-migratory species of the Vancouver Island Region, and the federal Canadian Wildlife Service is responsible for migratory birds--many of which, in order to complete their life cycles, must fly across provincial and international boundaries (Appendix 9.1).

1. TERRESTRIAL SPECIES:

The effects of soil fertilization, density and food quality on blue grouse (*Dendragapus obscurus*) populations in the Quinsam River watershed have been studied for many years by J.F. Bendell (University of Toronto) and his graduate students (Bendell, et al., 1972; Zwickel and Bendell, 1972; and Bendell, pers. comm., 1977).

The Mitlenatch Natural History Society of Campbell River carries out annual Christmas bird counts, paralleling the efforts of similar organizations across Canada and the United States. The group has been able to cover a variety of terrestrial habitats within several miles of Campbell River: their species lists are reported in Audubon Field Notes. On January 2, 1977, they recorded 84 species of 8,151 birds between Duncan Bay, the Oyster River, Sutil Channel and McIvor Lake.

The European starling (*Sturnus vulgaris*) arrived in British Columbia in 1947, and by 1960, nesting activity was reported from Campbell River (Guiguet, 1961).

A report prepared by EPEC Consulting Western Ltd. of Edmonton

(1975) for Weldwood of Canada contains a great deal of general information on terrestrial species found in the study area but points to a lack of site-specific information for all but the blue grouse.

2. AQUATIC SPECIES:

Canada Land Inventory charts describing waterfowl capability zones in the Campbell River Area (sheets 92 K/SW and 92 F/NW) identify the Campbell River estuary, the heads of Duncan and Menzies bays (Menzies and Trout creek estuaries - Fig. 6.1), and a small portion of the north arm of Gowlland Harbour as being unimportant for waterfowl breeding, but definitely important habitats for migrating and overwintering birds (class 3m). These regions are important because of the highly productive biota that develops there around a vegetative base like eelgrass (*Zostera*) or sedge (*Carex*); (Noble, 1972). It is because these productive, estuarine habitats are relatively restricted in the Campbell River area that many people are concerned with protecting the estuary. The Canada Land Inventory Waterfowl Capability charts indicate that nearly all of the Campbell River watershed is severely to totally limited in waterfowl-producing habitat, except for those estuarine areas noted above, and scattered sites in and south of the Quinsam watershed.

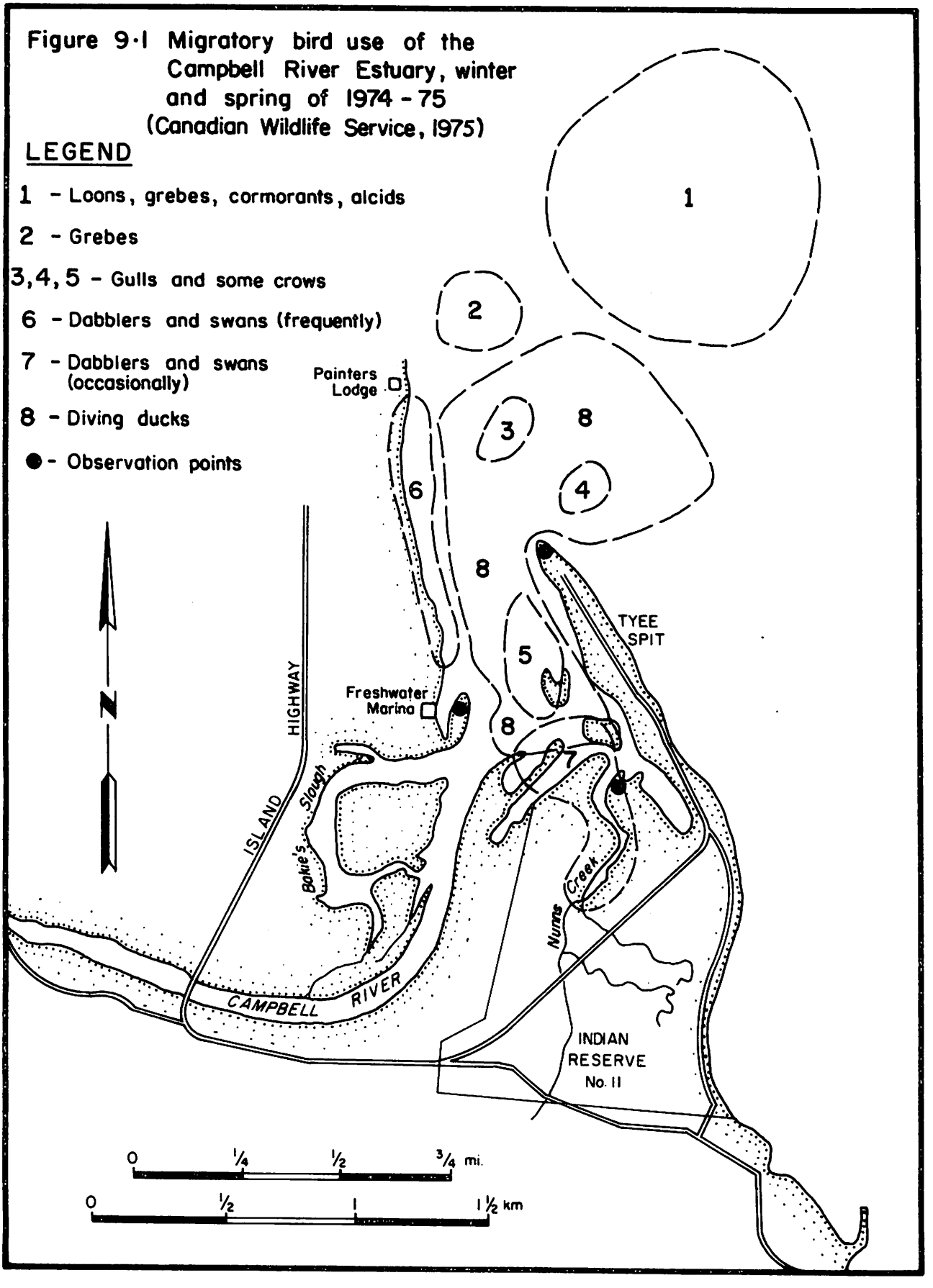
There is no question that the Campbell River estuary is an important habitat for birds. Unpublished data collected by the Mitlenatch Natural History Society from September 1973 to January 1976, and by D. Trethewey of the Canadian Wildlife Service in Delta, B.C. during the same period, indicate that 140 species of birds have been observed in the estuary in recent years (Appendix 9.1). Telosky (unpubl. data) believes that 69 species are resident, 24 of which are "common residents". These birds are in the estuary because of its rich food supply, which includes vegetation, benthic and planktonic invertebrates, and small fish. There is a critical lack of information concerning the exact

extent of this avian food resource in the Campbell River estuary (Canada Department of the Environment, 1973). Nor is information available concerning the nesting habits of birds in the estuary, although Trethewey (1973) felt that water level fluctuations due to operations in the John Hart generating station might hamper nesting activity.

Distribution of birds in the estuary is illustrated in Figure 9.1, based on surveys carried out by the Canadian Wildlife Service (1975) during the winters of 1972-3, 1973-4 and 1974-5. Gulls and others (including raptors, shorebirds, game birds and passerines) were the most abundant species in the winter of 1974-5 (66.8%), followed by diving ducks (bufflehead, goldeneye, mergansers, scoters, oldsquaw, harlequin and scaup 26.9%), and then loons, grebes, cormorants and alcids (5.2%). Dabbling ducks (mallards, pintail, wigeon and green-winged teal) were regular visitors in small numbers until mid-March. Total numbers increased from December 1974 to a peak in January, thereafter declining to the end of the survey period on April 30, 1975. Shoreline surveys from aircraft were carried out during the winters of 1975-7 by the Canadian Wildlife Service and the B.C. Fish and Wildlife Branch (unpublished data, Ladner and Nanaimo).

About 8-10 trumpeter swans (*Olor buccinator*) used the Nunns Creek marsh as a food supply during the winter of 1972-3 (Trethewey, 1973; see also Benson 1964; Blood 1969; and Smith 1970). These birds are among the quarter of the world's population of trumpeter swans presumed to winter on Vancouver Island.

No comprehensive information exists concerning the avifauna of Discovery Passage. Annual Christmas bird counts by the Mitlenatch Natural History Society have yielded species lists for waters as far east as Sutil Channel, as far north as Duncan Bay and as far south as the Oyster River (Audubon Field Notes). Taylor (1972) reported that one of 18 pelagic cormorant


Figure 9·1 Migratory bird use of the Campbell River Estuary, winter and spring of 1974 - 75 (Canadian Wildlife Service, 1975)
LEGEND
1 - Loons, grebes, cormorants, alcids
2 - Grebes
3,4,5 - Gulls and some crows
6 - Dabblers and swans (frequently)
7 - Dabblers and swans (occasionally)
8 - Diving ducks
● - Observation points
1
2
3
4
5
6
7
8
Painters Lodge
Freshwater Marina
TYEE SPIT
ISLAND HIGHWAY
Bokie's Slough
Nunns Creek
CAMPBELL RIVER
INDIAN RESERVE No. 11
N
0 1/4 1/2 3/4 mi.
0 1/2 1 1 1/2 km

(*Phalacrocorax pelgicus*) nesting sites in the Strait of Georgia is on Quadra Island north of Quathiaski Cove. Sealy and Nelson (1973) discussed horned puffin (*Fratercula corniculata*) sightings near Seymour Narrows. The Mitlenatch Natural History Society annually prepares a report on black brant (*Branta bernicla*) sightings for an American agency. King (1973) observed marsh hawk (*Circus cyaneus*) nesting near Campbell River and Campbell (undated) mentioned briefly the importance of Mitlenatch Island as a breeding ground for glaucous-winged gulls (*Larus glaucescens*), pelagic cormorants, pigeon guillemots (*Cepphus columba*), and a few individuals of terrestrial species.

The report prepared by EPEC Consulting Western Ltd. (1975) for Weldwood of Canada, details biological resources in a wide study area extending from Campbell River to the south of Horne Lake. This document comprises a useful concentration of information on the biology and habits of water birds that frequent the area, and points out that the region is an important overwintering region because of the presence of large numbers of ice-free water bodies and productive estuarine marshes.

Information describing bird hunting near Campbell River is limited to a Vancouver Island-wide compilation of data (B.C. Department of Recreation and Conservation, 1975) which yields little information relative to the watershed itself. Ruffed grouse (*Bonasa umbellus*), blue grouse (*Dendragrapus obscurus*), mallard (*Anas platyrhynchos*), other ducks, and geese (except snow geese) are favourite targets of Campbell River hunters (Smith, pers. comm., 1977).

9 (ii) MAMMALS

There are 27 species of land mammals on Vancouver Island (EPEC, 1975) and several species of marine mammals in the waters

off its shores, but virtually no information exists with respect to mammalian populations in the Campbell River watershed or Discovery Passage. Field data for a species list of mammals present in the Campbell River estuary has not been collected to substantiate the list compiled by us (Appendix 9.2).

1. TERRESTRIAL SPECIES:

As many as 25 species of terrestrial mammals might be present in the vicinity of Campbell River. Cowan and Guiguet (1973) proposed that this fauna lies in the Coast Forest Biotic Area, a timbered region with mild winters, cool summers and high precipitation. The Area includes the greater part of Vancouver Island, the coastal islands north of Jervis Inlet and the entire western slope of the Cascade and Coast Mountains. Isolated from the mainland, Vancouver Island harbours a distinctive fauna. The British Columbian distribution of Roosevelt elk (*Cervus canadensis roosevelt*) is now restricted to Vancouver Island for example, although herds can be found in Oregon, Washington and California.

Canada Land Inventory map sheets 92F/NW and 92K/SW describe ungulate (deer and elk) capability for the Campbell River watershed. Both shorelines of Discovery Passage south of Seymour Narrows are rated as having slight limitations to the production of ungulates owing to: (1) snow depth being such as to limit mobility or the availability of food; and (2) poor soil moisture characteristics for the growth of vegetative cover that permits mobility and the availability of food plants for black-tailed deer (*Odocoileus hemionus*). Much of the Campbell River hinterland and all of the Quinsam watershed is rated as having slight or very slight limitations for the production of ungulates (Classes 2 and 3), with some good winter range potential in certain localities (Classes 2W and 3W).

A good general description of the ecology of the various terrestrial species which inhabit the Campbell watershed can be

found in the report prepared by EPEC Consulting Western Ltd. (1975) for Weldwood of Canada, as a guide to the biological resources of a study area bounded on the north by Campbell River and on the south by Horne Lake. The bibliography in that report contains useful sources of biological information that can be extrapolated to understand mammalian ecology in the Campbell River watershed.

On-site mammalian information is fragmentary. Dolan (M.Sc.F., in progress, University of Toronto) is examining populations of mice (*Peromyscus* spp.) and deer in plots of land where the vegetation has received doses of fertilizer. Campbell (1972) reported on a Big Brown Bat (*Eptesicus fuscus*) found in Miracle Beach Park in 1959 and suggested that the species ranges as far north as Campbell River. Marshall, et al. (1976) reported that anadromous fish in the Quinsam and lower Campbell Rivers are subject to predation by black bears (*Ursus americanus vancouveri*). The B.C. Fish and Wildlife Branch is preparing elk and deer density maps for Vancouver Island (Hebert, pers. comm., 1977).

2. HUNTING:

Hunting has long been a popular activity in the vicinity of Campbell River. Harvest data have been collected by in-person regional game checks since 1955 (gate seasonally staffed by the B.C. Fish and Wildlife Branch at Campbell River to examine kills from the entire north end of Vancouver Island) and by mail-in questionnaires from hunters. About 50% of the hunters resident on Vancouver Island have traditionally responded to these postal surveys. Both programs have annually generated data which until recently were integrated at the level of the Vancouver Island Game Management Area No. 1 (B.C. Department of Recreation and Conservation, 1975), making it impossible to assess hunting activity in a particular watershed. The problem is being rectified by the Vancouver Island Region office of the B.C. Fish and Wildlife Branch. Campbell River's watershed is being divided into 3 "management units" and 7 "management subunits" (maps on file with

B.C. Fish and Wildlife Branch, Nanaimo) and Kale (M.Sc., in progress, University of British Columbia) is mapping the area's wildlife resource at the level of subunits, to permit a clear understanding of site-specific management problems. His analysis has revealed, for example, that the kill of deer on Vancouver Island has moved northward since 1964, a trend that was masked by previous methods of data collection and integration.

Mammals hunted near Campbell River include black-tailed deer (*Odocoileus hemionus columbianus*), black bear (*Ursus americanus vancouveri*) and cougar (*Felis concolor vancouverensis*). Although closed for the last several years, the possibility exists that Roosevelt elk (*Cervus canadensis roosevelt*) might be legal game in the area during 1977 (Smith, pers. comm., 1977), under a scheme of limited entry.

3. MARINE SPECIES:

Marine mammals appear to make good use of the productive and well protected waters of Discovery Passage but evidence for this has not yet been published. Personal communications from M. Bigg (Pacific Biological Station, Nanaimo, B.C.) and brief observations in the 1974 Annual Narrative Report for Statistical Area 13 (Canada Department of the Environment, 1975) provide the basis for the discussion to follow.

Campbell River appears to lie at the centre of two groups of killer whales (*Orcinus orca*), although Discovery Passage supports one resident pod of about 10 animals. Seven other pods of 107 whales (33% of British Columbia's population) use the Passage on an irregular basis. Concentrations of killer whales in the southern half of Discovery Passage can probably be attributed to schools of Pacific salmon present there during migration to and from home streams in the Strait of Georgia.

Smaller Cetacea that inhabit the Passage include the

dall porpoise (*Phocoenoides dalli*) and harbour porpoise (*Phocoena phocoena*). Other species that might be sighted (on the basis of distributional notes by Cowan and Guiguet, 1973) include the Pacific striped dolphin, the common finback whale, the sei whale and the humpback whale (Appendix 9.2).

Harbour seals (*Phoca vitulina*) have been seen at the mouth of the Campbell River (Canadian Wildlife Service, unpublished data) but this particular species is difficult to census. Bigg (pers. comm., 1976) estimated that there are about 20 harbour seals in Menzies Bay and about 50-75 in the whole of lower Discovery Passage. A herd of 30-40 northern (Steller's) sea lions (*Eumatopias jubata*) resides in the Stuart Island area at the mouth of Bute Inlet. The herd breaks up to feed: singles, pairs and small groups have been observed throughout Discovery Passage (Canada Department of the Environment, 1976).

10. LAND AND WATER USE

10 (i) GENERAL

Campbell River, the largest municipality within the Regional District of Comox-Strathcona covers an area of 13,387 ha (30,055 ac.), extending from Oyster Bay in the south to Duncan Bay in the north. The Municipal District of Campbell River was incorporated on January 1, 1965. In 1976, it had a population of 11,954 compared to 10,000 enumerated in the 1971 Census of Canada (Statistics Canada, 1972, 1976b).

Five electoral areas border the Campbell River District Municipality (Figure 10.1). Of these, two unincorporated districts, Quinsam and North Campbell River, are situated in close proximity to the estuary. In the central part of the study area no organized municipalities exist and the population is confined almost entirely to logging camps in the Upper Campbell Lake area and Sayward District, and to mining operations of the southern end of Buttle Lake. The small permanent population here is associated with recreation and tourist facilities.

A summary report of development possibilities for northern Vancouver Island (B.C. Dept. Economic Development, 1976) states that the forestry sector dominates the economy, with logging, lumber manufacturing and pulp and paper production contributing the largest share to the area's employment income.

The Campbell River area also contains a small non-resource related secondary manufacturing base, including metal fabricating, glass products manufacture, food processing and custom machine shops.

A map of the current land status of the Campbell River area is contained in a report on the land use and resources within the region (Reg. Dist. Comox-Strathcona, 1975).

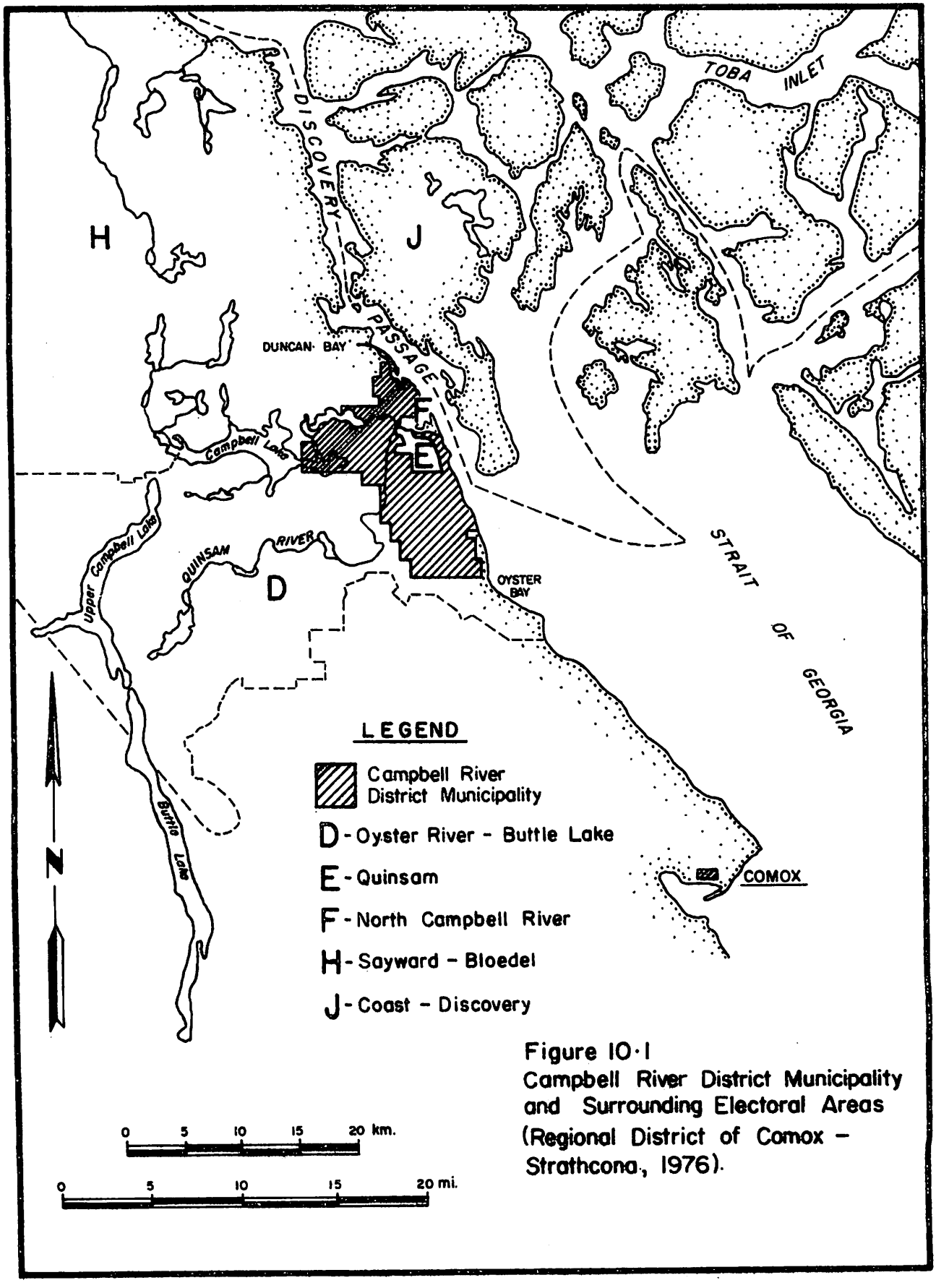


Figure 10·1
Campbell River District Municipality and Surrounding Electoral Areas (Regional District of Comox – Strathcona, 1976).

129. Land and Water Use

The official Regional Plan for the District of Comox-Strathcona currently in the draft stage was adopted on March 28, 1977 and contains maps showing proposed land use for the Campbell River, Menzies Bay, and Oyster Bay areas.

The intent of the Regional Plan is to set out in general terms objectives with respect to future land use in the region, and to establish clear cut policies which the Regional Board can use to govern future decisions with respect to:

a) requests for zoning changes
b) amendments to subdivision regulations
c) establishing areas and priorities for the provision of water, sewer and similar services
d) parks and regional recreation
e) use of land as it pertains in broad terms to energy conservation and transportation

Land use planning policies have been formulated with respect to:

(1) Urban areas; these include all major settlements and lands that are physically or geographically suitable for accommodating future growth.

(2) Urban low density areas, which include existing and proposed areas suitable for housing, and are in proximity to existing urban centres.

(3) Rural resource areas, such as tree farm licence lands and agricultural reserve lands.

(4) Rural low density areas, these are areas where it is felt that the land is undesirable for urban development, or in certain cases, this type of development may provide a buffer between urban and rural areas.

(5) Commercial and industrial areas. The plan does not allocate specific sites, but does set out

policies and guidelines for development. Two types of development are recognized, namely urban and resource oriented. Commercial and industrial development in the estuary is strongly discouraged.

Departmental reference maps compiled by the British Columbia Lands Service provide much useful information regarding current land and water use in the area. Foreshore leases in the Campbell River estuary and adjacent shorelands are shown on Departmental Reference maps R92 F/NW and R92 K/3-6 at a scale of 1 inch to 1/4 mile. A list of the major lessees in the Campbell River estuary is contained in Table 10.1, and corresponds to the lot numbers and locations shown in Figure 10.2

Canada Land Inventory maps provide general information on the land capability for agriculture, forestry, recreation, ungulates and waterfowl within the study area. Indexes and lists of available maps are obtainable from the Environment and Land Use Committee Secretariat library in Victoria, B.C. General mapping of British Columbia land capability was completed in 1972. Current mapping, carried out under the direction of the B.C. Ministry of Environment, Resource Analysis Branch, is confined to special projects for site-specific areas. A list of CL1 land capability maps, B.C. Lands Service departmental reference maps, topographic and geological maps, charts, aerial photographs and other miscellaneous information relating to the study area, is contained in Appendix 10.1.

10 (ii) RESIDENTIAL LAND USE

It has been estimated that of the total 1975 Comox-Strathcona regional population, 92 percent reside within the area of the eastern coastal plain and adjacent islands (Reg. Dist. Comox-Strathcona, 1975). Within the Municipality of Campbell River, residential land use is mainly confined to the western

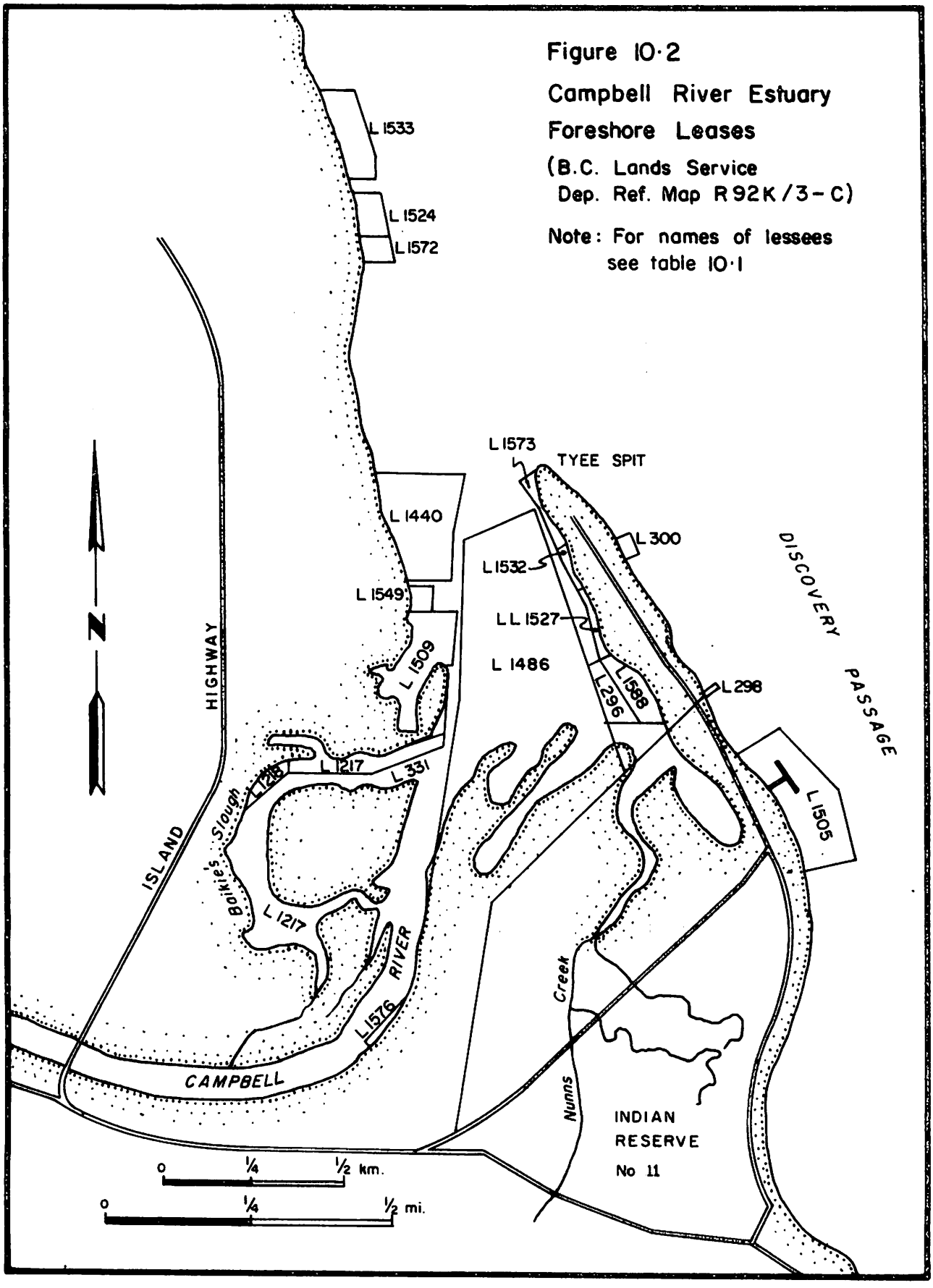

Figure 10·2
Campbell River Estuary
Foreshore Leases
(B.C. Lands Service
Dep. Ref. Map R92K/3-C)
Note: For names of lessees
see table 10·1
L 1533
L 1524
L 1572
L 1573
TYEE SPIT
L 1440
L 300
L 1532
L 1549
LL 1527
L 1509
L 1486
L 1588
L 296
L 298
DISCOVERY PASSAGE
HIGHWAY
ISLAND
L 1217
L 331
L 1218
Bolkie's Slough
L 1217
L 1505
RIVER
L 1576
CAMPBELL
Creek
Nunns
INDIAN
RESERVE
No 11
0 1/4 1/2 km.
0 1/4 1/2 mi.

Table 10.1: Foreshore leases in the Campbell River estuary (For lot location see Figure 10.2).

LESSEE	LOT NO.	SIZE Ha	SIZE Ac	LEASE EXPIRY DATE	USE
R. Thompson	1576	0.04	0.1	Oct. 1976	Mooring floats.
Raven Lumber Limited	1217 B&D	6.6	16.4	Sep. 1974	Log booming and storage.
J.W. Timber Company	1217 A&C	2.8	7.0	Dec. 1974	Marina and island access.
A.J. Robinson	1218	0.4	1.0	Sep. 1974	Marine ways.
R. Kreuger	321 A	0.1	0.2	Jul. 1976	Boat launching and moorage.
Ocean Cedar Products	321 B	0.2	0.4	--	Log storage and burner site.
J.W. Timber Company	1509 A	1.3	3.1	May 1985	Marine ways, shipyard & warehouses.
J.W. Timber Company	1509 B&C	2.2	5.3	- 1973	Marina.
J.W. Timber Company	1509 D	0.6	1.5	Jan. 1976	Log dumping, booming and storage.
Mercury Marina and Trailer Park Limited	1549	0.5	1.3	Feb. 1979	Boat storage.
Elk River Timber Co. Ltd.	1440	6.4	15.7	Oct. 1976	Log storage.
Elk River Timber Co. Ltd.	1486	32.8	81.0	Jul. 1975	Log dumping, booming and storage.
Marian J. Painter	1572	0.8	1.4	Jan. 1991	Boat moorage.
Empress Inn Ltd.	1524	-	-	--	--
Discovery Resorts Ltd. Resort Ltd.	1533	-	-	--	Lodge, boat moorage.

Table 10.1: Foreshore leases in the Campbell River estuary - (continued)
(For lot location - see Figure 10.2).

LESSEE	LOT NO.	SIZE Ha	SIZE Ac	LEASE EXPIRY DATE	USE
*Tyee Trailer Park Marina Limited	1573	1.7	4.2	Dec. 1990	Trailer park and marina.
*Trans Mountain Airlines Ltd.	1532	1.1	2.7	Aug. 1973	Float plane moorage.
*George Cox and Sons logging	1527	0.1	0.3	Aug. 1980	Floats lease.
*Island Airlines Limited	1527	1.1	2.7	Aug. 1980	Float plane moorage.
*Island Ready Mix Co.Ltd.	1588	1.0	2.5	Apr. 1973	Redi-mix plant, sand & gravel storage.
*Island Ready Mix Co.Ltd.	296	1.1	2.8	Apr. 1973	Gravel removal.
Elk River Timber Co.Ltd.	1588	1.7	4.2	Apr. 1973	Log storage.
Elk River Timber Co.Ltd.	300	-	-	Apr. 1980	Boat launch ramp.
Ron Matheson					
Tyee Club					
Okanagan Helicopter					
District of Campbell River	298	0.1	0.3	Feb. 1991	Public boat launch ramp.
Western Mines Limited	1505	-	-		Ore loading dock.

shore of Discovery Passage.

A Regional Plan for the Campbell River area, including the unincorporated districts of Quinsam and North Campbell River, (Reg. Dist. Comox-Strathcona, 1976a), shows the residential land zoned as either urban, or rural low density, with a small area of urban low density located adjacent to Oyster Bay (Figure 10.3). In the Campbell River area 40 percent of the rural population resides within two miles of the municipal boundary.

Indian Reserve lands occupy 142 ha (350.5 ac.) on the south side of the mouth of the Campbell River, and 130 ha (320 ac.) south of Campbellton adjacent to the Quinsam River (Figure 10.3). The Campbell River Band reserve adjacent to the estuary is a flat low-lying property with the highest part a 6 m (20 ft.) high gravel ridge along the eastern side. The central area is subject to daily flooding from tides backing up Nunns Creek which flows through the reserve. The reserve land has 1,707 m (5,600 ft.) of shoreline along Discovery Passage, 975 m (3,200 ft.) of which are a gently sloping tidal flat. The northern 732 m (2,400 ft.) of shoreline drop off more rapidly, accommodating the present site of Western Mine's deep-sea ship loading facility.

In 1924, 32.8 ha (80.9 ac.) of the northern end of the reserve lands were sold to the Elk River Timber Company. In adddition right-of-ways have been granted for the Island Highway (1.69 ha) (4.17 ac.) and the Spit Road (3.55 ha) (8.77 ac.),which pass through the southern end of the reserve. Land leases have also been granted to B.C. Telephone, 0.61 ha (1.50 ac.) until 1992, Western Mines, 2.15 ha (5.30 ac.) until 1990, and for a Municipal ballfield, 0.76 ha (1.88 ac.) on an annual permit.

Plans for development of reserve lands have been prepared by architects and economists (Rawson and Wiles, 1967, Ross, 1972) and include proposals to develop a section adjacent to Tyee Spit,

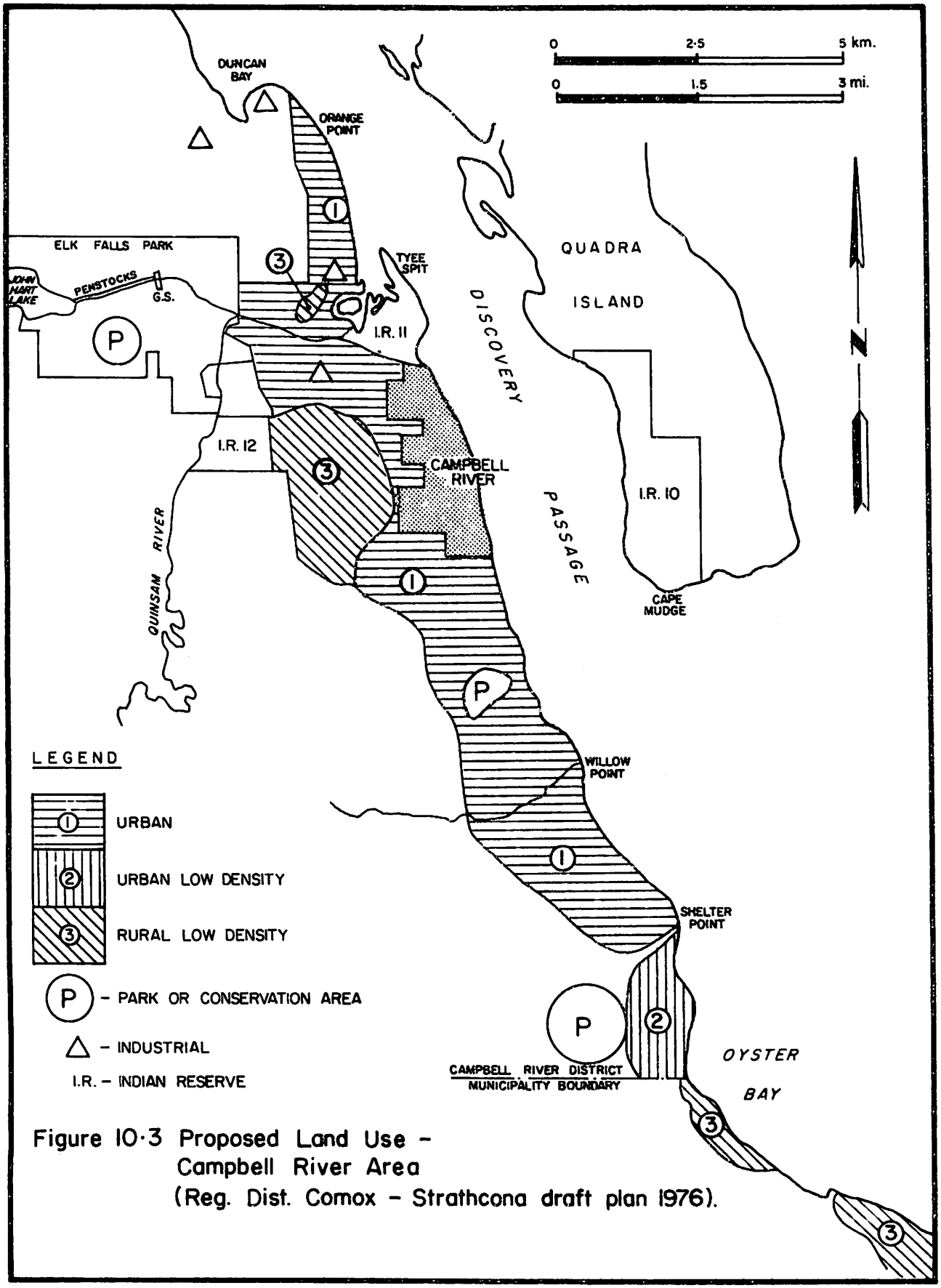


Figure 10·3 Proposed Land Use - Campbell River Area (Reg. Dist. Comox - Strathcona draft plan 1976).

for its recreational, tourist and marina potential. An impact assessment of the proposed marina development on the fisheries resource of the estuary was subsequently prepared by Environment Canada (Goodman and Vroom, 1974). The report recommended that the Campbell River Indian Band Marina development not be located at the site proposed and alternate locations, with much reduced environmental impact, be fully investigated.

10 (iii) RECREATIONAL LAND AND WATER USE

The rivers, lakes and undeveloped lands of the Campbell River area are used extensively for fishing, hiking, camping and other outdoor activities. An outdoor recreational and environmental survey of the entire Campbell River drainage system (Yeomans, 1973) concluded among other things that:

> (1) "Wildlife characteristics of estuarine habitats - the Campbell River in this case - are of enough significance to warrant consideration in any plans made to alter the river's ecosystem". This statement was made in relation to the proposal to increase the power generating facilities at the John Hart G.S.
>
> (2) "The Campbell River and its estuary are capable of supporting with high use in most areas, a variety of recreation activities, including camping, hiking, viewing (of seasonal spawning runs as well as scenery) angling, picnicking, boating, beach activities (on Tyee Spit), waterfowl viewing, canoeing and scuba diving."

The Campbell River system provides a major freshwater sport fishery for steelhead and cutthroat trout. Downstream of the John Hart G.S., the lower reaches of the river are fished extensively for salmon. As early as 1900, the estuary and its contiguous waters had received world-wide recognition among sportsmen for salmon fishing, in particular the Tyee (chinook salmon weighing more than 30 lbs.). The history of the Tyee Club, formed in 1924, and the sport fishery catch statistics have been discussed previously in Chapter 6.

Land capability maps for recreation have been prepared

by the Canada Land Inventory and up-dated to June 1972. Maps are available for the Campbell River area at a scale of 1:50,000 and 1:126,720 (1 inch = 2 miles), and for the Buttle Lake area, at a scale of 1:126,720. These maps show a low to moderate capability for outdoor recreation.

The outdoor recreation capability of the estuary and the Campbell River from John Hart Dam to the river mouth has been analyzed by Yeomans (1973). His findings, based on the Canada Land Inventory land capability classification for recreation, showed that the Campbell River and its estuary are capable of supporting, with high use in most areas, a variety of recreation activities, including angling, boating, camping and hiking.

The estuary marshlands westward from Tyee Spit provide an important habitat for waterfowl and wildlife (see Chapter 9), and having good accessibility, affords a high recreational capability for wildlife viewing. Tyee Spit, without its present industrial land use, could have high recreational capabilities. Yeomans (1973) points out that it is a strategic location for sport fishermen and scuba divers, and could provide good camping, boat launching and mooring facilities. Two trailer parks (Tyee and Silver King) and boat launching ramps are presently leased from the Elk River Timber Co. Ltd., on the north and east sides of the Spit, lots 300 and 1573 (Figure 10.2).

Recreation guide maps for the Menzies Bay and Iron River Divisions have been published by MacMillan Bloedel Limited (Appendix 10.1). These maps show, at a scale of 1 inch to 2 miles, roads, trails, parks, campsites, boat launching locations and points of interest in an area extending from Mohun Lake in the north to Buttle Lake in the south.

A more detailed map showing the same recreational facilities, as well as private roads and trails, has been

compiled and drawn by Doris Stastny Maps, Victoria, B.C. The map of Campbell River and Buttle Lake (updated to 1972), at a scale of 3/4 inch to 1 mile, provides much useful information to supplement the National Topographic Map series.

Maps showing the locations and classes of parks in the Campbell River area are available from the British Columbia Ministry of Recreation and Conservation, Parks Branch, in Victoria. The British Columbia Provincial Park Act, 1965 (Appendix 12.2) defines among other terms, natural resources, parks and recreation areas in the context of land use. The duties of the Provincial Parks Branch, the classification of parks and recreation areas, and the protection of parks under the Archaeological and Historic Sites Protection Act (1965) and other related acts are also outlined in the Park Act.

Provincial parks within the study area occupy a land area of 216,096 ha (533,570 ac.). Most of this land, however, lies within the boundaries of Strathcona Park 56 km (35 mi.) west of Campbell River, the oldest Provincial Park in British Columbia. Della Falls, the highest waterfall in Canada, with an overall drop of 440 m (1443 ft.) in three cascades, is located in the southern section of the park. The highest point on Vancouver Island, Golden Hinde of the Vancouver Island Range, elevation 2,200 m (7,219 ft.) stands almost in the middle of the park west of Buttle Lake.

Two other Provincial parks, Elk Falls and Morton Lake, are located within 30 km (19 mi.) of Campbell River. Within the boundaries of the Campbell River District, municipal parks occupy 32 ha (80 ac.) of land, most of which is south of the Campbell River. A summary of parks located within the study area is shown in Table 10.2.

Table 10.2. Parks located within the Campbell River Study Area.

PARK	SIZE ha	SIZE ac.	LOCATION	JURISDICTION
Strathcona	214,779	530,319	Upper Campbell Lake, Buttle Lake	Provincial
Elk Falls	1,088	2,686	John Hart Lake	Provincial
Morton Lake	67	165	West of Menzies Bay	Provincial
McIvor Lake	162	400	Upper Campbell Lake	Campbell River Municipality
Campbell River Parks	32	80	Within the Campbell River District Boundaries	Campbell River Municipality

A report on the evaluation of proposed greenbelt sites (Reg. Dist. Comox-Strathcona, 1974) included a 4.5 ha (11 acre) parcel of land in North Campbell River. While the site was identified as having few direct fish and wildlife values, it was considered worthwhile preserving as it is one of the few undeveloped sites remaining in the area.

10 (iv) INDUSTRIAL LAND AND WATER USE

The amount of land and water surfaces within the study area that have been developed for industry, storage and manufacturing is significantly higher than the acreage utilized by commercial developments such as tourist resorts, marinas, motels and general retail establishments.

Crown Zellerbach's Elk Falls pulp and paper mill at Duncan Bay is the largest single industrial development on the east coast of the Comox-Strathcona Regional District. The John Hart, Ladore Falls and Strathcona generating stations, with a combined capacity of more than 200,000 kilowatts, have been developed on the Campbell River system, which provides the largest source of power on Vancouver Island. Mining of lode metals, iron near Upper Quinsam Lake, and copper, lead and zinc, at the southern end of Buttle Lake, provides a third major industrial use of land in the study area.

1. THE FOREST INDUSTRY

The forest industry dominates the economy of the Campbell River area. Logging, lumber manufacturing and the production of pulp and paper contribute a major share to the area's employment income. The Elk Falls mill alone, employed an average of 1,219 people in 1976 (Leedham - pers. comm.).

The Sayward Provincial Forest occupies most of the study area north of Campbell Lake. In 1938 the Campbell River fire started about 20 km (12 mi.) west of Campbell River and spread southward, destroying some 30,375 ha (75,000 ac.) of prime timber and immature forest. The Elk River fire of 1951, burned another 9,112 ha (22,500 ac.) before it was brought under control. These and other large fires, combined with the lack of seed sources on large continuous clear-cuts necessitated artificial reforestation by hand planting of large acreages. Over 31,590 ha (78,000 ac.) of Crown and private forest land have been planted since 1930 (B.C. Forest Service, 1962). Most of the seedlings

for reforestation have been produced at the Campbell River forest nursery located on the Quinsam River about 1.6 km (1 mi.) west of Campbell River. The nursery, established in 1940, had produced over 53 million trees by 1962.

In 1970 a Forest Productivity Committee was established by the Deputy Minister of Forests to provide guidelines and leadership in the intensification of forest management practices in British Columbia. An experimental program was designed to provide an adequate data-base for forest management. Among the areas selected for field investigation were installations at John Hart and Menzies Bay. A summary of basic data from these installations is contained in the Forest Productivity Committee, 1972 Annual Report (British Columbia Forest Service, 1972a).

More recently a special committee has been established to formulate a master management plan for the Sayward Forest. In addition to both provincial and federal forestry personnel, the committee includes representatives of the Fish and Wildlife Branch and other land-use agencies (B.C. Forest Service - in progress; see the Flora Section).

In the Campbell River drainage basin the majority of the forested areas have been logged off. While new stands of timber are growing in the area, some logging is still being carried out. In 1974, Crown Zellerbach started logging second growth timber in the Tree Farm Licence 2 area, part of which lies within the Campbell River estuary study limits. West of Menzies Bay, in the Mohun Lake area, logging is being carried out in the Tree Farm Licence 7 area by MacMillan Bloedel.

In 1976, the Crown Zellerbach Elk Falls mill, at Duncan Bay, received 280,000 cunits of logs for processing. Of these, 260,000 were delivered by raft, 10,000 by truck and 10,000 by barge. The mill designed to produce bleached kraft pulp and paper, was opened in 1952. It was the first Canadian pulp and

paper mill designed to sustain production from residual wood fibre (the waste chips, sawdust and hog fuel from logging and lumber operations, that were formerly burned). Much of this material comes from the lumber mills in Campbell River. Again, based on 1976 figures, the mill received 577,900 cunits of chips, sawdust and hog fuel by barge, and 130,900 cunits by rail.

Mill production, based on 1976 figures (Leedham - pers. comm.), was newsprint 724 ADT/D, kraft paper 228 ADT/D and kraft pulp 540 ADT/D. In addition, a sawmill and planer mill produced 210 MBM/D (495.6 cu.m) of lumber from fir and hemlock logs.

The use of the Campbell River estuary for log storage is currently under review by a joint provincial and federal inter-agency task force. A preliminary review of individual estuary uses and their impacts on the environment were analyzed by the British Columbia Lands Branch (Burns, 1976). The Burns report, "A Conservation Plan for the Campbell River Estuary", includes a complete listing of the foreshore leases showing lot number, size, lease expiry date, owner and purpose of lease.

The Elk River Timber Company Ltd., and Raven Lumber are the principal lesseesfor the purpose of log handling, booming and storage in the estuary. Elk River Timber leases 41 ha (101 ac.) of foreshore property (Figure 10.2), while Raven Lumber occupies an additional 6.6 ha (16.4 ac.). By way of comparison, an additional 7.7 ha (19 ac.) of the estuary is leased for boat moorage and marinas, while 2.6 ha (6.4 ac.) are sub-leased on Tyee Spit from Elk River Timber by Island Ready Mix, Island Air, and Tyee Trailer Park (Figure 10.2).

2. POWER DEVELOPMENT

The Campbell River system provides the largest source of power on Vancouver Island. Development of the river for power began in 1945 immediately after the British Columbia Power Commission (now the British Columbia Hydro and Power Authority)

was formed by the Government of British Columbia. In addition to the construction of dams, powerhouses and pipelines, the development of full storage on the system, between 1945 and 1968, required the clearing of about 4,455 ha (11,000 ac.) of land and logging of 35.4×10^7 dm^3 (150 MMfbm) of timber (Ballantyne, 1960).

For a detailed description of the construction of the John Hart, Ladore Falls and Strathcona Projects, including the Salmon, Quinsam and Heber River diversions, the reader is referred to Ballantyne (1960). Table 10.3 summarizes generating capacity and key data for the three projects.

Table 10.3. Campbell River hydro-electric power developments. Power generating capacity and other data.

		JOHN HART	LADORE FALLS	STRATHCONA
Capacity MW		126	54	67.5
Number of Units		6	2	2
Date units placed in service	1 & 2	1947	1957	1958
	3 & 4	1949	-	-
	5 & 6	1953	-	-
Head m (ft.)		123 (402)	38 (125)	43 (142)
Average river flow	cms (cfs)	111.8 (3,950)	111.8 (3,950)	84.9 (3,000)
Maximum plant discharge	cms (cfs)	123.1 (4,350)	172.6 (6,100)	202.1 (7,140)
Usable reservoir storage	cu.m (ac. ft.)	pondage only	319.5×10^8 (259,000)	869.6×10^8 (705,000)

The first stage of the John Hart development, completed in 1947, included a 30 m (100 ft.) high concrete gravity dam, which raised the water above it to elevation 140 m (458 ft.). The dam created an artificial lake (headpond) covering an area of 3.6 sq. km (1.4 sq. mi.), the principal dimensions of which are shown in the following table:

Table 10.4. Morphometry of the John Hart G.S. Headpond (McMynn and Larkin, 1953).

Length	6.4 km (4 mi.)
Width	0.8 km (1/2 mi.)
Mean depth	12.2 m (40 ft.)
Max. depth	22.9 m (75 ft.)
Length of shoreline	27.9 km (17.3 mi.)
Total area	3.6 sq. km (1.4 sq. mi.)
Volume	0.04×10^9 cu. m (1.52×10^9 cu. ft.)

The Ladore storage dam, at the outlet of Lower Campbell River above Ladore Falls, was completed in 1949, and controls 320.71×10^6 cu. m (200,000 ac. ft.) of water in Lower Campbell Lake to an elevation of 178 m (584 ft.). The flooding of the reservoir above Ladore Dam involved the clearing of approximately 1,215 ha (3,000 ac.) of previously logged timber land (Ballantyne, 1960). The morphometry of Lower Campbell Lake before and after flooding has been compared by McMynn and Larkin (1953). Their comparison of the principal dimensions is shown in Table 10.5.

Table 10.5 Morphometry of Lower Campbell Lake, converted from British units. (McMynn and Larkin, 1953).

	Before Flooding	After Flooding	Change
Area	1,088 ha	2,694 ha	+1,606 ha
Length	8 km	15 km	+26 km
Width	0.4 to 3.2 km	0.4 to 4.8 km	
Maximum depth	60 m	76 m	+15 m
Average depth	17 m	17 m	+0.3 m
Length of shoreline	35.7 km	89.1 km	+53.4 km
Shoreline development	4.92 km	7.9 km	3.0 km
Area (hectares)	1,370	1,380	+10

The construction of the Strathcona Development, the third major power system on the Campbell River, was commenced in 1955 and completed in 1958. The project included the clearing of some 3,240 ha (8,000 ac.) of forest land extending 56.4 km (35 mi.) from the damsite to the south end of Buttle Lake, in mountainous terrain, much of which supported dense stands of timber.

Part of the reservoir site lay within the Strathcona Provincial Park. Because of its highly recreational capability, the British Columbia government required that four main conditions be met (Ballantyne, 1960).

1. That merchantable timber be salvaged.
2. That all debris be removed from the reservoir site.
3. That the area be preserved or enhanced for park purposes.

4. That an access road be built for public use.

To meet the fourth condition, 19 km (12 mi.) of road were constructed at a cost of approximately one million dollars. Reservoir clearing was divided into two general sites. One, 721 ha (1,780 ac.) on the shores of Buttle Lake between elevations 214 m (700 ft.) and 225 m (737 ft.), and the other 2,511 ha (6,200 ac.) in the Upper Campbell Lake Valley, between elevations 189 m (620 ft.) and 225 m (737 ft.). In the Buttle Lake area, approximately 2.36×10^8 dm^3 (1×10^8 fbm) of timber were logged and sold. Stand densities of up to 4.72×10^5 dm^3 (2×10^5 fbm), or 400 cords per acre, were common in this area. Details of the clearing operations, including methods, have been described by Ballantyne (1960).

Since 1970, plans to increase the total generating capacity of the Campbell River system have been prepared for the British Columbia Power Authority (IPEC, 1970, 1973), but to date, have not progressed further than the feasibility study stage. Comparisons have been made of three alternative schemes for a 150 MW power development utilizing the present John Hart forebay, and discharging either into Duncan Bay on the coast, or Campbell River near the existing powerplant. The three arrangements studied were:

1. An underground powerplant having underground conduit and discharging into Duncan Bay at tidewater.

2. An underground powerplant having underground conduits and discharging into the Campbell River, about 182 metres (600 feet) upstream of the existing plant.

3. A surface powerplant having surface conduits, and discharging into the Campbell River about 30 metres (100 feet) upstream of the existing plant.

Subsequently, a report was prepared (IPEC, 1973) on the downstream flow conditions (Campbell River below the John Hart powerplant), associated with increased discharge from the proposed arrangements. Downstream flow conditions have been discussed previously under the Hydrology Section. The effects on fish habitat and the industrial and recreational use of the river and the estuary are discussed in Section 6 (Fish) and Section 12 (Effects of Development).

3. MINING

Land use related to the production of lode metals, iron, copper, lead and zinc, and the excavation of gravel and sand for commercial use, has been discussed in Section 2 (Geology and Soils). Operations currently active are confined to the south-west end of Buttle Lake (Western Mines) and to a sand and gravel plant operation approximately 8 km west of Campbell River (Island Redi-Mix).

4. AGRICULTURE

The Canada Land Inventory agricultural capability maps for the Campbell River area (Appendix 10.1) show very little land in the study area suitable for agriculture. Most of the local farming is carried out in the Quinsam Valley, where moisture deficiency in the soil makes the land only suitable for permanent pasture or forage. A small area on and adjacent to the Indian Reserve No. 12 is classified as suitable for growing a reduced range of crops due to undesirable soil structures.

5. PORT FACILITIES

Campbell River is classified as a Canadian Port of Entry with a resident Collector of Customs (Can. Hydrographic Service, 1965). A federal government wharf and small craft harbour are located on Discovery Passage, just south of the city centre. The harbour is sub-leased from the government by the Regional District of Comox-Strathcona.

Facilities to handle deep-sea ships are located on the eastern side of Tyee Spit and at the Elk Falls mill in Duncan Bay. The Argonaut wharf, 122 m long, with a depth of 11.8 m alongside, was built off Tyee Spit to ship iron concentrate from the Iron Hill mines to Japan and the United States of America. A total of 2,193,917 short tons of concentrate, left Campbell River between 1951 and 1957, destined mainly for Japan. The wharf fell into a state of disrepair after 1957, but was rebuilt in 1966 by Western Mines Limited to ship copper and zinc ore and concentrate from their mines at Buttle Lake. A summary of the tonnages of concentrate shipped during the period 1972 to 1975 is shown in Table 10.6.

Docking facilities for barges and deep-sea vessels have been built in Duncan Bay at the site of the Elk Falls pulp and paper mill. These facilities have been designed to accommodate vessels ranging from 30,000 ton freighters, to tug-towed coastal barges of 800 tons. There are two wharves, a shipping wharf and a pulp wharf, with a depth alongside of 9.1 m. (Can. Hydrographic Service, 1965).

An average of six ships a month are loaded with pulp, newsprint or lumber for markets in Holland, Australia and the Far East, in addition to the West Coast ports (Crown Zellerbach, 1975). A summary of tonnages of forest industry products loaded and unloaded for the period 1972 to 1975 is shown in Table 10.6.

Table 10.6. Total metric tonnes of cargoes loaded at Campbell River and Duncan Bay (Elk Falls mill) for foreign destinations, for years 1972, 1973, 1974 and 1975. (Statistics Canada, 1974b, 1975a, 1975b, 1976a).

Commodity	Metric Tonnes Loaded			
	1972	1973	1974	1975
Copper ore and conc.	21,156	10,007	13,518	4,980
Zinc ore and conc.	23,614	35,328	35,133	11,594
Lumber and timber	52,321	38,924	27,088	10,004
Pulp	281,081	279,550	234,335	79,577
Newsprint paper	174,434	168,866	186,096	132,018

10 (v) MUNICIPAL SERVICES

1. WATER SUPPLY

Water supply systems in the Campbell River area are managed by two water districts, the Greater Campbell River Waterworks District and the North Campbell River Waterworks District.

The former was incorporated in 1962, by a Provincial Act of Parliament (Appendix 12.2). The corporation formed by the Act included:

(a) The Corporation of the Village of Campbell River
(b) The Willow Point Waterworks District
(c) The Quinsam Heights Waterworks District

Surveys of existing water supply systems in the Campbell River area and evaluations of future requirements have been carried out by the Water Rights Branch, B.C. Department of Lands and Forests (Marr, 1961) and Dayton and Knight Ltd. (1972).

In 1949, the Village of Campbell River, under agreement with the B.C. Power Commission, installed a new water system using the newly formed headpond for the John Hart generating station as

a supply source. A single 8-inch supply main connected to the power plant penstocks fed the village distribution system and a 682.5 cu. m (150,000 Imp. gal.) tank, providing storage near the south end of the system.

Prior to 1962, the residents of Quinsam Heights had no piped water supply, and relied on water pumped from individual wells. A study of groundwater resources of the coastal lowland on the east coast of Vancouver Island, includes the Campbell River area (Halstead and Treichel, 1966). Wells dug in the vicinity of the Quinsam River, Quinsam Indian Reserve and Willow Point showed the water table ranging from 4 m (13 ft.) to 8.5m (28 ft.). Wells drilled in the Willow Point area encountered aquifers ranging in depth from 8.7m (29 ft.) to 28 m (93 ft.). Groundwater in the Campbell River area is found in confined aquifers beneath till or older sediments. Large diameter wells recover limited supplies of water from till deposits. At the Quinsam Indian Reserve a 20,000 gallon tank stores water pumped from a 4.8 m (16 ft.) well dug in fluvial and channel deposits in the Quinsam River Valley.

Water pumped to a 910 cu. m (200,000 gal.) storage tank, from a reservoir on Willow Creek, originally supplied the Willow Point District. By 1960, this system was considered inadequate, being severely limited by dependable flows at its source.

Four sources have been investigated for the future water supply for the Greater Campbell River Water District (Dayton and Knight Ltd., 1972). These were: groundwater sources, Campbell River - Buttle Lake, Oyster River and Quinsam River.

Groundwater was excluded as a supply source on the results of a preliminary groundwater survey by Robinson, Roberts and Brown Ltd. (1968), who concluded that the major part of the area between the Campbell River and the Oyster River is not suitable for the development of large capacity wells.

The Dayton and Knight (1972) report concluded that the Oyster River watershed offers the Campbell River Water District an excellent alternate source to the Campbell - Buttle Lake system. Water from the Quinsam watershed was thought to be of questionable quality. The report recommended that in addition to obtaining rights for a peak supply of 11.0×10^6 (gpd) from the John Hart penstocks, the Water District take the necessary steps to secure water rights and a map reserve on the Oyster watershed.

Subsequent to the 1972 water supply survey, a design report was prepared for the Water District (Dayton and Knight, 1975), for a second water supply main from the John Hart penstocks. A preliminary survey of the area between the penstocks and Campbell River (Willow and 14th) was completed in January 1975, to establish a preferred routing for the first phase of the proposed supply main.

The North Campbell River Waterworks District incorporated in 1953 under the British Columbia Water Act (Appendix 10.2) includes the area north of the Campbell River to the Municipal Boundary, from the shoreline of Discovery Passage to a boundary line just west of the Island Highway (AESL, 1971). Two of the major users within the District are the Elk Falls mill, in Duncan Bay, which consumes approximately 45 percent of the total usage in the District, and the Raven Lumber Company, which in 1970 used an average of 10,000 gpd.

The North Campbell River Water District receives its water supply from the penstocks of the John Hart powerplant, under an agreement allowing the diversion of 400,000 gpd. The water is fed to the District's distribution system by a 10-inch line installed in 1957.

A water report completed by Associated Engineering Services Limited (1971), concluded that the present supply system was adequate to meet the estimated domestic and industrial

water consumption until 1990. The report also recommended that should the water supply agreement with B.C. Hydro and Power Authority have to be amended, the maximum daily diversion should be increased from 400,000 gpd to 800,000 gpd.

In addition, the District should acquire sites for future storage reservoirs that will eventually be required for balancing and emergency water supply. The installation of a new 10 inch high pressure distribution main to service the increasing domestic demand at the north end of the District was also recommended. This line would also replace the existing 5 inch woodstave pipe, which presently supplies Elk Falls from a pumphouse on the Campbell River 300 m (1,000 ft.) upstream of the confluence with the Quinsam River.

2. SEWER SYSTEMS

In 1967, the Campbell River sewer system served a small area comprising the nucleus of the town of Campbell River. A study of the alternatives available for the development of a sanitary sewerage system to serve all the developed and developing areas south of the existing sewer system was undertaken for the District of Campbell River, by Willis, Cunliffe, Tait and Company Ltd. (1967). This was followed by a second study (Willis, Cunliffe, Tait and Company Ltd., 1969), which outlined three alternative schemes for a system of trunk sewers, a treatment plant and outfalls to serve the entire community from Campbellton south to Willow Point.

Of the three alternatives proposed (schemes A, B and C), scheme C was chosen by the District Municipality to meet the requirements of the time. The proposal was to direct the sewage from all areas to the location of the existing outfall near Fisherman's Wharf, and to build a primary treatment plant near the outfall. Subsequent to the consulting engineer's report, the District acquired the necessary land to build the treatment plant as proposed.

In 1971, Willis, Cunliffe, Tait and Company Ltd. completed a study of the capacities of existing pump stations, force mains and trunk sewers installed at that time. The study reviewed the recommendations of the 1969 report, and provided an up-dated cost analysis of the original scheme C amended to include an initial treatment plant capable of providing secondary treatment for 15,000 persons. The plant, located near Fisherman's Wharf, at the junction of Island Highway and 6th Avenue, was subsequently constructed and officially opened on August 23, 1974 (R. Fuoco - pers. comm.). Treated sewage is discharged into Discovery Passage via a 61-cm (24-in.) diameter outfall extending 305 m (1,000 ft.) offshore. Prior to the construction of the treatment plant, raw sewage was discharged 183 m (600 ft.) offshore, through a 30-cm (12-in.) diameter outfall.

A study, initiated by the Regional District of Comox - Strathcona (Willis, Cunliffe, Tait and Company Ltd., 1973), described the existing municipal sewer system for Campbell River, and investigated the feasibility of integrating it with additional systems for the Quinsam District (Electoral Area "E") and North Campbell River.

The study also noted that in the Campbell River area, the nature of the terrain and soil conditions, do not make the disposal of effluent on land from sewage treatment plants economically feasible. Alternate sites for the disposal of effluent offshore or into the Campbell River were reviewed. One such site was that of the present outfalls owned by Crown Zellerbach at the Elk Falls mill.

At this location, flows up to 0.91 cms (12,000 gpm) of industrial waste are pumped through outfalls which discharge some 30 m (100 ft.) to 60 m (200 ft.) offshore. A small secondary sewage treatment plant with a rated capacity of 25,000 I.g.p.d. treats domestic wastes and plant effluents (Willis, Cunliffe, Tait and Company Ltd., 1973). It was suggested that with agreement from

Crown Zellerbach, it might be possible to dispose of treated sewage from parts of North Campbell River through their outfalls.

The construction of an outfall discharging into the Campbell River, while considered technically feasible, was discounted on the basis that it would receive many objections, especially in view of the fact that other alternative sites were available.

In 1975, a further study of the alternatives available for the provision of sanitary sewers for the Quinsam District was made for the Regional District (Associated Engineering Services Ltd., 1975). The study evaluated two alternative proposals:

> (1) "That the Regional District acquire the additional function of owning and operating trunk and treatment facilities, and provide trunk and treatment services to what would be two independent sewer authorities."
>
> (2) "That the District of Campbell River retain responsibility for all their existing facilities, and provide trunk and treatment plant service to Quinsam Specified Area for an annual fee."

3. PROPOSED NATURAL GAS SYSTEM

The preliminary routing of the proposed B.C. Hydro and Power Authority natural gas transmission system follows a route approximating that of the present 138 kv transmission line from Duncan Bay to the southern extremity of Vancouver Island.

The proposed pipeline route crosses the Campbell River, the Quinsam River and Menzies Creek. Both buried pipeline and aerial crossings of the Campbell River have been proposed. The timing of river crossings for construction, and their impact on the sensitivity of the local fishery resource to disruption has

been evaluated for B.C. Hydro by H. Paish and Associates Ltd. (1974). The results of their investigations have been discussed earlier in this report under Section 6 (Fish).

10 (vi) TRANSPORTATION

The Campbell River airport located west of Willow Point was officially opened on September 28, 1959 (Mitchell, 1966). A runway 91 m (300 ft.) long by 1,372 m (4,500 ft.) wide handles scheduled flights from Vancouver, for aircraft operated by Pacific Western Airlines.

In 1946, B.C. Airlines Limited established a seaplane base at the mouth of the Campbell River. In 1959, a second company was established, Island Airlines Limited. At the present time, three air services operate from bases located at Tyee Spit. These companies, Island Airlines Ltd., Gulf Air Aviation Ltd., and Okanagan Helicopters Ltd., provide the main service for supply and transportation to the isolated logging camps and communities on northern Vancouver Island.

A ferry terminal, located near Tyee Plaza in Campbell River, provides a daily service from the city centre to Quathiaski Cove on Quadra Island. Island Highway No. 19 provides the main access between Campbell River and the coastal communities on the eastern coast of Vancouver Island.

11. POLLUTION AND WATER QUALITY

11 (i) GENERAL INTRODUCTION

This chapter describes the technical nature of pollution problems in the Campbell River watershed, estuary and contiguous marine waters and discusses water quality data for those areas. Socio-economic factors are touched upon in the Section entitled "Effects of Development", and a brief discussion of environmental law comprises Appendix 12.

11 (ii) POLLUTION CONTROL BRANCH PERMITS

The mechanism for controlling solid, liquid or gaseous pollution by shore-based industrial installations in British Columbia consists of a Pollution Control Board, which prescribes standards for pollutant emission, and the Pollution Control Branch of the B.C. Ministry of the Environment, which applies those standards by deciding whether to issue a permit allowing contamination of the environment, according to criteria established by the Board. (The legality of this system is established by the Pollution Control Act 1967, R.S.B.C., C34, S1). Most industrial discharges in the Campbell River region are now under Pollution Control Branch permit (see Appendix 11.1 for the list).

The permittee is usually required to monitor its own emissions. Data accumulated in this fashion are stored in the computer data base ("EQUIS") of the B.C. Ministry of the Environment (described by Clark and Ellis, 1975), and can be retrieved by permit number, jurisdictional boundaries, watersheds, types of industry, geographical location and sampling agency. A retrieval from EQUIS on February 15, 1977 yielded emission, effluent, and ambient air and water quality data for nearly 100 sites in the Campbell River watershed and nearby marine waters (Appendix 11.2).

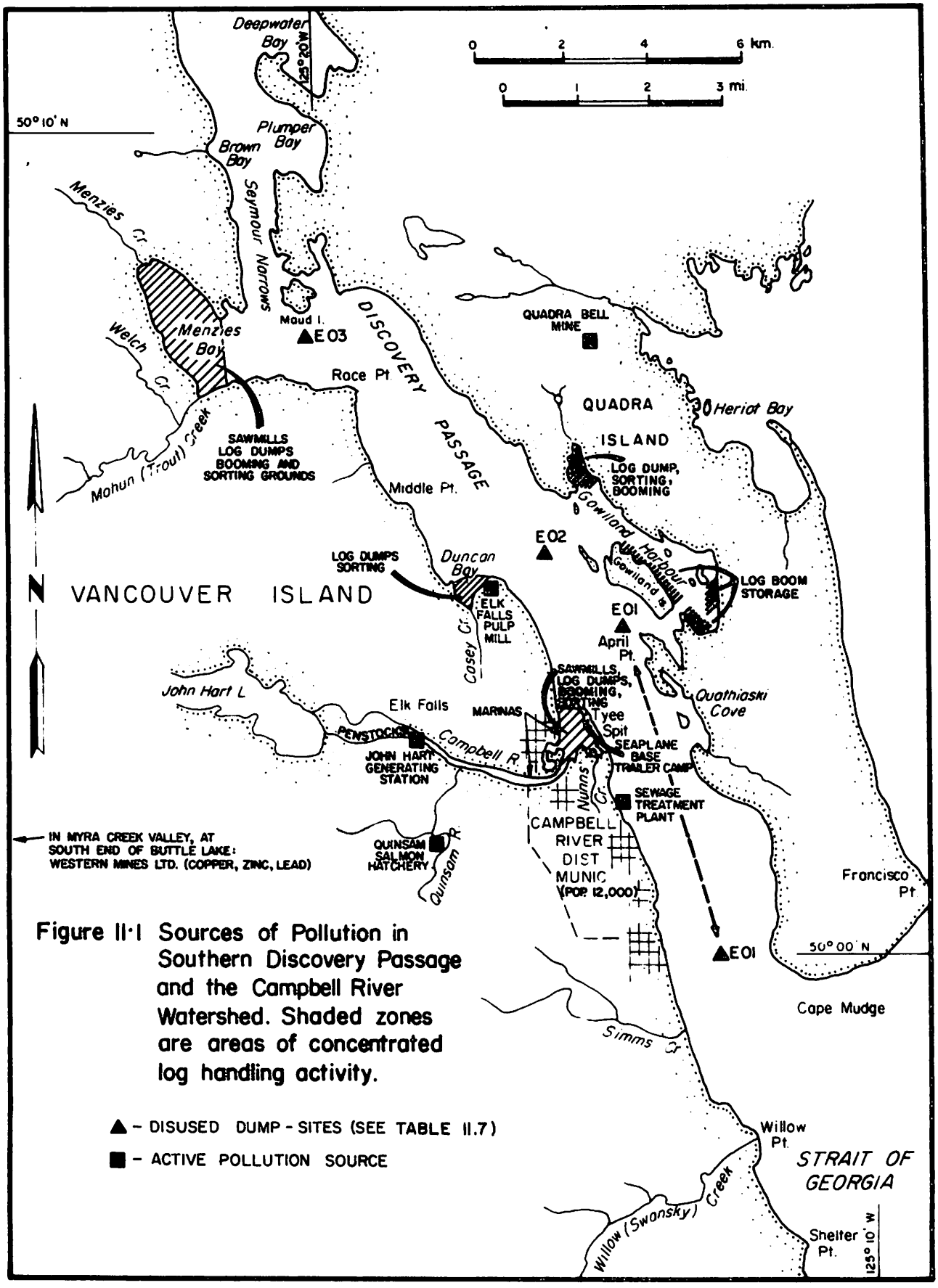


Figure II·1 Sources of Pollution in Southern Discovery Passage and the Campbell River Watershed. Shaded zones are areas of concentrated log handling activity.

Disposal of three classes of pollutants are exempt from the provisions of the Pollution Control Act:

1. Discharges of domestic sewage from single or double-unit dwellings.

2. Discharges of domestic sewage totalling less than 5,000 Imperial gallons per day and not discharging into surface water. This usually includes septic tanks. Information on septic tank operation must be obtained from the local office of the B.C. Ministry of Health.

3. Certain farm wastes. (Farming is not practised extensively in the Campbell River area - see Land Use).

11 (iii) CAMPBELL RIVER WATERSHED

1. WATER QUALITY BASELINE

Historical water quality data for the Campbell River watershed is available from several sources. The first is a series of three papers by Carl (1937), McMynn and Larkin (1953) and Sinclair (1965). Carl's report is a preliminary limnological survey carried out before hydroelectrical development disrupted the watershed in 1945. McMynn and Larkin (1953) were concerned with determining the effects of development by 1951, and predicting the impact of future work on fish habitats in the upper river system. Their report documents lake morphometry, character of the flora and fauna, and water chemistry, indicating that in June, 1951 Buttle Lake, upper and lower Campbell Lakes and the John Hart Head Pond all contained soft (40-68 ppm total dissolved solids), well oxygenated (83-90% saturation) and clear water. Only lower Campbell Lake exhibited a thermocline, which existed in the summer at a depth of 7.6 - 12.2m. The temperature in the epilimnion was 18.2^{o}C and the underlying hypolimnionic temperature was 4.0^{o}C.

Sinclair (1965) compared this information with data he collected after Upper Campbell Lake and Buttle Lake were flooded by the Strathcona Dam in 1958. We discuss his findings more fully in "Effects of Development", but it is relevant here to note that the only physical or chemical change in these two lakes and Lower Campbell Lake was an increase in water level fluctuation, while thermal, oxygen, light penetration and hardness regimes appeared to remain the same.

Several years of water quality data for two stations in Buttle Lake, and one station on the Campbell River near John Hart are available from the Water Quality Branch (Canada Department of the Environment, 1974a for data collected 1967-1971, and unpublished data since 1972). These values are to be regarded as tentative baseline information, particularly the values for nutrients like nitrogen and phosphorus (McBratney, pers. comm., 1977), but it does point out the coldness (75% of 54 samples were below 14.4°C) and softness (16.4-23.0 mg $CaCO_3$/l) of Campbell River water above the Quinsam confluence.

A second important compilation of water quality data from 1970 onwards exists in the form of B.C. Pollution Control Branch computer files. Those stations for which chemical data exist are listed in Appendix 11.2, and the complete suite of values for one site on each of the three major freshwater sources for the Campbell River estuary (Campbell River, Quinsam River and Nunns Creek) are reproduced in Table 11.1, providing the reader with an indication of (1) the quality of the freshwater draining from the entire watershed, and (2) the character of the freshwater that enters both the Elk Falls Pulp Mill and the Campbell River estuary.

No such data are available for other streams that enter Discovery Passage between Seymour Narrows and Oyster Bay, on either Quadra or Vancouver Islands.

Table 11.1. Water quality data for the Campbell River at John Hart Generating Station, Nunns Creek below Giasson Mobile Home Park, and the Quinsam River above its confluence with the Campbell River. The symbol "L" indicates "less than".

PARAMETER	UNITS	P.C.B. SITE NO. 0920099 CAMPBELL RIVER	P.C.B. SITE NO. 0125221 NUNNS CREEK	P.C.B. SITE NO. 0126400 QUINSAM RIVER
Colour true	rel unit	--	7: 25 (20 - 40)	17: 10
Colour apparent	rel unit	14: 5 (0 - 10)	--	--
pH	rel unit	13: 7.4 (7.0-7.7)	10: 7.55 (7.2-8	19: 7.5 (6.8 - 8.2)
specif. cond.	µmho/cm	13: 41 (38 - 56)	10: 134.5 (100 -150)	20: 51.5 (14 - 90)
temperature	deg C	14: 7.3 (3.6- 17)	7: 14 (2.5 - 20)	13: 10 (1 - 13.5)
turbidity	J.T.unit	13: 0.9 (0.3- 12)	7: 1.3 (0.8 - 13)	17: 1 (0.3 - 2.3)
alkal. (total)	mg/1	13: 18 (15-20)	--	--
chloride	mg/1	10: 0.5 (0.9-10)	1: 13.5 (13.5 -13.5)	--
fluoride	mg/1	4: 0.05 (L.05-07)	--	--
hardness	mg/1	14: 18.9 (16.5-20.9)	6: 39.95(24.5 - 55)	16: 26.8 (18.1-37.8)
ammonia	mg/1	4: 0.1 (.05-L.1)	--	--
NO_2/NO_3	mg/1	13: 0.02 (L.003-.03)	2: 0.66 (.35-.97)	5: 0.04 (.01 - .08)
Phosph. (total)	mg/1	3: .0033 (1.003-.02)	7: 0.021(.01-.06)	14: 0.011(.004-.026)
silica	mg/1	13: 3.7 (3.2 -4)	--	3: 6.8 (6.7 - 7.7)
sulphate	mg/1	10: 1.7 (0.6 -2.2)	5: 5 (L5 -6.2)	14: 5 (1.7 - 5)
CO_2:free	mg/1	9: 1.74 (.8 -3.16)	--	--
bicarbonate	mg/1	2: 21.5 (21 - 22)	--	--
carbonate	mg/1	2: 0 (0 - 0)	--	--
calcium (diss.)	mg/1	10: 6.3 (6 - 6.7)	4: 7.65 (5.7 -11.5)	9: 7.4 (5.1 - 11)
copper (total)	mg/1	2: 0.01 (.01 -.01)	4: .001(L.001-.011)	15: 0.001(L.001-L.01)
iron (diss.)	mg/1	6: 0.005 (0 -.02)	*4: 0.43 (.35 - 3.6)	2: 0.26 (0 -0.4)
lead (total)	mg/1	2: 0.01 (.01 -.01)	4: 0.002(L.001-.011)	15: 0.001(L.001-.011)
magnesium (diss.)	mg/1	10: 0.6 (.3 - 1)	4: 3.25 (2.5 - 4.5)	9: 1.37 (1 -2.5)
solids (total)	mg/1	--	8: 101 (76 - 124)	17: 46 (36 -64)
solids (diss.)	mg/1	--	3: 92 (80 - 102)	7: 40 (32 -54)
solids (susp.)	mg/1	--	6: 1.65 (L1 - 18.5)	15: 2 (1 -10)
oxygen (diss.)	mg/1	--	7: 9.9 (8 - 13)	13: 10.4 (7.8 -13.7)
nitrate	mg/1	--	6: 0.515(.21 - .97)	15: 0.04 (L.02 -.22
nitrite	mg/1	--	6: 0.007(L.005-.008)	15: 0.005(L.005-L.005)

PARAMETER	UNITS	CAMPBELL RIVER	NUNNS CREEK	QUINSAM RIVER
BOD	mg/l	--	2: 10 (L10 - L10)	--
COD	mg/l	--	6: 14 (L10 - 23)	14: 10 (7.5 -13.5)
surfactants	mg/l	--	5: 0.03 (L.03 - L.03)	9: .03 (0 -L.03)
tannin-lignin	mg/l	--	7: 0.4 (L.01 - 1.3)	13: .3 (0.2 -0.6)
mercury (total)	µg/l	--	3: 0.05 (L.05 - 0.3)	14: 0.05 (.02 -.13)
zinc (total)	mg/l	--	4: 0.005(L.005- .02)	15: 0.005(L.005-L.005)
fecal coliform	MPN	--	8: 240 (20 -G2400)	12: 18.5 (L2 - 240)
total coliform	MPN	--	6: 2400 (542 - 3500)	12: 121 (2 -G2400)

NOTE: These data are from the period January 01, 1970 to February 18, 1977. The Campbell River station was also surveyed between 1967 and 1971, data for which recorded in a publication by the Water Quality Branch (1974), as Station 00BC08HD001. The locations of all three stations are given in Appendix 11.2.

The first figure in each set indicates the number of measurements available, the figure after the colon indicates the fiftieth percentile (the value below which 50% of the values fall), and the two numbers in parentheses indicate the range of values (i.e. maximum and minimum). Data compiled from B.C. Pollution Control Branch computer files, reported in a printout supplied in February, 1977 by M.Clark (P.C.B., B.C. Ministry of the Environment, Victoria).

* This entry is for total (not dissolved) iron.

Halstead and Treichel (1966) have written a summary of information pertaining to groundwater between Nanoose Bay and Campbell River, providing a description of: surficial and historical geology; the occurrence and use of groundwater; well records; and groundwater quality. Chemical tests were not run on groundwater closer to Campbell River than Comox and Quadra Island. An artesian well was plotted in 1966 very near the Quinsam River just below Cold Creek, although the urban region surrounding the estuary is supplied with water from the Campbell River system.

2. WESTERN MINES (BUTTLE LAKE)

The fact that the town of Campbell River receives its domestic water from the Campbell River explains why a great deal of concern arose over tailings disposal from Western Mines Ltd. operations in Myra Creek Valley on the south end of Buttle Lake, uppermost lake in the watershed (B.C. Research, 1966; Wright Engineers, 1966a, b; Langford, 1968, 1969; Binnie, 1971; Barren and Binnie, 1972; Steward, 1972; B.C. Research, 1974; Baillie and Morrison, 1977).

The mine yields copper, zinc and lead ores, which are processed through a concentrator on the site, generating a considerable volume of slurry-like tailings. When the plant opened in December, 1966, these tailings were pumped into a small, confined tailings pond, but in 1967 the B.C. Pollution Control Branch permitted Western Mines to dump the tailings slurry into Buttle Lake through a submerged outfall (permit No. 185, May 8, 1967). In the years that followed, as many as five agencies monitored water quality in Buttle Lake. Finally in 1974, B.C. Research (under contract to the Pollution Control Branch) published a summary and review of everyone's findings:

1. Between the five agencies, 50 different water quality parameters were measured.
2. Pollution Control Branch and B.C. Fish and Wildlife Branch values for copper, total lead and dissolved zinc were

influenced by brass samplers used prior to April 1971. Heavy metals and total and dissolved solids values reported by Western Mines were influenced by the laboratory doing the analysis.

3. The only parameters found to increase in value were cyanide and dissolved copper when the mill changed its process. This was corrected for cyanide by adjustment of the process.
4. Significant increases of total zinc, dissolved zinc, total solids, dissolved solids and turbidity were discovered in deeper water. There was no difference between any of the surface stations.
5. There was no difference in water characteristics measured between the unaffected stream water entering Buttle Lake and the water leaving Buttle Lake through its outfall.
6. Zinc concentrations in the livers of fish from Buttle Lake have not changed since 1966. Copper increased between 1966 and 1969, whereupon it levelled off. Liver content of lead increased significantly between 1969 and 1971, and 1971 and 1972.
7. Water quality leaving Buttle Lake was better than Canadian Drinking Water Standards, and in fact, copper and zinc levels were lower than the standards.
8. Lake water--even in the vicinity of the tailings outfall did not exceed suggested standards for fish when expressed as mean values.
9. The tailings were non-toxic to rainbow trout (*Salmo gairdneri*) in 96 hour bioassays when a flocculent was added, as was the practice on site.

A recent report by Baillie and Morrison (1977) reported that the levels of copper in fish livers from Buttle Lake were six times those in livers from fish in unaffected lakes (average 621 µg/g, as opposed to 103 µg/g in background fish--Table 11.2). The concentrations of mercury, zinc and moisture in the livers and muscle of fish from Buttle Lake were not significantly different from those of unaffected lakes on Vancouver Island (Alice, Comox, Great Central, Maynard, Kennedy and Benson lakes).

Table 11.2 Heavy metal and moisture content of the tissues of fish sampled from Buttle Lake and unaffected lakes (Alice, Benson, Comox Great Central, Maynard and Kennedy lakes). From Baillie and Morrison (1977).

Constituent	Concentration in µg/g
Mercury (dry muscle)	0.05 - 0.60 (average 0.33)
Zinc (liver)	44.5 - 360 (average 124.1)
" (dry muscle)	10.7 - 175 (average 28.3)
Moisture (liver)	70.4 - 88.4% (average 78.4%)
" (muscle)	64.0 - 83.5% (average 77.7%)
Copper (liver)	Buttle Lake 20.9 - 1980 (avr. 621)
	Other lakes 1.98 - 1303 (avr. 103)
" (dry muscle)	All lakes 0.50 - 6.6 (avr. 2.2)

The final conclusion was that tailings disposal to the bottom of Buttle Lake had no detrimental effect on the quality of the water for domestic purposes. But there was insufficient data to judge the effect on flora and fauna, other than the fact that no fish kills were reported. A complete list of P.C.B. permits for Western Mines can be found in Appendix 11.1.

3. HYDROELECTRIC DEVELOPMENT

Developments anywhere in the watershed can perturb an estuarine ecosystem. Hydroelectric developments on the Campbell

River have been shown to affect the habitats of flora and fauna upstream of regions inaccessible to anadromous fish due to clearing, flooding and water level fluctuations (Carl, 1937, McMynn and Larkin, 1953, and Sinclair, 1965). These limnological changes have presumably affected food supply and water quality in the estuary, but the lack of available information makes that premise difficult to support. The pertinent documents here are Hamilton and Buell's (1976) report on the effects of modified hydrology on salmonid populations in Campbell River below John Hart, and a report being prepared by B.C. Research for the British Columbia Hydro and Power Authority (Ferguson, pers. comm., 1977) on the limnology of the lakes in Campbell River's watershed, although both of these are geographically directed at the aquatic environment upstream of the estuary. Refer to "Effects of Development" for a discussion of these reports.

4. OTHER DISTURBANCES

Local District Conservation Officers and Habitat Protection biologists of the B.C. Fish and Wildlife Branch have files detailing problems with stream crossings and diversions, siltation, and the dumping of noxious substances in the watershed. Pesticides are not used in the Campbell River watershed for forest protection (Dehart, pers. comm., 1977) and in fact the only recent pesticide use to come to light was a proposal by B.C. Hydro and Power to spray Brushkiller 96 (2,4-D + 2,4 5-T 150-acetyl esters) on its power transmission corridor between Campbell River and Kelsey Bay to keep down alder and maple growth (B.C. Department of Agriculture Project Number 105-47-76). Fertilization of lakes and trees in the Sayward Forest is being planned (Barker, pers. comm., 1977), but no unusual nutrient loading is expected to result in the lower Campbell River (Sjolund, pers. comm., 1977).

Jurisdictional overlap between federal and provincial authorities can occur in those portions of the Campbell River system used by anadromous salmon. For this reason, some information on acts of pollution in the watershed can be gleaned

from federal Fisheries Operations Files (Fisheries and Marine Service, Vancouver) and discussions with authorities in the federal Environmental Protection Service. The Quinsam River file in Fisheries Operations details how fisheries personnel from the Habitat Protection Directorate of the Fisheries and Marine Service monitored construction of a 30-inch (76.2-cm) water main from John Hart Head Pond across the Quinsam River and Kingfisher Creek in order to minimize the impact on salmonid stocks.

Crown Zellerbach's Elk Falls Pulp Mill draws about 60 million gallons of water per day (3.16 cms) from the Campbell River just above its confluence with the Quinsam for use in its pulping operations, after which it is discharged to Duncan Bay in Discovery Passage.

The Quinsam Salmon Hatchery represents a potential nutrient loading problem for the Quinsam River because of the waste organic matter generated by culturing fish. A clarifier was therefore built into the hatchery to treat its effluent. Its operational performance is discussed by W.E. McLean (memo to D. Sinclair, Fisheries and Marine Service, Vancouver, June 3, 1976).

The only air pollution source is the Western Mines operation in Myra Valley (permits detailed in Appendix 11.1). No sonic pollution above the estuary has been documented.

11 (iv) CAMPBELL RIVER ESTUARY

1. WATER QUALITY BASELINE

The Campbell River estuary basin contains a mixture of water from the Campbell River, Nunns Creek, Discovery Passage and rainfall run-off. Tidal cycles and fluctuations in output from upstream hydroelectric facilities change the relative proportions of these elements almost hourly, making it difficult to assess the meaning of water quality data generated from analyses of individual water samples. The presence of an apparently

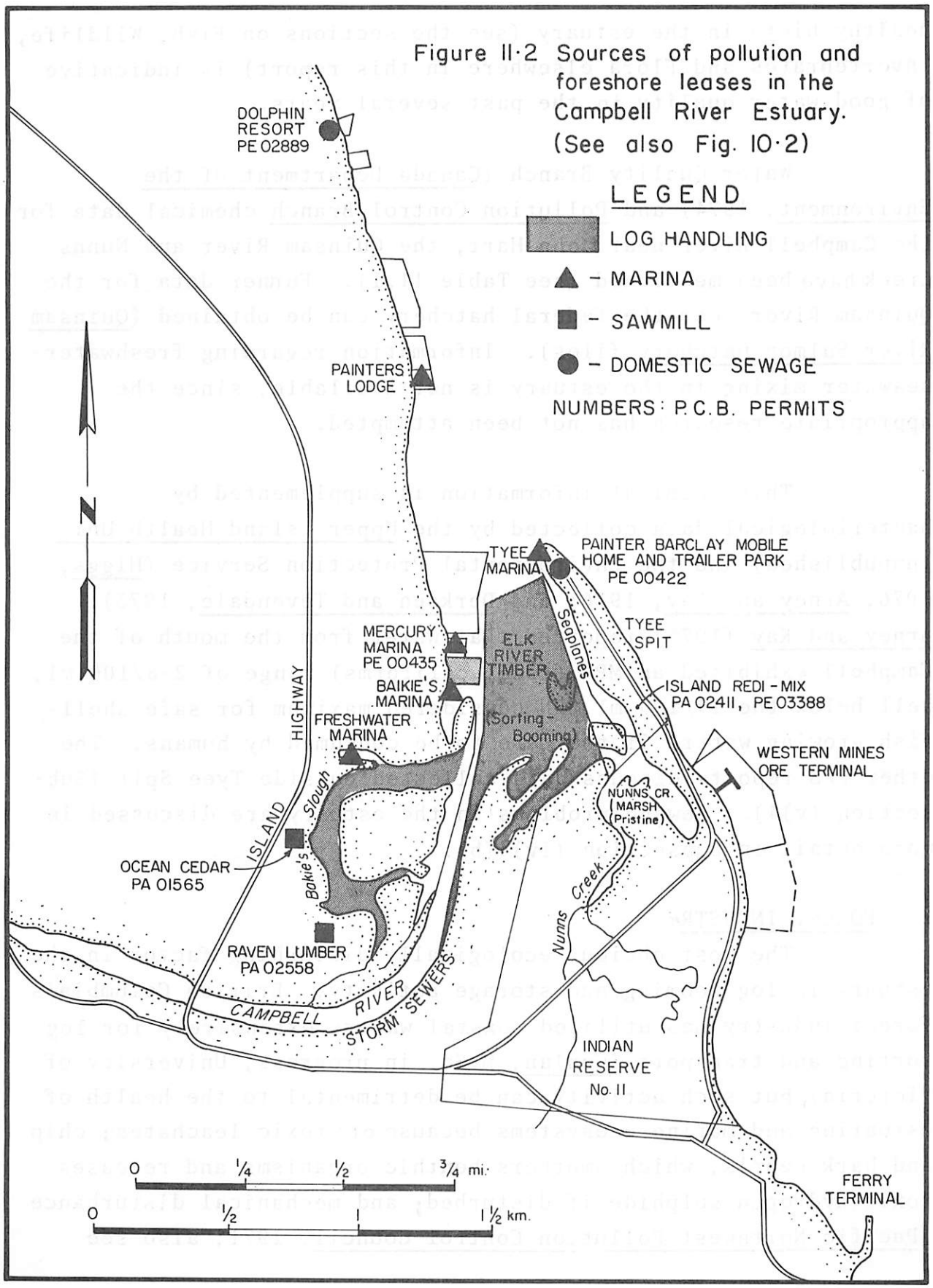


Figure 11·2 Sources of pollution and foreshore leases in the Campbell River Estuary. (See also Fig. 10·2)

LEGEND

- LOG HANDLING
- ▲ – MARINA
- ■ – SAWMILL
- ● – DOMESTIC SEWAGE

NUMBERS: P.C.B. PERMITS

healthy biota in the estuary (see the sections on Fish, Wildlife, Invertebrates and Flora elsewhere in this report) is indicative of good water quality in the past several years.

Water Quality Branch (Canada Department of the Environment, 1974) and Pollution Control Branch chemical data for the Campbell River near John Hart, the Quinsam River and Nunns Creek have been mentioned (see Table 11.1). Further data for the Quinsam River near the federal hatchery can be obtained (Quinsam River Salmon Hatchery files). Information regarding freshwater-seawater mixing in the estuary is not available, since the appropriate research has not been attempted.

This chemical information is supplemented by bacteriological data collected by the Upper Island Health Unit (unpublished) and the Environmental Protection Service (Higgs, 1976, Arney and Kay, 1976; and Derksen and Tevendale, 1973). Arney and Kay (1976) reported that water from the mouth of the Campbell exhibited an MPN (fecal coliforms) range of 2-8/100 ml, well below the 14/100 ml MPN considered maximum for safe shellfish growing water, if they are to be consumed by humans. The other EPS reports discuss data collected outside Tyee Spit (Subsection (v)4). Sewage problems in the estuary are discussed in more detail in Subsection (iv)4(b).

2. FOREST INDUSTRY

The most obvious ecologically disturbing factor in the estuary is log booming and storage activity. British Columbia's forest industry has utilized coastal waters extensively for log sorting and transport (Conlan, M.Sc. in progress, University of Victoria), but such activity can be detrimental to the health of estuarine and marine ecosystems because of: toxic leachates; chip and bark debris, which smothers benthic organisms and releases toxic hydrogen sulphide if disturbed; and mechanical disturbance (Pacific Northwest Pollution Control Council, 1971; also see

Table 11.3. Log handling leases in the Campbell River estuary. Foreshore lease numbers, area of lease and a description of each company's operation on the lease site are detailed in the table. Data from Bond (1975). (Hectares x 2.47 = acres). [1]Data from Burns (1976).

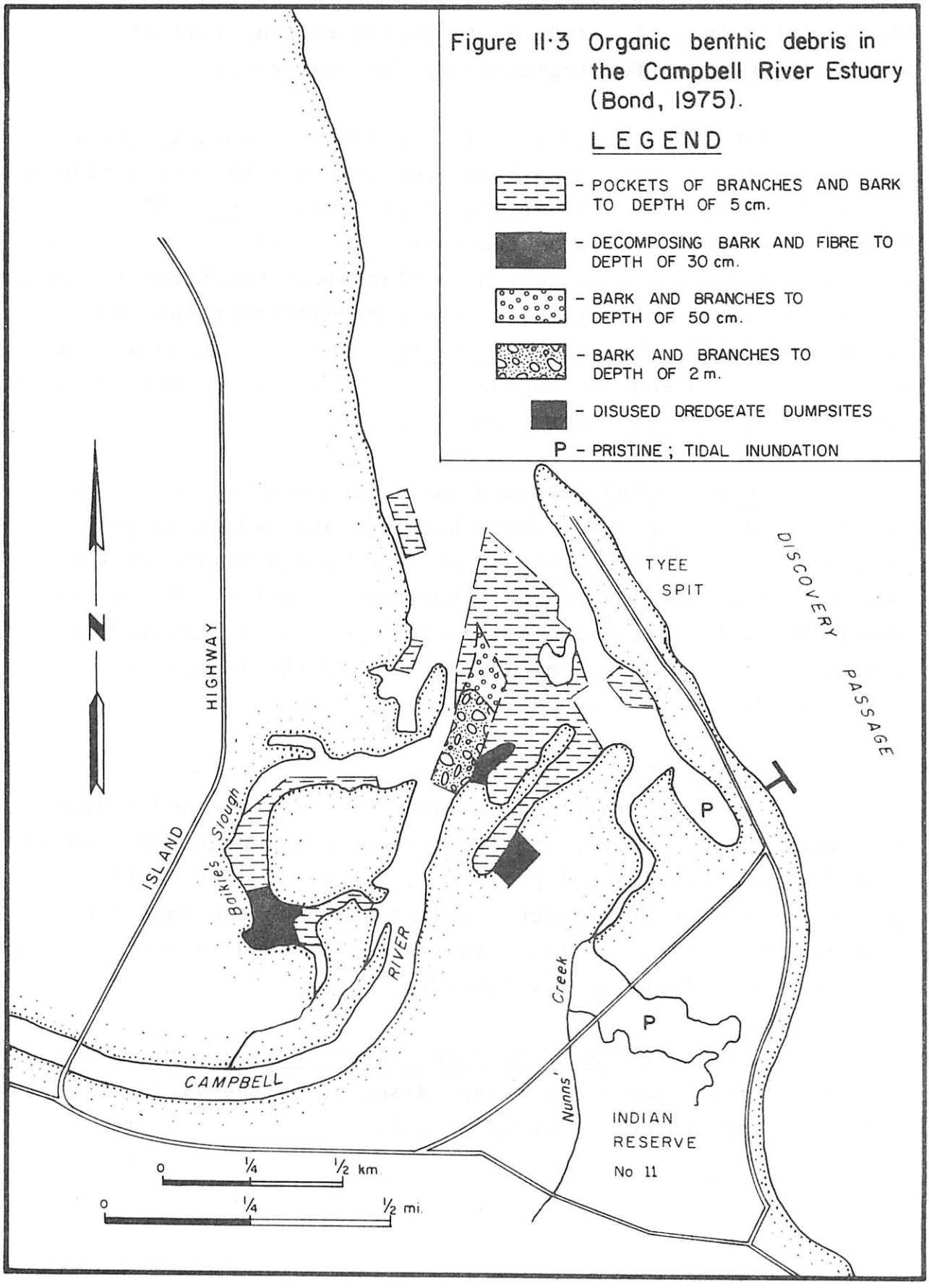
COMPANY	LEASE AREA (HECTARES)	FORESHORE LOT NOS.	OPERATION
Elk River Timber Co.Ltd.	36.56	1486	A-frame wet dump feeds fir (31%), hemlock (29%), balsam (22%) and cedar (11%) to a downstream wet sort and booming area. Requires periodic dredging. 75% flat rafting and 25% bundle booming.
Elk River Timber Co.Ltd.	6.08	1440	Intertidal area used for storage of raft and bundle booms.
Elk River Timber Co.Ltd.[1]	1.70	1583	log storage[1].
Raven Lumber Ltd.	8.41	1217	Bundle and flat booms stored prior to dry land sorting, logs are watered to facilitate transport from slough.
Ocean Cedar Products Ltd. (was Fortune Logging Co.) and Raven Lumber Co.	3.97	321	Storage of Cedar logs prior to shingle processing on the site. Also used by Raven for raft and bundle storage.
J. W. Timber (was W.E. Baikie Logging Co. Ltd.)	3.97	1509	Received bundles from dry land sort; also was site of wet booming and storage--no longer in use.

Conlan, 1974, 1975, for literature reviews). Unsightly log debris clogs beaches.

Bond (1975) estimated that 89% of the Campbell River estuary (65 hectares or 160 acres, in a total available of 73 hectares or 180 acres) has been alienated to commercial use. About 83% of the estuary (59 ha, 146
the forest industry for log handling, as detailed in Table 11.2.

Bond (1975) reported the results of a scuba survey carried out in the estuary in July 1975 to determine the extent and depth of deposition of log handling fallout. As illustrated in Figure 11.3, as much as 2 metres of bark and branches accumulated under the upstream end of Elk River Timber's sorting area, where the logs bump together after being carried downstream from the dump. About 5 cm of bark and branches blanketed the rest of the lease. Most of the bottom of Baikie's slough was covered by 5-30 cm of bark, branches and decomposing fibre.

Dredging is carried out periodically on several of these foreshore leases in order to maintain an adequate depth. Dredge spoil from the Elk River Timber Co. has been deposited on an upland salt marsh plot on their lease in the past, but while they have dredged parts of the booming ground every second or third year since 1954, the company has joined with fisheries biologists to reduce the ecological impact for several years (letter from P. Vroom and D. Goodman to T. Bird, Fisheries and Marine Service, Vancouver, file 31-3-C12). Hydrogen sulphide concentrations during dredging have ranged from 2.0 to 4.5 ppm, which explains why numerous fish and invertebrates have been killed, since only 0.03-1.0 ppm is lethal to salmonids (Bond, 1975). Companies wishing to dredge their leases must now work closely with fisheries officials to ensure that the operation will have a minimum impact on the estuary's fish populations (cf. Fisheries Operations Files, Fisheries and Marine Service,


Figure II·3 Organic benthic debris in the Campbell River Estuary (Bond, 1975).
LEGEND
- POCKETS OF BRANCHES AND BARK TO DEPTH OF 5 cm.
- DECOMPOSING BARK AND FIBRE TO DEPTH OF 30 cm.
- BARK AND BRANCHES TO DEPTH OF 50 cm.
- BARK AND BRANCHES TO DEPTH OF 2 m.
- DISUSED DREDGEATE DUMPSITES
P - PRISTINE ; TIDAL INUNDATION
N
HIGHWAY
ISLAND
Baikie's Slough
RIVER
CAMPBELL
TYEE SPIT
DISCOVERY PASSAGE
Creek
Nunns'
INDIAN RESERVE No 11
P
P
0 1/4 1/2 km
0 1/4 1/2 mi.

Vancouver). In fact, dredging to remove rotting fallout can be an important means for regenerating the substrate.

But such cooperation is regarded by some experts as a temporary measure, and calls have been made for the evacuation of log handling from the estuary entirely (e.g. Burns, 1976). Economic realities faced by the companies involved have caused the B.C. Lands Branch to convene a "Technical Committee to Advise on the Economic Implications of the Campbell River Task Force Recommendations", chaired by J. Perry, Lands Branch Manager in Nanaimo. This agency is hoping to have a report completed by the summer of 1977 (Perry, pers. comm., 1977).

Burns (1976) examined the activities of forest industry leaseholders on their foreshore holdings and made a largely subjective assessment of the degree and reversibility of the impact of log handling on the estuarine ecosystem. His paper summarizes data describing foreshore lease permits granted for logging operations, boating industries and the Island Redi-mix gravel dredging operation.

3. MARINA DEVELOPMENT

The boat traffic associated with marinas and lodges in the Lower Campbell River and its estuary has undoubtedly caused petroleum and vibrational pollution, but no studies of the problem have been undertaken. A discussion of the impact of constructing marinas in the estuary can be found in Section 2 of Chapter 12: Effects of Development.

A list of B.C. Pollution Control Branch permits issued to marinas and resorts for sewage disposal in the vicinity of the estuary is presented in Appendix 11.1.

4. OTHER AQUATIC DISTURBANCES

(a) A widely held rumour indicates that Campbell River's seaplane base on Tyee Spit is seasonally the second busiest in the world. Aircraft taxi across the estuary and tie up inside the Spit, generating oil and vibrational pollution that has not been adequately documented, although authors of the 1973-74 Tyee Club Yearbook voice the fear that heavy motorized traffic on and near the estuary has caused the big salmon to be distributed more loosely than before, when they used to concentrate in holes.

(b) Sewage pollution causes two disturbances: nutrient overload (not usually a problem in the marine environment), and contamination by pathogenic microorganisms. Most of the District Municipality of Campbell River is now on a system that processes the town's sewage through the Campbell River Water Pollution Control Centre, which discharges into Discovery Passage south of the river mouth. Septic tanks and absorption fields are used in Electoral Areas "E" (Quinsam) and "F" (North Campbell River), on Tyee Spit, and in parts of the Campbell River Indian Band Reservation (Anderson, pers. comm., 1977). Coliform data for the waters of the estuary and the streams that flow into it are held unpublished in the files of the Upper Island Health Unit in Campbell River. Federal Environmental Protection Service staff have carried out bacterial surveys of the marine shores in Discovery Passage in order to locate uncontaminated shellfish growing areas, but only one study (Arney and Kay, 1976) had a station actually located in the estuary. Data from that station, situated in the mouth of the river, are set out in Table 11.4. These figures indicate that in February 1976 the surface waters of Campbell River were evidently safe for growing shellfish destined to be consumed by humans, since the sampled range of <2-8 Most Probable Number (MPN) of fecal coliforms per 100 ml of surface water was well below the safe standard of 14 MPN/100 ml. For drinking water to meet American Public Health Association (1975) standards, the count must not exceed 2.2 MPN/100 ml, but

Table 11.4. Coliform data from a station in the Campbell River estuary due west of Tyee Spit, indicating sampling date, time, condition of the tide, water temperature, precipitation at time of sampling, salinity and Most Probable Number (MPN) of fecal coliforms per 100 ml of surface water. The maximum count considered safe for growing shellfish that are to be consumed by humans is 14 MPN/100 ml. (Data from Arney and Kay, 1976).

DATE (1976)	TIDE CONDITIONS TIME	TIDE CONDITIONS HEIGHT (m)	SAMPLING TIME	WATER TEMP (°C)	TOTAL PRECIP. (mm)	WIND (KNOTS)	SALINITY (°/oo)	FECAL COLIFORM MPN/100 ml
Feb. 3	1420 1850	2.6 3.7	1530 (Flood)	3.5	nil	NW@8	0.2	<2
4	0740 1500	4.4 2.4	0955 (Ebb)	3.0	nil	nil	1.5	2
5	0755 1530	4.4 2.2.	0905 (Ebb)	2.7	nil	nil	6.0	2
6	0825 1600	4.3 2.0	0850 (Ebb)	3.0	nil	nil	1.5	2
9	0940 1840	4.1 1.6	1040 (Ebb)	3.8	trace	nil	1.5	<2
10	0545 1035	3.7 4.1	0910 (Flood)	3.5	4.6	nil	2.0	8

the values given in Table 11.4 for that single station should not be taken to characterize microbial conditions in the estuary generally, particularly since some mixing of fresh water and sea water occurs at that station (salinities 0.2-6.0 $^{o}/oo$). Septic tanks are under B.C. Health Branch permits.

(c) For several years, Island Redi-Mix dredged gravel from a foreshore lease inside Tyee Spit, creating a depression about a fifth of a hectare in size in the shallow subtidal zone (lot number 296, Figure 10.2). Fisheries and Marine Service agents assisted the Company in finding an alternate source of gravel in the hinterland; dredging in the estuary by Island Redi-Mix has now ceased (Bird, pers. comm., 1977). Local fishermen report taking Tyee (chinook) salmon in the pool, but no mention is made anywhere of recolonization by natural estuarine biota, other than Burn's (1976) opinion that reversibility can be expected to be poor.

(d) Siltation can frequently be a problem when construction is carried out in a river system. Habitat protection officials from both the B.C. Fish and Wildlife Branch (Campbell River office files) and the Canada Fisheries and Marine Service (Vancouver files) have been involved in monitoring construction projects in the watershed, but no information is available concerning the impact of either artificial or natural (rainfall, snowmelt) siltation in the estuary, beyond federal spawning reports.

(e) Dumping of dredge spoil can frequently create serious ecological disturbances (Pollutech Pollution, 1976). Bond (1975) identified two marshy areas in Elk River Timber Company's foreshore leases where bark dredgeate from their log booming grounds has been dumped (Figure 11.2), but the impact of this dumping was not discussed. Fisheries biologists have been able to negotiate with companies doing the dredging, to ensure that spoil is deposited in approved areas at sea or in harmless upland sites.

5. AIR QUALITY

B. C. Pollution Control Branch permits setting standards for air emission have been granted to four companies operating in the vicinity of the estuary (Appendix 11.1), including two sawmills owned by Ocean Cedar and Raven Lumber, an asphalt plant owned by Tayco Paving, and a silo owned by Island Redi-mix on Tyee Spit. It is unlikely that any of these plants emit substances harmful to the estuary's biota, but data collected from studies of the sawmills are not yet published (Bollans, pers. comm., 1976).

11 (v) DISCOVERY PASSAGE

The marine waters of Discovery Passage south of Seymour Narrows receive fresh water from the Campbell River at the rate of 108 cms averaged over the year (see page 35) or 85.5 million Imperial gallons per hour. But the Elk Falls Pulp Mill uses 60 million gallons (3.16 cms) of Campbell River water per day, hence 3% of the River's average annual discharge in fact enters Discovery Passage at Duncan Bay. The quality of water in Discovery Passage and the Campbell River estuary is therefore a function of pollution phenomena in the freshwater network of the hinterland as well as in the marine waters offshore. The swift tidal currents through Discovery Passage transport a large amount of water between Johnstone Strait to the north and the Strait of Georgia to the south, making water quality in Discovery Passage a topic of general ecological interest.

A summary of B.C. Pollution Control Branch permits granted for air emissions, aquatic outfalls, and refuse dumps along Discovery Passage is provided in Appendix 11.1.

1. WATER QUALITY BASELINE

The marine flora and fauna of Discovery Passage are collectively among the most diverse and abundant of any of the world's oceans. Between the spectacular growths of sponges and

Table 11.5. Water quality data for three stations in Discovery Passage: (1) Duncan Bay the Elk Falls Pulp Mill loading docks, (2) Duncan Bay 152 m off the Elk Falls bu dock, and (3) the surface waters over the Campbell River sewage treatment plant outfall.

PARAMETER	UNITS	P.C.B. SITE NO. 0150161 DUNCAN BAY	P.C.B. SITE NO. 0150163 DUNCAN BAY	P.C.B. SITE NO. 0150180 CAMPBELL RIVER
color (true)	rel unit	4: 5 (5 - 5)	4: 5 (5 - 5)	--
pH	rel unit	4: 7.75 (7.7 - 8)	4: 7.9 (7.8 - 8)	5: 7.9 (7.7 - 8.3)
solids (susp)	mg/1	4: 2.5 (2 - 23)	4: 3 (2 - 4	1: 1
specif. cond.	umho/cm	4: 44450*	4: 41300*	5: 44500*
turbidity	J.T.Unit	2: 0.35 (0.2 - 0.5)	2: 0.3 (0.2 - 0.4)	7: 0.5 (0.2 - 1)
C.O.D.	mg/1	4: 39 (24.6 -74.3)	4: 39.1 (24.6 -53.3)	1: 12
lignin-tannin	mg/1	4: 0.2 (0.1 - 12)	4: 0.15 (L0.1 - 0.3)	--
boron (diss.)	mg/1	4: 1.7 (0.8 - 2.5)	4: 2.9 (2.5 - 3.2)	--
coliforms(fecal)	MPN	--	1: L2	7: 20 (L20-20000)
coliforms(total)	MPN	--	1: 2	5: 2400 (20-L20000)
oil & grease	mg/1	--	--	3: 1 (L1 - 1)
solids (tot.)	g/1	--	--	1: 29
oxygen (diss.)	mg/1	--	--	1: 13.2
carbon (org.)	mg/1	--	--	2: 4.5 (3 - 6)
B.O.D.	mg/1	--	--	1: L10
copper (tot.)	mg/1	--	--	1: 0.011
lead (tot.)	mg/1	--	--	1: 0.003
zinc (tot.)	mg/1	--	--	1: 0.006

NOTES: The first figure in each set reveals number of measurements made. The figure after the colon is the fiftieth percentile (50% of the values are lower or higher), and the two figures in parentheses are minimum and maximum, respectively.

Data compiled from B.C. Pollution Control Branch computer files. Printout supplied by M. Clark, PCB, B.C. Ministry of Environment, Victoria, (February, 1977).

Data collected by various means betweeen January 1, 1970 and February 18, 1977. Station locations are listed in Appendix 11.2.
The symbol "L" indicates "less than".
*These ranges are (40800-45200), (40100-45200) and (38400-46666), respectively.

the massive migrations of Pacific salmon, there ranges a collection of life forms which indicates that a high standard of water quality exists in the Passage. Most papers that provide water quality baseline information for the marine waters of Discovery Passage are the result of pollution studies, best discussed in the appropriate sections below (Elk Falls Pulp Mill, Section 2; Sewage, Section 4).

The most comprehensive source of chemical and microbiological data is the computer file of the B.C. Pollution Control Branch in Victoria, B.C. Stations in Discovery Passage for which water quality information is recorded in the file are listed in Appendix 11.2, and some of these data are reproduced in Table 11.4, providing the reader with an indication of water quality conditions in selected areas of Discovery Passage between 1970 and 1977: (1) Duncan Bay, off the Elk Falls Pulp Mill, and (2) Campbell River sewage treatment plant receiving waters.

It is relevant to note here the report by Albright, et al. (1975) who sampled red snapper (*Sebastes ruberrimus*), sole (*Pleuronectidae*), ratfish (*Hydrolagus colliei*), tomcod (*Microgadus proximus*), skate (*Raja* sp.), and rockfish (*Sebastes* spp.) from the vicinity of Campbell River and analyzed their tissues for a variety of chlorinated hydrocarbons (the insecticides dieldrin, DDT, DDD, DDE, heptachlor dioxide and PCB's): none were found in the tissues of these fish. This result contrasts sharply with data from the Fraser estuary, where crabs and fish were found to have absorbed these substances to a significant degree, suggesting that the marine waters of Discovery Passage are free of pollution by these chlorinated hydrocarbons.

2. ELK FALLS PULP MILL

Crown Zellerbach of Canada Ltd. has operated a newsprint, kraft and lumber mill on Duncan Bay since 1952, drawing water from the Campbell River below the powerhouse and discharging it to Discovery Passage at the eastern limit of Duncan Bay. Today the

effluent consists of 60 million gallons per day (3.16 cms)--a composite of domestic sewage, mechanical pulping effluent and bleached kraft mill effluent (BKME) that is monitored (Beak 1974, 1976) according to Pollution Control Branch permits (Appendix 11.1 is a list of the permits, Appendix 11.5 is a list of the required effluent quality standards, and Appendix 11.2 is a list of measured effluent quality data).

In 1976 the mill employed 1,219 people and produced 1,354 ADt per day of: newsprint (657 ADt/D), kraft paper (207 ADt/D), and bleached kraft pulp (490 ADt/D). A sawmill on the site daily produced 496 m^3 (210 MBM) of hemlock and fir lumber.

Raw materials for this production are brought to the mill by land and sea. Chips and sawdust were delivered to the pulp digesters via barge (3,272,000 m^3 or 1,156,000 cunits in 1976) and truck (741,200 m^3 or 262,000 cunits in 1976). Logs were delivered to Duncan Bay for the sawmill and pulping process by: trucks (28,310 m^3 or 10,000 cunits/1976); barges (28,310 m^3 or 10,000 cunits/1976); and rafts (736,060 m^3 or 260,000 cunits/1976). It takes 50 railcars per month to supply the mill with chlorine, salt cake, sulphur dioxide and other chemicals used in the digesting, bleaching and papermaking processes (Elk Falls Pulp Mill publicity brochure, 1975; Leedham, pers. comm. 1977; Hanelt, pers. comm. 1977).

The Elk Falls Mill has been studied by environmental experts since it commenced operations (Table 11.6) largely because Pacific salmon (*Oncorhynchus*, spp.) use Discovery Passage extensively when they migrate from their breeding streams in the Strait of Georgia to rich feeding grounds in the open Pacific Ocean. As many as 80% of the adults returning from the ocean via Johnstone Strait evidently use Discovery Passage (Argue, pers. comm. 1977). The consensus of opinion has been that the mill's impact on Discovery Passage has been limited to (1) smothering of

Table 11.6. Chronological list of scientific literature that makes specific reference to pollution at the Elk Falls Pulp and Paper Mill, Duncan Bay (Crown Zellerbach of Canada, Ltd.)

REFERENCE	DATE OF STUDY	PURPOSE	RESULT
Waldichuk, 1957	1957	- Oceanographic observations in Discovery Passage off Duncan Bay.	- High water quality: tidal currents flush and dilute mill effluent efficiently.
Waldichuk, 1962	1961	- Oceanographic observations in Duncan Bay and Discovery Passage	- Noted the highly-mixed clear waters of Discovery Passage, with minimal effect from the pulp mill in Duncan Bay.
Waldichuk, 1963	1963	- Monitor black liquor spill.	- Fate of black liquor spilled into Discovery Passage.
Waldichuk, et al. 1968	1964-1966	- Physical and chemical oceanography re pollution off Duncan Bay.	This report is data record only
Werner and Hyslop, 1968	1964-1966	- Analyze gases from nearby sediments and waters.	- Data record only.
Brothers, 1971	Jan. 1971	- Dissolved oxygen and dredge survey of benthos near mill.	- Layer of rotting hydraulic barker debris on bottom off sawmill; tides prevent chronic problem but there could be fish kills during dredging.
Werner and Choo, 1972	--	- Study wood decay chemistry and microbiology.	- Results of scientific interest only.
Werner & Angotti,1973	--	- Same.	- Same.
Thompson, et al., 1976	1971,73	- (1) Boron effects and distribution in marine environment; (2) toxicity of Boron to salmon and oysters.	- Sea water concentrations of Boron in Discovery Passage in line with natural surface waters before switch; non-accumulative, and non-toxic to salmon at levels of mill discharge.
Pollution Control Branch Permit PE-1164	1973 onwards	- Set standards for gaseous emissions and aqueous effluents.	

REFERENCE	DATE OF STUDY	PURPOSE	RESULT
Nelson and Goyette, 1976	1973	- Analyze shellfish for zinc content (was used in groundwood pulp bleaching).	- Contamination found, but lower than less turbulent receiving waters.
Environment Canada, 1973	1973	- Analyze environment of pulp mills for effects of zinc and boron.	- Same data as Nelson and Goyette, 1976 for zinc in shellfish.
Stockner, et al., 1975	1973,74	- Study effect of BKME on phytoplankton production in Duncan Bay.	- Little effect compared to mills dumping into less turbulent receiving waters.
Beak Consultants 1974, 1976	1973-1976	- Bioassays, chemical and benthic surveys to comply with Pollution Control Branch permit conditions.	- Reduced abundance of biota in immediate vicinity of outfalls; one 96 LC50 in 10 was 35% (*Salmo gairdneri*), the rest acceptable.
H.A. Simons 1974a	1974	- Current studies in Discovery Passage to site outfall diffuser.	- Extensive hydrologic information.
H.A. Simons, 1974b	1974	- Geophysical survey to site outfall diffuser.	- Seismic, sonar, bottom soil and television data describing bottom of Discovery Passage off the mill.
Fisheries Operations (F.M.S. Vancouver)	Files	- Contain correspondence regarding conflicts with fisheries interests.	- Largely historical information; some data.
Beak Consultants Ltd., 1977	1976-1977	- Determine effectiveness of new effluent diffuser system.	- Reduced turbidity at site of old outfalls.

benthos by log and debris and hydraulic debarker effluent, which can release toxic hydrogen sulphide, when the rotting mass is disturbed by dredging and propellor wash (Brothers, 1971); and (2) stress on the intertidal and subtidal biota within 200 m of the outfalls used before January, 1977 (Beak Consultants Ltd., 1976). No study on the effect of the mill on fish has been carried out, and charges of fish kills have never been substantiated with evidence (Fisheries Operations Files). Hamilton and Buell (1976) wondered whether the mill's discharge of 273,000 m^3 per day of Campbell River water into Discovery Passage would affect salmon migrating to the river to spawn.

Researchers have long felt that the mill is situated in one of the most fortunate locations on the B.C. coast since heavy tidal action in Discovery Passage rapidly dilutes the effluent, dispersing its effects (Waldichuk, 1957; Stockner et al., 1975; Nelson and Goyette, 1976). Crown Zellerbach has taken advantage of this situation. In January, 1977 a six-million dollar diffuser system was brought into action which replaced the four simple outfalls used up to that date. The new outfall was designed by H.A. Simons Ltd. (1974a, b). A study of its effect on water quality by Beak Consultants Ltd. (1977) suggests that the zone of influence has been reduced considerably from the 200 metre radius previously measured, owing to:

(1) an averaging of water quality characteristics, as a result of mixing the four effluent streams;
(2) removal of coarse debris from the effluent;
(3) foam containment (aesthetic value); and
(4) discharge of the effluent through a series of diffuser nozzles, designed to cause rapid dilution of the effluent.

The diffuser is the latest in a series of pollution abatement techniques and devices that have been integrated with the mill's sawmill and pulping machinery.

Zinc was a problem before the mill switched to a safer brightening process in 1973. Nelson and Goyette (1976) reported that oysters (*Crassostrea gigas*), as far away as Francisco Point and Oyster Bay, had moderately elevated levels of zinc concentrated in their tissues. The zinc came from zinc dithionite (ZnS_2O_4, more commonly known in industry as zinc hydrosulphite), a chemical used to brighten groundwood pulp. In 1973 B.C. pulp mills began to switch to sodium dithionite ($Na_2S_2O_4$), which in its manufacture produces sodium metaborate as a by-product that is released with the mill's effluent. A study of boron by Thompson et al. (1976) revealed that boron, unlike zinc, does not accumulate in living tissue. While it can be toxic to fish and oysters, no mill in the province is releasing it at a concentration higher than one µgB/ml. The level of boron in Discovery Passage prior to the switch from zinc dithionite was a natural 4.68 µg/ml (Thompson et al., 1976).

Stockner, et al. (1975) studied the growth of phytoplankton in the waters off Discovery Passage and found that tidal turbulence probably minimizes the inhibitory effect of BKME (bleached kraft mill effluent). Primary production figures from their investigation are reproduced in Table 11.7, from which it can be seen that primary production, whether measured as 14C uptake or chlorophyll 'a' concentration in the mill's receiving waters, is not much different than at a control station in Gowlland Harbour.

Derksen and Tevendale (1973) discovered unacceptably high counts of coliform bacteria (in terms of shellfish harvest) in Duncan Bay during July 1973 and stated that "the foreshore waters...are subject to fecal contamination from the Crown Zellerbach pulp mill". The mill installed a sewage treatment plant in January 1973 (Hamelt, pers. comm. 1977).

Table 11.7. Results of a study of phytoplankton production in waters receiving effluent from Crown Zellerbach's Elk Falls Pulp Mill on Duncan Bay, Discovery Passage. Figures in parentheses are values measured at a control station in relatively natural water (Stockner, Cliff and Munro, 1975).

	SAMPLING DATES		
PARAMETER	OCT. 3, 1973	SEPT. 26, 1974	UNITS
primary production	357 (205)	1269 (1489)	mg C $m^{-2}day^{-1}$
Chlorophyll a, at 0 and 20 m	.69 .52 (.04 0.0)	1.48 -- (2.51 1.93)	mg m^{-3}
incident light at surface	300	474	g-Cal $m^{-2}day^{-2}$
mill site	75(65)	56 (70)	% surface incidence
light extinction coefficient	.4533 (.2562)	-- (.1707)	--
secchi depth	8.0 (7.5)	7.0 (7.5)	meters

3. LOG HANDLING

Menzies Bay (Trout Creek and Menzies Creek estuaries) and Duncan Bay are both used to handle logs. Trucks, barges and booms dump logs into Duncan Bay to supply the Elk Falls Pulp Mill. The following forestry-oriented companies are established in and near Menzies Bay.

1. MacMillan Bloedel Ltd. (A-frame log dump and wet sort booming operation).
2. Trout Creek Sawmills (Pallan Timber Products--sawmill and booming).
3. Shoreline Forest Products (inactive sawmill).
4. Kinnick (sawmill and dry dump).
5. Seymour Terminals (wet sort booming cooperative).
6. Reliable Logging (Wonnock Lumber: dry sort and booming ground).
7. Triangle Pacific (Canadian Pacific Railway--dump).

Pollution Control Branch permits control stack and refuse pollution by Shoreline and MacMillan Bloedel, respectively (Appendix 11.1). The only data available to describe the impact of these operations were collected by Conlan (M.Sc. in progress, University of Victoria) who reports that the MacMillan Bloedel dump has been in use for a good many years and has "badly affected" natural habitats. Crown Zellerbach has expressed interest in obtaining the rights to Elk River Timber Co. Ltd. to convert the massive E.R.T. wet-sort and booming operation in the Campbell River estuary to a dry-sort in Duncan Bay (Fisheries Operations files, Fisheries and Marine Service, Vancouver).

4. SEWAGE

The federal Environmental Protection Service has carried out surveys of the sanitary condition of the marine waters along Discovery Passage shorelines in the vicinity of Campbell River since 1973. Their intent has been to locate areas that should be closed to the taking of shellfish, which are filter feeders capable of concentrating pathogenic bacteria and viruses (Arney and Kay,

1976; Derksen and Tevendale, 1973), and to test the effectiveness of Campbell River's sewage system and treatment plant, which was established in 1974 (Higgs, 1976). The three reports have: (1) identified several sources of human and animal fecal contamination along Campbell River's foreshore that are the result of lack of contact with the municipality's sewage system; (2) recommended closures to the taking of shellfish at the mouth of Simms and Willow Creeks, and at the foreshore between Middle Point and a southern limit midway between Pinecrest and Evergreen Roads (which opens some areas previously closed by section 65A of the British Columbia Fishing Regulations, Schedule J, based on the pre-treatment plant survey by Derksen and Tevendale, 1973), and (3) discovered, through observations of a dye tracer injected into the sewage treatment plant's effluent, that neither normal nor overload discharges from the plant are likely to affect bacteriological water quality of the nearby foreshore areas, owing to Discovery Passage's strong tidal currents. Higgs (1976) also made specific recommendations regarding health threats imposed by mechanical aspects of the existing sanitary sewer system. For a history of the Campbell River sewage system, see the Land and Water Use chapter.

4. OTHER AQUATIC DISTURBANCES

(a) Ripple Rock Explosion: Discovery Passage is a primary navigation route for: fishing vessels; barges carrying chemicals, sawdust and logs for the forest industry; recreational craft; and a multitude of other seacraft sailing between ports in the Strait of Georgia and the north coast of British Columbia and Alaska. The most difficult hazard in the passage is the torrential tidal current in the bottleneck created by Seymour Narrows (Figure 11.1). On April 5, 1958, 1375 tons of high-grade explosive were used to blow 25 feet of rock from the pinnacles of Ripple Rock, a reef that had plagued ships' masters in the deadly Narrows. The Pacific Biological Station in Nanaimo sent a scientific staff to investigate the effect of the explosion on marine life in

Discovery Passage, using caged fish to estimate the radius of impact. It appears that the effect was limited to waters within 0.8km (0.5mi.) of the blast. Evidently rockfish (*Sebastes* spp.) were the only fish seriously affected, although the reader should consult Thomson (1958) for a discussion of the uncertainty in the observations.

(b) Landfill: Landfill, employed in foreshore zones to provide a structural base for buildings and roadways, can affect nearshore marine ecosystems by filling in previously submerged environments, by silting nearby habitats and by changing littoral current patterns that normally distribute nutrients, planktonic larvae of benthic fauna, seaweed spores and substrate material; i.e., dynamic, seasonal processes that maintain the integrity of established coastal biota. On the other hand, the possibility exists that landfill or dredging on the foreshore could stimulate a more productive biotic community to develop than was there before.

Several engineering projects, including marina development, wharf construction (see Land Use chapter) and the 1960 landfill project on which Tyee Plaza and the Island Highway have been built (Fuoco, pers. comm., 1977), have disturbed the foreshore near Campbell River. No environmental impact studies were undertaken for these projects, since they were performed in the years before the appropriate methods and governmental expertise had developed. Biologists from the Habitat Protection Directorate of the federal Department of Fisheries and the Environment in Vancouver are being asked by the B.C. Land Management Branch, which controls foreshore leases, to assess the environmental consequences of proposed marina developments on the Campbell River foreshore (Bell-Irving, pers. comm., 1976).

(c) Dredge Spoil Dumping: Dredging operations disturb marine ecosystems twice: once when the substrate is picked up and once when it is dumped as "spoil", or "dredgeate" (see Pollutech Pollution Advisory Services, 1976 for literature review).

Table 11.8. Six locations in Discovery Passage south of Seymour Narrows, where dredge spoil has been dumped into the marine environment. A description of the spoil and its origin are outlined. The first three sites are from Ward (1976), the fourth and fifth are from Can. Dept. of the Env. (1977) and the last is from a letter to Raven Lumber from F.C. Boyd, A/Director of Habitat Protection Directorate, Fisheries and Marine Services, Vancouver (April 22, 1975). See also Figure 11.1.

	SOURCE OF SPOIL	AMOUNT OF SPOIL (m^3)	DUMPING SITE AND I.D. NUMBER (Fig.11.1)	DEPTH (m)	SPOIL MATERIAL
(1)	Iron mine and Campbell River Townsite	<143,000 (1950-1973)	$50^{o}00'N$, $125^{o}12.7'W$ to $50^{o}04'N$, $125^{o}14.5'W$ (E.C. No. E01)	42-46	sand and gravel
(2)	Elk Falls Mill (Duncan Bay)	19,000 (annually)	$50^{o}05'N$, $125^{o}16.4'W$ (E.C. No. E02)	96.9	log boom waste
(3)	MacMillan Bloedel (Menzies Bay)	1,500 (annually)	$50^{o}07.3'N$, $125^{o}20.05'W$ (E.C. No. E03)	100.5	log boom waste, wood chips, mud
(4)	Campbell River Boat Harbour (Public Works Canada)	3,822 m^3 (permit maximum -- 1,000 m^3 disposed of by 31/12/76)	$49^{o}57.50'N$, $125^{o}07.50'W$ (ODCA* permit 4443-0183)	182	mud, sand and gravel
(5)	Campbell River ferry terminal (B.C. Dept. Highways)	12,997 (permit maximum -- none disposed of by 31/12/76)	$49^{o}57.50'N$, $125^{o}07.50'W$ (ODCA permit 4443-0183)	182m	silt, sand and gravel
(6)	Baikie's Slough Campbell estuary (Raven Lumber)	? (April 22-24, 1975)	460 m (2.5 cables) west of April Point on Quadra Island	100.5	log boom waste

* ODCA - Ocean Dumping Control Act.

Canada's Ocean Dumping Control Act was passed on December 13, 1975, whereupon the federal government obtained control over dumping into marine waters by demanding that dumping permits be obtained through the Environmental Protection Service. Two permits have been issued to allow dumping at a site southeast of Cape Mudge (49° 57.50'N; 125° 07.50;N) in the year following December 13, 1975, when the Act became effective (Canada Department of the Environment, 1977). Both permits covered dredging at Campbell River port facilities.

Table 11.8 describes these and other dumping zones that have been used in Discovery Passage (Ward, 1976). Spoil from previous dumping incidents involved: (1) about 143,000 m^3 (<246,000 yd^3) of sand and gravel from an iron mine and the Campbell River townsite (1950-1973); (2) 19,000 m^3 annually of log boom waste from Elk Falls mill (active); and (3) 1,500 m^3 annually of log boom waste from MacMillan Bloedel operations in Menzies Bay (active). The strong tidal currents in Discovery Passage are expected to prevent any but the densest and largest particles from reaching bottom at the dump site.

(d) Numerous observations concerning ecological disturbances in Discovery Passage and the rivers that flow into it have been reported in "Annual Narrative Reports for Conservation District No. 5" (Fisheries Operations Files, Fisheries and Marine Service, Vancouver, B.C.). These documents suggest that petroleum products spilled from shore facilities and marine vessels are the most common pollutants, although wood waste from the forest industry runs a close second in terms of nuisance. In 1972, for example, raft-based A frame log dumps (a method fast becoming obsolete) dumped enough log debris into Discovery Passage that net fishing operations were hampered, and navigation was made hazardous.

5. AIR QUALITY

Ambient air quality sampling stations have been established in Campbell River and vicinity by the B.C. Pollution

Control Branch, although air quality data from these and industry -specific monitoring programs have not yet been reduced to a manageable form (Bollans, pers. comm., 1976). A list of air and gaseous emission sampling stations is provided in Appendix 11.2, and Pollution Control Branch permits issued to air polluters along the shores of Discovery Passage can be found in Appendix 11.1. Seven air permits have been issued to the Elk Falls Pulp Mill on Duncan Bay, detailing maximum permissible values for discharge rate, particulate discharge, and sulphur dioxide, toluene and chloride content of the stack fumes. These permits also dictate expected behaviour of the permittee regarding emergencies and routine monitoring of the emissions. An air permit has been issued to Shoreline Forest Products in Menzies Bay, but their sawmill is no longer in operation.

12. EFFECTS OF DEVELOPMENT

Evidence reviewed in earlier chapters of this report proves that salmon and birds use the Campbell River estuary at critical periods of their life cycles: salmon as juveniles preparing to go to sea and as adults returning to the river to spawn, and birds as adults feeding through the winter months before returning to breeding grounds in the north. Studies have identified zones in the estuary that should remain undeveloped (see Section 2 of this chapter), and experts have called for the removal of the forest industry from the estuary.

The Land Management Branch of the B.C. Ministry of the Environment is presently carrying out a study of the economic feasibility of moving established industries out of the estuary (Technical Committee to Advise on the Economic Implications of the Campbell River Task Force Recommendations, in progress), and is critically examining new foreshore lease applications to determine what impact those developments will have on the natural ecosystem of Campbell River's estuary, with input from federal and provincial fish habitat protection experts (Perry and Egan, pers. comm., 1977)

Pertinent environmental legislation is discussed in Appendix 12.

1. Hydroelectric Development

Five papers have documented studies aimed at determining the effect of developing the Campbell River watershed for the purpose of generating electrical power.

Carl (1937) surveyed Campbell Lake in an attempt to obtain baseline data before the first dam (John Hart) was constructed in 1947. McMynn and Larkin (1953) carried out limnological investigations in all of the large lakes (Buttle, Upper Campbell, Lower Campbell and John Hart), in order to understand

the character of the watershed prior to the construction of Strathcona Dam, which led to the flooding of Buttle and Upper Campbell Lakes in 1958. Sinclair's M.Sc. dissertation (1965) involved comparing his post-impoundment data with the two previous studies, in an effort to determine the limnological effect of impoundment. These papers contain a good deal of information and we suggest that the reader examine the data personally before forming an opinion regarding the impact of hydroelectric development in the upper watershed. B.C. Hydro is continuing to monitor limnological conditions in the Campbell River system (Ferguson, pers. comm., 1977).

The remaining two papers which discuss the biological impact of hydroelectric development are by Hamilton and Buell (1976), and Mundie and Mounce (1976). Both were concerned with the effect of proposals by B.C. Hydro to expand the John Hart hydroelectric facility on Campbell River salmonid populations and yield valuable information regarding the normal operation of John Hart with respect to salmonid ecology. Proposed expansion alternatives are:

(a) enlargement of the present station, with the subsequent increase in periodic maximum discharge from the present 122 cms (4,300 cfs) to 263 cms (9,300 cfs); or

(b) the periodic diversion of up to 142 cms (5,000 cfs) through an underground tunnel and generating plant to Duncan Bay.

Plan (a) would result in severe modifications to the entire reach of the lower Campbell River, available to salmonids for spawning. Discharge rates ranging between 31 cms (1,100 cfs) and 263 cms (9,300 cfs) would have three detrimental effects:

(1) Increased water depths and velocities beyond the range tolerated by adult spawners would reduce total potential spawning area.

(2) Large, abrupt changes in flow would displace or inhibit adults attempting to spawn. Juvenile salmonids would be stranded or forced downstream.

(3) Preferred rearing habitat in shallow, low velocity areas on the river margin would be inundated during high discharges, forcing juvenile salmonids to occupy habitats lacking preferred characteristics.

The authors (Hamilton and Buell, 1976) point out that a minimum flow of less than 70 cms (2,500 cfs) is undesirable from September to July because prime rearing area is reduced, potential spawning area is reduced, food production is reduced (Mundie and Mounce, 1976) and redds may be exposed. The rate of change of discharge is also critical: 0.25 cms/min (9 cfs/min) was considered to be the maximum tolerable by salmonids and their zoobenthic food sources. The ideal flow pattern from a fisheries viewpoint for Campbell River (as proposed by Hamilton and Buell) is shown in Figure 4.5.

Plan (b), the diversion to Duncan Bay of water from John Hart Lake, was considered to be an acceptable alternative to increasing the discharge to the Lower Campbell River beyond the present maximum of 122 cms (4,300 cfs) with the following conditions: (1) that flow rates in the Lower Campbell River are not interfered with, and (2) that the diversion should not be constructed until completion of an ecological baseline study, requiring a minimum of one year and consisting of determining the impact of this freshwater load on Duncan Bay biota. Salmonid behaviour, marine benthic invertebrate freshwater tolerance, and the distribution of salmon fish prey were singled out for attention. The Duncan Bay alternative would result in a periodic maximum input of 142 cms (5,000 cfs). The Elk Falls Pulp Mill presently pours about 3.16 cms (60 million gallons per day) into Duncan Bay from the Campbell River. The average annual discharge of the Campbell

and Quinsam Rivers through the estuary amounts to 105 cms (range: 17.8 - 1,016 cms), as outlined in the Hydrology chapter.

Hamilton and Buell (1976) discussed the scouring of gravel by the river current from the already limited spawning beds in the Lower Campbell River. Under present conditions, periodic flooding through the natural canyon is insufficient to recruit much new gravel to the beds, as must have happened before the dam was constructed. The largest species (chinook) prefer gravel in the 5-15.2 cm range, while the smallest (pinks) prefer 1.3 - 5 cm particles.

2. Marina Development

Marina construction can have significant ecological impact, since marina shore facilities may be built in part on vegetated intertidal or marsh zones in the estuary. Dredging and landfill must at times be undertaken to provide navigational access or structural support for the marina. These operations can uproot vegetation, change the nature of the substrate, and reshape the estuary's basin so as to alter salinity distributions. Such physical disturbances may result in biotic changes; loss of benthic fauna and flora that characteristically form the basis of salmonid food chains in B.C. estuaries being the most disastrous (see Waldichuk, 1977 and Goodman and Vroom, 1974 for discussion of these food chains in B.C. estuaries).

In response to a 1972 proposal by the Campbell River Indian Band to develop part of their property into a marina and gravel dredging operation, Fisheries and Marine Service personnel undertook an examination of biotic processes in the estuary (Goodman and Vroom, 1974). Their study revealed that the property is in the vegetated, intertidal portions of the estuary, where food chains that support juvenile salmonids are based. Since the area between the mouth of Nunns Creek and the Spit (labelled "pristine"

in Figure 11.2) is the only remaining undisturbed intertidal area within the Campbell River estuary,which is covered with appropriate vegetation, and harbours an abundance of juvenile coho, chum and chinook salmon, Goodman and Vroom (1974) recommended that the Indian band locate its proposed development elsewhere. Private developers have applied to the B.C. Lands Branch for foreshore rights enabling them to construct marinas elsewhere in the vicinity of the estuary. Similar investigations are being undertaken to assess their impact on aquatic life as well (Bell-Irving, pers. comm., 1976).

Four marinas already exist in the estuary (Figure 11.2). No documentation is available regarding the impact that the development of these establishments has had on the estuary's biota. Burns (1976) observed that some of the intertidal zone had been dredged or filled in each case (Figure 12.1), but confirmed that no historical information has come to light which could be used to determine the character of the habitat lost.

Now that communication between the government agency that regulates foreshore leases (B.C. Land Management Branch) and agencies with environmental expertise (Fisheries and Marine Serivce and B.C. Fish and Wildlife Branch) has developed to a high level of cooperation, it has become unnecessary for developers to forge ahead without understanding the ecological damage they might inflict. An example of the way this mechanism operates is the case of the proposal by D.G. Jesse (Discovery Resorts Ltd., Campbell River) to develop a marina on Foreshore Lease No. 1533 Sayward (B.C Lands Service Departmental Reference Map R92K/3-c). Local sports fishermen were afraid that this would disrupt salmon that use Frenchman's Pool just off the proposed marina. For ecological reasons, the federal Fisheries and Marine Service (Vancouver) recommended against the marina. Consequently, the B.C. Land Management Branch has refrained from renewing the company's foreshore lease until it submits development plans that

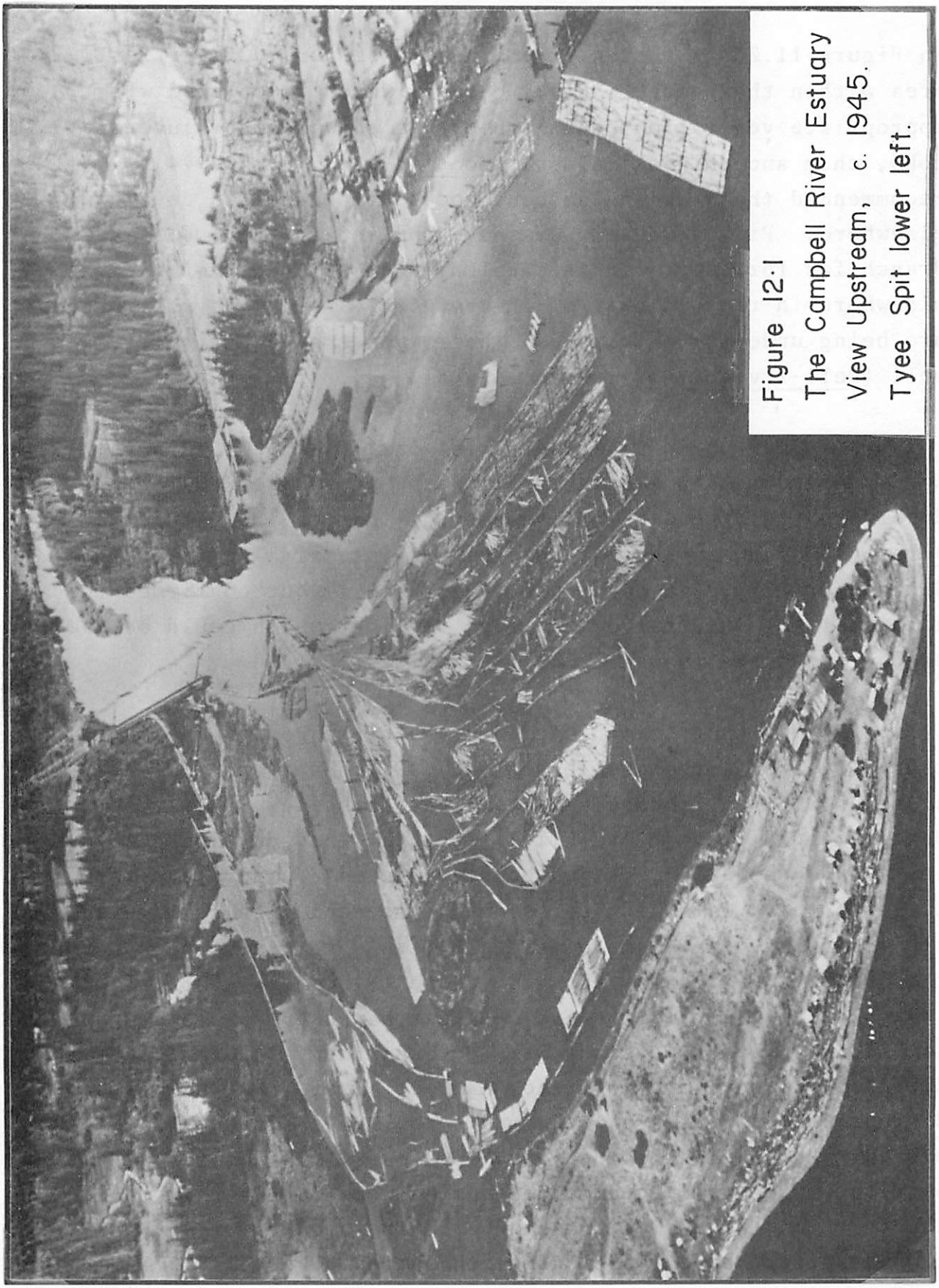


Figure 12·1
The Campbell River Estuary
View Upstream, c. 1945.
Tyee Spit lower left.

meet the approval of fisheries biologists. A private consultant has been contracted by Discovery Resorts Ltd. to conceive an acceptable plan (Egan, pers. comm., 1977).

Once established, marinas are a chronic source of petroleum, sewage and vibrational pollution to the marine environment, as discussed in the Pollution and Water Quality chapter. Periodic dredging is necessary to keep navigational channels open. Federal fisheries personnel supervised dredging in the Campbell River Boat Harbour during March, 1977, using cages of pink salmon fry from the Quinsam hatchery to ensure that toxic conditions were not created in the marina basin. The dredge spoil from that project was dumped at an ocean site south of Cape Mudge (Table 11.7, Number 4).

3. Forest Industry

Available information describing the present chronic impact of forest industry activities in the Campbell River estuary has been detailed in Section 11, and it need not be reiterated. Log booming and sorting have been carried out in the estuary for 73 years (since 1904), but there is no historical information with which to assess the impact of the development of the various sawmills, log dumps and booming grounds on the estuary's biota. Refer to Figure 12.1 to appreciate the use of the estuary for log handling in 1945. The interdepartmental "Technical Committee to Advise on the Economic Implications of the Campbell River Task Force Recommendations", chaired by J. Perry of the B.C. Land Management Branch in Nanaimo, is engaged in efforts to remove the forest industry from the estuary. Considerable log handling activity is taking place in Menzies Bay and Gowlland Harbour, but the effects have not been documented.

4. Sewage Disposal

As discussed in Section 11, sewage pollution along the Discovery Passage shoreline south of Race Point was severe until

the sewage treatment plant was opened in 1974. The effect of such pollution was both nutrient enrichment (to an undetermined extent) and pathogenic contamination. The treatment plant has effectively removed the threat of disease along the beach, but nutrients continue to be released to the sea from the town of Campbell River, since its sewage treatment plant does not possess tertiary treatment facilities. During February, 1976, the final effluent of the Campbell River Water Pollution Control Centre had a mean population equivalent of 360, which is to say that the effluent contained raw sewage from 360 people per day after treatment. The discharge rate that month was 0.05-0.08 cms (0.95 - 1.60 mgd: Higgs, 1976), the average being about 0.08% of the mean discharge of the Campbell River watershed.

Sources of bacterial pollution to Discovery Passage from the District of Campbell River were:

the 6th Ave. storm drain,
Simms Creek, and
Willow Creek (Higgs, 1976)

The unorganized electoral area of North Campbell River does not have sewers, nor does the electoral area of Quinsam, hence some bacterial and viral pollution can be expected in the Campbell River and on the Discovery Passage shoreline north of the estuary. Data to examine this are available in the Upper Island Health Unit files in Campbell River.

5. Western Mines Ltd., Buttle Lake

The development of a copper, zinc and lead mine in Myra Creek Valley at the south end of Buttle Lake has had no detrimental effect on the quality of Campbell River's domestic water supply. Concern to that effect arose from the mine's practice of dumping slurry tailings from the concentrator into Buttle Lake. There are insufficient data to judge the impact of tailings disposal on wild flora and fauna in the watershed or estuary, except that fish tissue levels of copper were six times

those for fish from unaffected lakes, while moisture, zinc and mercury levels were not significantly different (see Chapter 11).

6. Elk Falls Pulp Mill

The Crown Zellerbach pulp and paper mill on Duncan Bay is located in one of the most pollution-tolerant coastal regions on the B.C. coast: heavy tidal currents in Discovery Passage appear to dilute the mill's effluent very effectively. Its toxic effects were confined to within 200 m of the outfalls used before January 1977. Stress on the benthic fauna was evidenced by depressed numbers of organisms in the benthos nearby (Beak, 1974, 1976). A single diffuser pipe installed early in 1977 promises to reduce the impact of the effluent even further. Nothing is known concerning the effect of the freshwater influence of the BKME effluent on migrating juvenile and adult salmonids, but one study (Stockner, Cliff and Munro, 1975) found little apparent impact on the primary productivity of Duncan Bay waters. Log handling has resulted in the deposition of organic debris in parts of Duncan Bay. These deposits can release toxic hydrogen sulphide during dredging and log handling operations. Pollution abatement devices have been placed on line with the mill's debarkers, and the effluent has been routed to Discovery Passage rather than to the relatively quiet waters of Duncan Bay, in an attempt to reduce this organic load. The mill's location on Discovery Passage makes it the object of intense environmental interest, since as many as 80% of the salmon migrating to and from the Strait of Georgia via Johnstone Strait appear to use the Passage (Argue, pers. comm., 1977). The effect of the smoke plume from the mill on nearby terrestrial and marine ecosystems is unknown.

7. Shipping

Discovery Passage is the favoured route for vessels travelling in and out of the north end of the Strait of Georgia. This concentration of ship traffic in the narrow channel has been a source of petroleum pollution and large numbers of free-

floating logs. Ripple Rock was blasted from Seymour Narrows in 1958 to make the route safer; a violent explosion that killed rockfish within 0.8 kilometers (Thomson, 1958).

13. CONCLUSIONS

(i) INTRODUCTION

A primary function of this report is to indicate deficiencies in our knowledge of the environment of the Campbell River estuary. In the pages to follow we have explicitly identified those deficiencies, leaving it to the reader to search the main text and Summary for details of environmental information that is already available.

(ii) CONCLUSIONS BY TOPIC

1. Meteorological Data. A lack of detailed information on atmospheric dispersion parameters (i.e. from boundary layer wind and temperature profiles) in the area of the Campbell River estuary precludes accurate determination of the drift patterns of atmospheric emissions from sources such as the Elk Falls Mill. Continuous wind records from an exposed site near the outer estuary would assist in hindcasting wave heights affecting the area.

2. Surficial Geology. An increasing awareness of the impact of pollution from industry and other sources on the benthic ecology of the estuary points up the need for the initiation of surficial sediment sampling programs carried out in conjunction with biological research. Research projects investigating bottom sediments in the Strait of Georgia have covered the east coast of Vancouver Island south of Cape Mudge, but have not included Discovery Passage or the Campbell River estuary.

3. Fish. Ichthyological research in the watershed above anadromous fish habitats has not been intensive and is only now being pursued in earnest (see Sjolund, Appendix 1.2).

202. Conclusions

The anadromous fish habitat includes the lower 26 km of the Quinsam River, and the Campbell River below the John Hart Generating Station (Figure 6.1). Pacific salmon spawning and adult migration activities in these regions have been well studied, but information describing river rearing of young salmonids, non-salmonid ichthyofauna, food sources and the impact of hatchery production on wild river populations of salmonids does not exist.

In the inner estuary, federal biologists sampled the fish fauna of various habitats with seines during 1972 and 1973, composed a preliminary list of resident species (including relative abundance), and examined juvenile coho, chinook and chum salmon (*Oncorhynchus* spp.) for length, weight and stomach contents. This evidently is the only ichthyological work done in the Campbell River estuary. They were unable to dissertate the estuarine ecology of pink salmon or steelhead, nor could they determine how much time individual fish spent in the estuary. Even less information is available for Discovery Passage south of Seymour Narrows. Nose-tag returns of coho and chinook indicate the importance of the Passage for salmonid migrations between Georgia Strait and the Pacific Ocean. B.C. Provincial Museum divers have qualitatively examined the fish fauna of Steep Island (off Gowlland Harbour). But no studies have been done on the ecology of fish in Duncan Bay, to determine the influence on migrating salmonids of the freshwater effluent from the Elk Falls Pulp Mill, nor in fact have any other species been studied in the southern Passage.

Commercial fishing activity has only been studied at the level of Statistical Area 13, which integrates data over such a broad geographical region, that a statistical understanding of commercial fishing in the vicinity of the estuary is not possible. Local fisheries officers are valuable sources of unpublished information.

4. Invertebrates. Terrestrial invertebrates have not been documented for the Campbell River watershed, except for a mention in Mundie and Mounce (1976) of their contribution to drift fauna in the Campbell River. Freshwater invertebrates in the watershed above the estuary are mentioned in the same reference. They were sampled by other investigators concerned with assessing the impact of hydroelectric development on the limnology of the large lakes, but no major taxonomic or ecological studies of these animals have been undertaken. The invertebrate fauna of the estuary is known only from chinook, chum and coho stomach contents. It is largely estuarine (brackish water) in character, indicating freshwater dominance of the estuary's hydrological character. But no direct sampling has been carried out which could determine the location and extent of habitats utilized by invertebrates living in the estuary.

Invertebrates in southern Discovery Passage were extensively studied qualitatively--many unrelated studies potentially could yield a detailed species list,--but the ecology of these marine communities was examined only in relation to the bleached kraft mill effluent from Elk Falls. Nothing is known about the contribution of marine invertebrates in the Passage to fish food supplies, nor of the relationship of invertebrates in the Strait of Georgia to Discovery Passage fauna.

5. Flora. No comprehensive report on the terrestrial flora of the Campbell River watershed appears to exist. Freshwater plant life was mentioned only briefly in an inventory of the Quinsam River anadromous fish habitat, and in a series of reports documenting the effects of impoundment on the limnology of large lakes on the Campbell River. It is not possible to assemble a species list for freshwater flora in the upper watershed from available documents. Nothing is known about the presence of algae in the estuary, nor the role they play in providing habitats, nor their contribution to primary productivity. It is

suspected that shading from log booms might reduce potential algal productivity in the estuary, but that idea has not been tested. The distribution and identity of macrophytic algae and phytoplankton in Discovery Passage has been only partially recorded.

6. Wildlife. The only documentation of terrestrial avifauna in the watershed above the estuary consists of reports on the biology of blue grouse (*Dendragrapus obscurus*), and lists of species sighted during annual Christmas bird counts. Birds in the estuary have been well studied in terms of presence and abundance, but details of their feeding ecology and nesting habits are not available.

Mammals in our study area have not been discussed in the published literature; even a comprehensive species list is not available. Hunting is an economically important activity in the Campbell River area. But the present method of handling harvest data makes it impossible to draw conclusions with regard to the watershed, owing to the fact that the data are presently being integrated across the whole of Vancouver Island in a new system being developed.

The marine mammal community of southern Discovery Passage has not been described beyond the formulation of a species list, and an estimation of the number of killer whales (*Orcinus orca*).

7. Pollution and Water Quality

Major sources of pollution have been mapped and placed under P.C.B. permit, but the effect of pollution on natural biota is unknown for the following disturbances (see Chapter 11 for situations where the impact has been examined):

1. Tailings slurry deposition in Buttle Lake from

the Western Mines Ltd. operation in Myra Creek Valley.

2. Organic fallout from log sorting storage and booming in Menzies Bay, Duncan Bay and the inner estuary (other than the toxic effect of hydrogen sulphide when the sediments are disturbed).

3. Nutrient enrichment from septic tank seepage and the secondary treatment facilities of the District of Campbell River and various private institutions.

4. Petroleum spills from marinas and the seaplane base.

5. Leaching from the piles of sawdust and other forest products in the sawmills around the estuary (Raven Lumber and Ocean Cedar).

6. Changes in the estuary's basin morphology due to industrial development.

7. Changes in groundwater level and flow due to urban development on the surface.

8. Impact of the freshwater effluent from the Elk Falls Pulp Mill on migrating salmonids.

8. Effects of Development

There is insufficient published evidence to indicate the impact of the forest industry on biological activity in the Campbell River estuary, beyond the occurrence of occasional fish kills when hydrogen sulphide is released from rotting log debris. Historical data are needed which could be examined to recreate a

model of the estuary's biota before any development took place. The spawning escapement records from 1929 (Appendix 6.6) are the most readily available numerical data. Almost all biological information comes from studies carried out since the start of the present decade (1970), when industry had already become established.

14. APPENDICES

APPENDIX 1.1:

Sources of Information

The information used in this report was gathered from many sources, particularly the members of the Estuary Working Group (see Preface Table). The following is a list of agencies whose personnel and libraries provided much information.

1. Canada, Department of the Environment

Environmental Protection Service, Pacific Region (Vancouver, B.C.)
- Pollution Abatement Branch
- Ecological Protection Branch
- Environmental Emergency Branch

Fisheries and Marine Service (Vancouver, Campbell River)
- Fisheries Management
  - Economics and Special Assistance Programs Directorate
  - Field Services Directorate
  - Habitat Protection Directorate
  - Research and Resource Services Directorate
    - Pacific Biological Station (Nanaimo, B.C.)
  - Pacific Environment Institute (West Vancouver, B.C.)
- Ocean and Aquatic Sciences (Institute of Ocean Sciences, Patricia Bay, B.C.)
  - Canadian Hydrographic Service

Environmental Management Service (Vancouver, B.C.)
- Canadian Forestry Service
  - Pacific Forest Research Centre (Victoria, B.C.)
  - Western Forest Products Laboratory (Vancouver, B.C.)
- Canadian Wildlife Service (Delta, B.C.)
- Inland Waters Directorate
- Lands Directorate

Atmospheric Environment Service (Vancouver, B.C.)

2. Canada, Department of Energy, Mines and Resources

Geological Survey of Canada (Coastal and Terrain Sciences)
Surveys and Mapping Branch (Vancouver, B.C.)

Appendix 1.1. Sources of Information (cont'd.)

3. Statistics Canada

User Advisory Service (Vancouver, B.C.)

4. Province of British Columbia

Ministry of Recreation and Conservation (Victoria, B.C.)
- Fish and Wildlife Branch (Victoria, Nanaimo and Campbell River)
- Marine Resources Branch
- Provincial Museum
- Provincial Parks Branch (Victoria and Black Creek, B.C.)
- Surveys and Mapping Branch

Ministry of the Environment (Vancouver, B.C.)
- British Columbia Forest Service - Research Division
- Environment and Land Use Committee Secretariat
- Pollution Control Branch
- Water Investigations Branch

Ministry of Municipal Affairs and Housing

Ministry of Economic Development

Ministry of Agriculture (Victoria, Saanichton and Cloverdale, B.C.)

Ministry of Mines and Petroleum Resources

Ministry of Health (Victoria and Campbell River, B.C.)

5. District of Campbell River

- District Planning Department
- Office of Municipal Manager
- Campbell River Centennial Museum

6. Regional District of Comox-Strathcona (Courtenay, B.C.)

7. Crown Zellerbach of Canada Ltd., (Campbell River, B.C.)

8. Western Mines Ltd. (Vancouver, B.C.)

Appendix 1.1. Sources of Information (cont'd.)

9. Non-governmental Environmentalists

West Coast Environmental Law Association (Vancouver, B.C.)
Mitlenatch Natural History Society (Campbell River, B.C.)
Tyee Club of British Columbia (Campbell River, B.C.)
Steelhead Society of British Columbia (Campbell River, B.C.)
Sierra Club (Campbell River, B.C.)
Campbell River Fishing Guides Association
Campbell River District Fish and Wildlife Association
Strathcona Park Lodge (Campbell River, B.C.)
Biology Department, Campbell River Junior and Secondary Schools
Campbell River Estuary Association
Courtenay and District Fish and Game Protective Association
Kiwanis Club (Campbell River, B.C.)
National Second Century Fund (Vancouver, B.C.)

10. Environmental and Engineering Consultants (see author index for mention of their work).

Associated Engineering Services Ltd.
Austin, W.C.
AVG Management Science Ltd.
Beak, T.W. Consultants Ltd.
Binnie, R.F.
British Columbia Research Council
Burns, J.E.
Dayton and Knight Ltd.
EPEC Consulting Western Ltd.
Galbraith, D.M.
Hinton, B.R. and Associates Ltd.
International Power and Engineering Consultants Ltd.
Ker, Priestman, Keenan and Associates Ltd.
Langford, G.B.
Pollutech Pollution Advisory Services Ltd.
Robinson, Roberts and Brown Ltd.
Simons, H.A. (International) Ltd.
Stanley Associates Engineering Ltd.
Underwood, McLellan and Associates Ltd.
Willis, Cunliffe, Tait and Company Ltd.
Wright Engineers Ltd.
Yeomans, W.C.

11. University of British Columbia (Vancouver, B.C.)

Departments of Biology, Botany, Geography, Geological Sciences, Soil Science and Zoology
Faculty of Forestry
Institute of Animal Resource Ecology
Institute of Oceanography

Appendix 1.1. Sources of Information (cont'd.)

12. University of Victoria

Departments of Biology and Chemistry

13. British Columbia Hydro and Power Authority (Vancouver, B.C.)

14. Libraries

City of Vancouver and Municipal Public Libraries
Federal and Provincial Government Department Libraries
University Libraries and Reading Rooms
North Island College (Courtenay and Campbell River, B.C.)

APPENDIX 1.2:

Research in progress in the Campbell River estuary and area

Austin, A. and R. Adams: Summarization of research into the distribution and ecology of marine macrophytic algae on the east coast of Vancouver Island. University of Victoria, Victoria, B.C.

Bernard, F.R.: Samples of benthic invertebrates collected in B.C. coastal waters since the nineteenth century are being analyzed under the direction of this scientist. Some stations were in Discovery Passage, and some taxa have been identified. Canada Department of Fisheries and the Environment, Fisheries and Marine Service, Pacific Biological Station, Nanaimo

B.C. Fish and Wildlife Branch: Branch biologists are preparing a map showing the density of deer and elk on Vancouver Island. Nanaimo, B.C.

Campbell River Senior Secondary School: Biology teachers Van Egan and Dave Brown have organized their classes in an effort to collect data concerning salinity and *Anisogammarus confervicolus* (Amphipoda) distributions in the inner estuary. Similar efforts continue to generate data from a program of tagging dogfish sharks *(Squalus acanthias)* in northern Georgia Straits. 350 Dogwood Street, Campbell River, B.C.

Coates, K.: M.Sc. project on the taxonomy of marine Enchypraeid oligochaetes distributed between Victoria and Prince Rupert, with some samples from the Discovery Passage shoreline between the Campbell River estuary and Duncan Bay. University of Victoria, Victoria, B.C.

Coon, M: Harvest analysis of the commercially significant algal seaweed, *Iridaea cordata*, on Cape Mudge and Vancouver Island in the Cape Lazo area, Marine Resources Branch, B.C. Ministry of Recreation and Conservation, Victoria, B.C.

Diggle, P: Multidisciplinary analysis of resource use in the Sayward Forest, including fish, wildlife, recreation and forest harvest. B.C. Forest Service, Victoria, B.C.

Kennedy, K.: Plant communities and productivity of estuaries on the east coast of Vancouver Island. M.Sc. University of British Columbia, Vancouver, B.C.

Appendix 1.2 (cont'd)

Perry, J.: Chairman of the "Technical Committee to Advise on the Economic Implications of the Campbell River Task Force Recommendations"--an examination of the necessity and feasibility of removing industrial disturbance from the Campbell River estuarine ecosystem. Land Management Branch, B.C. Ministry of the Environment, Victoria, B.C.

Quinsam River Salmon Hatchery: Biologists at the Hatchery are studying (1) the implications of releasing artificially hatched salmonids into the Quinsam River for natural rearing above existing obstructions to anadromous migrations; (2) the behaviour of hatchery-raised chinook and coho after release to the river; (3) the distribution of hatchery chinook and coho at sea (nose-tagging experiments); and (4) the function of the clarifier which treats hatchery effluent before it is returned to the Quinsam River.

Sjolund, R.: Freshwater fisheries research into (1) potential harvest levels of Campbell River watershed lakes, (2) artificial fertilization of Mohun Lake; (3) survey of fish parasites; and (4) angler surveys. B.C. Fish and Wildlife Branch, Campbell River, B.C.

Upper Island Health Unit: Routine coliform bacteria surveys in the Comox-Strathcona Regional District, Campbell River, B.C.

APPENDIX 1.3:

Metric Conversion Factors

EXISTING UNIT	x CONVERSION FACTOR =	SI UNIT
acre	0.405	hectare
acre foot	1,233.48	cubic metre
board foot	0.00236	cubic metre
cubic foot per second	0.0283	cubic metre per second
cubic yard	0.7646	cubic metre
cunit (100 cubic feet)	2.831	cubic metre (solid timber)
degrees Fahrenheit (^{o}F)	5/9 (F-32)	degrees Celsius
fathom (6 feet)	1.8288*	metre
foot	0.3048*	metre
foot per second	30.480*	centimetre per second
gallon (Imp.)	0.004546	cubic metre
gallon (U.S.)	0.003785	cubic metre
grain per standard cubic foot (68^{o}F, 1 ATM)	55.044	milligram per mole
inch	2.54*	centimetre
inch of mercury	3.386	kilopascal (kPa)
knot (nautical miles per hour)	51.444	centimetre per second
mile	1.609	kilometre
nautical mile (Int.)	1.852*	kilometre
parts per million	1.0	milligrams per litre
pound	0.4536	kilogram
pounds per cunit	0.1602	kilograms per cubic metre (solid wood)
pounds per short ton	0.500*	kilograms per tonne
square miles	259	hectares
standard cubic foot per minute (air pollution)	0.0196	moles per second
cubic foot per minute	0.0005	cubic metre per second
ton (2,000 lbs); ADT	0.90718	tonne (1,000 kg); ADt

* *exact conversion factor*

Appendix 1.3. Metric Conversion Factors (cont'd.)

Note: Metric equivalents of measurements for use in hydraulic computations are taken from list on page v in, Environment Canada, Surface Water Data, B.C. 1974, Water Survey of Canada, Ottawa. The common usage of metric units by the Water Survey of Canada and the United States Water Resources Division is currently under discussion.

References:

British Columbia Department of Environment. 1976. The international system of units (SI), metric practice guide. Water Resources Service, Victoria, B.C. 9 p.

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Gabour, J.A.M. 1968. Conversion factors and tables. P.O. Box 24, Station "B", Montreal 110, Que., Canada, 71 p.

Rennie, P.J. 1967. Measure for measure. Canada Department of Forestry and Rural Development, Forestry Branch, Dept. Publ. No. 1195. 31 p.

APPENDIX 2.I:

Geologic Time Scale

ERA	PERIOD	APPROXIMATE NUMBER OF YEARS AGO*
Cenozoic	Quaternary	
	Recent	Last 10,000
	Pleistocene (Ice Age)	10,000 to 1,000,000
	Tertiary	(Millions)
	Pliocene	1 to 13
	Miocene	13 to 25
	Oligocene	25 to 36
	Eocene	36 to 58
	Paleocene	58 to 63
Mesozoic	Cretaceous	63 to 135
	Jurassic	135 to 181
	Triassic	181 to 230
Palaeozoic	Permian	230 to 280
	Pennsylvanian and Mississippian	280 to 345
	Devonian	345 to 405
	Silurian	405 to 425
	Ordovician	425 to 500
	Cambrian	500 to 600
Proterozoic	Keweenawan Huronian	600 to 2,000
Archaean	Temiskaming Keewatin	2,000 to 4,800

* *Science, April 14, 1961, p.1111.*

Appendix 4.1: Campbell River Estuary Streamflow Data (Can. Dept. Env., 1976).

STATION NO.	LOCATION LAT. AND LONG.	NAME	DRAINAGE AREA	DISCHARGE RECORD
08HD001	50°00'08"N 125°23'20"W	Campbell River at outlet of Campbell Lake (formerly Campbell River)	542 sq. mi. 1404 sq. km	Natural flow (1910-49). Discontinued.
08HD003	50°02'17"N 125°17'41"W	Campbell River near Campbell River	564 sq. mi. 1461 sq. km	Regulated since 1947. (1949-70). Discontinued. Water quality data available.
08HD004	49°57'54"N 125°35'10"W	Campbell River near Quinsam	444 sq. mi. 1150 sq. km	Natural flow (1953-56). Discontinued.
08HD005	50°01'45"N 125°17'55"W	Quinsam River near Campbell River	108 sq. mi. 280 sq. km	Regulated. (1914, 1915, 1949-55, 1956-72).
08HD010	49°57'45"N 125°23'40"W	Quinsam River below Quinsam	89 sq. mi. 230 sq. km	(1975-58, Data not 1959-62, published. 1968-72 cont.) Recorded by Fisheries Service (DOE)

APPENDIX 6.1:

List of fish species found in and near the Campbell River estuary (Goodman and Vroom, 1974, except for entries marked by an asterisk, which are from Hamilton and Buell, 1976).

Absolute numbers of each species caught are indicated, along with percent of total catch (in parentheses). Hart (1973) provided the taxonomic authority used to prepare this table.

ORDER PETROMYZONTIFORMES		
*	*Lampetra tridentatus*	Pacific lamprey
FAMILY AMMODYTIDAE		
501 (3.9%)	*Ammodytes hexapterus*	Pacific sand lance
FAMILY COTTIDAE		
1	?	"Aleutian sculpin"
1	*Artedius lateralis*	smoothead sculpin
15	*Clinocottus acuticeps*	sharpnose sculpin
5	*Enophrys bison*	buffalo sculpin
273 (2%)	*Leptocottus armatus*	Pacific staghorn sculpin
18	*Myoxocephalus polyacanthocephalus*	great sculpin
31	*Oligocottus maculosus*	tidepool sculpin
27	*Oligocottus rimensis*	prickly sculpin
FAMILY CLUPEIDAE		
614 (4.7%)	*Clupea harengus pallasi*	Pacific herring
FAMILY CYCLOPTERIDAE		
2	?	liparids
1	*Liparis callyodon*	spotted snailfish
FAMILY EMBIOTOCIDAE		
4	*Cymatogaster aggregata*	shiner perch

Appendix 6.1 (cont'd.)

FAMILY GADIDAE		
1	*Microgadus proximus*	Pacific tomcod
FAMILY GASTEROSTEIDAE		
3002 (23%)	*Gasterosteus aculeatus*	threespine stickleback
FAMILY HEXAGRAMMIDAE		
1	*Hexagrammos stelleri*	whitespotted greenling
FAMILY PHOLIDAE		
21	*Pholis laeta*	crescent gunnel
FAMILY PLEURONECTIDAE		
48	*Platichthys stellatus*	starry founder
FAMILY SALMONIDAE		
*	*Oncorhynchus gorbuscha*	pink, humpback salmon
1179 (9.1%)	*Oncorhynchus keta*	chum, dog salmon
1687 (13.%)	*Oncorhynchus kisutch*	coho, silver salmon
*	*Oncorhynchus nerka*	sockeye, red salmon
5369 (42%)	*Oncorhynchus tshawytscha*	chinook, king, tyee, spring
1	*Salmo gairdneri*	rainbow, steelhead trout
2	*Salmo clarki clarki*	coastal cutthroat trout
*	*Salvelinus malma*	Dolly Varden char
FAMILY SCORPAENIDAE		
3	*Sebastes* spp.	rockfish
FAMILY STICHAEIDAE		
2	*Lumpenella longirostris*	longsnout prickleback
1	*Lumpenus sagitta*	Pacific snake prickleback

APPENDIX 6.2: Sport Catch (in pieces) of Pacific salmon in federal Fisheries and Marine Service Statistical Area 13, which includes the Campbell River sport fishery. Compiled from Annual "Salmon Sport Fishing Catch Statistics for British Columbia Tidal Waters" (Fish. Mar. Serv., Vancouver, B.C.)

YEAR	CHINOOK	JACKS	COHO	CHINOOK GRILSE	COHO GRILSE	PINKS & OTHERS	TOTAL	EFFORT (BOAT DAYS)	AVERAGE CATCH PER BOAT PER DAY
1975	8,455	3755	46,760	690	6545	3772	69,977	45,670	1.5
1974	14,282	2859	53,778	1155	1350	207	73,631	47,463	1.6
1973	14,579	2837	46,317	249	1689	2201	67,872	42,287	1.6
1972	12,799	2974	32,812	700	1543	2313	53,141	41,087	1.3
1971	6,465	2640	50,323	680	2491	1930	64,529	40,811	1.6
1970	4,075	4000	28,950	925	2525	1850	42,325	37,900	1.1
1969	5,650	650	10,575	275	2125	725	20,000	36,100	0.6
1968	4,840	850	25,960	5120		630	37,400	32,120	1.2
1967	6,450	1100	29,750	1700		4100	43,100	34,125	1.3
1966	4,050	475	48,600	3200		1025	57,350	33,280	1.7

APPENDIX 6.3: Steelhead fishery data for the Campbell (first number) and Quinsam Rivers. Figures shown are estimated values derived from a mail-in survey of licence holders. (Compiled from Steelhead Harvest Analysis (Ann. rep.) B.C. Dept. Rec. Cons.).

YEAR	EFFORT (DAYS FISHED)	NUMBER OF ANGLERS	CATCH (PIECES)	NO. FISH RELEASED	SUCCESS (CATCH/DAY)
1975-6	4640-1545	777-433	1264-656	598-416	.274-.432
1974-5	3673-1506	638-335	1015-754	490-307	.277-.441
1973-4	3704-1485	735-353	737-534	390-283	.093-.170
1972-3	2478-792	603-279	524-291	187-95	.139-.248
1971-2	2828-746	510-238	453-163	272-83	.161-.222
1970-1	5132-1888	688-482	723-237	347-150	.141-.130
1969-70	4827-2010	685-467	392-247	?	.018-.123
1968-9	2774-1346	549-311	515-296	?	.184-.222
1967-8	3459-1906	556-487	481-443	?	.129-.235
1966-7	3746-1596	600-573	569-888	?	.15 -.56

APPENDIX 6.4: Campbell River Statistical Area 13 landed values (in $000) of commercially caught fish and invertebrates. Only salmon, octopus, lingcod and some halibut and herring are landed from Discovery Passage south of Seymour Narrows. "Other fish" includes salmon roe, sole, red and rockcod, greycod, blackcod, flounder, skate, perch and dogfish. "Shellfish" includes prawns, crabs and clams. ⊕ indicates less than $1,000. (Compiled from Area 13 1A Worksheets, Fish. Mar. Serv., Vancouver).

YEAR	SALMON	HERRING	HALIBUT	LINGCOD	OCTOPUS	OTHER FISH AND ROE	SHELLFISH	AREA TOTAL
1976	4374	44	⊕	46	⊕	17	19	4503
1975	2031	203	2	36	2	23	35	2353
1974	2078	113	none	66	1	13	136	2407
1973	8257	112	⊕	32	⊕	65	59	8525
1972	1950	109	⊕	37	⊕	3	74	2173
1971	1265	15	⊕	29	1	4	36	1350
1970	1496	none	⊕	47	1	4	13	1561

APPENDIX 6.5: Escapement records for the lower Campbell River and Quinsam River. From Hamilton and Buell (1976). (n.o. - none observed. u.d. - present but not enumerated.)

(1) LOWER CAMPBELL RIVER:

YEAR	CHINOOK	COHO	PINK	CHUM	SOCKEYE	STEELHEAD
1957	1,500	25	75	400	n.o.	75
1958	3,500	400	750	1,500	n.o.	400
1959	1,500	750	75	750	n.o.	u.d.
1960	3,500	75	400	400	n.o.	u.d.
1961	1,500	400	75	1,500	n.o.	u.d.
1962	4,000	750	400	750	n.o.	u.d.
1963	4,000	400	400	2,950	n.o.	u.d.
1964	6,000	750	3,500	750	n.o.	u.d.
1965	8,000	1,500	400	400	n.o.	u.d.
1966	3,500	3,500	3,500	750	n.o.	u.d.
1967	3,500	400	750	750	n.o.	u.d.
1968	3,500	500	3,500	750	200	u.d.
1969	6,000	400	750	3,500	200	u.d.
1970	3,500	3,500	3,500	3,500	n.o.	u.d.
1971	7,500	1,500	750	1,500	75	u.d.
1972	7,500	1,500	3,500	3,500	75	u.d.
1973	4,300	1,000	1,000	4,000	150	u.d.
1974	2,500	1,500	4,000	3,500	75	u.d.
1975	2-2,500	3-500	1-2,000	2-4,000	1-50	u.d.
1976	4,000	1-300	10,000	5,500	25	u.d.

(2) QUINSAM RIVER:

YEAR	CHINOOK	COHO	PINK	CHUM	SOCKEYE	STEELHEAD
1957	25	7,500	3,500	1,500	n.o.	750
1958	75	1,500	7,500	3,500	n.o.	1,500
1959	25	7,500	3,500	200	n.o.	u.d.
1960	25	1,500	750	200	n.o.	u.d.
1961	n.o.	7,500	3,500	750	n.o.	u.d.
1962	n.o.	7,500	750	750	n.o.	u.d.
1963	n.o.	3,500	3,500	750	n.o.	u.d.
1964	n.o.	3,500	1,500	200	n.o.	u.d.
1965	n.o.	12,000	3,000	400	n.o.	u.d.
1966	n.o.	3,500	1,500	400	n.o.	u.d.
1967	n.o.	1,500	1,500	750	n.o.	u.d.
1968	n.o.	3,500	1,500	200	75	u.d.
1969	n.o.	750	750	400	n.o.	u.d.
1970	n.o.	3,500	1,500	750	n.o.	u.d.
1971	25	1,500	400	400	25	u.d.
1972	75	1,500	3,500	1,500	200	u.d.
1973	5	4,600	4,000	1,000	40	u.d.
1974	75	3,500	7,500	400	25	u.d.
1975	1-300	2-5,000	30,000	3-500	1-50	u.d.
1976	1-50	986	24,000	800	1-50	u.d.

APPENDIX 6.6:

Escapement record for the Campbell-Quinsam River system (from Goodman and Vroom, 1974 and Fisheries Officers Annual Spawning Reports, Fisheries and Marine Service, Vancouver).

n.o. none observed
u.d. present, but not enumerated
LT less than

YEAR	CHINOOK	COHO	PINK	CHUM	SOCKEYE	STEELHEAD
1929	heavy	heavy	light	light	n.o.	medium
1930	very light	medium	medium	medium	n.o.	medium
1931	light	light	n.o.	light	n.o.	medium
1932	medium	medium	light	heavy	n.o.	medium
1933	good	heavy	light	heavy	n.o.	medium
1934	15,000	75,000	100,000+	100,000+	n.o.	u.d.
1935	3,500	3,500	750	7,500	n.o.	400
1936	750	1,500	3,500	7,500	n.o.	200
1937	750	3,500	750	7,500	n.o.	750
1938	3,500	7,500	1,500	3,500	n.o.	750
1939	3,500	1,500	7,500	7,500	n.o.	200
1940	750	1,500	7,500	7,500	n.o.	400
1941	3,500	75,000	7,500	35,000	n.o.	750
1942	7,500	3,500	750	7,500	n.o.	3,500
1943	3,500	3,500	750	7,500	n.o.	400
1944	u.d.	u.d.	u.d.	u.d.	u.d.	u.d.
1945	u.d.	u.d.	u.d.	u.d.	u.d.	u.d.
1946	3,500	500	400	7,500	n.o.	750
1947	3,500	3,500	7,500	7,500	n.o.	1,500
1948	3,500	1,500	7,500	15,000	n.o.	1,500
1949	1,500	400	200	3,500	n.o.	1,500
1950	1,500	750	7,500	3,500	n.o.	1,500
1951	1,500	750	400	7,500	n.o.	750
1952	3,500	3,500	7,500	3,500	n.o.	750
1953	3,500	750	75	1,500	n.o.	1,500
1954	1,500	750	1,500	3,500	n.o.	750

Appendix 6.6 (cont'd).

YEAR	CHINOOK	COHO	PINK	CHUM	SOCKEYE	STEELHEAD
1955	3,500	750	200	750	n.o.	750
1956	750	750	1,500	1,500	n.o.	750
1957	1,525	7,525	3,575	1,900	n.o.	825
1958	3,575	1,900	8,250	5,000	n.o.	1,900
1959	1,525	8,250	3,575	950	n.o.	u.d.
1960	3,525	1,575	1,150	600	n.o.	u.d.
1961	1,500	7,900	3,575	2,250	n.o.	u.d.
1962	4,000	8,250	1,150	1,500	n.o.	u.d.
1963	4,000	3,900	3,900	3,700	n.o.	u.d.
1964	6,000	4,250	5,000	950	n.o.	u.d.
1965	8,000	13,500	3,400	800	n.o.	u.d.
1966	3,500	7,000	5,000	1,150	n.o.	u.d.
1967	3,500	1,900	2,250	1,500	n.o.	u.d.
1968	3,500	7,000	5,000	950	275	u.d.
1969	6,000	1,150	1,500	3,900	200	u.d.
1970	3,500	7,000	5,000	4,250	n.o.	u.d.
1971	7,500	3,000	1,150	1,900	100	u.d.
1972	7,500	3,000	7,000	5,000	275	u.d.
1973	4,375	5,600	5,000	5,000	190	u.d.
1974	2,575	5,000	11,500	3,900	100	u.d.
1975	LT2,800	LT5,500	LT32,000	LT4,500	LT100	u.d.
1976	4,050	LT1,286	34,000	6,300	LT75	u.d.

APPENDIX 7.1: Index to Figure 7.1: List of benthic invertebrate and macrophyte investigations carried out in and near southern Discovery Passage. The superscript on each date refers to one of the following references:

Faunistic Surveys:

1: Dawson (1886), cited in Bernard, et al. (1967)
2: Austin and Haylock (1973)
3: Bernard, et al. (1970)
4: Bernard and Quayle (1973)
13: Bousfield (1956)
14: Bousfield (1963)

Other Faunal Studies:

2: Cockbain (1963)
6: Nelson and Goyette (1976)
7: Beak Consultants Ltd. (1974, 1976)
8: Goodman and Vroom (1974)
9: Mundie and Mounce (1976)

Marine Floral Studies:

7: Beak Consultants Ltd. (1974, 1976)
10: Widdowson (1964)
11 Druehl (1965, 1967)
12 Austin and Adams (1974, 1975)

Appendix 7.1. (cont'd).

Code to Fig. 7.1	Month, Year and Stn. No.	Location	Depth (FM)	Gear Used	Substrate	Comments re Biota
1	1885[1]7	50°05'N 125°17'W	18-37 (6-10 FM)	--	--	invertebrates
--	1885[1]8	50°16'N 125°25'W	46 (25 FM)	--	--	"
2	8-1955[13]G2	Tyee Spit	intertidal	--	stone	"
3	8-1955[13]G1	Menzies B.	"	--	sand, mud stone	"
--	1960[2]64	49°58'54"N 125°01'48"W	123	core or grab	--	.....
--	1960[2]66	50°06'48"N 125°07'24"W	250	core or grab	--	. .
--	1960[2]67	50°02'48"N 125°07'36"W	258	core or grab	--	surveyed for foraminiferal fauna
--	1960[2]68	49°58'54"N 125°07'30"W	42	core or grab	--	. .
--	1960[2]69	49°54'42"N 125°07'24"W	50	core or grab	--	.....
--	6-1962[3]15	49°59'.0"N 125° 5.1"W	146	rocker dredge	boulders gravel	6 *Ophiopholis aculeata kennerlyi*
4	6-1959[14]V20	Brown Bay	intertidal	--	rock, stone, coarse sand	kelp, invertebrates

Appendix 7.1 (cont'd).

Code to Fig.	Month, Year and Stn. No.	Location	Depth (m)	Gear Used	Substrate	Comments re Biota
--	9-1968[4]77	50 22.4N 125 38.1W	260	--	mud, sand	gastropods dominant
--	5-1969[3]29	49 49.5N 125 9.5W	0	on foot	rock	some *Ophiopholis aculeata*
--	3-1970[3]53	49 50.1N 125 18.2W	0	--	mud, sand	many *Amphiodia occidentalis*
--	8-1970[3]169	(same)	8	triangle	(same)	(same)
--	9-1970[3]190	50 5.3N 125 18.2W	0	diving	mud, weed	some *A. occidentalis* 50 *Ophiura luetkeni*
--	6-1970[5]14	50 05.0N 125 17.5W	46	triangle	shell, gravel	tubeless polychaetes dominant
--	6-1970[5]15	50 06.0N 125 18.5W	64	triangle	mud, sand	tunicates dominant
5-10	5,8-1973[6]	see Fig. 7.1	0	on foot	--	shellfish for heavy metals analysis
11-22	1973-76[7]	see Fig. 7.1	--	grab, scuba, photo	--	benthos for estimate of pollution impact from pulp mill
23	1973-74[8]	estuary	--	seine	--	invertebrates from stomach contents of juvenile salmon
24	9-1973[9]	lower Campbell River	--	drift net	--	drift invertebrates in the river

Appendix 7.1. (cont'd).

Code to Fig.	Month, Year and Stn. No.	Location	Depth (m)	Gear Used	Substrate	Comments re Biota
25, 26	1964[10]	see Fig. 7.1	--	--	--	*Alaria* morphology (kelp)
27	1965-67[11]	Cape Mudge	--	--	--	*Laminaria* (kelp) ecology
Stipp-ling	1970-75[12]	see Fig. 7.1	subtidal	photo, scuba, foot	--	seaweed distribution and abundance

APPENDIX 8.1:

List of vascular plant species found in the Campbell River estuary during July 1976. Code symbol indicates that the species was dominant (D), subdominant (S) or present (P), and identifies the plant community in which it was growing. Data prepared by K.Kennedy (M.Sc., in progress, University of British Columbia, Vancouver).

Key to Community Numbers:

1. *Carex lyngbyei* (Lyngby's sedge),
2. *Potentilla pacifica* (Pacific silverweed) and *Eleocharis palustris* (spike-rush),
3. *Deschampsia cespitosa* (tufted hairgrass),
4. *Alnus rubra* (red alder), *Rubus laciniatus* (evergreen blackberry), *Cytisus scoparius* (broom), *Rosa nutkana* (Nootka rose), and *Rubus spectabilis* (salmonberry),
5. *P. pacifica* and *D. cespitosa*,
6. *Myrica gale* (sweet gale) and *Scirpus acutus* (hardstem bulrush),
7. *Ruppia maritima* (ditchgrass),
8. *Alnus rubra* (red alder), *Rosa nutkana* (Nootka rose), and *Symphoricarpos albus* (snowberry).

TREES		COMMUNITY NUMBER							
		1	2	3	4	5	6	7	8
Rhamnus purshiana	cascara								P
Alnus rubra	red alder				S				S
Pseudotsuga menziesii	Douglas fir								S
Pyrus fusca	Pacific crabapple				P				S
Thuja plicata	western red cedar								P
Acer macrophyllum	common maple								P
		1	2	3	4	5	6	7	8

Appendix 8.1 (cont'd).

SHRUBS		COMMUNITY NUMBER							
		1	2	3	4	5	6	7	8
Holodiscus discolor	ocean spray				P				
Rubus laciniatus	evergreen blackberry				S				
Cytisus scoparius	broom				S				
Myrica gale	sweet gale			P	P		D		
Rosa nutkana	Nootka rose				S				
Lonicera involucrata	black twin-berry				P				
Rubus spectabilis	salmonberry				S				S
Physocarpus capitatus	ninebark				P				
Samburus racemosa	Elder berry				P				P
Rubus parviflorus	thimbleberry								S
Rosa gymnocarpa	little wild rose								P
Ribes sp.	gooseberry								P
Spiraea douglasii	hardhack								P
Berberis nervosa	Oregon grape								P
Vaccinium parvifolium	huckleberry								P
Symphoricarpos albus	snowberry								S
Amelanchier alnifolia	serviceberry								P
Rubus pedatus	fiveleaved bramble								P
Rubus ursinus	Pacific blackberry								S
Lonicera ciliosa	orange honeysuckle								S
Salix sp.	willow								P
FORBS									
Triglochin maritimum	arrow-grass	P	P	P		P			
Lilaeopsis occidentalis	lilaeopsis	P	P						
Sidalcea hendersonii	Henderson's checker		P	P	P	P			
Trifolium repens	white clover			P	P				P
Trifolium wormskjoldii	springbank clover		P	P	P				
Castilleja levisecta	golden Indian-paintbrush			P	P				
Trifolium pratense	red clover			P	P				
Achillea millefolium	yarrow			P	P				
Rumex crispus	curly dock				P		P		P
Plantago lanceolata	ribgrass		P		P				P
		1	2	3	4	5	6	7	8

Appendix 8.1 (cont'd).

FORBS (cont'd).		COMMUNITY NUMBER							
		1	2	3	4	5	6	7	8
Hypochaeris radicata	hairy cats-ear				P				
Plantago maritima	sea plantain		P			P			
Plantago macrocarpa	Alaska plantain			P		P			
Montia parvifolia	miner's lettuce								P
Potentilla pacifica	Pacific silverweed	P	D	S	P	S	P		
Erigeron philadelphicus	Philadelphia fleabane			P	P	P			
Glaux maritima	sea-milkwort		P	P		P			
Sisyrinchium angustifolium	blue-eyed grass			P					
Typha latifolia	common cat-tail			P					
Prunella vulgaris	self-heal			P	P				
Cirsium arvense	Canada thistle			P	P				S
Aquilegia formosa	red columbine				P				P
Vicia gigantea	giant vetch				P				
Equisetum arvense	common horsetail				P		P		
Epilobium angustifolium	fireweed				P				P
Fritillaria camschatcensis	chocolate lily			P					
Maianthemum dilatatum	false lily-of-the-valley								P
Rumex acetosella	sourweed								P
Lupinus sp.	lupine								P
Trifolium dubium	least hop clover								P
Galium sp.	bedstraw								P
Polystichum munitum	sword-fern								P
Trillium ovatum	trillium								P
Lilium columbianum	Columbia lily								P
Trifolium tridentatum	sand clover								P
Pterillium aquilinum	bracken								P
Streptopus amplexifolius	twisted-stalk								P
Convolvulus sepium	morning-glory				P				P
Heracleum lanatum	cow-parsnip			P	P				P
Habenaria dilatata	bog-candle			P	P				
Oenanthe sarmentosa	water-parsley			P	P		P		
Achlys triphylla	vanillaleaf								P
		1	2	3	4	5	6	7	8

Appendix 8.1 (cont'd).

FORBS (cont'd).		COMMUNITY NUMBER							
		1	2	3	4	5	6	7	8
Hypericum formosum	St. John's wort			P	P		P		
Ranunculus sp.	buttercup			P	P				
Lathyrus palustris	marsh pea			P	P		P		
Dodecatheon pulchellum	shooting-star			P					
Spergularia marina	saltmarsh sandspurry					P			
Ruppia maritima	ditch-grass							D	
Myosotis discolor	yellow and blue forget-me-not								P
GRASSES									
Holcus lanatus	velvet-grass			P	P				P
Deschampsia cespitosa	tufted hairgrass	P	P	D		D			
Hordeum brachyantherum	meadow barley			P	P		P		
Hierochloe odorata	Seneca grass			P					
Elymus mollis	dune wildrye				P				
Aira sp.	hairgrass								P
Festuca sp.	fescue			P		P	P		
Agrostis tenuis	colonial bentgrass			P					
SEDGES									
Carex lyngbyei	Lyngby's sedge	D	P	P	P	S	P	P	
Eleocharis palustris	spike-rush	P	D	P	P	P	P	P	
Scirpus microcarpus	small-fruit bulrush								
Scirpus americanus	three-square bulrush	P	S						
Scirpus acutus	hardstem bulrush						S		
Carex lenticularis var. *limnophila*	sedge			P					
Scirpus validus	bulrush	P							
RUSHES									
Juncus articulatus	jointed rush		P						
Juncus balticus	Baltic rush	P	S	P		P	P		
Juncus effusus	common rush			P	P				
		1	2	3	4	5	6	7	8

APPENDIX 9.1:

List of bird species observed in the Campbell River estuary between September 1973 and January 1976. Compiled from Mitlenatch Natural History Society data sheets (Telosky, unpub.). Two-letter symbol gives an indication of how heavily that species uses the estuary:

first	second
a - abundant	r - resident
c - common	s - summer visitor
u - uncommon	w - winter visitor
r - rare	m - migrant (fall and/or spring)
v - vagrant	

Bird nomenclature is based on Godfrey (1966) except where recent taxonomic revisions take precedence (American Ornithologists' Union, 1973). Entries are arranged according to the accepted A.O.U. order (Trethewey, pers. comm., 1977). The letter "P" signifies that the species is protected under federal law * (Envi. Can., 1974b).

1.	*Gavia immer*	P	common loon	cw/rs
2.	*Gavia arctica*	P	Arctic loon	rw
3.	*Gavia stellata*	P	red-throated loon	rw
4.	*Podiceps grisegena*	P	red-necked grebe	uw/um
5.	*Podiceps auritus*	P	horned grebe	uw
6.	*Aechmophorus occidentalis*	P	western grebe	rw
7.	*Podilymbus podiceps*	P	pied-billed grebe	rm
8.	*Phalacrocorax auritus*		double-crested cormorant	uw
9.	*Phalacrocorax pelagicus*		pelagic cormorant	cr
10.	*Phalacrocorax penicillatus*		Brandt's cormorant	rw

Migratory Birds Convention Act R.S. 1970 c.m-12.

Appendix 9.1 (cont'd).

11.	*Ardea herodias*	P	great blue heron	ur
12.	*Olor buccinator*	P	trumpeter swan	rw
13.	*Branta canadensis*	P	Canada goose	cm
14.	*Anser albifrons*	P	white-fronted goose	um
15.	*Branta bernicla*	P	black brant	um
16.	*Anas platyrhynchos*	P	mallard	cr
17.	*Anas acuta*	P	pintail	uw
18.	*Anas crecca*	P	green-winged teal	cw
19.	*Anas discors*	P	blue-winged teal	um
20	*Anas americana*	P	American wigeon	cw/us
21.	*Spatula clypeata*	P	northern shoveler	rm/vw
22.	*Aythya valisinera*	P	canvasback	vw
23.	*Aythya marila*	P	greater scaup	cw
24.	*Aythya affinis*	P	lesser scaup	rw
25.	*Bucephala clangula*	P	common goldeneye	aw
26.	*Bucephala islandica*	P	Barrow's goldeneye	rw
27.	*Bucephala albeola*	P	bufflehead	aw
28.	*Clangula hyemalis*	P	oldsquaw	uw
29.	*Histrionicus histrionicus*	P	harlequin duck	uw
30.	*Melanitta deglandi*	P	white-winged scoter	rs/rm
31.	*Melanitta perspicillata*	P	surf scoter	uw
32.	*Melanitta nigra*	P	black scoter	uw
33.	*Lophodytes cucullatus*	P	hooded merganser	uw
34.	*Mergus merganser*	P	common merganser	cr
35.	*Mergus serrator*	P	red-breasted merganser	rw
36.	*Cathartes aura*		turkey vulture	rm

Appendix 9.1 (cont'd).

37.	*Accipiter striatus*		sharp-shinned hawk	rw
38.	*Accipiter cooperii*		Cooper's hawk	rm
39.	*Buteo jamaicensis*		red-tailed hawk	ur
40.	*Haliaeetus leucocephalus*		bald eagle	cw/us
41.	*Circus cyaneus*		marsh hawk	rm
42.	*Pandion haliaetus*		osprey	rs
43.	*Falco columbarius*		pigeon hawk (merlin)	rr
44.	*Falco sparverius*		sparrow hawk (American kestrel)	um
45.	*Bonasa umbellus*		ruffed grouse	rr
46.	*Rallus limicola*	P	virginia rail	vw/us
47.	*Fulica americana*	P	American coot	um/rw
48.	*Charadrius vociferus*	P	killdeer	ar
49.	*Pluvialis squatarola*		black-bellied plover	rm/vw
50.	*Capella gallinago*		common snipe	cm/uw
51.	*Actitis macularia*	P	spotted sandpiper	cs
52.	*Tringa melanoleuca*	P	greater yellowlegs	rm
53.	*Calidris melanotos*	P	pectoral sandpiper	um
54.	*Calidris minutilla*	P	least sandpiper	um
55.	*Calidris alpina*		dunlin	um
56.	*Limnodromus griseus*	P	short-billed dowitcher	rm
57.	*Limnodromus scolopaceus*	P	long-billed dowitcher	rm
58.	*Stercorarius parasiticus*	P	parasite jaeger	um
59.	*Larus hyperboreus*	P	glaucous gull (CWS, 1975)	rw
60.	*Larus glaucescens*	P	glaucous-winged gull	ar
61.	*Larus argentatus*	P	herring gull	cm
62.	*Larus californicus*	P	California gull	rm

Appendix 9.1 (cont'd).

63.	*Larus canus*	P	mew gull	cw/um
64.	*Larus philadelphia*	P	Bonapartes gull	cm
65.	*Rissa tridactyla*	P	black-legged kittiwake	rs/um
66.	*Cepphus columba*	P	pigeon guillemot	ur
67.	*Brachyramphus marmoratus*	P	marbled murrelet	uw/rm
68.	*Columba fasciata*	P	band-tailed pigeon	cs
69.	*Columba livia*	P	rock dove	cs
70.	*Zenaida macroura*	P	mourning dove	vs
71.	*Otus asio*		screech owl	rr
72.	*Bubo virginianus*		great-horned owl	rm
73.	*Nyctea scandiaca*		snowy owl	vw
74.	*Asio flammeus*		short-eared owl	um
75.	*Cypseloides niger*	P	black swift	us
76.	*Selasphorus rufus*	P	rufous hummingbird	am/cs
77.	*Megaceryle alcyon*		belted kingfisher	cr
78.	*Colaptes auratus*		common flicker	cr
79.	*Dryocopus pileatus*	P	pileated woodpecker	ur
80.	*Dendrocopos villosus*	P	hairy woodpecker	cr
81.	*Dendrocopos pubescens*	P	downy woodpecker	cr
82.	*Empidonax traillii*	P	willow flycatcher	us
83.	*Empidonax hammondii*	P	Hammond's flycatcher	rs
84.	*Empidonax difficilis*	P	western flycatcher	us
85.	*Contopus sordidulus*	P	western-wood peewee	vm
86.	*Nuttallornis borealis*	P	olive-sided flycatcher	rm

Appendix 9.1 (cont'd).

87.	*Tachycineta thalassina*	P	violet-green swallow	cs
88.	*Iridoprocne bicolor*	P	tree swallow	cs/rm
89.	*Stelgidopteryx ruficollis*	P	rough-winged swallow	cs
90.	*Hirundo rustica*	P	barn swallow	as
91.	*Petrochelidon pyrrhonota*	P	cliff swallow	rs
92.	*Perisoreus canadensis*		gray jay	vw
93.	*Cyanocitta stelleri*		Steller's jay	cw/rs
94.	*Corvus corax*		common raven	uw/rs
95.	*Corvus caurinus*		northwestern crow	ar
96.	*Parus rufescens*		chestnut-backed chickadee	cr
97.	*Psaltriparus minimus*	P	bushtit	rm
98.	*Certhia familiaris*		brown creeper	ur
99.	*Troglodytes troglodytes*	P.	winter wren	ur
100.	*Thryomanes bewickii*	P	Bewick's wren	ur
101.	*Telmatodytes palustris*	P	long-billed marsh wren	vw/m
102.	*Mimus polyglottos*	P	northern mockingbird	vs
103.	*Turdus migratorius*		American robin	as/rw
104.	*Ixoreus naevius*	P	varied thrush	uw
105.	*Catharus ustulatus*	P	Swainson's thrush	cs
106	*Regulus satrapa*	P	golden-crowned kinglet	cr
107.	*Regulus calendula*	P	ruby-crowned kinglet	rs/uw
108.	*Anthus spinoletta*		water pipit	um
109.	*Bombycilla cedrorum*	P	cedar waxwing	cs

Appendix 9.1 (cont'd).

110.	*Lanius excubitor*	P	northern shrike	rw
111.	*Sturnus vulgaris*		common starling	ar
112.	*Vermivora celata*	P	orange-crowned warbler	as
113.	*Dendroica petechia*	P	yellow warbler	cs
114.	*Dendroica coronata*	P	yellow-rumped warbler	as/rm
115.	*Oporornis tolmiei*	P	MacGillivray's warbler	cs
116.	*Geothlypis trichas*	P	common yellowthroat	us
117.	*Wilsonia pusilla*	P	Wilson warbler	us
118.	*Sturnella neglecta*		western meadowlark	vm
119.	*Agelaius phoenicus*		red-winged blackbird	as/uw
120.	*Euphagus cyanocephalus*		Brewer's blackbird	cs/vw
121.	*Molothrus ater*		brown-headed cowbird	cs
122.	*Hesperiphona vespertina*	P	evening grosbeak	uw/vs
123.	*Carpodacus purpureus*	P	purple finch	cw/vs
124.	*Carpodacus mexicanus*	P	house finch	cs/uw
125.	*Spinus pinus*		pine siskin	cr
126.	*Spinus tristis*	P	American goldfinch	cs
127.	*Loxia curvirostra*	P	red crossbill	ur
128.	*Pipilo erythrophthalmus*	P	rufous-sided towhee	cs/uw
129.	*Passerculus sandwichensis*	P	Savannah sparrow	cm
130.	*Junco hyemalis*	P	dark-eyed junco	cw
131.	*Spizella passerina*	P	chipping sparrow	us
132.	*Zonotrichia leucophrys*	P	white-crowned sparrow	cs/rw
133.	*Zonotrichia atricapilla*	P	golden-crowned sparrow	cm/rw
134.	*Passerella iliaca*	P	fox sparrow	ur/vs
135.	*Melospiza melodia*	P	song sparrow	ar
136.	*Calcarius lapponicus*	P	Lapland longspur	rm
137.	*Plectrophenax nivalis*	P	snow bunting	rw

APPENDIX 9.2:

List of mammals likely to be found in the Campbell River estuary and environs, compiled from the reference text written by Cowan and Guiguet (1973). Species known to exist in the area are indicated by numerical superscripts which refer to these references:

[1]Canadian Wildlife Service (unpublished data)

[2]Bigg, pers. comm. (1976)

[3]Canada Department of the Environment (1975b)

[4]specimen referred to by Cowan and Guiguet (1973)

[5]Smith, pers. comm. (1977)

Taxonomic authority: Cowan and Guiguet, 1973, except where Banfield (1974) is referenced.

Order Insectivora

1.	*Sorex vagrans*	wandering shrew
2.	*Sorex palustris*	"

Order Chiroptera (Bats)

3.	*Myotis californicus*	California myotis
4.	*Myotis evotis*	long-eared myotis
5.	*Myotis lucifugus*	little brown myotis
6.	*Myotis yumanensis*	Yuma myotis

Order Rodentia

7.	*Tamiasciurus douglasi*	Douglas squirrel
8.	*Castor canadensis*	American beaver
9.	*Permyscus maniculatis*	white-footed mouse
10.	*Microtus townsendi*	Townsend vole
11.	*Onaatra zibethica*	muskrat
12.	*Rattus norvegicus*	Norway rat
13.	*Mus musculus*	house mouse

Appendix 9.2 (cont'd).

Order Cetacea		
14.	*Orcinus orca*[2] (Banfield,1974)	killer whale
15.	*Phocoenoides dalli*[2]	dall porpoise
16.	*Phocoena phocoena*[2,1] (Banfield,1974)	harbour porpoise
17.	*Lagenorhynchus obliquidens*	Pacific striped dolphin
18.	*Balaenoptera physalus*	common finback whale
19.	*Balaenoptera borealis*	sei or pollack whale
20.	*Megaptera novaeangliae*	humpback whale
Order Carnivora		
21.	*Canis lupus*	wolf
22.	*Ursus americanus*[5]	black bear
23.	*Procyon lotor*	raccoon
24.	*Martes americana*	marten
25.	*Mustela ermina*	short-tailed weasel
26.	*Mustela vision*	mink
27.	*Gulo luscus*	wolverine
28.	*Felis concolor*[5]	cougar
Order Pinnipedia		
29.	*Callorhinus ursinus*[2,4]	northern fur seal
30.	*Phoca vitulina*[2,3]	hair or harbour seal
31.	*Eumatopias jubata*[2,3]	northern or Steller's sea lion
Order Artiodactyla		
32.	*Cervus canadensis*[5]	Roosevelt elk
33.	*Odocoileus hemionus*[5]	black-tailed deer

APPENDIX 10.1:

Maps, charts and aerial photographs of the Campbell River region.

TOPOGRAPHIC MAPS	SHEET NO.	SCALE
Quadra Island	92K/3	1:50,000
Brewster Lake	92K/4	1:50,000
Comox	92F/10	1:50,000
Forbidden Plateau	92F/11	1:50,000
Buttle Lake	92F/12	1:50,000
Upper Campbell Lake	92F/13	1:50,000
Oyster River	92F/14	1:50,000
Powell River	92F/15	1:50,000

GEOLOGICAL AND SOILS MAPS

Geological Survey of Canada:

Geology Comox Lake Area Map 2-1965 1:126,270 (1 inch = 2 miles)
(J.E. Muller, 1964)

Surficial Geology Oyster River Map 49-1959 1:63,360
Comox, Nanaimo and Sayward Districts (1 inch = 1 mile)
(J.G. Fyles, 1956-1957)

B.C. Department of Mines and Petroleum Resources
Preliminary geological map, Buttle Lake Area 1 inch = ½ mile
(W.G. Jeffry, 1964)

British Columbia Physiographic Subdivisions 1 inch = 30 miles
Bulletin 48 (S.S. Holland, 1964)

Canada Department of Agriculture
Soil map of Vancouver Island 1:63,360
Courtenay - Campbell River Sheet (1 inch = 1 mile)
Report No. 6 of the British Columbia
Soil Survey (J.H. Day, L. Farstad
and D.G. Laird, 1959)

Appendix 10.1 (cont'd).

MISCELLANEOUS MAPS

British Columbia Lands Service Departmental Reference Maps (Foreshore leases, timber leases survey lots and sections).	MAP NO.	SCALE
South Campbell River and Quadra Island	R92K/3-B	1 inch = ¼ mile
Campbell River - Duncan Bay - Menzies Bay	R92K/3-C	1 inch = ¼ mile
Campbell Lake - Sayward Forest. - Johnstone Strait	R92K/SW	1 inch = 1 mile
Upper Campbell Lake-Quinsam River - Buttle Lake	R92F/NW	1 inch = 1 mile
Oyster Bay - Willow Point	R92F/14E½	1 inch = ½ mile

Canada Land Inventory, Land Capability Maps	SHEET NO.	SCALE
Agriculture - Campbell River	92K/3	1:50,000
- Quinsam	92F/14	1:50,000
Recreation - Campbell River	92K/3	1:50,000
- Campbell River	92K/SW	1:126,270
- Buttle Lake	92F/NW	1:126,270
Present Land Use - Campbell River	92K/SW	1:126,720
Ungulates - Campbell River	92K/SW	1:126,720
Waterfowl - Buttle Lake	92F/NW	1:126,720

Land Use Maps ARDA Present Land Use Project 1969	SHEET NO.	SCALE
Campbell River & Campbell Lake	92K/3	1:50,000
Salmon River (Mohun Lake)	92K/4	1:50,000

Appendix 10.1 (cont'd).

Land Use Maps (cont'd).	SHEET NO.	SCALE
Buttle Lake	92 F/12	1:50,000
Upper Campbell Lake	92F/13	1:50,000
Quinsam Lake to Willow Point	92F/14	1:50,000

(all maps include forest data from Forest Inventory Maps)

British Columbia Ministry of Recreation and Conservation

Parks, recreation areas and recreation reserves (Campbell River - Buttle Lake area)	92K/NW; 92F/NW 92K/SW; 92F/SW	1 inch = 2 miles

Recreation Guide Maps	Published By
Strathcona Provincial Park	Provincial Parks Branch
Provincial Parks on Vancouver Island	B.C. Ministry of Recreation and Conservation
A recreation guide to Menzies Bay Division, Map 8.	MacMillan Bloedel Ltd.
A recreation guide to Iron River Division, Map 9	MacMillan Bloedel Ltd.
Campbell River and Buttle Lake, including Upper Campbell Lake Miracle Beach and Kelsey Bay Scale: 3/4 inch = 1 mile	Doris Stastny Maps, Box 5277 Postal Station B, Victoria, B.C. V8R 6N4

Campbell River District Municipality

Indian Reserve No. 11 Land use map Scale 1 inch = 200 feet	Compiled Sept., 1968 J.R. Austin & Associates B.C. Land Surveyors Campbell River
District of Campbell River Scale 1 inch = 2,000 feet	Compiled 1975 J.R. Austin & Associates Campbell River

Appendix 10.1 (cont'd).

Regional District of Comox-Strathcona

District of Campbell River Scale 1 inch = 1,000 feet	Planning Department Regional District of Comox-Strathcona
Regional District of Comox-Strathcona Electoral Areas	Ditto

HYDROGRAPHIC CHARTS

Vancouver Island	3001	1:525,000
Plans in the vicinity of		
Discovery Passage (Duncan Bay)	3556	1:6,082
Discovery Passage and Seymour Narrows	3565	1:38,000
Discovery Passage, Toba Inlet and connectiong channels	3594	1:75,000

AERIAL PHOTOGRAPHS (B.C. GOVERNMENT)

	Date	Flight Line	Scale
Buttle Lake	Sep. '72	BC 5056*	20 chain (1 in. = ¼ mi.)
Campbell Lake	June '64	BC 5097	40 chain (1 in. = ½ mi.)
Campbell River/Buttle Lake	July '64	BC 5101*	40 chain
Campbell River/Sayward Forest	June '67	BC 5239	40 chain
Campbell River	July '72	BC 5493	80 chain (1 in. = 1 mi.)
Campbell River Watershed	Aug. '72	BC 5496	80 chain
Campbell River/Quinsam	July '68	BC 7077	20 chain
Campbell Lake	July '68	BC 7078	20 chain
Campbell River	July '72	BC 7406	20 chain
Campbell River/Quinsam	July '75	BC 7761	20 chain
Campbell River watershed	July '75	BC 7764/67	20 chain

Appendix 10.1 (cont'd).

Aerial Photographs (B.C. Government) (cont'd).

	Date	Flight Line	Scale
(East coast Vancouver Island to Esquimalt and Nanaimo Railway Land Grant Boundary)	Sep. '75	BC 7791/92	20 chain
	Sep. '75	BC 7794/95	20 chain

*Flight Lines BC 5056 and BC 5051 include some photographs flown for special projects. The photograph numbers and index maps showing the locations of all flight lines may be obtained from:

B.C. Lands Service
Map and Air Photo Sales
553 Superior Street
Victoria, B.C.

SPECIAL AERIAL PHOTOGRAPHY

Pacific Survey Corporation Limited, Vancouver, B.C.

Campbell River estuary and Menzies Bay included in special project covering 24 river estuaries on Vancouver Island

Lines flown: 22 March 1973
Photo scale: 1 inch = 400 feet

Negative numbers:

Campbell River estuary 67304B - 67320B
Menzies Bay 67320B - 67325B

APPENDIX 11.1: List of B.C. Pollution Control Branch permits, issued to and applied for by industries operating in the Campbell River watershed and nearby marine waters (Discovery Passage). The permits have been grouped into (1) watershed, (2) estuary and (3) Discovery Passage in order to indicate where the pollution occurs. Each entry provides PCB identification number (first letter P: permit issued, first letter A: application in process); name of permittee; location of pollution; type of pollution (gas, liquid, solid); and specific source of discharge. Entries marked with an asterisk (*) are those for which monitoring data exists: see Appendix 11.2. Although not indicated by this method considerable data exist for the Western Mines operation in Buttle Lake: see page 162 of text, and the summary by B.C. Research (1974). The locations of these pollution sources are indicated by Figures 11.1 and 11.2. Longitude-latitude positions are only accurate to within 0.5 minute (30").

CAMPBELL RIVER WATERSHED

PERMIT NUMBER (AND DATE)	PERMITTEE	APPROXIMATE DISCHARGE LOCATION (± 30")	DISCHARGE TYPE	DISCHARGE SOURCE
PE 00162-01 (15-09-66)	Western Mines	Myra Creek	aqueous	mining industry
PE 00163-01 (15-09-66)	"	Buttle Lake	"	"
PE 00164-01 (15-09-66)	"	"	"	"
PE 00185-01 (31-12-74)	"	"	"	mill tailings

CAMPBELL RIVER WATERSHED (cont'd).

PERMIT NUMBER (AND DATE)	PERMITTEE	APPROXIMATE DISCHARGE LOCATION (± 30")	DISCHARGE TYPE	DISCHARGE SOURCE
PR 02561-01 (21-05-74)	Western Mines	Myra Creek Area	refuse	mining industry
PA 02408-01 (21-06-74)	"	"	gaseous	crushers
PA 02408-02 (21-06-74)	"	"	"	"
PA 02408-03 (21-06-74)	"	"	"	dryers, roasters
PA 02408-04 (21-06-74)	"	"	"	"
PA 02408-05 (21-06-74)	"	"	"	"
PA 02408-06 (21-06-74)	"	"	"	diesel generator
PA 02408-07 (21-06-74)	"	"	"	"
PA 02408-08 (21-06-74)	"	"	"	ventilation
PA 02408-09	"	"	"	diesel generator
PA 02408-10	"	"	"	"
PA 02408-11	"	"	"	"

1. CAMPBELL RIVER WATERSHED (cont'd).

PERMIT NUMBER (AND DATE)	PERMITTEE	APPROXIMATE DISCHARGE LOCATION (± 30")	DISCHARGE TYPE	DISCHARGE SOURCE
PA 02408-12	Western Mines	Myra Creek Area	gaseous	assay office
PA 02408-13	"	"	"	ore dressing plant
PR 02401-01 (29-11-73)	District of Campbell River	49° 53' 00" 125° 18' 00"	refuse	townsite dump
PE 03890-01 (10-01-75)	Island Redi-mix Ltd.	50° 00' 30" 125° 21' 14" (groundwater)	aqueous	washing (gravel operation)

2. CAMPBELL RIVER ESTUARY

PA 01565-01* (07-06-72)	Ocean Cedar Products Ltd.	50° 02' 00" 125° 16' 20"	gaseous	wood-waste burner
PA 02411-01 (16-01-74)	Island Redi-mix Ltd.	50° 03' 00" 125° 15' 20"	"	silo
PA 02558-01 (25-09-73)	Raven Lumber Ltd.	50° 02' 10" 125° 16' 18"	"	wood waste burner
PA 02558-02 (25-09-73)	"	"	"	cyclones
PA 03984-01 (13-6-75	Tayco Paving Ltd.	50° 01' 24" 125° 21' 38"	"	ashphalt plant

2. CAMPBELL RIVER ESTUARY (cont'd).

PERMIT NUMBER (AND DATE)	PERMITTEE	APPROXIMATE DISCHARGE LOCATION (± 30")	DISCHARGE TYPE	DISCHARGE SOURCE
PA 03984-02 (13-6-75)	Tayco Paving Ltd.	50° 01' 24" 125° 21' 38"	gaseous	ashphalt plant
PA 03984-03 (13-6-75)	"	"	"	"
PE 02889-01 (25-10-74)	Dolphins Resort Ltd.	50° 03' 44" 125° 15' 57" (marine)	aqueous	treated sewage
PE 03388-01 (28-01-75)	Island Redi-mix Ltd.	50° 02' 45" 125° 15' 12" (groundwater)	"	truck washout
PE 03815 01* (17-10-74)	Lost Erra Resort and Mobile Home Park	50° 02' 37" 125° 16' 34" (groundwater)	"	treated sewage
PE 00320-01* (31-12-69)	Giasson Mobile Home Park	50° 00' 35" 125° 15' 10" (Campbell River)	"	"
PE 00422-01 (20-07-71)	Painter Barclay Land Co. Ltd. (Mobile Home Park)	50° 02' 50" 125° 15' 10" (marine)	"	domestic waste
PE 00435-01 (30-09-71)	Mercury Marine and Trailer Park (not yet built)	50° 01' 50" 125° 16' 12" (marine)	"	"

2. CAMPBELL RIVER ESTUARY (cont'd).

PERMIT NUMBER (AND DATE)	PERMITTEE	APPROXIMATE DISCHARGE LOCATION (± 30")	DISCHARGE TYPE	DISCHARGE SOURCE
AR 04509-01 (in process)	Raven Lumber Ltd.	50° 02' 54" 125° 10' 52"	refuse	sawmill yard waste
3. DISCOVERY PASSAGE				
PA 03341-01*	Crown Zellerbach Can. Ltd. (Elk Falls Kraft and groundwood pulp mill)	50° 04' 25" 125° 16' 57" (Atmosphere)	gaseous	kraft pulp mill - recovery area
" -02*	"	"	"	(not spec.)
" -03	"	"	"	bleach plant area
" -04*	"	"	"	hog power boiler
" -05*	"	"	"	oil hog power boiler
" -06	"	"	"	"
" -07	"	"	"	(not spec.)
PE 0036-01 (10-09-70)	"	50° 04' 17" 125° 15' 30" (Disc. Pass.)	aqueous	industrial mill complex
PE 01164-01* (31-08-73)	"	50° 04' 30" 125° 16' 55" (Disc. Pass.)	"	kraft pulp mill

3. DISCOVERY PASSAGE (cont'd).

PERMIT NUMBER (AND DATE)	PERMITTEE	APPROXIMATE DISCHARGE LOCATION (± 30")	DISCHARGE TYPE	DISCHARGE SOURCE
PE 01164-02 (31-08-73)	Crown Zellerbach Can.Ltd. (Elk Falls kraft and groundwood pulp mill)	50° 04' 30" 125° 16' 55" (Disc. Pass.)	aqueous	mechanical barker
PR 01602-01 (15-12-72)	"	50° 04' 30" 125° 17' 30" (dry land)	refuse	misc. mill waste
AE 00778-01 (in process)	"	50° 00' 00" 125° 00' 00" (groundwater)	refuse	dump area "A"
AR 00779-01 (in process)	"	"	"	dump area "B"
PR 04467-01 (02-11-76)	MacMillan Bloedel Ind. Ltd. (Menzies Bay)	50° 05' 26" 125° 25' 06" (groundwater)	"	(forest industry unspec. waste)
PA 01567-01 (01-05-72)	Shoreline Forest Prod. Ltd. (Menzies Bay)	50° 07' 00" 125° 22' 45" (Atmosphere)	gaseous	modified wood waste burner (not operating)
PE 00109-01* (21-12-64)	District of Campbell River Sewage Plant	50° 01' 26" 125° 14' 32" (Disc. Pass.)	aqueous	treated domestic sewage
AE 01413-01 (in process)	Quadra Bell Mining Co. Ltd.	50° 07' 11" 125° 15' 00" (Disc. Pass.)	"	(mine-unspec.waste)

APPENDIX 11.2: List of air and water sampling stations in the Campbell River watershed and nearby marine waters for which chemical data are available in the computer files of the B.C. Pollution Control Branch. Each entry in the list includes P.C.B. identification number; type of effluent, emission, or natural air or water body sampled; location of sampling site; and list of parameters for which data exist. Compiled from printout supplied by M. Clark (P.C.B., B.C. Ministry of Environment, Victoria). (Note: (1) Sampling stations in the Buttle Lake area where Western Mines is operating have been missed -- see page 162 in the text. (2) Map co-ordinates are accurate only to ± 30".)

SITE NO.	TYPE OF SITE	LOCATION	PARAMETERS MEASURED
PA 01565-01	stack	Ocean Cedar, Campbell River (50°02'00",125°16'20")	opacity, temp.
PA 03341-01	stack	Crown Zellerbach, Elk Falls (50°04'25",125°16'57")	total particulates, hydrogen sulphide, sulphur dioxide
" 02	"	"	total particulates, sulphur dioxide
" 04	"	"	total particulates
" 05	"	"	total particulates
PE 00109-01	outfall	Campbell R., sewage plant (50°01'26",125°14'32")	pH, residues, specific conduct., temp., diss. oxy., turbidity, B.O.D.
PE 00320-01	outfall	Giasson mobile home park (50°00'35",125°15'10")	solids, spec. conduct., temp., diss. oxy., cl. reside., chloride, B.O.D., coliforms

Appendix 11.2 (cont'd).

SITE NO.	TYPE OF SITE	LOCATION	PARAMETERS MEASURED
PE 00360-01	outfall	Elk Falls Mill (50 04 17, 125 15 30)	solids, spec. conduct.,temp., diss. oxy., BOD, coliforms
PE 01164-01	outfall	Elk Falls Mill (50 04 30, 125 16 55)	color, pH, solids, specif.conduct, temp., Cl_2 resid., flow rate, set. solids, color: TAC, flt. solids, BOD, tannins and lignins, sulphide, resin acid mercaptans, boron, zinc.
PE 03815-01	outfall	Lost Erra Resort (50 02 37, 125 16 34)	pH, solids, spec. conduct., temp.,diss. oxy., BOD.
0100120	outfall	Crown Z. "A" sewer pre-discharge liquid (50 04 30, 125 16 55)	color tr, pH, solids, temp., Cl_2 residues, flow rate, solids, BOD, sulphide, resin acid, boron, zinc.
0100121	outfall	Crown Z "B" sewer pre-discharge liquid (")	same, less boron, zinc
0100122	outfall	Crown Z "C" sewer pre-discharge liquid (")	"
0100123	outfall	Crown Z "D" sewer pre-discharge liquid (")	"
0110100	ambient air	Shoreline Forest Products #1 (50 07 00, 125 23 15) Menzies Bay	total particulates, soluble part., insol. part., soluble and insoluble ash.

Appendix 11.2 (cont'd).

SITE NO.	TYPE OF SITE	LOCATION	PARAMETERS MEASURED
0110401	ambient air	Raven Lumber dustfall #1 (50°02'10",125°15'18")	total and combined particulates
0110402	"	Raven Lumber dustfall #2 (50°02'10",125°15'18")	"
011045	"	Dolphins Resort (50°03'50",125°16'00")	total, soluble and insoluble particulates, soluble and insolubie ash, sulphation index.
0110406	"	Campbell R. courthouse (50°01'30",125°14'30")	"
0110407	"	C.R. senior second. school (50°01'15",125°14'55")	"
0110408	"	C.R. school board (50°01'50",125°--'00")	"
0110409	"	1621 14th ave. (50°01'30",125°15'30")	"
0110410	"	Cape Mudge lighthouse (49°59'00",125°11'40")	"
0125220	stream	Nunns Creek above Giasson Mobile Home Park (50°00'35",125°13'10")	solids, specif. conduct, temp., diss. oxy, turbidity. color, chloride, hardness, NO_2/NO_3, nitrate, nitrite, ortho phosph, total phosph, sulphate, surfacan, tannins and lignins, diss. calcium, copper, iron, lead, magnesium, mercury, zinc, coliforms.

Appendix 11.2 (cont'd).

SITE NO.	TYPE OF SITE	LOCATION	PARAMETERS MEASURED
0125221	stream	Nunns Creek below Giasson Mobile Home Park	solids, specif. conduct, temp, diss. oxy, turbidity, color chloride, hardness, NO_2/NO_3 nitrate, nitrite, BOD, COD, ortho phosph, total phosph, sulphate, surfacan, tannins and lignins, diss. calcium, copper, iron, lead, magnesium, mercury, zinc, coliforms.
0125222	"	Nunns Creek at Hwy 1 ($50^{o}00'50''$ $125^{o}15'10''$)	"
0126400	"	Quinsam River above confluence with C.R., ($50^{o}01'45''$, $125^{o}19'55''$)	"
0126401	"	Quinsam River at end of Quinsam Road ($50^{o}01'45''$, $125^{o}18'55''$)	"
0130140	lake	Campbell Lake ($50^{o}00'30''$, $125^{o}22'00''$)	"
0150160	Discovery Pass.	Elk Falls Pulp Mill, edge of foam boom ($50^{o}04'17''$, $125^{o}15'30''$)	color, color true, oil and grease, pH, solids, spec. conduct, temp, diss oxy, turbidity, organic carbon, chloride, COD, sulphate, surfacan, tannin-lignin, boron, copper, lead, zinc, aluminum, coliforms.

Appendix 11.2 (cont'd).

SITE NO.	TYPE OF SITE	LOCATION	PARAMETERS MEASURED
0150161	Discovery Pass.	Elk Falls Pulp Mill off loading docks (50°04'35",125°15'30") Background #2	color true, pH, solids, specif. conduct., turbidity, COD, tannin-lignin, boron
0150162	"	Elk Falls Background #3 152 m offshore from foam boom (50°04'35",125°17'20")	"
0150163	"	Elk Falls Background #4 off oil dock 152 m (50°04'40",125°17'00")	" & coliforms
0150180	"	C.R. sewage plant receiving waters, (50°01'30",125°--'05")	oil and grease, pH, solids, specif. conduct, temp, diss. oxy., turbidity, organic carbon, chloride, BOD, COD, copper, zinc, lead, coliforms
0150420	"	Duncan Bay (50°04'12",125°17'28")	color true, pH, solids, spec. conduct., temp, diss.oxy, color, COD, sulphate, lignin-tannin, sulphide, zinc
0150421	"	Duncan Bay (50°04'19",125°17'40")	" & boron
0154051	"	305 m off Dolphin Resort (50°03'48",125°15'18")	coliforms
0154052	"	305 m off Painters Lodge (50°03'30",125°15'18")	"
0154053	"	off tip of Tyee Spit, (50°03'00",125°15'18")	"

SITE NO.	TYPE OF SITE	LOCATION	PARAMETER MEASURED
0154054	Disc. Passage	305 m north of sewage plant, at end of wharf (50°01'18",125°14'06")	coliforms
0154055	"	on shore at outfall line (50°01'12",125°14'06")	"
0154056	"	305 m south of sewage plant (50°01'06",125°14'00")	"
0154057	"	244 m in front of 0154054 (50°01'24",125°13'54")	"
0154058	"	over sewage plant outfall (50°01'12",125°13'54")	"
0154059	"	244 m off 0154056 (50°01'06",125°13'48")	"
0190001	groundwater	Campbell River Municipal dump (50°01'30",125°50'--")	color true, pH, solids, specif. conduct, temp, diss. oxy., flow rate, color, chloride, BOD, COD, sulphate, lignin-tannin, sulphide, diss. calcium, sodium, zinc
0900202	Discovery Pass.	SE corner of boomsticks enclosing Elk Falls Mill outfall (50°04'30",125°16'55")	dissolved boron
0920099	stream	Campbell River (50°02'40",125°18'30")	color, pH, temp, turbidity, alkalinity, chloride, fluoride, hardness, ammonia, NO_2/NO_3, tot phosphate, silica, sulphate, free CO_2, bicarbonate, carbonate, diss. calcium, copper, iron, lead magnesium, manganese, potassium, sodium, zinc

APPENDIX 11.3: Standards for effluent from (1) the chemical (kraft) and mechanical (groundwood) pulping processes, and (2) the woodmill hydraulic debarkers at the Crown Zellerbach of Canada Ltd., Elk Falls Pulp Mill on Duncan Bay. This information is extracted from Appendices -01 and -02 respectively of B.C. Pollution Control Branch Permit PE-1164 (August 31, 1973).

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(1) CHARACTERISTICS OF THE PULPING PROCESS EFFLUENT SHALL BE EQUIVALENT TO OR BETTER THAN:

Total Suspended Solids	30 lbs/ADT (15 kg/ADt)
Settleable Solids	2.5 ml/l
Floatable Solids	negligible
BOD_5	53 lbs/ADUT (26.5 kg/ADUt)
pH Range	6.5 to 8.5 within 4.6 m of diffuser
Toxicity (TLm 96)	50% survival at 12.5% effluent conc.
Temperature	$95^oF(20.8^oC)$
Mercaptans	less than 2.0 mg/l
Sulphides	less than 1.0 mg/l
Residual Chlorine	less than 0.1 mg/l

(WORKS AUTHORIZED: Fibre recovery, in-plant spill control facilities, conversion to sodium hydrosulphite bleaching, submerged outfall and diffuser, and related appurtenances.

(2) CHARACTERISTICS OF THE HYDRAULIC DEBARKER EFFLUENT SHALL BE EQUIVALENT TO OR BETTER THAN:

Total Suspended Solids	4.0 lbs/cunit (0.601 kg/m^3)
Settleable Solids	2.5 ml/l
BOD_5	4.0 lbs/cunit (0.601 $kg.m^3$)
Floatable solids	negligible
pH Range	6.5 to 8.5 within 4.6 m of diffuser
Toxicity (TLm 96)	50% survival at 12.5% effluent conc.

(WORKS AUTHORIZED: Facilities for solids reduction and related appurtenances.)

APPENDIX 12:

Environmental Law

Canada's legal system, at all three levels of government, has permitted some form of control over pollution for decades. But only in the last 20 years has the field of environmental law started to become a discrete branch of the legal system, with the subsequent development of branches of government departments which are equipped with the expertise, technology and legislative mandate to administer those laws (see Appendix 1.1 for a list of such agencies).

As understood from various pieces of literature prepared for laymen by lawyers (Rounthwaite, 1975; Ince, 1976; Vancouver People's Law School, 1976), there are two kinds of environmental law in British Columbia: legislation, a written law which has been accepted by either the federal or provincial legislatures and clearly defines the crime and punishment, and common law, which permits a judge in civil court to determine the guilt of an offender, based on the decisions of judges hearing similar cases in the past rather than specific laws embodied in preconceived legislation.

Legislation is a more promising avenue for the development of a legal system permitting human society to live within the laws of nature than common law, because it permits society to define an act of pollution before the fact*, either through writing details into the wording of a statute, or by providing a designated agency with the power to design regulations. For example, the federal Environmental Contaminants Act contains no enforceable provisions, yet it does give the Minister of the Environment the ability to present regulations to Cabinet for their approval, whereupon they become Orders-in-Council controlling the manufacture, importation, sale and emission of specified

*i.e. make pollution *per se* a crime (rather than drawing on non-pollution law)

contaminants (Vancouver People's Law School, 1976). The B.C. Pollution Control Act of 1967 established a Pollution Control Board which is charged with a similar function within the provincial Ministry of the Environment. By-laws at the municipal level can be enacted to control litter and dumping (for example) within municipal district boundaries.

Unlike common law, legislated law has a very recent history in Canada, its immaturity evidenced by the fact that the federal Northern Inland Waters Act, Canada Water Act, Arctic Waters Pollution Prevention Act, Weather Modification Information Act and Clean Air Act were not passed through Canada's Parliament until 1970 and 1971. The oldest environmental act in Canada -- the Fisheries Act - is still being amended to make it more effective in controlling environmental problems (McLaren, 1975) and as late as July 1976, the Environmental Contaminants Act was without regulations that would make it effective. The federal government established the Department of the Environment (now Department of Fisheries and the Environment) only six years ago (1971) at which time one of its new branches, the Environmental Protection Service, was formed.

Considering this newness, and the social, economic and technological complexity of ecological problems, it is a credit to Canadian society that many gaseous and liquid emissions in British Columbia have at least been placed under permit by the B.C. Pollution Control Board, that the dumping of waste at sea has similarly been regulated to some extent by the federal Environmental Protection Service, and that applications for foreshore leases in the Campbell River estuary are being passed to federal and provincial environmental agencies by the B.C. Lands Branch for advice concerning the impact that use of those leases will have on the estuarine ecosystem.

Section 33(2) of the federal Fisheries Act has been used to prosecute four companies found guilty of polluting waters

local to Campbell River (Fisheries and Marine Service, Campbell River):

(1) 18-3-76 Island Salvage and Metals Ltd. Oil deposition into a minor tributary of the Campbell River. Fine $200.

(2) 18-3-76 Ram Building Supplies Ltd. Deposition of a deleterious substance (silt) into a minor tributary of the Campbell River. Fine $1,500.

(3) 2-6-76 Seaway Towing Ltd. Deposition of oil into the Campbell River. Fine $1,500.

(4) April 1974. Pallan Co. Deposition of oil into Kingfisher Creek, a tributary of the Campbell River. Prosecuted by Provincial Fish and Wildlife Branch. Fine unknown.

Appendices 12.1 and 12.2 are partial lists of federal and provincial statutes that can be employed to cope with environmental problems in estuaries on Canada's Pacific coast. It must be remembered that under some definitions the "environment" of an estuary can be taken to include human activities remote from the immediate vicinity of the estuary, conceivably invoking any of 114 federal and B.C. Acts listed by Ince (1976). See also Appendix 1.1, for a useful checklist of the governmental agencies that administer environmental legislation with respect to B.C. estuaries.

APPENDIX 12.1:

Partial list of federal and provincial legislation designed, at least in part, to control abuse of the natural environment (from Rounthwaite, 1975; Ince, 1976; and Vancouver People's Law School, 1976).

A. FEDERAL (CANADA)

(1) Fisheries Act. R.S.C. 1970c. F-14 as amended (various amendments).

The oldest piece of environmental legislation in Canada, the Fisheries Act permits control of environmental abuse on showing proof that an action is or might be detrimental to the health of fish (McLaren, 1976). Applies, in part, to all waters in Canada.

(2) Ocean Dumping Control Act. S.C. 1974-75c. 55.

Applies only to intentional disposal in marine waters. Permits issued to allow dumping under controlled conditions. Violation of the Act can be penalized by fines up to $100,000. Administered by the Environmental Protection Service, supported by the Regional Ocean Dumping Advisory Committee, with representation from EPS and Fisheries and Marine Service.

(3) Canada Water Act R.S.C. 1970c. 5(1st supp.) as amended.

Offers a mechanism to create an organized management system for water resources, with special attention to pollution problems. Permits federal-provincial cooperation.

(4) Canada Shipping Act R.C.S. 1970c. S-9 as amended.

The Shipping Act controls oil pollution and garbage dumping from ships (vessels not propelled by oars) and lists other substances controlled by regulations. The act's provisions

concern civil consequences arising from pollution by ships.

(5) Navigable Waters Protection Act R.S.C. 1970c. N-19.

Although not concerned directly with pollution, it is possible to use the Act to prevent dumping fill or dredge spoil, constructing causeways, or otherwise disturbing the environment -- if it can be proven that such disturbance interferes with navigation.

(6) Migratory Birds Convention Act R.S.C. 1970c. M-12 as amended.

This Act protects migratory bird habitats (see Appendix 9.1).

(7) Environmental Contaminants Act.

Enables the Minister of the Environment to assemble information regarding contaminants, and grants cabinet the power to formulate regulations controlling the emission, sale and manufacture of such substances.

(8) Clean Air Act S.C. 1970-71-72c. 47.

Enables the Minister to monitor and control the emission of contaminants into the air, where they would endanger health or violate international agreements.

A. PROVINCIAL (BRITISH COLUMBIA)

(1) Pollution Control Act 1967 S.B.C. 1967c. 34 as amended.

Established the Pollution Control Board, which sets standards for the discharge of pollutants. These standards are

used as guides in issuing permits to specific industrial establishments which privileges them to discharge substances to the environment. Violators are subject to fines up to $10,000.

(2) Water Act R.S.C.B. 1960c. 405 as amended.

Applies mainly to water consumption. Requires that water use must be licenced. Some water quality provisions.

(3) Health Act R.S.B.C. 1960c. 170 as amended.

The Health Act gives the B.C. Cabinet wide powers in regulating threats to the public health but is rarely used to control pollution, although it does have potential. The Act authorizes private prosecutions. Section 6(L) applies to stream pollution.

(4) Fisheries Act R.S.B.C. 1960c. 150 as amended.

The federal government has constitutional jurisdiction over the fish resource while it is in the water, but the provinces have limited powers owing to their proprietary ownership of parts of the estuary, which stems from their jurisdiction over the foreshore. Of most interest in this Act are the sections preventing stream and river obstructions.

(5) Environment and Land Use Act S.B.C. 1971c. 17.

The most potentially powerful environmental statute in force in British Columbia. Established the Environment and Land Use Committee. Can be applied to environmental problems with implications too general for the application of other Acts in the Statutes of British Columbia. Useful for emergency situations like oil spills.

(6) Municipal Act R.S.B.C. 1960c. 225 as amended.

Through the Municipal Act, local governments are able to establish resolutions or by-laws which control a wide variety of pollution problems within their boundaries.

(7) Department of Recreation and Conservation Act. R.S.B.C. 1960.

APPENDIX 12.2:

Partial list of provincial legislation (British Columbia) relevant to land and water use.

1. Park Act S.B.C. 1965. C31 as amended.

The primary statute controlling parks in the province. The Act lists five purposes for which a park can be established: (1) to preserve the environment or ecology; (2) to preserve features of a scientific, historic or scenic nature; (3) enjoyment of the travelling public; (4) recreational opportunity for a specific community;and (5) recreational opportunity of a specific nature. The Park Act is subject to the Environment and Land Use Act and the Pollution Control Act (Appendix 12.3), but no others.

Activity in provincial parks is regulated by a variety of statutes, examples being:

(a) Mineral Act R.S.B.C. 1960c. 244 as amended - prohibits the exploration or development of minerals within a provincial park unless authorized by the Cabinet.

(b) Forest Act R.S.B.C. 1960c. 153 as amended - prohibits hunting and shooting in certain provincial parks and places restrictions on the removal of wildlife.

(c) Department of Recreation and Conservation Act, R.S.B.C. 1960 - controls the landing of aircraft and the use of firearms and powerboats in provincial parks.

2. Ecological Reserves Act S.B.C. 1971c. 16.

The purpose of this Act is to reserve Crown land for ecological purposes, including

(a) areas suitable for scientific research and educational purposes associated with studies in productivity and other aspects of the natural environment;

(b) areas that are representative examples of natural ecosystems within the Province;

(c) areas that serve as examples of ecosystems that have been modified by man and that offer an opportunity to study the recovery of the natural ecosystem from such modification;

(d) areas in which rare or endangered native plants and animals in their natural habitat may be preserved; and

(e) areas that contain unique and rare examples of botanical, zoological, or geological phenomena.

3. Archaeological and Historic Sites Protection Act R.S.B.C. 1972c. 15.

Enacted to authorize the Minister of Recreation and Tourism to designate land and objects as archaeological or historic

sites or objects. The moving, excavating, or altering in any way any such site or object except by permit is prohibited.

4. Land Commission Act S.B.C. 1973c. 46.

This Act established the British Columbia Land Commission which is responsible for specific facets of land use in the province, including the preservation of agricultural greenbelt and park lands.

5. Greater Campbell River Water District Act 1962

Act by which the Greater Campbell River Water District was formed, incorporating

(a) The Corporation of the Village of Campbell River.
(b) The Willow Point Waterworks District.
(c) The Quinsam Heights Water Works District.

The objects of the Corporation are to provide water in bulk to the communities and for that purpose to design, construct and operate major facilities.

15. GLOSSARY

GLOSSARY OF SELECTED TERMS

advection: refers to the horizontal or vertical flow of seawater as a current.

algae: a non-taxonomic term for a group of mainly aquatic plants without vascular systems and variously one-celled, colonial, or filamentous, containing chlorophyll and/or other pigments (especially reds and browns), e.g. seaweeds, phytoplankton.

alluvial: pertaining to alluvium, a general term for all detrital deposits resulting from the operations of modern rivers, thus including the sediments laid down in river beds, flood plains, lakes, fans at the foot of mountain slopes, and estuaries.

alevin: young fish that have hatched, but still possess a yolksac.

amphipod: one of an order of crustacea, mostly marine, characterized by having the first and perhaps the second thoracic segment fused with the head; the abdomen is not well differentiated from the thorax, and the legs are modified for various functions; the body is laterally compressed.

anadromous: describes a fish with a life cycle in which maturity is attained in salt water, and the adults enter fresh water to spawn.

angler-day: a day on which a fisherman participates in a sport fishery for any reasonable length of time.

anoxic: anaerobic, without oxygen.

aquatic: growing or living in, or frequenting, water; occurring, or situated in, or on, water. Analogous to "terrestrial" for the case of land.

aqueous: liquid solution where water is the solvent.

aquifer: a layer of rock which holds water and allows water to percolate through it.

artesian well: a type of well which normally gives a continuous flow, the water being forced upwards by hydrostatic pressure.

atmospheric pressure: the pressure exerted by the atmosphere as a consequence of gravitational attraction exerted upon the column of air lying directly above the point in question. The metric unit of atmospheric pressure adopted by Canada is the kilopascal (1 kPa equals 0.2953 in. of mercury).

avian: of, relating to, or derived from birds.

bacteria: microscopic organisms living, either singly or in colonies, in soil, water or the bodies of plants and animals (including man).

batholith: a large body of intrusive rock.

bathymetry: the science of measurement of the depths of oceans, seas, or lakes. Sometimes refers to the bottom topography of marine or lake systems.

bedrock geology: the study of the geology of any solid rock exposed at the surface of the earth or underlain by unconsolidated material.

benthic algae: a group of mainly aquatic plants, variously one-celled, colonial, or filamentous, containing chlorophyll and/or other pigments (especially reds and browns), and having no vascular system, which live in or on the bottom sediments of a water body.

benthos: organisms living in or on the bottom sediment of a body of water; can be broken into three size groups - macro (greater than 1.0 mm), meio (1.0 mm to 0.5 mm), and micro (less than 0.5 mm).

bioassay: a determination of the concentration, or dose, of a given material necessary to affect a test organism under stated conditions; or, the use of living organisms as an index to determine environmental conditions.

biochemical oxygen demand (B.O.D.): a measure of the amount of oxygen used by micro-organisms to consume biodegradable organics in waste water. The 5 day BOD test is widely used to measure the organic strength of waste water in terms of dissolved oxygen that would be consumed if the waste water were discharged into a natural body of water.

biochronology: geologic time scale based on dating of fossils.

biogeoclimatic zone: a regional ecosystem characterized by vegetation and soil types that are a product of the macro-climate in which they occur.

biomass: the weight of living or dead organic tissue; e.g. biomass of zooplankton per m^3, or stomach contents biomass.

biota: living organisms, as distinct from abiotic or non-living entities.

bivalve: one of a class of molluscs, soft unsegmented animals, most of which are protected by a shell containing calcium in some form. They are either permanently attached to a material

(e.g. sediment or wood) or burrow into it. The class includes clams, mussels and oysters.

brackish: describes water having a salinity less than about $17^{o}/oo$ and more than $0.5^{o}/oo$ (parts per thousand).

catchment area: same as drainage area or drainage basin. The area drained by a watercourse or providing water for a reservoir.

chironomid: any of a family of tiny flies (Midges) in the order Diptera; their larvae usually live submerged in freshwater.

cladocera: an order of Crustacea commonly known as "water-fleas".

clear cuts: areas from which trees have been completely removed during logging operations.

climax community: a final, self-perpetuating assemblage of plants and animals that develops in a particular climate and soil; it will persist as long as the same conditions prevail.

cloud cover: the percentage or fraction of sky covered by cloud, e.g. 2/10:scattered cloud; 10/10 overcast.

coliform: designating of, or like the aerobic bacillus normally found in the mammalian intestine. A coliform count is designated most probable number (MPN) of bacteria derived statistically from a series of cultures in different dilutions. It is often used as an indicator of fecal contamination of water supplies.

comminute: to reduce to small, fine particles.

community: a naturally occurring assemblage of organisms inhabiting a common environment and interacting with each other.

concentrator: mining equipment used to separate metal or ore from non-metal bearing rock or non-valuable minerals in the ore.

conifer: any of an order (Coniferales) of cone-bearing trees and shrubs, mostly evergreens, like the pine, spruce, fir, cedar, yew, etc.

copepod: any of a large order of usually small marine and freshwater crustaceans. Most species range between about 0.5 to 10 millimetres in length. They often form an important source of food for fish in temperate and subpolar climates, living as they do in the plankton and benthos of marine, estuarine and fresh waters.

crustacean: any of a large class of mostly aquatic creatures having an outer skeleton ("exoskeleton") composed of calcium carbonate and chitin, or of a form of carbohydrate; it includes

shrimps, crabs, wood lice, barnacles, cladocerans, amphipods, isopods and mysids.

dabbling ducks: ducks that usually obtain their food by submerging only the head, while the body remains floating on the water surface, usually in freshwater or estuarine habitats.

decapod: crustaceans having ten legs such as lobsters, crabs and shrimps. Also any cephalopod having ten arms, as a squid.

delta: an alluvial deposit at the mouth of a river emptying into a lake or sea.

detritus: dead organic matter, both plant and animal in origin. Fragments of matter that have been removed - by disintegration weathering or other processes - from the surface of rocks; a deposit of any of all forms of detritus (adjective: detrital).

diatom: one of an algal class (Bacillariophyceae) of microscopic organisms, characterized by thin shells of silica. Commonly abundant in both benthos and plankton of marine, estuarine and fresh waters.

diffusion: the spreading, scattering or transfer of matter under the influence of a change in its concentration with distance; the movement is from the stronger to the weaker concentration.

dipteran: any of a large order (Diptera--true flies) of insects, including the housefly, mosquito, gnat, etc., having one pair of functional membranous wings and usually a vestigial second pair; some species have larval stages that live in fresh water.

diurnal: daily; recurring once a day, having a period or cycle of approximately one tidal day.

diving ducks: ducks which obtain their food by diving below the water surface; found in marine, estuarine and fresh water habitats.

drainage area: the region that drains all the rainwater and snow that falls onto it (apart from that removed by evaporation), into a river or a stream which then carries the water to a sea or a lake; its boundary is defined by the ridge beyond which water flows in the opposite direction - away from the basin.

driftpole observations: observations of water currents made by following the movements of a weighted pole suspended vertically in the water.

drogue: a current-measuring assembly consisting of a weighted cross-piece, parachute, or similar device and an attached

surface buoy. The drogue can be placed at any desired depth. Current speed and direction are determined by tracking and timing of the surface buoy.

dyke (dike): in geology, a tabular body of igneous rock that cuts across the structure of adjacent rocks.

ebb tide: outgoing or falling tide.

ecology: that branch of science which attempts to define the biological functions of living organisms and of factors in their environments.

ecosystem: all the organisms and non-living elements of a three-dimensional space which function to support living organisms in that space; e.g., an estuarine ecosystem or a forest ecosystem.

eddy: circular movement of water usually formed where currents pass obstructions, between two adjacent counter-flowing currents, or along the edge of a permanent current.

eelgrass: a submerged marine vascular plant that has long narrow leaves, produces seeds and generally grows on a sand or mud substrate in the lower intertidal and upper subtidal zones; e.g., *Zostera marina* in B.C. coastal waters.

effluent: liquid waste material (such as sewage or liquid industrial refuse) discharged into the environment, especially when considered as a pollutant.

emission: in pollution work, usually refers to gaseous or vaporized wastes, as opposed to liquid wastes which are called effluents.

entrainment: the transfer of fluid from one water mass to another; occurs if the masses are in motion relative to one another, and results from mixing due to frictional effects at the interface between the masses.

environment: collective term for conditions in which an organism lives.

escapement: a statistical term that describes the number of fish that pass unharmed from place to place; indicates the number of salmon adults which survive ocean life and start up a river to the spawning grounds, or the number of juvenile salmon that go to sea after hatching in a stream (usually the former).

estuary: a semi-enclosed coastal body of water which has a free connection with the open sea and within which sea water is measurably diluted with fresh water derived from land drainage.

eulachon: marine food fish (*Thaleichthys pacificus*) of the north Pacific coast; anadromous; related to the smelt (Osmeridae) and rendered by coast Indians for its oil which remains solid at ordinary temperatures.

fauna: animal life of a specific region or time (microfauna - organisms that pass through a 100-micron mesh; meiofauna - organisms that pass through a 500-micron mesh but are retained by a 100-micron mesh; macrofauna - organisms retained by a 500-micron mesh).

fetch: in wave forecasting, the continuous area of water over which the wind blows in essentially a constant direction.

fingerling: a small finger-sized fish or a young fish up to the end of the first year. (cf *fry*).

floc: a very fine, fluffy mass formed by the aggregation of fine suspended particles, as in a precipitate.

flood plain: the area of land, adjacent to a river channel, subjected to flooding when floodwater levels reach a predetermined height.

flood tide: rising or incoming tide.

flora: plant life of a specific region or time.

fluvial: of or pertaining to rivers; produced by river action, as a fluvial plain.

food chain: a series of organisms in a community in which each uses the next lower member in the sequence as a food source and is in turn consumed by animals on the next level above.

food web: the totality of and interrelationships between all the food chains operating in a community.

foraminifera: a group of protozoa, mostly marine, which form shells of lime or silica; common in marine benthos.

foreshore: with respect to land use in British Columbia, the land between mean high tide and mean low tide. The foreshore is under the jurisdiction of the B.C. government pursuant to the British North America Act and the B.C. Environment and Land Use Act.

freshet: a sudden increase or rise in river flow or level because of melting snow and/or heavy rain.

fry: with respect to salmonids, young fish of a year that have absorbed their yolk sacs. (cf *fingerling*).

game birds: wild birds hunted for sport or food; usually refers to members of the grouse family, and to ducks and geese.

gauging station: a location where systematic records of stage (water level) and/or discharge are obtained.

glacio: a combining form frequently used with other words to denote formation by or relationship to glaciers.

grilse: immature, post-smolt, sea-going chinook or coho salmon.

groundwater: water found underground in porous rock strata and soils, as in a spring.

habitat: the place where an organism or a population lives.

harmonic constants: the amplitude and epoch of a constant, recurring motion such as tides; used in prediction of local tide height and timing relative to reference datum.

headwaters: the streams and creeks that are the sources of a river or other water body.

hinterland: the land or district behind that bordering on a coast or river.

hog fuel: waste wood chips burned to produce steam.

hydrogen sulfide: a chemical compound (H_2S) produced with methane (CH_4) and ammonium (NH_4+) during the decay of lignin and cellulose ($C_nH_nO_nNS$) from wood, a process that consumes oxygen. Hydrogen sulfide has an offensive odour and is toxic to fish and invertebrates.

hydrograph: a graph showing changes in water flow over a period of time.

hydrography: that science which deals with the measurement and description of the physical features of the oceans, seas, lakes, rivers and their adjoining coastal areas, with particular reference to their use for navigational purposes.

igneous rocks: rocks formed by the solidification of hot mobile material termed magma.

intertidal zone: the area of shore bounded by the levels of high and low tide.

invertebrate: an animal not having a backbone (true of most animal species).

isohyet: lines of equal amounts of rainfall.

isopod: any of an order of crustaceans, mostly aquatic, with a flat, oval body and seven pairs of walking legs of similar size and form, each pair attached to a segment of the thorax.

jacks: precocious male chinook salmon returing to spawn in their second or third year.

juvenile: not having attained maturity in all respects.

kelt: a steelhead trout (*Salmo gairdneri*) that is migrating back to sea after spawning.

larva: an organism at some pre-adult stage of development, incapable of reproduction and often morphologically and ecologically distinct from the adult stage.

leach: to subject to the action of percolating liquid (such as water) in order to separate the soluble components; to dissolve out by the action of a percolating liquid.

lithology: the physical character of rocks determined visually or with the aid of a microscope.

loam: a soil composed of a mixture of clay, silt, sand and organic matter.

lode metals: metals produced from mineral deposits in valuable ore deposits in the form of a lode or vein.

macrophyte: a large plant; used to describe algal species large enough to be readily apparent to the naked eye (e.g. seaweeds are macrophytic algae).

maritime climate: a regional climate that is under the predominant influence of the sea, and that is characterized by small diurnal and annual ranges of temperature.

marsh: a tract of soft, wet land, characterized by growth of plants such as sedges and grasses; a saltmarsh is subject to overflow by salt water through tidal action, and usually produces large amounts of food for fish and birds.

mercaptan: a malodorous substance containing the monovalent radical SH.

migratory: to pass, usually periodically, from one region or climate to another for purposes of feeding, breeding, etc.

mixed tide: type of tide in which a mixture of semi-diurnal and diurnal waves produces large inequalities in heights and/or durations of successive high and/or low waters.

morphology: the observation of the form of lands; or the study of the form and structure of organisms.

mysid: any of an order (Mysidacea) of small shrimp-like crustaceans with a carapace over most of the thorax and two branched appendages; free swimming filter feeders often abundant in marine, estuarine or freshwater habitats.

natural resources: Supplies of non-living substances and renewable stocks of plant and animal species considered to be of value to humanity.

nature conservancy area: a roadless area, within a park, retained in a natural condition for the preservation of its ecological environment and scenic features.

necrosis: the death or decay of tissue in a particular part of the body and/or plant.

nutrient: a substance used to maintain life and promote growth.

oceanography: the science that deals with the oceans, and includes the delimitation of their extent and depth, the physics, chemistry and biology of their waters and the exploitation of their resources; can be divided into branches according to basic interest, e.g. chemical oceanography (chemistry).

oligochaete: any of a class (Oligochaeta, Annelida) of segmented worms, such as earthworms, which lack a definite head and have relatively few body setae (bristles); common in soil, fresh water and marine benthos.

outfall: the point at which a sewer or land drainage discharges into the sea or a river.

pan: a natural basin or depression, especially one containing standing water or mud.

parameter: in ecology, a measureable quantity describing some abiotic aspect of the environment; e.g. salinity, temperature, soil depth, light intensity.

penstocks: a pressure pipe supplying water to a water turbine for the purpose of producing electricity.

permeability: the ease with which gases and liquids penetrate or pass through a rock or soil.

pH: a symbol for the degree of acidity or alkalinity of a solution, originally expressed as the logarithm of the reciprocal of the hydrogen-ion concentration in gram equivalents per litre of solution, but may have other operational definitions.

phytoplankton: plant life, mostly microscopic algae, found floating or drifting in the oceans or bodies of fresh water; forms the base of some aquatic food chains.

plankton: floating plants and animals that are distributed by currents more than by their ability to swim.

pluton: a body of igneous rock that has formed beneath the surface of the earth by consolidation from magma.

plutonic activity: activity associated with the formation of igneous rocks far below the surface of the earth, by intense heat, great pressure and slow cooling.

pollution (noun): the result of artificially disturbing an ecosystem by introducing a disruptive agent; severity of pollution is commonly judged on the basis of the value placed on the affected organisms by human society.

polychaete: any of an annelid class of mostly marine, segmented worms, usually having a pair of fleshy leg-like appendages covered with setae on most segments, and usually having a well-developed head. Common in marine and estuarine benthos when adult and in zooplankton when in the larval stage.

prevailing wind: the wind, indicated by direction at a certain place or area, that has a higher frequency of occurrence than any other.

primary productivity: the rate at which organic matter is produced from inorganic compounds.

pristine: in ecology, used to describe wild, undeveloped habitats.

raptorial bird: a bird of prey, usually having a strong hooked beak and sharp talons (e.g. eagles, hawks, owls, vultures).

roe: fish eggs, especially when still massed in the ovarian membrane.

run-off: the portion of rainfall which ultimately reaches the streams; it consists of the water which flows off the surface, instead of sinking into the ground, together with some of the water which originally sank into the ground and joined it later in the streams.

salinity: a measure of the quantity of dissolved salts in sea water. It is formally defined as the total amount of dissolved solids in sea water - in parts per thousand ($^{0}/_{00}$) by weight - when all the carbonate has been converted to oxide, the bromide and iodide replaced by chloride, and all organic matter is completely oxidized.

salmonid: any fish of the family Salmonidae (e.g. salmon or trout).

salt marsh: grassland over which salt water flows at intervals, usually a highly productive ecosystem.

saltchuck: a colloquial term for seawater.

sedge: any of a family (Cyperaceae) of grasslike plants often found on wet ground or in water, usually having triangular solid stems, three rows of narrow, pointed leaves, and minute flowers borne on spikelets; contributes to habitat and food source of organisms in food chains leading to salmonid in B.C. estuaries.

sedimentary rock: rock formed by the accumulation of sediment in water or from air usually having a characteristic layered structure known as bedding or stratification.

senescent: a life cycle stage; in Pacific salmon *(Oncorhynchus* sp.), the stage when the fish has spawned and will soon die.

seral: describes a stage of plant or animal community development preceding the climax community, that could be expected to develop in a given environment.

shorebird: any of a number of birds that feed (usually by wading) or nest on the shores of oceans, rivers, etc.; examples are sandpipers, snipes, etc.

silt: fine-grained (0.063 mm to 0.004 mm), unconsolidated sediment with particles intermediate in size between very fine sand and clay, carried or laid down as sediment by moving water.

slough: a swamp, bog or marsh, especially one that is part of an inlet or backwater.

slurry: any fluid mixture of fine solids and water.

smolt: in salmonids, the life stage older than a fry and physiologically adapted to leave fresh water and enter salt water.

spawn (verb): to produce or deposit eggs - usually used in reference to aquatic animals such as fish, crustaceans and oysters. (Noun): eggs of fish or invertebrates.

specific gravity: ratio of the weight or mass of a given substance to that of an equal volume of another substance (water for liquids and solids, air or hydrogen for gases) used as a standard.

stage: in hydrology, a water level.

stage gauge: the water level measured from any chosen reference line.

stock: in geology, a body of plutonic rock, that covers less than 40 square miles; in fisheries biology, a segment of the population that can be managed as a single unit.

stoma: a microscopic opening in the epidermis of plants, surrounded by guard cells and serving for gaseous exchange (plural: stomata).

stratification: the state of a fluid that consists of two or more horizontal layers arranged according to their density, the lightest layer being on top, and the heaviest on the bottom; e.g. saline stratification in some estuaries.

stratigraphy: the branch of geology relating to the formation, composition, sequence and correlation of the stratified rocks forming part of the earth's crust.

subtidal: below the lowest low tide.

sulfide: a compound of sulfur and some other element or radical.

supernatant: designating or of a liquid standing over a precipitate.

surficial geology: characteristic of, pertaining to, formed on, situated at, or occurring on the earth's surface; especially consisting of unconsolidated residual alluvial, or glacial deposits lying on the bedrock.

suspended solids: substances, the particles of which are dispersed through a fluid but not dissolved in it, and which will separate out on standing.

tailings: the portions of a washed ore that are regarded as too poor to be treated further.

temperature inversion: an increase of temperature with height above the earth's surface, being the reverse of the normal situation in which the temperature decreases with height.

thermocline: a vertical temperature gradient in some layer of a body of water, that is appreciably greater than the gradients above and below it.

tidal flat: a gently sloping marshy, muddy, sandy or sometimes pebbly area which is covered and uncovered by the rise and fall of the tide.

tidal flushing: replacement of some or all of the water mass of a semi-enclosed water body, such as an estuary, bay or inlet, by outside water, caused by the action of the tides.

till: nonsorted, nonstratified sediment carried or deposited by a glacier.

topography: the surface features of an area including its relief, usually represented by means of contours and physical features such as forests, rivers and lakes.

toxic: of, relating to, or caused by a toxin or poison which, through chemical action, kills injures or impairs an organism.

trawl: to fish by dragging a large bag-like net along the bottom of a body of water.

triangle: short form of "triangle drag", a device used to sample benthos by towing over the bottom.

troll: to fish with a moving line, especially one with a revolving lure, trailed behind a moving boat.

turbidity: the measure of the content of suspended and/or dissolved material in a body of water that inhibits light penetration, indicates the corresponding decrease in clarity.

tyee: local name used by B.C. sports fishermen to describe chinook salmon (*Oncorhynchus tshawytscha*) that weigh more than 30 pounds (13.6 kg).

ungulates: a non-taxonomic term referring to hoofed mammals; herbivorous, found living in herds, and usually adapted for running on firm open ground, e.g., deer, elk.

vapour pressure: the pressure exerted in the atmosphere by a substance through its vapourization, and usually measured in millimetres of mercury; in meteorology, this term is used almost exclusively to denote the partial pressure of the molecules of water vapour in the atmosphere.

vernal: relating to, or appearing, or occurring in, the spring.

visibility: the distance of visual perception, usually through the atmosphere, measured in kilometres; in meteorology, defined as the horizontal distance at which a prominent dark object can be seen and identified against the sky at horizon (daytime) or at which a known light source of moderate intensity can be seen and identified (nighttime).

volcanic rock: the class of igneous rocks that have been poured out or ejected at or near the earth's surface.

waterfowl: birds that live on or near water, especially swimming game birds like geese and ducks.

water quality: the totality of physical, chemical, biological and aesthetic characteristics of water;

the applicability, based on these characteristics, of water for various uses.

watershed: the summit and dividing line between two catchment areas (drainage areas), from which water flows away in two directions.

wind rose: a diagram illustrating the proportion of winds which blow from each of the main points of the compass at a certain place, taken over a considerable period.

zooplankton: animal life, usually microscopic, found floating or drifting in the water column of oceans or bodies of fresh water; form the bulk of the primary consumer link in aquatic food chains.

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