DATA REPORT

HABITAT WORKING GROUP

FRASER RIVER ESTUARY STUDY

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1979

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HABITAT WORKING GROUP

T. BIRD - CHAIRMAN
T. CLEUGH - EDITOR

1979

EDITOR'S COMMENTS

Every effort was made to retain the presentation of the original drafts. Some editorial changes were made by correcting obvious grammatical errors, however, no section was heavily edited. No effort was made to reduce duplication of information or presentation differences. Only two changes were made to the original material, these included:

1. Some figures, maps and tables required redrafting before being acceptable for publication.

2. Removal of the two appendices from the Wildlife Section as they were simply portions of the 1) B.C. Fishery Regulations and 2) Migratory Birds Convention Act.

PREFACE

The Fraser River Estuary Study has been undertaken to provide guidelines for the future management of the Fraser River and its estuary. The study has proceeded under the guidance of a federal/provincial Steering Committee within an administrative framework involving federal and provincial ministers, a study co-ordinator and several work groups. One of these work groups was the Habitat Work Group chaired by Mr. T. Bird. Within this work group are three sub-groups, Habitat, Fisheries and Wildlife. Each of these sub-groups prepared an individual report which was subsequently aggregated into the Habitat Report. The Habitat Report was then submitted to the Study Co-ordinator as the final submission of this Work Group. However, it was the considered opinion of each sub-group that each of these individual reports should also be published for referral purposes. This Data Report then is the individual reports received by the editor prior to compiling the Habitat Report for the Fraser River Estuary Study Task Force.

TERMS OF REFERENCE

The overall objective of the Habitat Work Group was to describe the fish, wildlife, and habitat characteristics of the Fraser estuary and to document present use and productivity. The Work Group was also required to identify and make recommendations concerning opportunities for maintenance, restoration and enhancement of habitat.

Habitat

1. Delineate the present terrestrial, intertidal and aquatic habitat zones;

2. Identify: Marine, brackish and fresh water areas; terrestrial, emergent and submerged plant associations; Benthic invertebrate populations; primary productivity indices; key breeding, feeding, resting and migratory sites and pathways;

3. Identify areas formally designated for fish and/or wildlife protection;

4. Identify the agencies whose jurisdictions, mandates and policies can influence habitat characteristics;

5. Describe integrated resource use potentials for all major habitat types;

6. Identify habitat maintenance, restoration and enhancement opportunities;

7. Identify the natural riverine and oceanographic factors affecting foreshore ecology, viz. depletion, accretion and biological productivity;

8. Make recommendations concerning opportunities for the maintenance, restoration and enhancement of habitat.

Fisheries

1. Describe the Fisheries Resource base;

2. Identify the agencies involved in the management and protection of the resource;

3. Describe the level of habitat utilization, the distribution and periodicity (where applicable) of use by fish stocks;

4. Outline habitat requirements for major species or groups, identify levels of habitat-oriented dependency, food chain relationships, water quality;

5. In conjunction with the Recreation Work Group describe recreational and commercial resource use;

6. In conjunction with the Land Use Work Group, identify present and proposed land use practices and industrial and urban developments and activities which have potentials, to decrease or increase the productive capacity of aquatic fisheries environments;

7. Identify information gaps.

<u>Wildlife</u>

1. Describe the Wildlife Resource Base;

2. Identify the agencies involved in the management and protection of the resources;

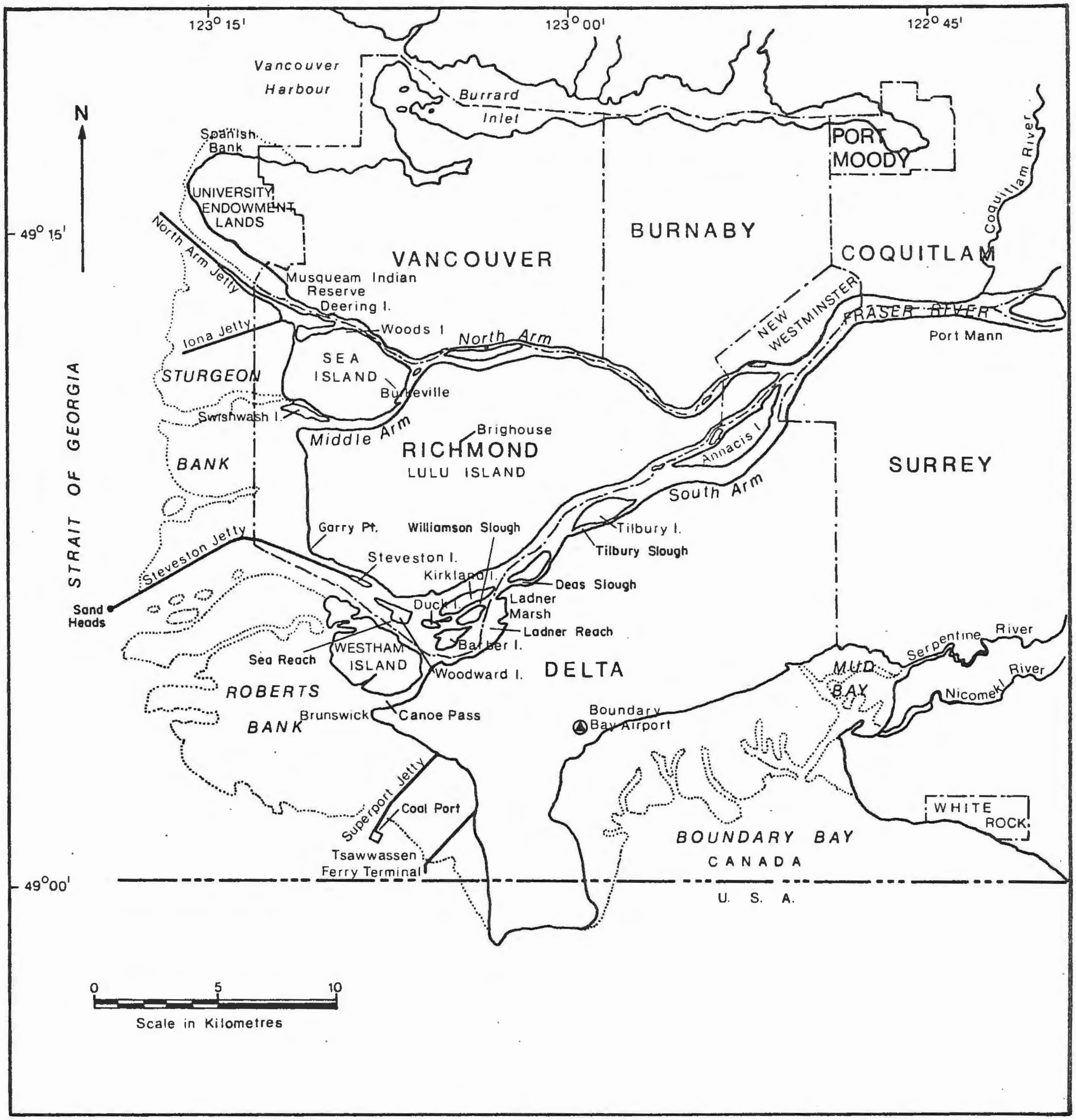
3. Describe the level of habitat utilization, the distribution and periodicity (as applicable) of use by wildlife populations;

4. Outline habitat requirements by major species or groups, identify the level of habitat-oriented dependency in terms of food, space, water quality, etc.;

5. In conjunction with the Land Use Work Group, identify present and proposed land use practices, industrial and urban developments and activities which have potentials to decrease or increase the productive capacity of terrestrial and aquatic wildlife environments;

6. In conjunction with the Recreation Work Group, describe commercial and recreational resource use;

7. Identify information gaps.



SOME PLACE-NAMES MENTIONED IN TEXT

<u>HABITAT</u>: <u>CHARACTERISTICS AND COMPONENTS</u>

A Report to the Fraser Estuary Study by the Habitat
Sub-group of the Habitat Working Group

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May, 1978

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Introduction

The importance of the wetlands of the lower Fraser River to a variety of resident and migratory fish and wildlife is, as yet, incompletely understood. The information that exists, however, indicates that these wetlands are critical to at least certain stages of the life cycles of a number of economically and socially important species; and contribute significantly to the richness of adjacent waters in the Strait of Georgia.

Estuaries and marshes are amongst the most productive biological communities on earth. Primary productivity values obtained for some of the communities of the Fraser Estuary are at the higher end of the range of such values reported in the literature (see sec. II E. below). In discussions on land use of the Fraser foreshore, one question that invariably arises is, "How much wetland must be preserved to meet fish and wildlife management objectives?" Little quantitative information exists on the degree to which present productivity is utilized and, in the absence of such information, that question cannot be answered. Nor is it possible at present to quantify the losses of fish and wildlife that might be caused by any reduction of the existing system. We know, however, that the present Fraser wetlands are but a vestage of the original estuarine and floodplain system which supported large numbers of both resident and migratory fauna. It has also been demonstrated that, <u>within limits</u>, biological systems possess a remarkable ability to sustain productivity in the face of gradual attrition. Some species may disappear and overall numbers may drop, but the changes are so gradual as to be relatively imperceptible in the short term. When pushed beyond a certain point, however, changes become rapid, catastrophic and, for some species, irreversible.

In the light of the forgoing then, it is valuable to consider the changes that have occurred to the estuary over the last century. Though somewhat speculative in nature, this exercise will serve to place the existing areas of wetland in a historical perspective. This comparison of the historic with the present day estuary will be based on two assumptions:

1. The configuration of the river channels and islands was much the same as it is now with the exception of minor changes brought about by the training structures.
2. Immediately prior to European settlement the estuary and flood plain were in a natural or nearly natural condition, largely unaltered by the activity of man. The important exception to this is the use of fire by native people to maintain successional meadow and shrub communities.

Sources of Information

This exercise consists of two components; first, to determine the extent of the area originally subject to flooding through either tidal action, river action or a combination of the two; and second, to estimate the distribution of plant communities on the estuary and floodplain. Of these, the second is the most speculative in nature. The main sources of information used in these determinations are:

1. Soils and surficial materials
   i.e. origin, textural properties, soil development processes, chemical properties and drainage
2. Topography
3. Tide and river-flow data
4. Historical records

The Extent of the Estuary and Floodplain

Prior to settlement the area flooded by tides and river freshet probably varied considerably from year-to-year. The present lowland probably represents somewhere between the 1 in 100 and 1 in 200 year flood level. Though extreme floods may have an effect on successional patterns of vegetation throughout the lowlands, it is the average annual flood level that has the most influence on vegetation maintenance, particularly of the marshes. Two studies have attempted to delineate the average annual flood level prior to dyking. Staff of the Inland Waters Directorate, using January high-tide data, established an average annual flood level equivalent to the 7 foot contour (I.W.D. 1973). Forrester et al (1974) approached the estimation of the average annual floodland within the context of habitat available to salmonid fry migrating downstream in the spring. The annual flood level was calculated from a combination of tidal and river flow information during the period April-July for the years 1958-68. The average flood level for this period was found to be approximately equivalent to the 5 foot contour.

These studies indicate that in their unaltered state, the Fraser lowlands were subject to two annual flooding peaks, each of which had profound effects on the extent and distribution of plant communities. The first peak coincided with the high winter tides and was composed of a mixture of salt and freshwater. The second peak occurred during spring freshet and was composed of silt-laden fresh water. In addition to the areas flooded directly by the action of tide and river, many low-lying lands were flooded during these periods by rising ground water. Since this ground water tended to be acidic and of low nutrient status, vegetational development was towards either sphagnum bog or coniferous swamp.

Vegetation of the Historic Estuary and Floodplain

In a recent study, Professor Margaret E. North of the Department of Geography, U.B.C. has estimated and mapped the distribution of plant communities on the Estuary and floodplain prior to European settlement. Map 1 is adapted from a preliminary draft of Professor North's map, the finalized version of which will be published by the Lands Directorate, Environment Canada. In preparing this map, Professor North used the flooding studies described in the last section, soils information coupled with observations of remnants of natural vegetation, and original note books of the B.C., and Dominion Land Surveyors and Royal Engineers from the period 1859-1888. A summary of the probable species composition of the vegetation types is shown in Table 1.

TABLE 1 Vegetation types of the historic Fraser Estuary and Floodplain. After North (in preparation)

Map Unit (re: Map 1)	Vegetation Type	Major Species Composition
1.	Salt marsh	Salt wort (Salicornia virginica), arrow-grass (Triglochin maritimum), Saltgrass (Distichlis stricata).
2.	Tidal marsh	Bulrush (Scirpus validus, S. paludosus, S. americanus), cattail (Typha latifolia), sedge (Carex lyngbyei, C. micro carpus, C. rostrata).
3.	Wet meadows	Grasses (Agreostis palustris, A. pallens, A. microphylla, A. oregonensis, Aira caryophyllea, Alopecuris pallescens, A. geniculatus, Calamagrostis nutkatensis, Festuca rubra, Glyceria occidentals, Holcus lavatus, Hordeum brachyantherum, Poa spp (confinis?), rushes (Juncus articulatus, J. balticus, J. effusus), sedges (Carex spp (stylosa, obnupta, kelloggii?).
4.	Riparian shrub meadows	Grasses, rushes and sedges as above, Willow (Salix hookeriana, S. scouleriana, S. sitchensis), Pacific crab-apple (Pyrus fusca), red-osier dogwood (Cornus stolonifera), hardhack (Spirea douglasii).
5.	Riparian deciduous tree/shrub	Cottonwood (Populus trichocarpa), willow (Salix spp) red alder (Alnus rubra), Pacific crab-apple, red-osier dogwood, wild rose.

6.	Riparian coniferous forest	Sitka spruce (*Picea sitchensis*), western red cedar (*Thuja plicata*), western hemlock (*Tsuga heterophylla*), red alder, Pacific crab-apple, willow, wild rose, vine maple (*Acer circinatum*).
7.	Bog	Sphagnum moss (*Sphagnum* spp.), bog cranberry (*Vaccinium oxyoccus*), labrador tea (*Tedum groenlandicum*), salal *Gaultheria shallon*), shore pine (*Pinus contorta* var *contorta*).
8.	Treed bog	Sphagnum moss, bog cranberry, labrador tea, Sitka spruce, western red cedar, western hemlock, shore pine, paper birch (*Betula papyrifera*).
9.	Cedar swamp	Western red cedar, red alder, willow, Pacific crab-apple, hard hack, skunk cabbage (*Lysichitum americanum*).
10.	Coniferous forest	Douglas-fir (*Pseudotsuga menziesii*), black hawthorn (*Crataegus douglasii*), Oregon grape (*Mahonia nervosa*), grand fir (*Abies grandis*), western red cedar, western hemlock, Sitka spruce, vine maple, red alder, flowering dogwood (*Cornus nuttallii*).

One of the objectives of preparing the vegetation map was to determine what proportion of the original wetlands (excluding swamps and bogs) was destroyed through dyking and subsequent development. The figures, which appear not to consider losses due to developments outside the dyke, are as follows (from Forrester, Squire, and North 1974):-

TABLE 2 The historic and present extent of the wetland communities of the Fraser Estuary and Floodplain.

Plant Community	Historic Extent (ha.)	Present Extent (ha.)
Salt Marsh	2,230	380
Bulrush Marsh	1,760	1,690
Cattail/Sedge Marsh	1,830	1,493
Wet Meadows	12,400	2,604
Wet Meadow/Willow	2,350	258
TOTAL	20,570	6,425

The area included in this study was the foreshore from the North Arm to Mud Bay, and the floodplains of the Fraser River below Mission, the Pitt River below Pitt Lake, the Serpentine River, and the Nicomekl River. Thus, of the area flooded, at least annually, that supported wetland vegetation, only 31% now remains in a relatively natural state.

Conclusion

The picture that emerges from these studies is of a dynamic complex of plant communities, the composition and distribution of which was determined in the short term by daily and annual flooding, the salinity or acidity of flood waters, rates of sediment deposition, the drainage quality of surficial materials, and periodic fire. Over the longer term the distribution and composition of communities varied with the effects of abnormal floods and the shifting of the river channels.

Quantitative information on fish and wildlife use of the wetlands prior to European settlement is lacking. Diaries and journals of early European visitors provide descriptive records indicating that the Fraser lowlands were intensively used by the Coast Salish people for food gathering:- berries from the bogs and shrub lands; salmon, sturgeon, smelt, herring and oolichans from the ocean, marshes and river; and beaver, ducks, geese, deer and Roosevelt elk from the marshes and meadows. As to the size of wildlife populations, we can only guess, however, some quotations from the journal of John Work, a member of a Hudsons Bay Co. expedition which visited the mouth of the Fraser in 1824 are noteworthy:-

> "Immediately we put ashore Pierre Charles went to hunt and shortly returned having killed 3 elk and a deer...... The great number of tracks seen by the hunters indicated that elk (Roosevelt) are very numerous about this place." (Semiahmoo Bay and the Campbell River valley)
>
> "Immense flocks of 'plover' were observed flying above the sand." (Boundary Bay)
>
> "There are the appearance of beaver being pretty numerous in this river......... Elk have been very numerous here some time ago but the

> hunters suppose that since this rainy season they have gone to high ground." (Nicomekl River)
>
> The marks of a great many beaver and numerous tracks of elk, some quite fresh, are to be seen all the way along the river." (Salmon River)
>
> On the low land at the entrance of the River, geese, particularly white ones, were very numerous and were by no means shy, they allowed themselves to be approached easily." (Fraser foreshore in the vicinity of the Main Arm)

One of the most graphic descriptions of Pacific Northwest estuary life is contained in the 1833 journal of William Fraser Tolmie in his visit to Cape Disappointment off the Columbia.

> "It seemed to us as if we were entering a firth or estuary. Large flocks of wild ducks closely agminated flying overhead and smaller ones skimming the surface of the foaming billows. A prodigious number of other birds almost darkening the air ahead actively engaged in the pursuit of prey, large masses of seaweed abundantly scattered about, perhaps affording them a supply of crustaceous and molluscous meals."

Today the Roosevelt elk are gone from the Fraser lowlands, and only remnant populations of beaver and deer remain. Only the migratory fish and waterfowl populations offer some indication of the former productivity of this system.

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B. Human Activities That Have Led to the Reduction and Degradation of Estuarine and Floodplain Communities.

Introduction

The first intensive human use of the Fraser delta probably occurred with the arrival of people of the Salish Nation on the coast. The abundance of fish, shellfish, waterfowl ungulates and other food items supported native populations at Tsawwassen, Musqueani, Marpole, and seasonally attracted parties from villages in the San Juan and Gulf Islands, and on Southern Vancouver Island. Their numbers were small, and the "hunter/gatherer" nature of their use made little impact on the estuary and floodplain. Probably the most noticeable effect on the vegetation was their use of fire to maintain successional meadows and shrub communities.

In the late 1850's the first European settlers began to pre-empt land in the Fraser Delta. The wet meadows and the grass/shrub communities were the first to be farmed because of the ease with which they could be prepared for cultivation. It soon became apparent, however, that the major barriers to improving agricultural practices in the delta were periodic flooding and poor drainage.

Dyking

Initially, dyking and drainage began on individual farms a few acres at a time. After the great flood of 1894 a continuous system of dykes was constructed along the foreshore and the banks of the Fraser, Serpentine and Nicomekl Rivers. The larger islands, such as Sea, Lulu and Westham, were also dyked at this time.

Another major flood occurred in 1948. In excess of 2050 ha. of lowland were flooded and approximately 2000 people left homeless. The total damage is unknown, however, $2,000,000 were paid in compensation for flood losses.

The 1948 flood stimulated a second programme of dyking culminating in the 1968 federal-provincial agreement to improve the existing river and sea dykes, bank protection, and drainage facilities. These improvements, originally scheduled for completion in 1978 but now set back to 1984, will provide 200 year flood protection at a cost of $120 million.

The dyking programmes at the turn of the century had the greatest impact on the delta. The dykes were usually located along beach ridges and the natural levees of the river and thus had relatively little effect on the brackish marshes of Roberts and Sturgeon Banks. The greatest impacts were on the freshwater marshes of the main river arms, large portions of which were destroyed by dyking; the wet meadows, which were almost entirely enclosed by dykes, drained and cultivated; and the salt marshes of Boundary Bay, major portions of which were dyked-off and filled. As indicated in the previous section, nearly 70% of the original wetlands were alienated from the estuary and floodplain by these early dyking programmes.

The present dyke upgrading and reconstruction under the auspices of the Fraser River Flood Control Programme is causing a further reduction of marsh communities. Though the area involved is not nearly as great as in previous programmes, the losses are significant when viewed within the historical context of what now remains of the estuarine and floodplain system.

Urbanization and Industrialization

Although dyking, drainage and cultivation markedly altered the appearance of much of the Fraser lowlands, some use by wildlife has continued. Farmlands provide habitat for many terrestrial birds and, when flooded during the winter rains, for grazing waterfowl and dabbling ducks. The conversion of farmlands to urban and industrial purposes precludes even these reduced levels of habitat use. Perhaps even more important, since the passage of the Land Commission Act in 1973, industrial development has been directed away from lands designated Agricultural Land Reserve and concentrated on areas outside the main dyke system. This places further pressure on the foreshore and the remnant freshwater marshes of the Fraser River. No reliable estimate exists of the area of fish and wildlife habitat lost to urban and industrial expansion over the past four decades.

Port Development

Two major developments have resulted in the destruction of intertidal foreshore communities on Roberts Bank:- the Westshore Terminals bulk-loading facility, and the B.C. Ferries terminal. Habitat losses resulting from port and causeway construction for these two developments were approximately 60 and 50 ha. respectively. In addition to the direct habitat losses the two projects have probably had profound effects on water circulation and sediment deposition patterns on Roberts Bank.

In both cases there exists the possibility of further habitat losses from facilities expansion.

River Training Structures

The objective of jetties and training walls on a river is to create a self-scouring action in the river channel by increasing water velocity. This in turn reduces the amount of dredging necessary to maintain navigational passage for large ships. A number of jetties (i.e. North Arm, Steveston, Albion Is.) and walls have been constructed, and current plans call for training structures throughout the lower river.

Training programmes have the potential to create serious, long-term changes in patterns of erosion, sediment deposition, and water circulation in the estuary and floodplain. The possible effects of planned programmes are currently under study.

Dredging

Substantial portions of the lower reaches of the Fraser River are dredged periodically to maintain navigability for ocean vessels as far upstream as Fraser Mills. In the past, the spoiling of dredgate destroyed significant areas of remnant washwater marsh.

Filling

In-filling, or land reclamation as it is sometimes termed, poses a significant threat to remaining marshlands, particularly small areas outside the dykes on the lower reaches of the river. Recent examples of marsh destruction are the dumping of fill material in Tilbury Slough by B.C. Development Corporation, on Sturgeon Bank adjacent to Lulu Island by local land owners, and on intertidal marshes next to the Iona Island causeway.

Logbooming

Many areas of the lower Fraser River, particularly on the North Arm, are used extensively for log storage and staging. Although the effects of this activity are difficult to quantify, studies indicate that it can be detrimental to water quality and benthic production, and result in the scouring and elimination of vegetation.

Water Quality Deterioration

Studies by the Westwater Research Centre indicate that, compared to other heavily-used rivers of the world, the quality of water in the lower Fraser River is still relatively high. There is clear evidence, however, of an accumulation of toxic materials - lead, mercury, biocides and P.C.B.'s - in the sediments and organisms of the river. These pollutants enter the river from municipal sewage treatment plants, as effluent from industrial operations, and in storm water run-off from urban areas.

It must be stressed that efforts to preserve the remaining wetland communities of the Fraser estuary and floodplain will be largely futile if the quality of river and estuarine waters is allowed to deteriorate either to the level where the commercial species are no longer edible, or to the point where the wetlands are no longer capable of supporting important fish and wildlife species.

Conclusion

Human activities over the past 100 years have destroyed or irreparably altered approximately 70% of the original wetland communities of the Fraser estuary and delta. While the fish and wildlife losses resulting from these habitat changes can not be measured, it is apparent from the descriptions of early visitors to the area that we have lost much of original populations of resident and overwintering aquatic waterfowl, and probably a portion of the migratory fish and waterfowl populations as well. Not all of these losses can be directly attributed to habitat deterioration in the estuary and delta, however, given the critical role of these wetlands in the life histories of many species, it is almost certainly a significant contributing factor. In the absence of quantitative data on the degree of present habitat use, it is impossible to predict the effects of further reductions of wetlands on fish and wildlife. In the light of historic losses, however, it might be prudent to assume that the present area of wetland is essential to the maintenance of fish and wildlife populations until clear evidence indicates otherwise.

Several developments have been proposed within the Fraser estuary and delta in recent years that would result in further reduction of habitat if approved. The most serious of these proposals are:-

1. Expansion of the Roberts Bank superport
2. Expansion of Vancouver International Airport
3. Filling and subdivision of private lands on Ladner Marsh

4. Marina development on Swishwash Island

5. Relocation of Rivtow Straits operations to Don and Lion Islands

6. Expansion of the B.C. Ferries terminal

7. Marina development at Ladner

8. Expansion of the Steveston fish boat harbour

9. Marina development at Musqueam

10. Scow basin development by the North Fraser Harbour Commission

11. Marina development by the North Fraser Harbour Commission

12. Expansion of the airport facilities at Boundary Bay.

II A Description of the Present Study Area

A. The Physical Substrate

i. Surficial Geology and Soils

The following discussion of surficial geology and soils of the study area is adapted primarily from Jones (1977). This publication contains a map of surficial deposits (1:50,000) and a list of major references, many of which contain more detailed mapped information for specific areas. Hoos and Packman (1974) also provide a map and summary of geological information for the study area.

Soil maps for the study area are available from the B.C. Resource Analysis Branch at a more detailed scale of 1:25,000; these maps and their accompanying reports contain information on surficial deposits, texture, drainage, and soil development.

The study area has had a complex geological history which has resulted in the presence of four major types of surficial deposits: nearshore marine sediments; fluvial sediments; organic deposits; and marine and glacio-marine deposits in upland areas (See Map 2).

The nearshore marine sediments are located below the normal high-water level and are influenced by both riverine and marine processes. Three major sediment domains of nearshore marine sediments have been differentiated: sand and silty sand deposits, silt and sandy silt deposits, and clayey silt deposits. These sediment domains have relatively uniform textural composition and a similar process-environment. Kellerhals and Murray (1969) have described the relationship between sediments, and biological and hydrological activity in the Boundary Bay area.

The fluvial deposits have high water tables, are susceptible to flooding and ponding, and may settle upon loading. These deposits have

TABLE 3 Generalized Capability and Engineering Limitations for the Major Surficial Materials in the Fraser Estuary and Floodplain

Material [1.]	Drainage Class [2.]	Engineering Limitations		Generalized Capability [3.]		
		Buildings	Roads	Agriculture	Forestry	Waterfowl
pW	WD	Slight*	Slight*	Low	High	Low
sW	WD	Slight*	Slight*	Low	High	Low
9cW	MWD	Moderate	Moderate	Low-Mod.*	High	Low
$cW	MWD	Moderate	Moderate	Low-Mod.*	High	Low
W	ID	Mod-severe	Moderate	Low-Mod.*	High	Low
W	PD	Severe	Severe	Low	Mod-high	Moderate
F	ID	Mod-severe	Moderate	High	High	High
F	PD	Severe	Severe	High	High	High
O	PD	Severe	Severe	Low	Low	Mod-high

* Assuming slope less than 8%

1. p = pebbly
   s = sandy
   g = gravelly
   $ = silty
   c = clayey

   W = Marine (upland)
   F = Fluvial
   O = Organic

2. WD = Well drained
   MWD = Moderately well drained
   ID = Imperfectly drained
   PD = Poorly drained

3. From C.L.I. land capability maps

a high agricultural capability. The associated organic deposits undergo extreme compaction when loaded and have very high water tables.

Knowledge of the distribution and extent of nearshore marine sediments provides information necessary for the understanding of sediment-biologic relationships.

Pebbly and sandy marine deposits (see Table 1) in upland landscapes have the fewest soil limitations for most engineering uses of land (e.g. developments such as paved roads and streets, and dwellings). These materials also have low capability for agriculture and waterfowl; thus negative impacts as a result of development on other resources is least.

Most fluvial deposits in the study area are poorly drained and thus have severe limitations for most engineering uses of land. This does not mean that a development cannot go on, only that construction costs associated with overcoming these limitations are likely to be significantly greater than on soils with only moderate or slight limitations for use. Fluvial deposits are also rated as having high capability for all other resource values - agriculture, forestry, waterfowl, and ungulates.

Conclusion and Recommendations

A comprehensive soil survey report for the Lower Fraser Valley including the study area is in the final stages of preparation by the Resource Analysis Branch in Kelowna. While a few minor gaps exist in this information, the soils and surficial materials of the study area are generally well defined. There is a need for more effective communication of existing soil and surficial geology information to urban planners and land managers.

It is, therefore, recommended that:

1. Steps should be taken to fill in the few remaining gaps in soil and surficial geology information for the study area.

2. In consultation with urban planners, interpretations of soil and surficial geology information should be developed which would indicate suitabilities and limitations for a range of land uses and types of development.

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ii. Fluvial and Oceanographic Factors Affecting the Substrate

Maps of substrate distribution are available for Boundary Bay (Murray and Kellerhals, 1969 and Swinbanks and Murray, 1977); Roberts and Sturgeon Banks (Medley and Luternauer, 1976) the South Arm of the Fraser River (Tamburi, 1976) Pitt River and Pitt Lake (Ashley, 1977).

Within the Pitt River and Pitt Lake system Ashley (1977) has investigated (1) aspects of the hydrodynamics of Pitt River and Pitt Lake as a tidal system, (2) effect of bidirectional flow on river and delta morphology, (3) processes of sediment movement in the river and of sediment dispersal on the delta and (4) present sedimentation rate on the delta. Tamburi (1976) and Western Canada Hydraulic Labs Ltd. (1977) have described modelling studies of river flow patterns in the South Arm of the Fraser River which have been completed or are underway. Murray and Kellerhals (1969) and Swinbanks and Murray (1977) have described the physical features, oceanographic processes and fluvial influences within Boundary Bay and the effects of elevation, large scale topographic rises, environmental energy, surface water salinities at low tide and substrate type on zonation, community structure and behaviour of sediment-dwelling organisms.

Oceanographic processes active at the Fraser River delta front have been described by Thomson (1977).

In the area of Sturgeon and Roberts Banks numerous investigations relating to surficial geology have recently been completed or are in progress by or in association with the Geological Survey of Canada. Grieve and Fletcher (1976) described the distribution of heavy metals in tidal flat and slope sediments; Luternauer (1976) described seasonal variations in patterns of sedimentation on the tidal flats; Luternauer (1977) described sedimentary successions in 8 cores collected within the foreshore marshes; Luternauer (1976) and Luternauer et al (1978) described hydrologic-oceanographic processes on the Sturgeon Bank tidal flat which appear to promote marsh colonization. Scotton (1978) described factors influencing the stability of the Fraser Delta slope. Currently studies are being completed on animal-sediment relationships on southern Roberts Bank, processes leading to the formation of a variety of sand structures on the tidal flats and plant-sediment relationships and sedimentation rates within the foreshore marsh.

It is apparent that the extensive marshlands and tidal flats of the western delta front of the Fraser River evolved as a result of the interaction of river and marine processes. Man-imposed alterations to river flow have not always been compensated for by accompanying changes in the activity of waves and currents. Furthermore, the sediment dispersal routes of both silt and clay (essential to the maintenance of the marsh) and of sand (essential to the stability of the outer sand flats on which development has taken place) have been and will be altered by the erection of engineering structures on or across the flats.

Conclusion and Recommendations

The patterns of water circulation and sediment flow, and the resulting processes of erosion and deposition within the Fraser estuary are, as yet, incompletely understood. In order to ensure that critical sand flat areas and marsh habitats are not degraded by alterations to the foreshore or river the following information is required:-

(a) Definition of the major sediment pathways in the estuary and river channels.

(b) The rates of sediment supply necessary to maintain the physical integrity and the biota of the foreshore.

Until such information is available the impacts of any structures on the foreshore or alterations to the flow of the river can not be predicted with any confidence.

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B. Major Water Zones:- Marine, Brackish, and Freshwater Areas

Status of Knowledge

Considerable study of salinity and water movement in the Fraser estuary and Georgia Strait have been conducted. These studies were largely related to the importance of these factors to navigation and the distribution of pollutants. Geological surveys of this area were done by Johnston in 1921 and up-dated by Mathews and Shepard (1962), and Mathews and Murray (1966). Physical oceanography, related to changes in sea level, was studied by Waldichuck (1964). Construction of the Iona Island sewage treatment plant stimulated studies of water movement and salt concentration in the late 1940's (Fjarlie 1950), and interest in salt water movement into marinas resulted in studies by Tabata (1956).

The implications of these studies to the delta ecosystem are discussed by Hoos and Packman (1974). Giovando (1975) summarized oceanographic factors related to the ecology of the delta, particularly in the vicinity of the Vancouver International Airport.

The most comprehensive studies of salinity in the Fraser delta is related to research for more accurate prediction of tides (Hughes and Ages 1975, and Ages and Wolard 1976). These studies are still in progress and should result in 1978 in a mathematical model capable of predicting salinity and water depth given a particular array of measurable parameters.

Factors Affecting Salt Content

The fundamental determinants of fresh, brackish and salt water zones in an estuary like the Fraser are the sources of fresh and salt water. Fresh water is primarily from the Fraser River which provides 80% of the fresh water input to the Strait of Georgia (Waldichuck 1957). In areas like Boundary Bay other rivers such as the Serpentine and Nicomekl are more important because of the isolation of the area from direct influence

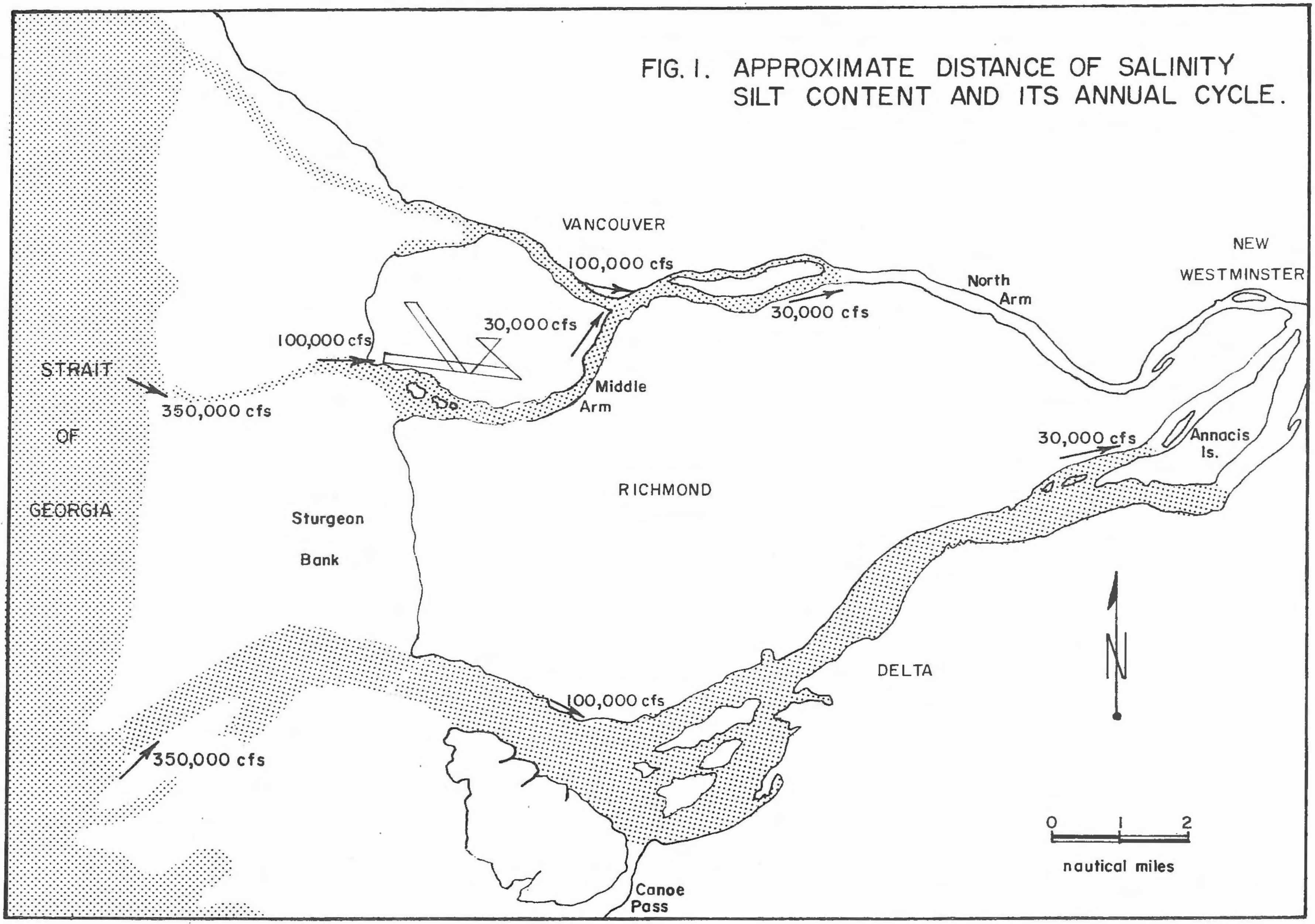

FIG. I. APPROXIMATE DISTANCE OF SALINITY SILT CONTENT AND ITS ANNUAL CYCLE.

by Fraser River waters. The salt water source in the Fraser estuary is primarily through the Strait of Juan de Fuca, which is the only area where salt content reaches ocean levels of 33.8 parts per thousand. Inside the Strait of Georgia, salt levels are mainly below 29 parts per thousand (Figure 1) indicating a dilution factor in Georgia Strait as a whole equal to the fresh water input of the Fraser River at a 1 1/3 year flow (Waldichuck 1957).

Movement and mixing of fresh and salt water from these sources is a dynamic process influenced by irregular factors such as fresh water volume and velocity, wind speed and direction, barometric pressure, water temperature, and daily fluctuations in tides overlain on relatively constant factors such as river depth, deflection of flow by geologic or man-made structures, and Coreollis effect (spin of the earth). The difficulty and perhaps futility of mapping the salinity distribution of estuarine water given these variables is described by Pritchard (1952). He noted that in Chesapeake Bay the typical summer gradients in the middle bay are such that salinity measurements used for deep-sea oceanography would be inadequate unless the position of the station were specified to within 40 feet, the time specified to within 90 seconds and the depth of sample specified to a quarter of an inch!

Marine, Brackish, and Fresh Water Zones

In spite of the extreme variation of factors affecting the extent and occurrence of marine, brackish and fresh water zones, certain areas are consistently more influenced by fresh water than other areas. As might be expected, sites near river mouths and shallow areas, (because the tendency of fresh water to float) are as a rule more fresh than are deep water sites. As Giovando (1975) stated for the Fraser foreshore, "Near the river a lighter, thin (3 - 30 ft) layer of brackish water (to 10 parts per thousand), overlies deeper water of much greater salinity (to 31 parts per thousand), the characteristic brackishness results from entrainment of sea water into the entrant river water. Both the density (salinity) contrast itself and the depth interval throughout which it occurs (approximately 20 parts per thousand through approximately 10 ft) is much more marked in the vicinity of the river mouths, particularly that of the main arm. However, tide, wind, and diffusive processes ensure extension of the two-layer structure throughout much of the Strait, depending on runoff."

Training structures (such as Iona jetty, the ferry and the super port causeways) on the banks have a major influence on salt water distribution because those structures deflect moving fresh water and maintain pockets of sea water. Geological features also affect the distribution of major water zones. Point Roberts, for example, prevents direct flow of Fraser River water into Boundary Bay.

<u>Annual and Diurnal Variations in Salt Content</u>

Effect on Biotic Communities

The interplay of all the factors previously described results in continual change in salt content at most sites in the estuary both daily and through the season. A specific site however has an average set of factors which greatly influence the salt content of the substrate and biota which it supports. Organisms in estuaries are euryhaline (able to live in waters of a wide range in salinity), but adapt to an average long-term condition. Long term changes through alteration of either the rate or volume of river flow would result in the replacement of existing species with forms more adapted to the new conditions. Sessile and slightly motile organisms have an optimum salinity range within which they grow best. When salinities deviate from this range, populations of these species decline (L. Smith 1966).

The Salt Wedge

As the fresh water from the river spreads out over the salt water its momentum, and friction with the salt water below causes salt water near the surface to be carried seaward. To replace this, salt water flows upstream under the fresh water layer. The meeting point between fresh and salt water is at a slight angle from the horizontal, the salt water being wedge-shaped with its point at the river bottom pointing upstream. The salt wedge moves back and forth daily with tidal change and with less regular seasonal change in river flow. At high tide low runoff conditions, salinity can be detected as far upstream as New Westminster but a definable salt wedge does not reach beyond the George Massey Tunnel. During freshet conditions, the salt wedge penetrates only as far as Steveston, and on ebb tide, convergence of salt and fresh water migrates several km. into the strait (Thomas 1954). These locations are indicated in Figure 1 as taken from Ages and Woollard (1976). Because the top of the salt wedge is higher at the mouth of the river than at its tip, and as the channel of the river is not very deep, the salt wedge continues to flow upstream as much as three hours after the surface water has started to flow out (Johnston 1921). Areas upstream of the salt wedge penetration but still within the tidal influence are sometimes termed surge plain (Bauer, 1977). These tidal influences can sometimes be detected as far upstream as Chilliwack during low runoff conditions.

Movement of fresh water into the Strait

Penetration of fresh water into the Strait is dependent on the volume and velocity of river flow, the mixing action of winds, coriollis, and ebb tide forces. The interaction of these factors is described by Giovando (1975) as follows:- "The core of the runoff especially in the south arm can move as a well defined jet several miles into the Straight of Georgia forming a cloud of fresh turbid water. Under favourable conditions a chain of such clouds will form, separated from the preceding or subsequent ones by the distance moved during the intervening flood tide interval. The presence of these more or less discrete entities could be expected to result in a considerable range of fluctuations in the salinity, especially in shallow water, through various scales of time and/or space."

Effect of Salt Content on Sedimentation

In an estuary like the Fraser, the turbid fresh water is less dense than the salt water and, when meeting the more saline water, floats on it and spreads over the surface. As this process occurs, salt water mixes with fresh through a process called entrainment. Salt ions flocculate much of the suspended material causing it to settle out. Rapid flocculation occurs at about fifteen parts per thousand (Waldichuck 1957). This is the approximate concentration when equal portions of salt and fresh water are mixed.

Recommendations for further study

A better picture of present knowledge of fresh, brackish and salt water movement in the Fraser Estuary will be available upon completion of the data collection and computer modeling of Ages. It is likely though, that on completion of this work there will still be insufficient information on salt movements in shallow areas such as the intertidal marshes, especially those covered by water only at high tide. More precise information is needed in such areas because relatively small structures may alter the average salinity and therefore the vegetative community. Salt levels of mud substrates are much more constant than surface waters in estuarine marshes (Mangelsdore Jr. 1967). Salinity readings a few mm. below the substrate surface may, for this reason, provide the best base line data.

An important related study would be the determination of the salt tolerance of various wetland species, in order to predict the effects of changes in salinity on the composition of marsh communities.

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C. Vegetation Zones

The vegetation zones discussed herein are primarily the submergent and emergent communites of the foreshore and floodplain. Only one upland community will be described, and that is the bog. This is not to imply that omitted regions are of little habitat value but rather there is insufficient information to adequately assess the contribution of the nearshore upland vegetation, although association patterns have previously been discussed in the literature (Hubbard and Bell, 1976). The use of flooded agricultural fields as a variable food source by wintering waterfowl shall be noted in the wildlife section.

Status of Knowledge

Most of the available marsh literature has focused upon the salt marshes of the eastern coast. MacDonald and Barbour (1974) in a survey of beach and salt marsh vegetation of the Pacific Coast of North America stated that descriptions of the Fraser River Delta marshes had not been found in the literature. However, several local studies of this decade have provided floral descriptions of the Fraser River foreshore marshes. Forbes (1972) whose work has been frequently cited, did a preliminary reconnaissance of the vegetation composition and distribution of the Fraser River Estuary and Boundary and Mud Bays. He identified eleven communities with extensive species lists and relative abundance of each. For the purpose of this study, five communities are considered, that is, cattail, sedge, bulrush, eelgrass and saltmarsh.

An earlier work by Burgess (1970), on food and habitat requirements of waterfowl using the Fraser River foreshore marshes, delineated marsh zones into two broad categories with the most abundant species being sedge, cattail and bulrush species. The upper zone, between the ten and thirteen foot mean tidal levels (datum, Point Atkinson) was vegetated predominantly by Carex lyngbyei (Lyngbye's sedge), interspersed with Typha latifolia (cattail) and Scirpus acutus (hardstem bulrush). The lower zone lying between the ten and seven foot levels consisted primarily of bulrush species, predominantly Scirpus americanus (three-square bulrush) with occasional dense stands of Scirpus validus (softstem bulrush) and Scirpus paludosus (prairie bulrush). Seed production of the major species was estimated and appeared to be inversely related to the degree of tidal flooding. In addition, he concluded that local distribution was influenced by tidal flooding (reflection of elevation) degree of drainage and possible differences in soil and water salinity. It was estimated that tidal marshes attract approximately one-half of the total of ducks observed on the delta in winter.

Yamanaka (1975) also dealt with emergent vegetation of the Fraser River delta foreshore investigating primary productivity. Fourteen "permanent" transects were established from Point Grey to Crescent Beach, indicating community order from the dyke seaward. The principal species from Point Grey to Brunswick Point were basically those identified by Burgess, (1970), Scirpus americanus, Scirpus paludosus, Carex lyngbyei and Typha latifolia. The common halophyte species of the Tsawwassen and Boundary Bay area were Distichlis stricta (green seashore saltgrass), Salicornia virginica (woody Glasswort) and Triglochin maritimum (seaside arrowgrass). He suggested that the zonation of the tidal marshes indicated that salinity and solid substrate level are the two most critical factors associated with tidal marshes.

Burton (1977), in his thesis on the ecology of Lesser Snow Geese, relied primarily on Burgess' vegetation categories. Core samples from water-filled depressions contained a significantly smaller amount of below-ground

Scirpus americanus vegetation (rhizomes) than samples of sites fully exposed at tides below 7.0 feet. However, crude protein content was similar for rhizomes from within a single geographical unit regardless of variations in water-cover, microrelief or season.

Hillaby and Barrett (1976), in an examination of the Tsawwassen salt marsh, described plant communities, and degree of plant cover (Braun-Blanquet system). The marsh was delineated at the 4.6 m tidal contour into an emergent and submergent zone according to degree of tidal flooding as suggested by Chapman (1974). It was concluded that the submergent plants Distichlis stricta and Salicornia virginica (assumed to be S. virginica cited as the local Salicornia, rather than S. validus mentioned in the report) colonize the mudflats, trapping sediments and organic detritus. Hence, hummocks thus created allow the emergent vegetation predominantly Grindelia integrifolia (gum weed) and Atriplex patula (orache) to replace the submergent vegetation.

In addition to the work by Forbes (1972), and Yamanaka (1975), on the Boundary and Mud Bay region, the major studies have been by Kellerhals and Murray (1969) on the Boundary Bay tidal flats, identifying four main sedimentologic-hydrologic divisions; salt marsh, high tidal flats with summer blue-green algal mats, intermediate tidal flats devoid of vegetation and the low tidal flats with eel-grass meadows flanking channel sides.

An update of this report and extension to the Roberts Bank area plus the inclusion of an animal-sediment relationship was done by Swinbanks and Murray (1977). The saltmarsh zone, algal mat zone and upper sand wave zone correlate with Murray and Kellerahals' (1969) saltmarsh, high tidal flats and intermediate tidal flats respectively. The eelgrass zone and lower sand wave zone correlated with Murray and Kellerhals (1969) two subdivisions of the lower tidal flat - the eelgrass community and sand dollar community respectively. O'Connell (1975) relied primarily on work by Forbes, Kellerhals and Murray (1969) and Taylor (1970) for the floral section of the biology of Boundary Bay mud flats.

Currently, studies are being conducted with G.V.R.D. in conjunction with the municipalities on three proposed park areas - Boundary Bay (Centennial Beach - Beach Grove area), Crescent Beach (including Blackie Spit) and Semiahmoo Beach. Tera Consultants, conducting an assessment of Semiahmoo Beach, have identified in a broad overview, habitat zones and comparative sensitivity towards recreational activities and recreational facilities. The Crescent Beach and Boundary Bay areas have developed alternate use plans basing the vegetation section on previous literature, such as, Forbes (1972).

Little information exists on the riparian habitat of the three arms of the Fraser River, other than the often referred to study by McLaren (1972) of the Islands and associated marshes at the mouth of the South Arm. More recently a survey of the marshes of the South Arm (component of the Fraser River data base Inventory - F.R.I., Dept. of Fisheries) was completed indicating distribution patterns of marsh plants and their relative abundance. In addition, a general survey noting marsh areas was done on the North and Middle Arms (F.R.I., 1976).

A preliminary study of the foreshore area adjacent to the Musqueam Indian Reserve No. 2 delineated three major vegetation communities (Bell-Irving, 1976).

An important upland community is the bog. Recent work by Biggs and Hebda (1976) has identified four general and eight specific vegetation types for Burns Bog. These associations would be assumed to apply to the other bog areas.

Barnard (1974), investigating yields of major plant communities as part of his thesis on primary and secondary productivity of the northern

Pitt Meadows, noted that secondary succession in both pumped and unpumped habitats indicated long-term development towards peat bog in many areas.

The ecology of phytoplankton has been studied in Howe Sound and the Strait of Georgia by Stockner et al (1977 and in preparation) and by Northcote et al (1975). Benthic algae, particularly aspects of primary productivity and energy flow, have been studied by Pomeroy (1977) both in research leading to a Ph.D thesis and in continuing research at the Pacific Environment Institute.

Descriptions of the Major Vegetation Zones

i. Submergent Vegetation

Submergent vegetation occupies the intertidal and subtidal zones. The dominant vegetation is eelgrass, with *Zostera marina* the dominant species and the shorter finer-leaved *Zostera americana* being occasionally found on exposed intertidal sites. This community is present in the vicinity of the Tsawwassen Ferry slip, the Roberts Bank Causeway, in Mud, Semiahmoo and Boundary Bays, and a small bed exists off of Iona Island (Dr. P.G. Harrison, Dept. of Botany, pers. comm.).

The preferred habitat of eelgrass is characterized by a temperature range of 7.8-17.5^{o}C, a salinity range of 13.8-30.0^{o}/oo, a substrate of sand or silty sand, low wave shock, gentle currents and a depth of within $\pm$ 1m. of mean low tide. The depth limit may be a factor of light penetration.

The greatest concentration of eelgrass was located at low-tide line (Forbes, 1972) and extends about halfway up the beach between the Tsawwassen Causeway and Roberts Bank Causeway (Levings and Coustalin, 1975). The plants exposed by low tide are located in shallow tidal pools (Forbes, 1972).

The borrow channel created during the construction of the Roberts Bank Causeway has not been revegetated by eelgrass (Levings and

Coustalin, 1975), in fact the denuded area is increasing and is now 2.5 times the area of the original channel (Beak Hinton Consultants, 1977). This is a possible reflection of reduced light penetration as a consequence of depth, and an alteration of water drainage patterns on the ebb tide across the eelgrass meadow resulting in drainage channel velocities too high for plant colonization (Beak Hinton Consultants, 1977). It has been suggested that the Causeway and Ferry slip are however, encouraging an expansion of eelgrass by reducing turbid water flow and hence increasing light penetration (Beak Hinton Consultants, 1977).

The eelgrass community of Boundary and Mud Bays, which is more extensive than that of Southern Roberts Bank, was delineated by Kellerhals and Murray (1969), and more recently by Swinbanks and Murray (1977), as generally below the -6 foot contour (geodetic datum) on the lower tidal flats and extending into the subtidal area. The major eelgrass beds are associated with the five main drainage channels (Taylor, 1970). At the western edge of Mud Bay, there is a sparse bed of Z. marina often exposed at low tides. A dense bed is located between the Pumphouse channel and Great channel and a small dense bed at the Airport channel. Beds of Z. americana occur closer to shore in the previous two areas (Taylor, 1970, Forbes, 1972). To the west almost to the mouth of the Benson Road channel is another small dense bed which continues westward in an unbroken mat to the mouth of Beach Grove channel. Kellerhals and Murray (1969) found that even though the eelgrass acts as a sediment trap, there was no difference in elevation between areas covered with the meadows and the adjacent non-meadow parts of the flat. They concluded that there was apparently no increase in sedimentation due to this trapping mechanism.

Semiahmoo Bay has substantial eelgrass meadows near the shore immediately below the low tide line. Diving waterfowl showed feeding activity concentrated in this area (Tera Consultants, 1977).

Eelgrass meadows serve numerous important functions in estuaries. As colonizers of soft substrate the plants reduce surface erosion, and the leaves reduce currents thus increasing sedimentation rates of organic and inorganic material. The eelgrass leaves support epiphytes which are grazed upon by invertebrates such as amphipods and possibly harpacticoid copepods. A few organisms, for example brant geese, may feed directly on the eelgrass. The leaves also provide a substrate for the attachment of herring spawn. In terms of nutrient exchange, eelgrass absorbs phosphorus through leaves and roots, and returns phosphate to the water upon decomposition. The roots also take up nitrogen which is transferred by the leaves into the water. One of the most important functions of eelgrass meadows is based on its contributions to detritus and related detrital food webs. The detritus initiates sulphate reduction, maintaining an active sulphur cycle (Beak Hinton Consultants, 1977).

ii. Pelagic and Benthic Algae

Phytoplankton, free drifting algae, are important converters of solar energy, as are all plants containing chlorophyll. In this role of primary producers they are the basis of many food chains (e.g. phytoplankton - zooplankton - fish).

The highly turbid Fraser River discharge has a major impact on phytoplankton through light attenuation and horizontal advention (Stockner et al., in prep.). This is evidenced by a low abundance of phytoplankton in the lower Fraser River even during the maximum spring growth period (Northcote et al., 1975) and near the river mouths where the shifting plume boundaries and changing light conditions result in some of the lowest algal biomass and mean annual productions yields in the Strait of Georgia (Stockner et al., in prep.). In areas not markedly affected by the Fraser River discharge, Stockner et al (in prep.) have attributed, in descending order of importance; nutrients, grazing, light and vertical instability, as the primary factors limiting production.

The regions of highest algal primary production (400 g $C \cdot m^{-2} \cdot yr$) are in boundary waters of inlets, in back eddies and plume boundaries of the Fraser River where light conditions improve, and in regions affected by industrial or domestic discharge (Stockner et al., 1977; Stockner et al., in prep.). The Boundary Bay area is both little affected by the Fraser River plume and a recipient of some domestic discharge. Hence it would be expected to have higher primary production than the areas of the lower Fraser reaches, however, there is no data available, to the author's knowledge, to support this assumption.

Stockner et al (in preparation) found that the highest concentrations of important inorganic nutrients for algal growth (nitrates, phosphates, and silicates) were usually found near the mouth of the Fraser River. In analyzing data of annual algal production over the past 10-15 years Stockner et al discovered an increase in production in the back eddies and along the plume boundaries of the Fraser River, and a corresponding decrease in Vancouver Harbour. They attributed this both to the diversion of sewage from Burrard Inlet to Iona Island (1963) and Annasis Island (1974), and to increased nitrogen and phosphorus loading due to population growth during this period.

Northcote et al. (1975) using Palmer's pollution index rating, of pollution tolerant algae species, found that algal communities of the lower Fraser River do not indicate high levels of pollution. This was qualified by the hypothesis that high turbidity may inhibit expression of organic pollutants on planktonic algal abundance. It is important to note that Stockner *et al*. (in preparation) cited areas where the effects of nutrient-rich water on phytoplankton production was similar in process and impact to what is occurring in the Strait of Georgia. Nitrogen from land drainage and domestic sources in a low salinity outflow was directly related to eutrophication of those coastal environments.

Diatoms are the dominant plankton species. In Georgia Strait, during the spring and fall the main diatom species were *Chaetoceros* spp., *Thalasiosira* spp., *Skeletonema costatum*, *Coscinodiscus* spp., and *Ceratauline bergonii* (Stockner et al., in prep.). Common diatom species recorded in a study by Northcote *et al*. (1975) for the lower Fraser River were *Melosira italica* and *Tabelloria fenestrata*. They noted that approximately two-thirds of the planktonic diatoms were also identified in the periphyton (attached algae), suggesting that most planktonic species in the river originate from detached periphyton.

The periphyton examined by Northcote *et al*. (1975) was limited to only those communities growing on wood surfaces (a favourable substrate) thus excluding mud, sand and gravel substrates. There were obvious algal concentration zones occurring a short distance beneath the water surface at most stations in the lower mainstem river. Diatoms were also the dominant group in the attached algae. The diatom *Achnanthes minutissima*, most abundant in the spring, was common in all three arms of the river, frequently accounting for more than a third of total cell number at many of the stations (Northcote et al., 1975).

Benthic algae (comprising micro algae, such as periphyton, and macro algae, the larger "seaweed" plants) are important as primary colonizers on sand and mud flats, and as a readily and continually available energy source. Pomeroy (1977) in his study of the nearby Squamish estuary, where Carex lyngbyei is a dominant in the tidal marsh (as it is in components of the Fraser River Estuary), found that the importance of benthic algae in the estuarine system was related more to the manner in which they contributed energy to the system rather than the total energy produced. Benthic algae provide a continuously available and readily utilized source of energy for invertebrates, such as amphipods, that constitute the lower levels of the estuarine food chain. Since there is little lag-time between production, decomposition and utilization, algae contribute almost immediately to detrital pathways. By contrast, vascular plants, such as C. lyngbyei, do not decompose as readily and thus serve as an energy "store", releasing energy slowly through time (Pomeroy 1977).

Ongoing investigations (Pacific Environment Institute - M. Pomeroy) of the Fraser River foreshore sand and mud flats indicate active production and a large biomass of micro benthic algae, primarily diatoms. This may provide large organic input to sediment feeders (M. Pomeroy, pers. comm.). Current research of invertebrates associated with micro algae growing on training walls suggests that the algae may provide cover and a food source on dyke rip-rap areas (M. Pomeroy, personal communication).

Hence algal communities appear to be a valuable component in an estuarine ecosystem as a continually available energy source which is important in both detrital pathways and to primary consumers.

iii. Intertidal Brackish Marshes of the Fraser Foreshore

Marsh vegetation common to fresh and brackish waters grows on the estuarine foreshore where the Fraser River mixes with the saline waters of Georgia Strait.

The brackish marsh communities, as adapted from Burgess (1970) and Yamanaka (1975), are defined by the dominant species present. There is a recognizable pattern in dominant species composition from the upper zone (nearshore) to the lower zone (seaward). Major species in the zone nearest shore (Burgess, 1970) are Typha latifolia, (these stands appear to have increased since Burgess' study), Carex lyngbyei and occasionally Scirpus acutus, which appears unable to withstand much submergence. Interspersed in the Sturgeon Bank Carex lyngbyei community were Juncus balticus (Baltic rush) located with Distichlis stricta (salt or brackish marshes, Duncan, 1974) and Potentilla pacifica (cinquefoil). Near the dyke species known to occur in higher salinity were found such as Distichlis stricta. This may be due to summer evaporation bringing salts to the surface increasing soil salinities (Dr. V.C. Brink, Dept. of Plant Science, UBC, pers. comm.). Yamanaka (1975) found plant diversity was usually greatest near the dykes.

The lower marsh zone (Burgess, 1970) is predominantly bulrush species, with Carex lyngbyei and Triglochin maritimum occurring in this zone only upon hummocks. Along the Sturgeon Bank foreshore there was a definite driftwood zone. Seaward of this the vegetation types were, first, a community consisting primarily of Scirpus paludosus interspersed occasionally with Scirpus validus, second, a mixture of S. paludosus (local species according to Hitchcock is S. maritimus var. paludosus rather than S. paludosus cited in the literature) and Scirpus americanus and, third, along the seaward edge, pure stands of S. americanus. Similar assemblages occurred along the Roberts Bank foreshore but frequency of occurrence and distribution varied with there being larger areas of Carex lyngbyei in the upper zone, especially on Reifel and Westham Islands and the Brunswick Point areas. The Brunswick Point marsh is progressing in a southernly direction (Dr. V.C. Brink, pers. comm.). The Scirpus americanus communities are more extensive on Sturgeon Bank than on Roberts Bank. Scirpus validus is most abundant on Reifel and Westham Islands whereas Scirpus paludosus is most abundant on Sturgeon Bank and the Brunswick Point foreshore (Burgess, 1970). Typha latifolia is also more abundant on Reifel and Westham Islands. Burgess (1970) has suggested that S. validus and S. paludosus occasionally form fairly dense stands which inhibit the growth of S. americanus.

S. americanus (tolerant of alkali but not requiring of it, Hitchcock, 1973) appears to be the main colonizer with primarily vegetative reproduction occurring along the seaward edge. Whether it has the ability to outcompete S. validus and S. paludosus, requires more inundation, or other factors account for its dominance in this zone is not known.

It is noteworthy that little plant life exists on the Iona Island foreshore where the tidal flat level is well below mean sea level. This is a factor to consider in any attempts at plant establishment (Yamanaka, 1975). The North Arm Jetty and Iona Island Causeway have prevented the dispersal of sediment from the north or south into this area (Luternauer, 1973), and the blocking of McDonald Slough has also impeded former sediment pathways. Presumably these developments have effectively prevented the area from becoming vegetated.

The only true salt marsh on either Sturgeon or Roberts Banks is at Tsawwassen where Yamanaka (1975) found high soil conductivity readings, and Levings and Coustalin (1975) recorded higher soil salinities than north of the Westshore Causeway. The Tsawwassen salt marsh contains simple communities consisting of a few major species. Salicornia virginica and Distichlis stricta and to a lesser extent Triglochin maritimum were the dominant colonizing species (Hillaby and Barrett, 1976), being able to withstand repeated submergences. These plants trap sediment and organic detritus, creating better drained hummocks where they are succeeded by Grindelia intergrifolia and Atriplex patula (Hillaby and Barrett, 1976).

Area estimates of the Tsawwassen marsh indicate that it has shrunk in size by approximately 15 hectares over the past 45 years (Beak Hinton Consultants, 1977). This erosion of the marsh front may be the result of a disruption, by the Tsawwassen Ferry Terminal, of the northward longshore drift. The Beak Hinton report (1977) suggests that the Westshore Terminal Causeway has not accelerated the erosion but instead has caused a rise in elevation of adjacent substrate permitting the colonization of Salicornia virginica and Triglochin maritimum.

iv. Emergent Vegetation in the Boundary and Mud Bays Area

The Boundary and Mud Bay region is largely under the influence of the saline waters of the gulf with a slight fresh water input from the Serpentine and Nicomekl Rivers. Hence, it generally has higher salinities than the Fraser River foreshore and this is reflected in the composition of plant communities. Yamanaka (1975) cited Salicornia virginica as the principal species, with Grindelia integrifolia, Atriplex patula and Distichlis sp., also occurring in the north-west section. A large band of driftwood occurred along the dyke. Progressing eastward the saltmarsh band narrows and S. virginica and Triglochin maritimum are the common vegetation. In Mud Bay the principal species was Triglochin m. with small areas of Spergularia marina. Yamanaka's (1975) transects off Beach Grove and Crescent Beach had virtually no emergent vegetation.

The salt marsh plants in Boundary Bay are of vital importance as sediment traps during storm tides or very high spring tides. (Kellerhals and Murray, 1969).

The vegetation on the fringe of the inner estuary of the Little Campbell River consists of Lyngbye's sedge, spike bentgrass Agrostis exarata, orache (Atriplex spp.), sea barley Hordeum brachyantherum and rushes (Tera Consultants, 1977). Upstream, about the top third of the Campbell River has fresh water marsh vegetation along the banks (Fisheries & Marine Service, Salmonid Enhancement Crew, 1978. Pers. comm.).

Small freshwater marshes consisting of rushes, bulrushes, cattails, algae and pondweed are also present within the Serpentine Fen Wildlife Management Area (Surrey Planning Dept., 1978).

v. Freshwater Riparian Marshes

The most extensive marsh area of the three arms is the Woodward, Duck, Barber Islands (Island Group) and Ladner Marsh complex near the mouth of the South Arm. These gently sloping marshes have a network of diverticulations and channels, utilized by juvenile salmonids (Dunford, 1975). The marshes, often termed tidal, are also heavily influenced by the Fraser River being flooded with almost entirely fresh water (0-5.0‰ (Dr. K. Hall, Westwater Research Centre, pers. comm.). Ladner Reach receives slightly more saline water (10‰

on the bottom) primarily on the ebbing tide (Dr. K. Hall, Westwater Research Centre, pers. comm.).

McLaren (1972) in her vegetation study of these marshes noted the limitations a late field start placed on plant identification. The three marsh communities she identified were cattail, sedge (transition between the other two communities) and the bulrush community which is submerged at high tides. The F.R.I. survey team (1976) found the same major communities with Typha latifolia growing on more elevated areas sometimes in association with Sium sauve and Lythrum salicaria (purple loosestrife). Carex lyngbyei was associated occasionally with rushes; Scirpus validus occurring more seaward was sometimes fronted by Eleocharis spp. (spike-rushes) and Esquisetum sp. (horsetail).

Interestingly, Scirpus validus is the dominant bulrush in the river marshes and S. americanus, the principal seaward bulrush species of the foreshore, is only rarely encountered.

The east shore of Reifel and Westham Islands has a narrow marsh band beyond the dyke. Albion and Harlock Island are vegetated primarily by T. latifolia, C. lyngbyei and Potentilla pacifica (pacific cinquefoil) with a minor occurrence of S. validus.

Steveston Island has marshes along the shore except for the downstream end which is mainly dredge spoil anchored by a few dune species. Upstream, the south shore of Lulu Island has scattered marsh pockets, becoming more prevalent along Annacis Channel. Annacis Island has a marsh along Patrick Island Slough and Purfleet Point (western tip), with booming along some of the marsh area. There are occasional conflicts between booming and marsh areas with inadequately controlled booms swinging into these areas (pers. observation). Booming problems are not just restricted to this area but have a potential for disturbance wherever they are adjacent to marshes.

Don and Lion Island also have an area of marsh vegetation with Lion Island predominantly upland marsh vegetation.

In addition to the extensive marshes of the Island Group, the southern shore of the South Arm has freshwater marshes along sections of Deas Slough, and along Tilbury Island and slough. Tilbury Island supported marsh species that were not common in riparian marshes of the South Arm (F.R.I., 1976). The remainder of the southern shore has scattered marsh pockets and small marsh remnants. The diminutive size of these areas may belie their value but until further studies are done or adequate marsh enhancement techniques are developed, even the smallest marsh remnant may be vital in the context of the local environment. Recent work on a variety of east coast salt marshes (Oviatt et al., 1977) investigated the idea of a correlation between visial esthetic perceptions of a marsh and its ecological characteristics. It was concluded that there was little, if any, reason to support correlations. The fact that a marsh may be surrounded by areas of intense development does not mean that its "ecological value" has been lost.

The North and Middle Arms differ from the South Arm in that only modified slough habitat and no side channel habitat exists (Dunford, 1975). Due to more concentrated development on these arms the only area of undisturbed marsh is Swishwash Island (mouth of the Middle Arm). According to Forbes (1972) the dominant species are those common to the foreshore, i.e. _Scirpus americanus_ (not _S. validus_) _Carex lyngbyei_ and _Typha latifolia_. Other than scattered marsh remnants noted in a 1976 cursory survey (F.R.I.), the only additional areas of significant marshland are McDonald Slough and the Musqueam Indian Reserve No. 2, displaying the same communities as the Island Group of the South Arm - T. latifolia, C. lyngbyei and S. validus (Bell-Irving, 1976).

Pitt Meadows, an alluvial plain formed from deltaic deposits from the Fraser and Alouette Rivers (Barnard, 1974) is encompassed by a series of dykes excepting the Widgeon Slough area. The vegetation of the lightly managed northern end (including Widgeon and Sturgeon Sloughs) is a mosaic of dense hardhack (Spirea douglasii) stands, sedgegrass meadows, peat deposits containing heath species, and marshes comprised of emergents such as Scirpus acutus and S. microcarpus and submergent aquatics. The reduction in peak flood levels in conjunction with wetter year-round conditions would be expected to create a more rapid progression towards bog or bog forest. This is evidenced by marsh vegetation extending further into channels of Sturgeon Slough thus reducing open water areas and hardhack growing in previous sedge areas. The rate of succession of Sturgeon Slough Marsh appears to be inversely related to the permanency of standing water. The greatest progression is in the following communities: Scirpus microcarpus - Calamogrostis canadensis - Spirea douglasii; S. microcarpus; Carex rostrata; S. microcarpus; Carex rostrata; S. microcarpus and C. rostrata. Further investigation may relate this more precisely to the duration and depth of flooding (Barnard, 1974). Hence, the vegetational succession trend in gravity-flow drainage habitats is from a marsh-wet meadow complex to a shrub-swamp bog environment (Barnard, 1974). In addition to bog succession there are a number of existing isolated bogs in the Pitt Meadows area.

vi. Peat Bogs

Peat bogs are areas of accumulated organic material with a high water table (at or near the surface), often occurring along river bends and old channel areas. The acidic nature of the water inhibits the bacteria responsible for decomposition.

In addition to the bogs of the Pitt Meadows there are several other major bog areas - Burns bog, Sussex Avenue bog, Richmond bog, Douglas Island bog, Surrey Bend bog, and Derby Reach bog.

In contrast to the extensive annual growth of marsh vegetation, bog plants grow very slowly. Bogs also tend to lack the species diversity found in adjacent wetland and terrestrial communities. The number of plant (and animal) species occurring is inversely proportionate to the acidity of the water (Cairns, undated).

The most important and characteristic peat bog plant is spahgnum moss which forms thick mats with large hummocks around any supporting vegetation. The cell structure allows the moss to draw up water keeping the water table high and in addition it secretes organic acids helping to maintain water acidity.

Biggs and Hebda (1976) stratified the Burns bog vegetation into four types:- heathland, pine woodland, birch/spirea, and mixed woodland bogs. Heathland vegetation, as the name implies, is dominated by members of the heath family which are able to utilize ammonia for their nitrogen source. Nitrates are present only in small amounts, because the bacteria which produce them cannot thrive in an acidic environment (Cairns). Labrador tea (Ledum groenlandicum) is the most common shrub and Vaccinium spp. (blueberry, huckleberry, cranberry) are also commonly found along with salal (Gaultheria shallon), bog laurel (Kalmia polifolia)bog rosemary (Andromeda polifolia), cloud-berry (*Rubus chamaemorus*), sundew (*Drosera rotundifolia*), beakrush (*Rhyncospora alba*) and cottongrass (*Eriophorum chamissionis*). Sphagnum mosses dominate the wettest sites of this group.

Pine woodland vegetation surrounds the heathland with the dominant tree lodgepole pine (*Pinus contorta*). There are also scattered plants particularly shrubs, common to the heathland although the ground is generally drier.

Birch (*Betula papyrifera*) and spirea or hardhack (*Spiraea douglasii*) occurs along the fringes of the bog. Where there are no trees present, hardhack chokes out other vegetation. Willows occur in some wet areas and in places bracken fern (*Pteridium aquilinum*) grows luxuriantly.

Mixed woodland vegetation occurs at the eastern end of Burns bog. Western red cedar (*Thuja plicata*), western hemlock (*Tsuga heterophylla*), sitka spruce (*Picea sitchensis*), cascara (*Rhamnus purshiana*) and western paper birch (*Betula papyrifera*) grow on peaty soils whereas red alder (*Alnus rubra*) dominates areas with mineral soils near the surface.

The wildlife noted in Burns bog (Biggs and Hepda, 1976) included black tailed deer, black bear, coyotes, raccoon, cottontail rabbits, sandhill cranes, marsh hawks, red-tailed hawks, passerines, and dabbling ducks.

Current Research and Information Gaps

Vegetation composition and distribution of emergent plants in the study area is adequately documented for the Fraser River foreshore, South Arm, and Boundary Bay. Currently foreshore vegetation community mapping from colour 1977 airphotos is being done for the Geological Survey (J. Luternauer) to develop a map aiding comparisons to past and future vegetation extent.

In addition, successional patterns with seaward depth changes are being examined.

A. Moody's thesis, Dept. of Plant Science, UBC, to be completed by May 1978 examines productivity of the Brunswick Point brackish marshes, responses of Carex lyngbyei, Scirpus paludosus, Triglochin maritimum and Salicornia virginica to transplanting, lab and field detrital studies, and historical changes of Brunswick Point marsh determined from old airphotos.

R. Moody's thesis, Dept. of Plant Science, UBC, which should also be completed by May 1978, explores the changes of productivity with depth for the Tsawwassen eelgrass beds. Dr. P.G. Harrison of the UBC Botany Department has been studying eelgrass detritus in Boundary Bay.

Plant communities can be understood as a combination of plants that are dependent on their environment, influence one another and modify their own environment (Mueller-Dombois, 1974). At present, with the exception of some specific autecology work, not enough is known about the role and limits local environmental factors impose upon vegetation in terms of species composition and distribution. This information would be crucial to any viable marsh enhancement programs.

Critical local elements in marsh development are suggested to be the degree of tidal flooding (involves the frequency and duration of inundation as a reflection of elevation), substrate composition and characteristics (when soil contains 0.5% or more by weight of soluble salts chemical attributes are more important in determining its ecologic character, otherwise physical differences are more important (Daubenmire, 1974) and salinity influences (Burgess 1970 and Yamanaka, 1975). Additional parameters influencing vegetation distribution are turbidity, local weather (winds, storms, radient energy, rainfall and evaporation), water currents, temperature, nutrient availability and possibly freshet timing with peak discharge occurring during the active growing season (K. Kennedy, pers. comm.). Also, interspecies competition and interaction with the physical and chemical environment needs to be explored.

A transplant program to determine physical characteristics governing the distribution of emergent vegetation has been proposed by the Habitat Protection Division, Resource Services Branch (K. Kennedy). The possibility of vegetating dredge spoil may also be investigated.

The value of marshes as detrital sources has been recognized. Westwater Research Centre is examining detrital pathways and nutrient cycling in the Island Group of the South Arm. The Centre's investigations as to whether the marshes and the mudflats are essential to salmon suggest that more information is needed to conclusively support this claim. This assertion highlights the need for a comprehensive understanding of the local food webs and appreciation of the dynamics involved in any component alteration. Questions arise as to which plant species are most valuable in terms of productivity, biogeochemical cycling and faunal usage.

Marshes do not exist in isolation. Because of the relative ease in delimiting a marsh area as an ecological or managerial unit, it should be realized that it is arbitrary to study or manage that unit without considering its bordering systems (Oviatt et al, 1977). With an adequate understanding of systems dynamics it may be possible to respond to questions raised by development pressure and to determine the total area of marsh and mudflats required to maintain or enhance the resources of the existing ecosystem.

The importance of coastal marshes as sediment stabilizers, detritus producers and habitat for fauna, such as migratory birds has previously been mentioned. In addition, the value of these areas for waste treatment (most effectively secondary and tertiary treatment), buffer zones for storms and nutrient recycling has only recently been appreciated (Odum, 1974).

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D. The Distribution and Abundance of Invertebrate Populations

Literature Review

The first quantitative sampling of the fauna of Sturgeon and Roberts Banks was done by Bawden et al. (1973) to provide a description of the tidal flat community, and to determine baseline pollutant levels in the common macrofauna. This study was biased towards larger, deeper benthos. A more recent study (Levings, C.D. and J.B. Coustalin 1975) complimented this work with sampling methods that emphasized smaller benthic organisms living in the sediment surfaces. Both papers considered animal sediment relationships, a subject which has been further explored for Roberts Bank and Boundary Bay (Swinbanks and Murray, 1977) with on-going investigations for Sturgeon Bank (D.D. Swinbanks).

Abundance, biomass, composition and diversity of benthic (living burrowed in the sediment), epibenthic (living on or attached to the surface sediment) and drift fauna of the Lower Fraser River was examined in relation to substrate and sampling site depth (Northcote, et al., 1976). Benthic and drift fauna were also sampled in the Duck - Barber - Woodward Island complex of the Fraser River South Arm, to consider possible effects of changing current velocities on the invertebrate fauna (Levings, C.D. and B.D. Chan, 1977).

A study of benthic invertebrate communities (Fisheries and Marine Service, in prep.) in the Tilbury Slough area of the Fraser River was carried out in 1976 and 1977, to determine differences in species composition between Tilbury Slough and the mainstem river. The study also included an examination of benthic invertebrates in areas of the Fraser River degraded by the dumping of hog fuel. Analyses of the stomach contents of salmon were undertaken to assess the composition and size of prey organisms and the relationships between salmon food organisms and benthic invertebrate assemblages.

The discussions of fauna in this report will consider mainly those organisms and their habitats not previously discussed in the fisheries sub-chapter or of a concern to the water quality group.

The Distribution of Invertebrates in Major Zones of the Study Area

i. Invertebrates of Sturgeon and Roberts Banks

The foreshore fauna are often subject to a wide variation in physical parameters. There are marked variations in sediment temperature (22.0^{o}C to - 2.0^{o}C), and surface water temperature can range from summer temperatures of 14.5 - 22.5^{o}C (Sturgeon Bank) to winter temperatures of 2.3 - 6.9^{o}C (Garry Point) (Levings and Coustalin, 1975).

Intertidal habitats near the shore are exposed to greater fluctuations in salinity than seaward sections and, as expected, those areas near freshwater discharge are also subject to wider salinity variations compared to areas further from the channels. Regions having structures, such as causeways and jetties, that deflect fresh water discharge (e.g. between the Tsawwassen and Westshore causeways) are characterized by higher salinities (Levings and Coustalin, 1975).

Hence, the foreshore benthos consists primarily of estuarine and marine crustaceans, polychaetes and molluscs. Estuarine species, generally polychaetes (i.e. Manayunkia aestuarina) and amphipods (i.e. Corophium salmonis and C. insidiosum), predominate in the intermediate or high intertidal zone. The lower intertidal zone contains species characteristic of marine environments, e.g. the cumacean crustacean, Cumella vulgaris, the amphipod Eohaustorius washingtonianus and the bivalve Macoma spp. Molluscs tended to dominate this lower region (Levings and Coustalin, 1975). This zonal differentiation was linked to sediment type with the finer muddy sediments occurring along the seaward edge of the vegetation (intermediate or upper intertidal) and the coarser grain sandy sediments occurring in the lower zone. This suggests that marine processes are more influential in the lower intertidal zone. Tsawwassen is an anomaly in that the faunal composition indicates that marine influences predominate in the entire intertidal zone (Levings and Coustalin, 1975). Bawden et al (1973) recorded the mollusc Cryptomya californica and the polychaeta Hemipodus borealis in the fine grain sediments, and the crustacean Callianassa californiensis in the coarse grain sediments.

Swinbanks and Murray (1977), in studying the distribution and macrofauna, generally concur with the findings of Levings and Coustalin (1975) and Bawden, et al (1973). However, the molluscs Mya sp. and Macoma sp. were considered to be abundant in the muddy inshore (intermediate and high intertidal) environment. Mya sp. was not present in the sandy offshore (lower intertidal) environment due, perhaps, to the higher wave energy of this region (Swinbanks and Murray 1977). Macoma sp. was also abundant in the lower intertidal region and the data indicated that Macoma sp. occurs over a wide range of elevation in both sand and mud sediments and high and low energy environments where surface salinity ranges from 5 - 20‰. Swinbanks and Murray (1977) also suggested that the abundance of Abarencola sp. and Batillaria sp. was determined more by salinity (preference for more saline water) than substrate.

Plankton collections from Sturgeon Bank indicated that a marine community can occupy the overlying water during high tide. However, fresh water forms of calanoid copepods (e.g. Epichura sp.) were also caught, suggesting that plankton from the Fraser River may be distributed over Sturgeon Bank (Levings and Coustalin, 1975). Sturgeon Bank plankton biomass was dominated by mobile estuarine epifauna (e.g. *Crangon franciscorum*) (Levings and Coustalin, 1975).

The benthic biomass on Sturgeon Bank between the Iona and North Arm jetties was significantly lower than that of the area south of the Iona jetty (Levings and Coustalin, 1975). This may be a consequence of the jetties disrupting the flow of silt-laden freshwater, and hence modifying the sediments. Also, dredge spoil that had been dumped in the intertidal area between the jetties may have prevented the development of algae and emergent vegetation which, through the detrital food web provides a food source for the benthos (Levings and Coustalin, 1975). Jetties may, however, be useful as a stable hard substrate for epifauna (e.g. barnacles, mussels, oysters).

Levings and Coustalin (1975) concurred with earlier work, verifying the degradation of benthic communities adjacent to the Iona Island sewage outfall. The benthic biomass, on a transect south of the sewage outfall channel, was higher at all elevations than on any other Sturgeon Bank transect (Levings and Coustalin, 1975). The addition of organic matter may be responsible for eutrophication and increased abundance of the benthos (Levings and Coustalin, 1975).

ii. Boundary Bay Invertebrates

Boundary Bay has a relatively stable substrate and, compared to the Fraser River foreshore, displays a more uniform physical environment. Surface sediments are predominately fine sands.

Studies done by Kellerhals and Murray (1969) and more recently by Swinbanks and Murray (1977) indicated four floral/sedimentological zones each having a distinct macrofaunal assemblage. The zones beginning at the edge of the saltmarsh and progressing seaward are respectively, the algal mat zone, upper sand wave zone, the eelgrass zone and the lower sand wave zone.

The algal mat zone has numerous burrows suspected to be caused by fly larvae. On the upraised portions of the algal mats Batillaria attramentaria pits exist and Spio sp. (polychaete) are abundant in the depressions. Isolated Mya sp. and rare burrows of Callianassa californiensis were noted.

The upper sand wave zone was characterized by the abrupt appearance of Abarenicola sp. A controlling factor to its upper distribution limit appeared to be exposure time as reflected in the constant elevation of its upper limit (averaging 2.75 feet, geodetic datum), even in the absence of algal mats. In the water filled troughs of the low amplitude sand waves, Abarenicola sp. reworks the sediment to a depth of 7.5 cm. (Swinbanks and Murray, 1977). This fosters a symbiotic relationship with the bacteria, flagellates and ciliates that Abarenicola sp. feeds upon, by providing an oxidizing microenvironment in which these organisms flourish. Callianassa californiensis burrows tend to be more abundant and have a uniform distribution in the lower half of this zone. The burrow morphology differed in having a short constricted apertural neck as compared to the longer aperture on the Roberts Bank burrows. These differences may be in response to lower surface salinities on Roberts Bank and/or a higher environment energy such as higher wave action (Swinbanks and Murray, 1977).

Mya sp. are also more numerous in the lower section of this zone. Spio sp. densities were an order of magnitude lower than in either the algal mat zone or the eelgrass zone. Trails from Batillaria sp. were abundant. Generally, faunal densities are highest in the shallow, water-filled, sand wave troughs (Swinbanks and Murray, 1977).

In the upper part of the eelgrass zone, (primarily *Zostera americana*) *Callianassa californiensis* attains maximum density. *Spio* sp. is also most abundant in this zone but is uniformly distributed in both the upper and lower sections. In the lower part of this zone, characterized by permanent beds of *Zostera marina*, *Upogebia pugettensis* (shrimp), *Praxillela* sp. (polychaete) and *Nassarius* sp. (gastropod) replace *C. californiensis*, *Abarenicola* sp. and *Batillaria* sp. respectively.

The lower sand wave zone appears to be less stable because of strong tidal currents. These unstable conditions are reflected in the low faunal densities throughout this zone. *Praxillela* sp. is the dominant invertebrate of this region.

The major parameters controlling faunal zonation, in Boundary Bay, appear to be elevation (and the related factors, such as, depth and frequency of inundation) and microtopography, (such as sand wave crests, algal mats, burrow and fecal mounds). Only deeper burrowing organisms, such as *Callianassa californiensis* are relatively unaffected by small micro-topographic changes (Swinbanks and Murray, 1977).

A unique population of the oyster, *Crassostrea virginica* exists in the Nicomekl River immediately upstream of Ward's Marina. This oyster stock is the only resident population existing on the west coast from California to British Columbia. The oysters were originally transplanted from the east coast of Canada and the U.S.A. and have been used for physiological studies by the University of British Columbia.

iii. Invertebrates of the Lower Fraser River

(a) Benthic Fauna

According to Northcote *et al* (1976), oligochaetes are the dominant fauna, both in number and biomass, of the Main and North Arms of the Fraser River. They are less numerous in the benthic communities of the mainstem above Annasis Island. Oligochetes were generally more abundant in fine substrate (mud and mud-sand).

The distribution of polychaetes and nemerteans was confined entirely to river mouth regions. Leeches, molluscs (primarily pelecypods) and amphipods (crustacean) extend upstream as far as Barnston Island but are most abundant in the river arms. Polychaetes and molluscs contribute 10 - 30% of the biomass in the river arms, although their numbers are low (Northcote et al., 1976).

Other crustaceans of minor importance in the faunal composition of the river arms, included copepods (mainly harpacticoid), cumaceans, isopods and mysids (primarily Neomysis mercedis).

Both dipteran larvae and lamprey ammoceotes were minor groups in the river arms but upstream of Barnston Island they contributed significantly to the benthos, both in numbers and biomass, (Northcote et al., 1976).

The benthic fauna reached its highest abundance and biomass at or near the mouth of the North Arm. Only in the Main Arm were there significant differences for abundance and biomass in relation to substrate with a preference for fines (Northcote et al., 1976).

Levings and Chang's (1977) data from stations in Ladner and Sea Reaches, concur with the findings of Northcote et al (1976) that oligochaetes were the most important animals in both numbers and biomass. Chironomids (Chironomus spp.) were the next most important in biomass but not in numbers. Nematodes were the next most abundant after oligochaetes. Ostracods were abundant but not significant in terms of biomass. Amphipods and isopods were rare and it was suggested that this may have been due to a lack of cover materials at sampling stations (Levings and Chang, 1977). Polychaetes were not common. Levings and Chang (1977) stated that the fauna reflected the low salinity during the sampling periods. Hence, the fresh water or low salinity forms such as oligochaetes and chironomids were the dominants and there were few more marine forms such as polychaetes.

Levings and Chang (1977) found that fauna was most abundant in the side channels where low current velocities allow the deposition of organic detritus, such as leaf litter.

(b) Epibenthic Fauna

Northcote et al (1976) found that the major groups in the epibenthic fauna showed a similar distribution and relative abundance to those organisms collected in benthic samples. They noted that the most striking difference was an apparent reduction in the epibenthic fauna of one or two orders of magnitude in both numbers and biomass of most but not all organisms.

Oligochaetes, dominant in the benthic community, were seldom dominant in the epibenthos. Mysids, particularly Neomysis mercedis, were the dominant fauna in both numbers and biomass, with biomass greatest in the shallow depths ($<$3m.) regardless of the substrate type (Northcote et al., 1976). The shrimp Crangon franciscorum was common as far upstream as Tilbury Island and together with brackish water amphipods constituted an important epifaunal group in the lower river reaches.

In general, Northcote et al (1976) found that the distribution and numbers of benthic and epibenthic organisms of the Lower Fraser River followed patterns common to estuarine reaches of most large temperate rivers. Marine forms were found mainly just at the river mouths with a few species such as the shrimp Crangon franciscorum recorded further upstream, perhaps entering passively with tidal flows along the bottom. The more euryhaline species extended much further up river, particularly the amphipod Anisogammarus confervicolus which went at least 40 km. upstream. Conversely, more strictly freshwater organisms (e.g. non-dipteran insect larvae and nymphs) decreased in abundance towards the river mouth. Northcote et al (1976) also noted that oligochaetes and dipteran larvae tended to be the major faunal groups in the mainstem reaches of many large temperate rivers. The Lower Fraser was more distinctive in having a dominance of lamprey ammocoetes in the benthos and the dominance of the mysid Neoysis mercedes in the epibenthic biomass.

iv. A Comparison of Benthic and Epibenthic Fraser River Faunas to the Benthic Foreshore Fauna

Northcote et al (1976) compared benthic faunal data (grouping the benthic and epibenthic faunas, as their general pattern of distribution was similar) with the Fraser River foreshore data of Levings and Coustalin (1975). Only samples taken from mud to sand substrates were considered. It was found that both the abundance and biomass of the benthic fauna in the foreshore nearest the river mouth were approximately ten times those of the river arms. Seaward, numbers and biomass decreased, reaching levels similar to the mainstem river approximately 5 km. from shore. Abundance and biomass was also tenfold higher for the North Arm and Sturgeon Bank stations than for the Main Arm and Roberts Bank.

This increase in abundance of benthos in the transitional zone between riverine and marine substrates is a well recognized feature of estuaries (Northcote et al., 1976).

v. Drift Fauna of the Lower Fraser River

Drift fauna catches were sparse when sampled with relatively coarse nets (1 m. diameter, 1.18 mm. mesh), (Northcote et al., 1976). The highest abundance was recorded at North Arm (mid-river) and Main Arm (nearshore) stations. The fauna was dominated by adult insects and benthic crustaceans.

Numbers of drift fauna captured in a finer net (0.5 m. diameter, 0.35 mm. mesh) was usually 1 - 2 orders of magnitude greater than those captured with the coarse net. Abundance was greatest at the mouth of the river arms. Cladocerans and copepods (mainly planktonic forms) were the dominant fauna (Northcote et al., 1976).

It was suggested that the low recorded abundance may have been a result of daytime sampling when river drift is minimal. Levings and Chang (1977) obtained drift samples with suspended nylon net bag samplers filled with seaweed, rather than the tow net method of Northcote et al (1976). These samples were dominated by the isopod Gnoremosphaeroma oregonensis, the amphipods Corophium spinicorne and Anisogammarus confervicolus, and chironomid drift larvae.

The drift fauna, despite its low abundance, was as diverse in species as was the benthic community (Northcote et al., 1976).

The destructive shipworm Bankia setacea, while it can not be categorized as benthic, epibenthic or drift fauna, deserves a note as to its distribution. The pockets of saline water in areas not flushed with fresh water and proximity to wooden pilings provides an excellent habitat for these molluscs. These conditions exist in Cannery Channel (Hoos and Packman, 1974).

Suggestions for Further Study

A number of important gaps exist in the knowledge of invertebrate populations in the study area. The following subjects are priorities for further study:-

1. The relationship of invertebrate populations to aquatic vegetation, such as marshes and eelgrass. Algal/invertebrate associations are being investigated by Levings and Pomeroy (Pacific Environment Institute, Fisheries and Marine Service) on the Steveston Jetty.
2. The relationship between invertebrates and types of sediment. This is a prerequisite to any attempts to predict the effects of river training structures on invertebrate populations.
3. The distribution, abundance and biomass of invertebrates in Boundary Bay.
4. Invertebrate food webs, and their role in energy and nutrient flow in the estuary and floodplain.

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E. Indices of Primary Productivity

Introduction

Primary Productivity is the rate at which energy is bound, or organic matter created by photosynthesis, per unit of the earth's surface per unit of time. Primary productivity is, for the most part, the result of the photosynthetic activities of green plants, including algae in which the green of chlorophyll is often masked by other colours. Green plants must use a part of the organic matter they create for their own respiratory processes. Thus the amount of energy bound or organic matter created per unit surface and time, that is left after the respiration of the plants is their net primary productivity. Net primary productivity is usually expressed in terms of dry organic matter in g (dry) $/m^2/yr$.

Table 1 compares the net primary productivity of major world ecosystems. As is evident from this comparison, freshwater swamps and marshes, estuaries, and shallow inshore waters are amongst the most productive ecosystems on earth.

The high productivity of these acquatic systems has been attributed to a number of factors (Keefe 1972):-

1. Swamps and marshes generally have a longer growing season than terrestrial communities,
2. Abundant soil water is used directly by the plants and also holds nutrients in a dissolved state in the sediments,
3. The leaves of most marsh plants have a vertical orientation which reduces intense heating, exposes the maximum leaf surface to sunlight during the day, and minimizes mutual shading,
4. The nutrient levels available to plants in marsh soils and water are generally higher than in terrestrial soils.

TABLE 4: Net Primary Production and Plant Biomass for Major Ecosystems and for the Earth's Surface

	AREA (10^6 Km^2)	NET PRIMARY PRODUCTIVITY PER UNIT AREA + (dry g/m^2/yr)		WORLD NET PRIMARY PRODUCTION** (10^9 dry tons/yr)	BIOMASS PER UNIT AREA ≠ (dry kg/m^2)		WORLD BIOMASS** (10^9 dry tons)
		Normal Range	Mean		Normal Range	Mean	
Lake and stream	2	100-1,500	500	1.0	0-0.1	0.02	0.04
Swamp and marsh	2	800-1,000	2,000	4.0	3-50	12	24
Tropical forest	20	1,000-5,000	2,000	40.0	6-80	45	900
Temperate forest	18	600-2,500	1,300	23.4	6-200	30	540
Boreal forest	12	400-2,000	800	9.6	6-40	20	240
Woodland and shrubland	7	200-1,200	600	4.2	2-20	6	42
Savanna	15	200-2,000	700	10.5	0.2-15	4	60
Temperate grassland	9	150-1,500	500	4.5	0.2-5	1.5	14
Tundra and alpine	8	10-400	140	1.1	0.1-3	0.6	5
Desert scrub	18	10-250	70	1.3	0.1-4	0.7	13
Extreme desert, rock and ice	24	0-10	3	0.07	0-0.2	0.02	0.5
Agricultural land	14	100-4,000	650	9.1	0.4-12	1	14
Total land	149	-	730	109.0	-	12.5	1,852.
Open ocean	332	2-400	125	41.5	0-0.005	0.003	1.0
Continental Shelf	27	200-600	350	9.5	0.001-0.04	0.01	0.3
Attached algae and estuaries	2	500-4,000	2,000	4.0	0.04-4	1	2.0
Total ocean	361		155	55.0		0.009	3.3
Total for earth	510		320	164.0		3.6	1,855.

* Square kilometers x 0.3861 = square miles

\+ Grams per square meter x 0.01 = t/ha, x 0.1 = dz/ha or m centn/ha (metric centres, 100kg per hectare, 10^4 square meters), x 10 = kg/ha, x 8.92 = lbs/acre.

** Metric tons (10^6g) x 1.1023 = English short dons.

≠ Kilograms per square meter x 100 = dz/ha, x 10 = t/ha, x 8922 = lbs/acre, x 4.461 = English short tons

From Whittaker, 1970.

The high nutrient status of estuarine communities is due in large part to the provision of nutrients in generous quantities from two sources; first, marine salts, replenished daily by tidal action, are made available to terrestrial plants by dilution with fresh water; and second, organic debris and fine soil particles brought down by the river are trapped by the marsh vegetation. The organic production of estuarine marshes is both used in situ by herbivorous and detrital primary consumers, and transported seaward by tidal action where it enriches adjacent marine waters. Perkins (1974) estimated that the total inflow of organic matter to the Strait of Georgia is in the neighbourhood of 1-2 x 10^6 tons per year. The major sources of these materials are the many rivers that empty into the Strait, debris from the harvest and transportation of timber, and wastes from urban/industrial areas. Yamanaka (1975) estimated the total contribution of organic matter from the Fraser Estuary at approximately 10^4 tons per year. He added that, while this figure may not appear significant in terms of the total amount of organic matter, it represents the contribution of only one estuary and, being herbaceous, it is in a highly available and recyclable form. It should be added that estuarine marshes provide available energy at times of the year when other sources are limited, and thus are probably critical to the survival of many species of fish and wildlife.

The Measurement of Primary Productivity

The primary production of angiosperms in marshes is usually measured by harvesting. Because of the difficulty of sampling root material, most investigators have measured production of only aerial parts. This is done in one of two ways (Keefe 1972):

1. At intervals throughout this growing season aerials are clipped on a sample-area basis. Production is determined from the total increase in weight of dry matter.

2. At the peak of the growing season, aerials are clipped in a unit area selected at random from a larger area. Only living material is collected and the weight of an average mature leaf is determined. Estimates are made from leaf scars and damaged leaves of the amount of material that died or was otherwise removed prior to harvest. Production is calculated from the weight of living material plus the weight of leaf that the investigator estimates was removed prior to harvest (Williams and Murdock 1969).

The problem with method 1 is that material consumed between samplings by herbivors is not accounted for. Teal (1962) estimated that for a study area in the southern U.S.A. herbivors, primarily insects, removed approximately 305Kcal/m^2/yr. Method 2 attempts to estimate the material that is eaten or that dies between samplings.

Above ground production is but one component of net primary productivity. Westlake (1963) estimated that underground structures may be up to five times the weight of harvested shoots. Two methods have been used to estimate the productivity of underground biomass (Keefe 1972):

1. Underground parts of individual plants are washed of excess non-living material, then dried and weighed. From the amount of root material per plant, the total underground living material in the sample area is determined.
2. Cores are taken throughout the sample area. Living and dead material are separated, dried and weighed. Total underground living material is determined from the amount of root material per core.

In each case, cumulative change in underground biomass is measured throughout the growing season.

Keefe (1974) cited 71 studies of marsh biomass and production. Results from the investigations involving species similar to those in the Fraser study area are shown in Table 2.

Table 5. Biomass and Production Values for Selected Marsh Types.

	Biomass g(dry)/m^2			Net Primary Productivity				
Species	Underground	Aerial	Total	Underground	Aerial	Total	Locality	Source
Distichlis spicata	-	360	-	-	-	-	Virginia	Wass & Wright (1969)
Atriplex spp.	-	700-800	-	-	-	-	Southern England	Ranwell (1961)
Scirpus americanus	-	150	-	-	150	-	South Carolina	Boyd (1970)
Typha latifolia	-	684	-	-	684	-	South Carolina	Boyd (1970)
	-	-	-	-	1358	-	Long Island	Harper (1918)
	912	404	1316	-	-	-	North Dakota	McNaughton (1966)
Carex spp.	-	1340	-	-	1699	-	New Jersey	Jervis (1964)
	-	400-630	-	-	-	-	England	Pearsall & Gorham (1956)

From: Keefe, C.W. 1972

Status of Knowledge for the Fraser Estuary and Tidal Marshes

The basis for this discussion will be the vegetation units noted in section (D) above.

A. Foreshore Vegetation

i. Mud-flats (Benthic algae and phytoplankton)

Westlake (1963) estimated that benthic marine plants in shallow, temperate waters may approach annual productivities of 25-33 metric tons/ha. (2500-3300 g(dry)/m^2). The apparently low standing crop of these organisms is no index of productivity since their tissues are readily decomposed, broken-up by wave action, and grazed upon by animals.

Little data on either productivity or standing crop is available for the Fraser Estuary. Beak Environmental Consultants (1977) estimated the standing crop of sea lettuce (Ulva lactuca), on a portion of Roberts Bank indicated to be impoverished, at 112.7 ± 16.6 g(dry) m^2. The Pacific Environment Institute, Fisheries and Marine Service, Environment Canada has been conducting chlorophyll studies on mudflats on both the Squamish and Fraser Estuaries. Some data on net primary productivity may be available in approximately two years time (Pomeroy 1978 personal communication).

ii. Eelgrass (Zostera marina)

The eelgrass beds of the Fraser foreshore were the subject of study in 1975 - 76 by a M. Sc. student in the Department of Plant Science, U.B.C. Standing crop and productivity data will be available in the thesis which is due for completion in April 1978 (Moody 1978).

Some standing crop data have been published for the eelgrass beds of Roberts Bank (Beak Hinton Consultants Ltd. 1977). Biomass is estimated to range from 59-207 g(dry)/m^2. The report cited a study on eelgrass beds in Puget Sound (Phillips 1972) which estimated a net primary productivity of 581 g(dry)/m^2/yr. on a maximum standing crop of 396g(dry)/m^2. The Beak Hinton report concluded that the eelgrass beds of Roberts Bank are probably somewhat lower in productivity than those in Puget Sound.

No data are yet available on the extensive eelgrass beds of Boundary Bay.

iii. Foreshore Marshes

The most comprehensive study of net primary productivity in the Fraser estuary was carried out during 1974 on the foreshore marshes (Yamanaka 1975). In the course of this work 14 permanent sample transects were established from Musqueam to Crescent Beach. This total included 1 in the Musqueam area, 5 on Sturgeon Bank, 3 on Roberts Bank, 3 in Boundary Bay and 2 in Mud Bay. Only above ground productivity of major marsh species was considered in this study. Productivity results for the twelve vegetated transects are shown in Figures 1-10. Productivity levels for major plant communities were as follows:

Salt Marsh	Net Primary above ground productivity g(dry)/m^2/yr	N*
- *Salicornia*/*Distichlis*/*Triglochin*	287 ± 118	11
- *Poa*/*Elymus*	395 ± 169	2
- *Triglochin*/*Elymus*	112 ± 45	3
- *Atriplex*/*Hordeum*/*Grindelia*	784	1
Brackish Marsh		
- *Typha latifolia*	445 ± 192	6
- *Carex lyngbyei*	1019 ± 377	5
- *Scirpus validus*	312 ± 96	2
- *Scirpus paludosus*	503 ± 96	4

- Scirpus paludosus/S. americanus	489 ± 209	8
- Scirpus americanus	451 ± 217	19

*N = number of sample quadrants.

The foreshore marshes were estimated to occupy 1901 ha., with a total standing crop on this area of 9,408 metric tons. Carex lyngbyei, Scirpus americanus and S. paludosus accounted for 81% of this standing crop.

The three main areas - Sturgeon Bank, Roberts Bank and Boundary Bay - made up approximately 41%, 46% and 13% of the total marsh area, and contributed 41%, 54% and 5% of the total standing crop respectively.

Net primary productivity was highest in stands of Carex lyngbyei, reaching a maximum of 1660g/m^2/yr on the Musqueam marsh. Though productivity declined in an approximately linear fashion with distance seaward from the dykes, a secondary peak occurred, irrespective of species, in nearly all transects (see Figs. 1-10) approximately 200-400 feet from the dyke. The location of this peak is dependent on gradient, and on two of the longest transects the peak occurred at approximately 700 feet. The author makes no attempt to explain this phenomenon.

The only study to date on below-ground productivity involved the estimation of rhizome and root standing crops of Scirpus americanus communities (Burton 1977). Estimates of standing crop for the six sample areas in this study were:

Area	Standing Crop of Roots Rhizomes (g(dry)/m^2)
Brunswick Pt.	188 ± 26
Reifel Refuge	205 ± 24
Sturgeon Bank (Outer Islands)	190 ± 22
Williams Road	226 ± 25
Westminster Highway	269 ± 23
Sea Island	131 ± 14

FIGURE I

POINT GREY / MUSQUEAM

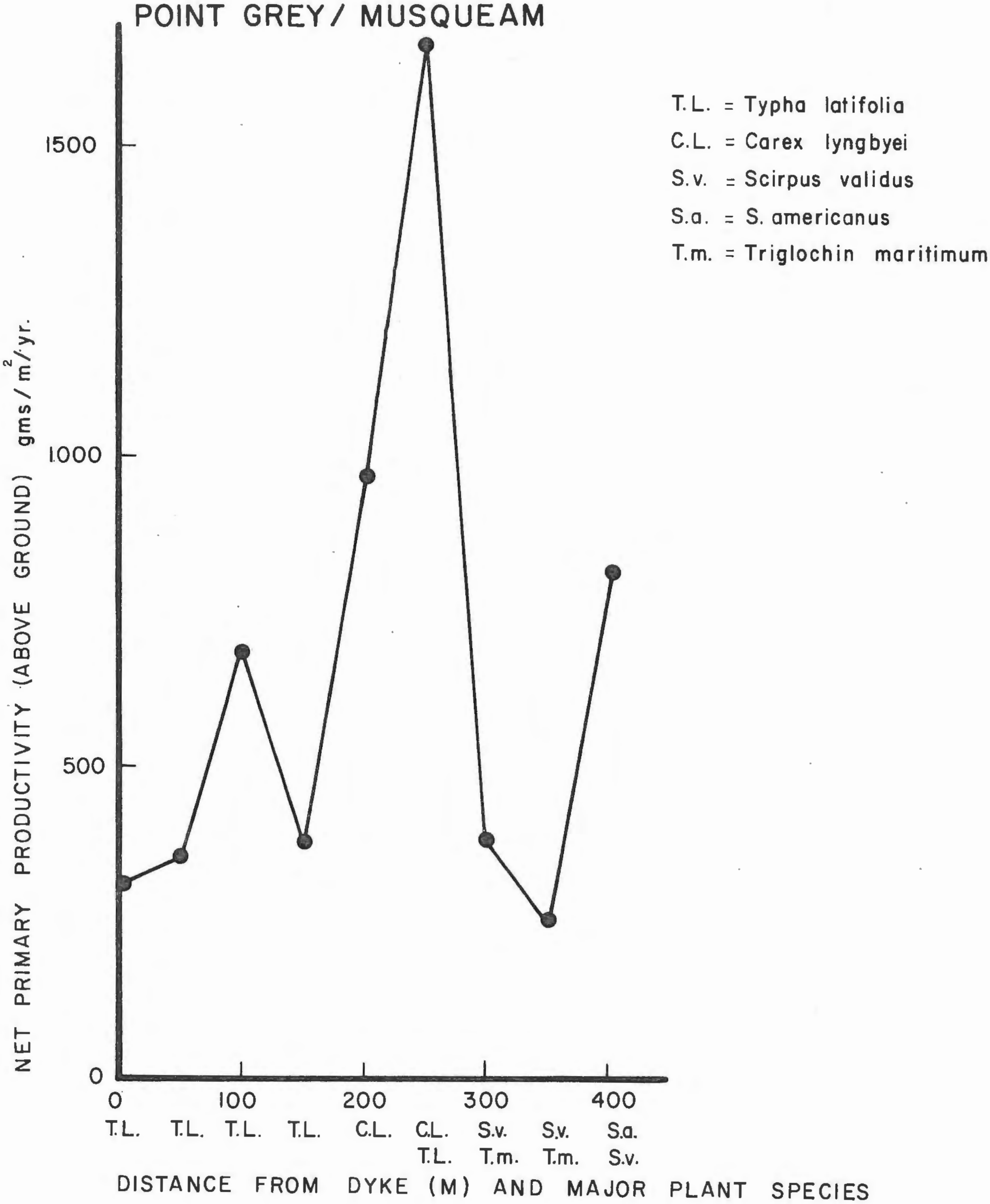


FIGURE 2.

STURGEON BANK

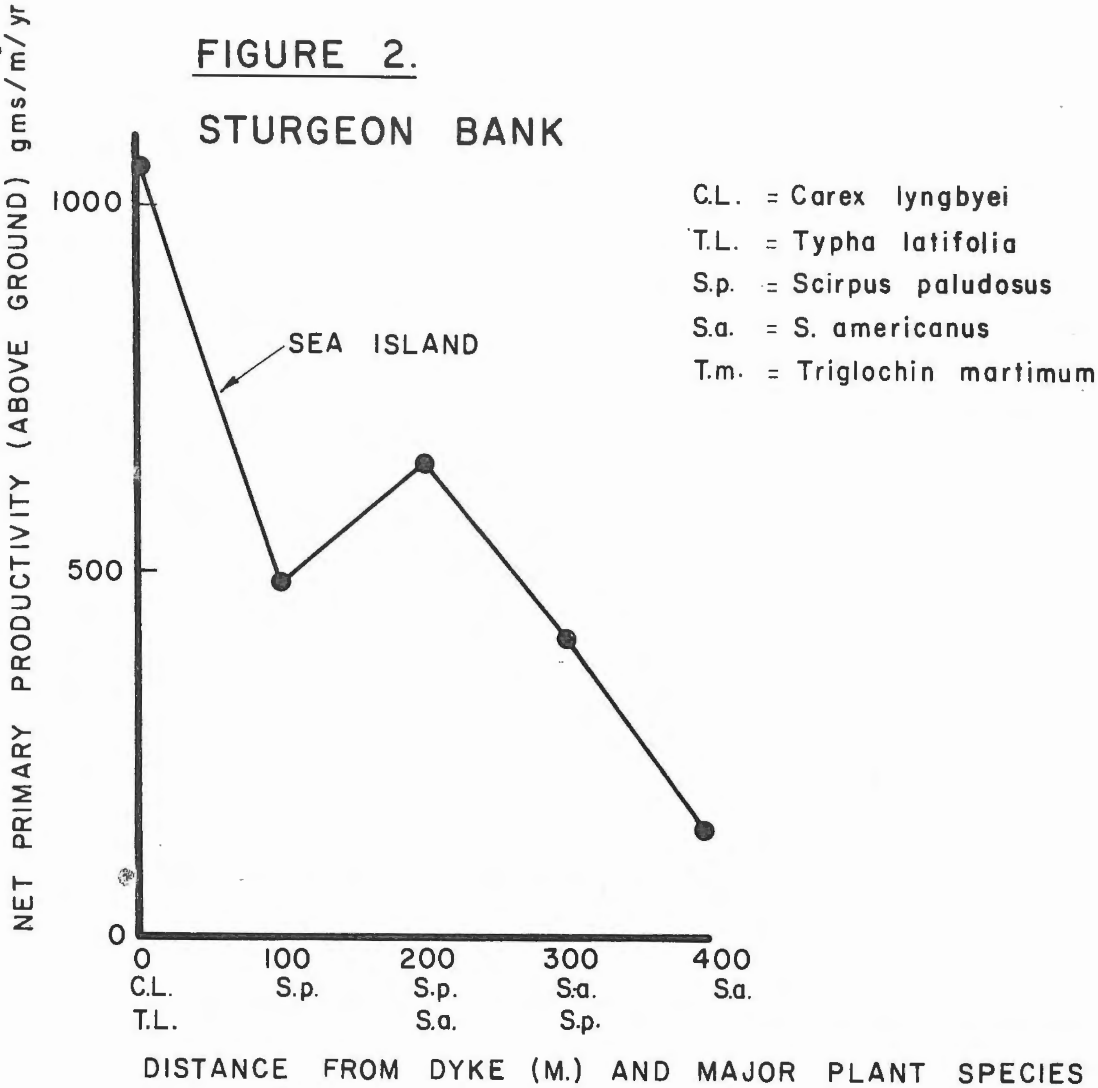


FIGURE 3.

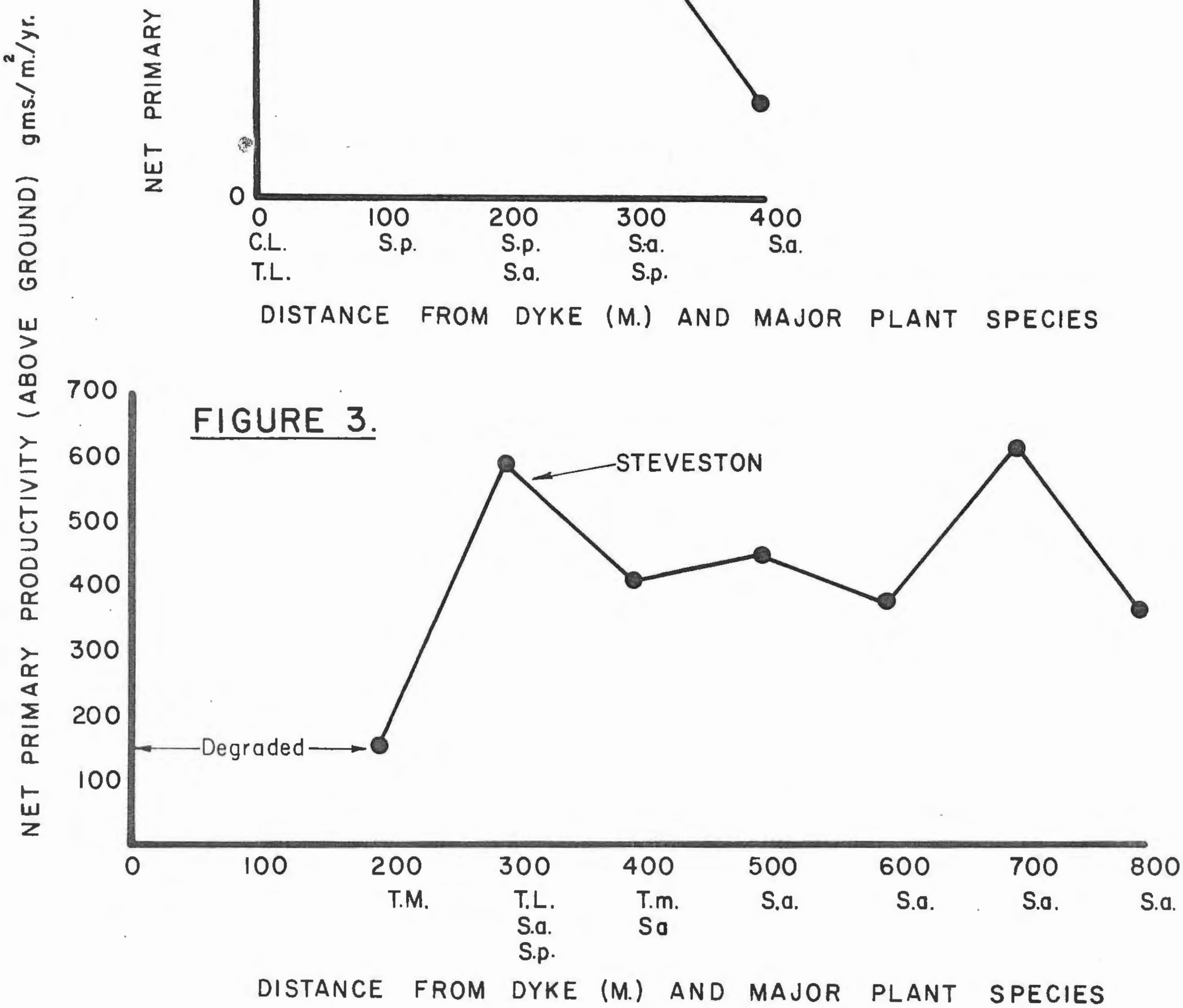
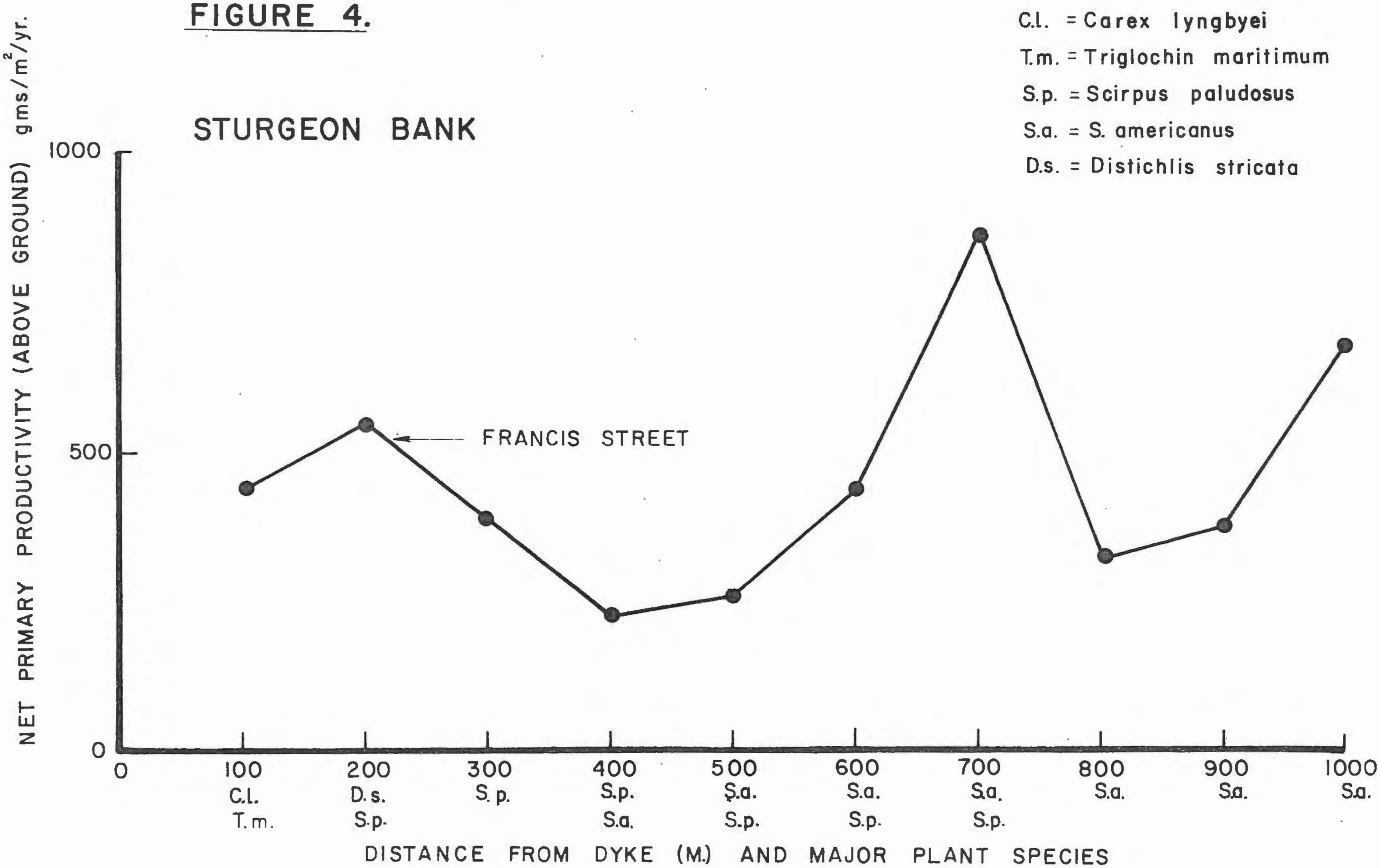


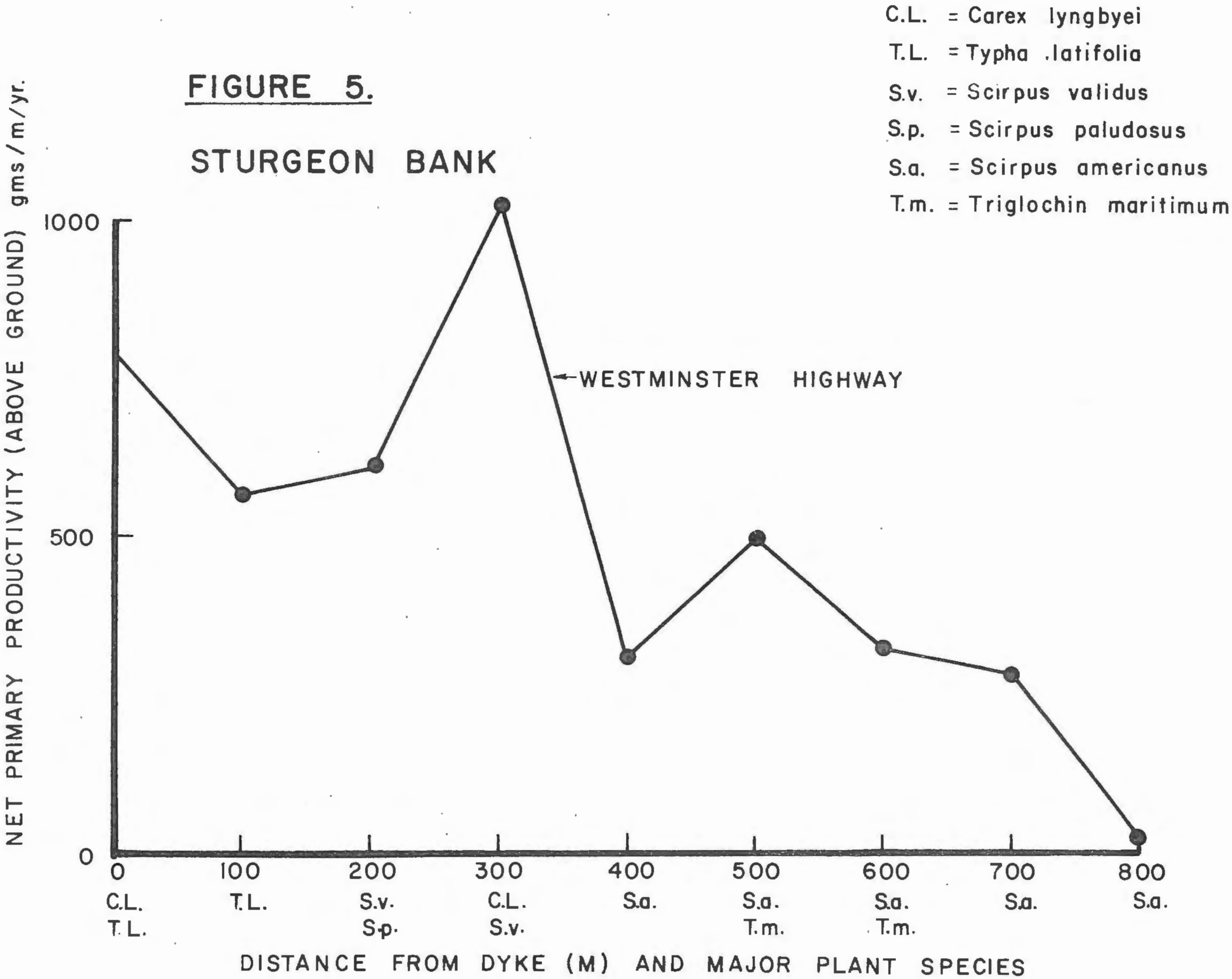
FIGURE 4.



STURGEON BANK
C.l. = Carex lyngbyei
T.m. = Triglochin maritimum
S.p. = Scirpus paludosus
S.a. = S. americanus
D.s. = Distichlis stricata
NET PRIMARY PRODUCTIVITY (ABOVE GROUND) gms/m²/yr.
1000
500
0
FRANCIS STREET
0
100 C.l. T.m.
200 D.s. S.p.
300 S.p.
400 S.p. S.a.
500 S.a. S.p.
600 S.a. S.p.
700 S.a. S.p.
800 S.a.
900 S.a.
1000 S.a.
DISTANCE FROM DYKE (M.) AND MAJOR PLANT SPECIES

FIGURE 5.

STURGEON BANK



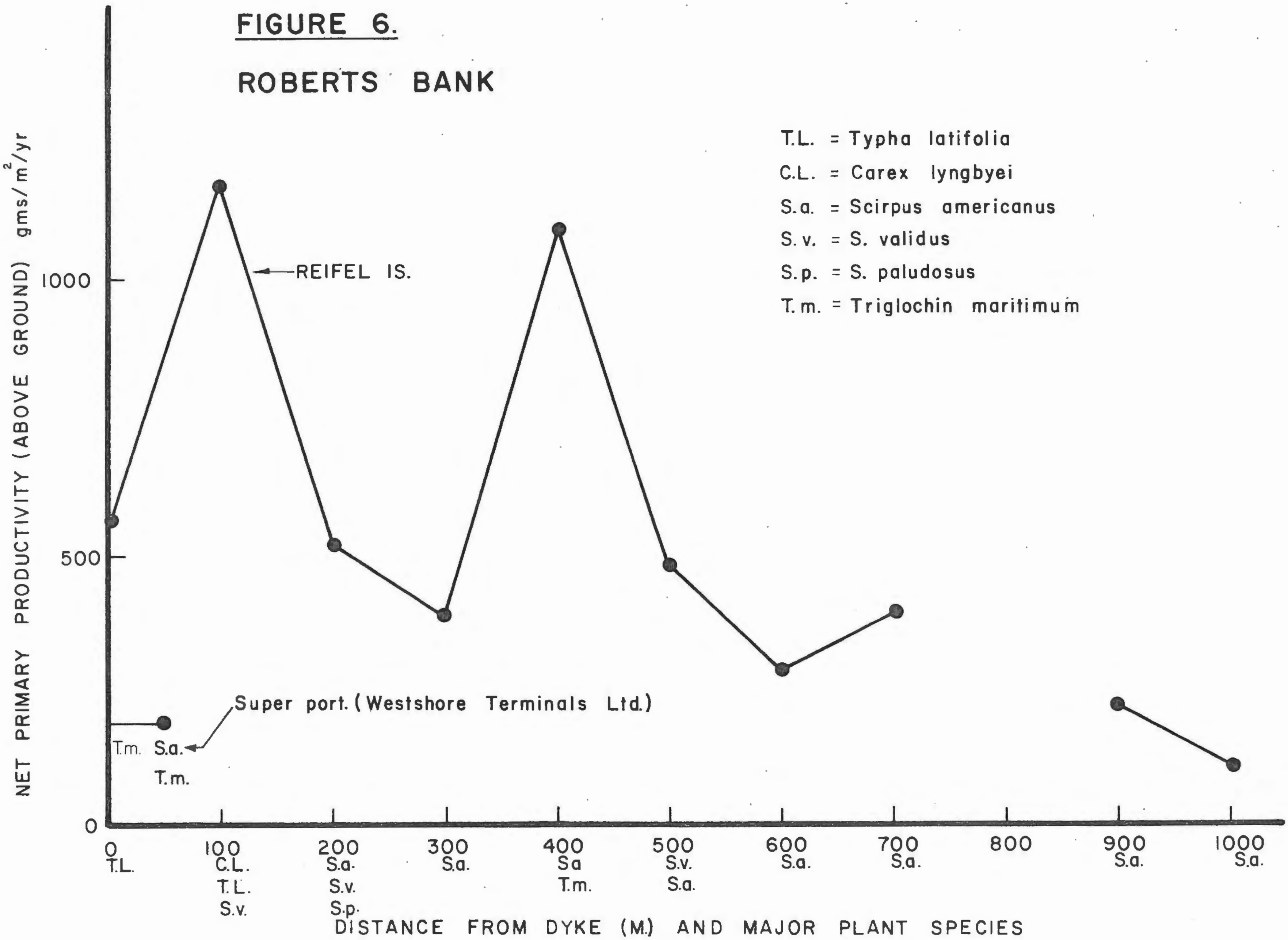


FIGURE 6.
ROBERTS BANK
T.L. = Typha latifolia
C.L. = Carex lyngbyei
S.a. = Scirpus americanus
S.v. = S. validus
S.p. = S. paludosus
T.m. = Triglochin maritimum
REIFEL IS.
Super port. (Westshore Terminals Ltd.)
NET PRIMARY PRODUCTIVITY (ABOVE GROUND) gms/m²/yr
1000
500
0
T.m. S.a.
T.m.
0 T.L.
100 C.L. T.L. S.v.
200 S.a. S.v. S.p.
300 S.a.
400 Sa T.m.
500 S.v. S.a.
600 S.a.
700 S.a.
800
900 S.a.
1000 S.a.
DISTANCE FROM DYKE (M.) AND MAJOR PLANT SPECIES

FIGURE 7.

ROBERTS BANK

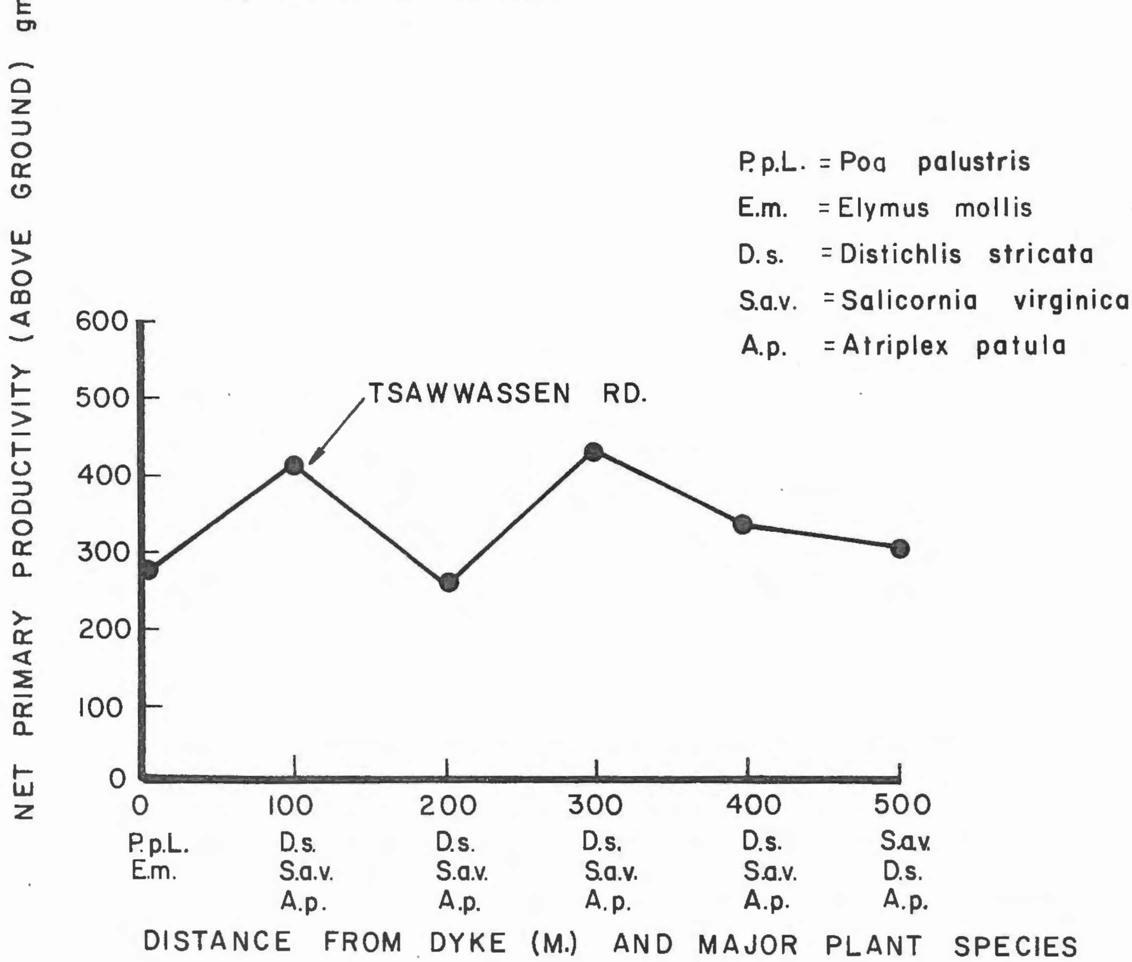


FIGURE 8.

BOUNDARY BAY / MUD BAY

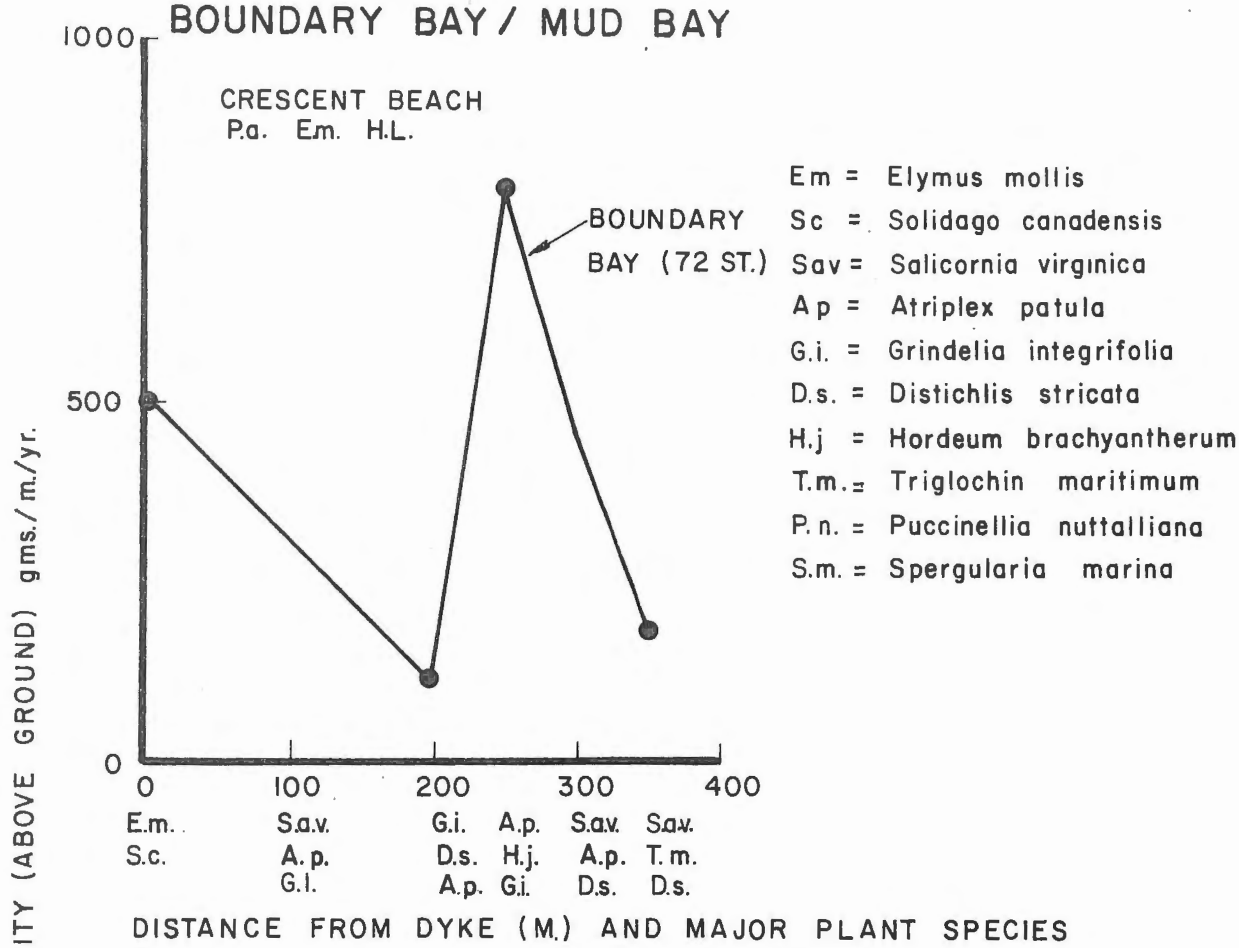


FIGURE 9.

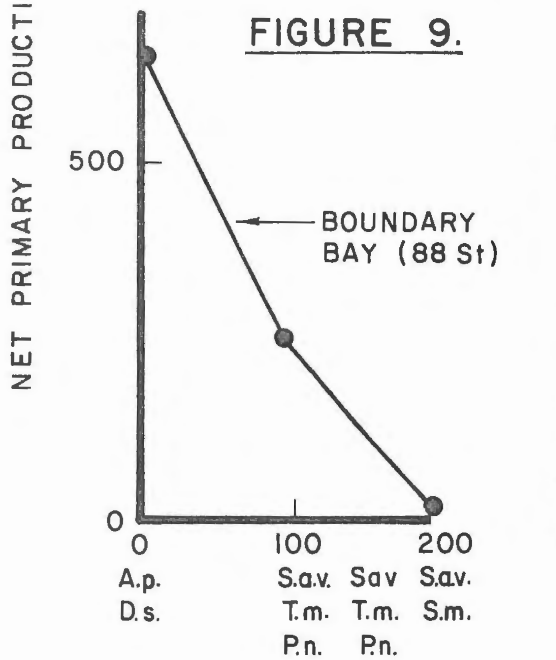
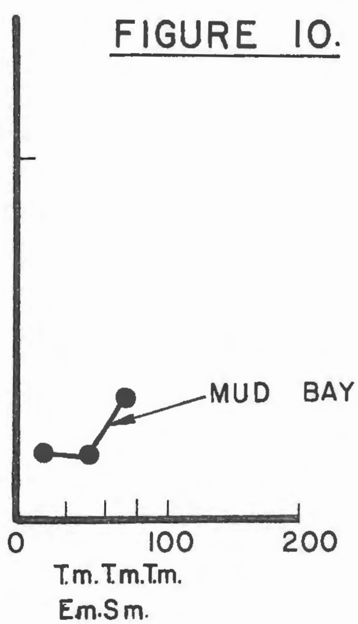


FIGURE 10.



DISTANCE FROM DYKE (M.) AND MAJOR PLANT SPECIES

Westlake (1963) estimates net primary productivity of the underground portions of marsh plants to be approximately 64% of standing crop. Using this approximation, and the data on above ground productivity from Yamanaka, a crude estimate of total net primary productivity for Scirpus americanus communities on Sturgeon and Roberts Banks would be 568g(dry)/m^2/yr.

B. Freshwater (Riparian) Marshes

The only study of the productivity of freshwater marshes in the lower Fraser system was carried out in 1973 and 1974 on the Pitt Polder area (Barnard 1975). Because of extensive dyking early in this century, these marshes have been isolated from river influences, and are in a transition to bog. They are thus not fully representative of freshwater marshes in the rest of the Fraser system. In the course of this study, total standing crop at the end of the 1973 season, and standing crop at various periods during the 1974 growing season were estimated for six marsh communities. From this data, crude net primary productivities can be estimated as follows:

Plant Community	Estimated Net Primary Productivity (g(dry)/m^2/yr)
Wetland Communities	
- Phalaris arundinaceae	995
- Spirea douglasii	1918
Emergent Communities	
- Typha latifolia	1075
- Scirpus microcarpus	1098
- Calamagrostis canadensis	1115
- Scirpus acutus	317

C. Bog

Biggs (1976), in an ecological and land use study of Burns Bog, delineated seven major bog vegetation types. In the course of his investigations he estimated net primary productivity for one of the seven types, the sphagnum heathland, in an attempt to determine the rate of peat accumulation. Two communities were found in this sphagnum heathland type and net primary productivity was as follows:

Plant Community	Net Primary Productivity $g(dry)/m^2/yr$
Sphagnum angustifoluim (wet depressions)	70 ± 27
S. Fuscum and S. capitatum (hummocks)	167 ± 58

Discussion

The limited data that exists for the Fraser Estuary and freshwater marshes, indicates that net primary productivity is within the range reported elsewhere in the literature for comparable plant communities. In fact, given that most of the data applies only to above-ground production of macro-vegetation, certain communities, such as Carex lyngbyei, may have total net primary productivity in the upper portion of the range given for estuaries and shallow coastal waters in Table 1.

As a basis for management decisions, particularly as an index of the relative importance of various communities, the present level of information has a number of short-comings:

1. Primary production estimates to date have dealt mainly with above-ground, macro-vegetation. In addition, a number of studies have dealt with standing crop and thus are only a very crude indication of productivity. The most obvious data-gaps are below-ground productivity of all marsh communities (with the exception of Scirpus americanus), and productivity estimates for both phytoplankton

and benthic algae. A systematic study of net primary productivity for all major vegetation zones is a prerequisite to an understanding of energy and nutrient flow, and of the interrelationships of the major ecological components of the study area.

2. The functional significance of the various components of the Fraser estuary and marsh system must be determined, to provide a sound, ecological basis for land-use planning. The energy relationships are probably very complex and the role of specific communities in both energy and nutrient flow may be highly variable. Land-use decisions which destroy or drastically alter a particular community may have significant unforeseen effects on both the populations of consumers and the energy-flow patterns of the entire system.

3. Virtually nothing is known about the degree to which present levels of energy production are utilized by the two main food webs in the estuarine system. In the absence of such information, it is impossible to quantify the losses of fish and wildlife that might be caused by any reduction of the existing system. Primary consumers include some of the larger waterfowl (snow geese, wigeon, puddle ducks, etc.), and a host of invertebrates and smaller birds that support predator populations. The only attempt to relate estimated productivity to comsumption of Scirpus americanus rhizomes by snow geese (Anser caerulescens) on the Fraser foreshore was 167 m. t., or 32 percent of total standing crop. He concluded that the existing 734 ha. of Scirpus americanus marsh was just adequate for the current population of 15 - 20,000 wintering birds. Any substantial loss of this community would result in progressive degradation of the remainder, unless the snow geese

population was reduced. The base for the second food web is the organisms that feed on plants as detritus, both on the marsh floor and in adjacent waters. Many species are supported, at least in part, by the detrital food chains; including diving ducks, salmon, herring, shellfish and marine mammals. Keefe (1972) estimated that populations of species dependent on the detrital food chain "would be reduced by almost half in some estuaries if there were no input of detritus from marsh production".

Recommendations

The dynamics of nutrient and energy flow is one of the most poorly understood aspects of the ecology of the Fraser estuary and marshes. Yet such information is vital to any rational attempt to assess the effects of further habitat destruction on fish and wildlife populations. For this reason it is recommended that:

1. A comprehensive research programme be undertaken to systematically estimate the total net primary productivity of all components of the lower Fraser system, and to delineate energy and nutrient flow patterns through the system. The basic objective of such a study would be to determine the importance of all major habitat units to the maintenance of fish and wildlife populations of social and economic significance.
2. Until the study proposed in recommendation #1 is substantially completed, no further reductions of marsh or estuarine communities should be permitted, and any activities proposed that will result in modifications to the foreshore or river channels should be assessed in terms of their potential effect on energy and nutrient flow patterns.

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F. Major Habitat Zones

On the basis of the foregoing discussions, 10 major habitat zones can be differentiated on the study area:-

1. Sand Flats
2. Mud Flats
3. Eelgrass beds
4. Salt marsh
5. Bulrush marsh
6. Cattail/Sedge marsh
7. Freshwater marsh
8. Riparian communities
9. Bog
10. Intensive agricultural lands

The extent of these zones is shown on Map 4, and their characteristics, and generalized capability for major groups of fish and wildlife are summarized in Table 6.

The habitat capabilities, and the relationship between habitat zones will be discussed in greater detail in the wildlife and fisheries sections of this report. It must be stressed that the generalized capabilities shown in Table 6 are, with few exceptions, subjective. Quantitative information on habitat use is fragmented and incomplete, particularly for many of the major fish species which cannot be directly observed, and whose use of the area is strictly seasonal.

One important component of habitat not included in Table 6 is water. Water is common to habitat zones 1-9, and the preservation of the habitat values of these zones is dependent to a large degree on the maintenance of water quality.

One of the most critical information requirements in the study area is quantitative data on the timing and degree of use of the major habitat zones by important fish and wildlife species. A study designed to provide such information must also address the important question of habitat needs for the major species in order to provide a basis for habitat restoration and management programmes. Information on habitat requirements and use for species of social and commercial importance is a prerequisite to any major decisions on land allocation in the study area. It is recommended that the provision of such information be made a priority in any further phases of the Fraser Estuary Study.

TABLE 6: MAJOR HABITAT ZONES OF THE STUDY AREA

MAJOR HABITAT ZONES	MAP UNIT	DOMINANT VEGETATION	SURFICIAL MATERIAL	MATERIAL TEXTURE	DRAINAGE	FLOODING HAZARD	GENERALIZED HABITAT CAPABILITY						
							WATERBIRDS	RAPTORIAL BIRDS	AQUATIC MAMMALS	LAND MAMMALS	FISH	SHELLFISH	CRABS & SHRIMP
Sand Flats	1.	Benthic algae (diatoms)	Marine	Sand	Underwater-Intertidal	Permanent-Daily	Low-Medium (w)	None	High (s)	None	Medium (cm, ck, co) I*	High (o); Medium (c)	High
Mud Flats	2.	Benthic algae	Fluvio-Marine	Clayey Silt - Sandy Silt	Underwater-Intertidal	Permanent-Daily	Medium-High (di, w, dc)	Medium-High	Medium (s)	None	High (cm, ck, co)	Low (c)	Medium
Eelgrass Beds	3.	Eelgrass (Zostera spp.)	Marine & Fluvio-Marine	Silt to Sandy Silt	Underwater	Permanent	Medium (di); High (b)	None	Low	None	High (cm, ck, co, h)	Medium (o)	High
Salt Marsh	4.	Saltwort (Salicornia virginica) Arrowgrass (Triglochin maritimum) Saltgrass (Distichlis stricta)	Marine & Fluvio-Marine	Silt to Clayey Silt	Very poor	Frequent to Daily	Medium to High (w)	Medium-high	Low	None	Medium-High I* (cm, ck, co)	Low	Low
Bullrush Marsh	5.	Softstem bullrush (Scirpus validus) Seacoast bullrush (Scirpus paludosus) Three-square bullrush (Scirpus americanus)	Fluvio-Marine	Silt to Clayey	Very poor	Frequent to Daily	High (g, s, w, sg)	High	Low	None	High (cm, ck, co)	High I*	High I*
Cattail/Sedge Marsh	6.	Cattail (Typha latifolia) Sedge (Carex lyngbyei)	Fluvio-Marine	Silt to Clayey Silt	Very poor	Frequent	High (g, w, da) I* (di)	High	Medium (m)	None-Low	High (cm, ck, co)	High I*	High I*
Freshwater Marsh	7.	Cattail (Typha latifolia Sedge (Carex lyngbyei, C. microcarpus, C. rostrata Bullrush (Scirpus validus)	Fluvial	Silt to Sandy Silt	Very poor	Frequent	High (g, w, da)	High	High (m, b, o, mi)	None-Low	High (cm, ck, co)	Low	Low
Riparian Communities	8.	Wet meadows Alluvial tree/shrub communities	Fluvial	Silt to Sandy	Poor	Frequent to Occasional	High (g, da)	High	High (m, b, o, mi)	Medium (r, sr)	Medium (cm, ck, co)	None	None
Bog	9.	Sphagnum spp., Shore pine (Pinus contorta) Labrador tea (Ledum groenlandicum)	Organic	Fibrous	Poor	Frequent to	Medium (da, wa)	Medium	Medium (m, b, o, mi)	Medium (d, b, c, r, h)	None	None	None
Intensive Agricultural Lands	10.	Vegetables, perenial pasture	Fluvial/Organic	Silt, Sandy Silt, Fibrous	Poor to Imperfect	Seasonal	Medium-High (da, g, w)	High	Low-medium	Medium (r, h, sr)		None	None

*I Indirect capability (i.e., zone plays a critical role in the food chain supporting these species).

Waterbirds: b = black brant; da = dabbling ducks; di = diving ducks; g = grazing waterfowl; s = swans; sg = snowgeese; w = wading birds.

Aquatic mammals: b = beaver; m = muskrat; mi = mink; o = otter; s = harbour seal.

Land mammals: b = bear; c = coyote; d = black-tailed deer; h = cottontail rabbit; r = raccoon; sr = small rodent.

Shellfish: c = clams; o = oysters. (Boundary Bay probably has the highest capability for oyster cultivation of any waters in the province; however, water quality degradation due to agricultural activities in the Serpentine Nikomekl lowlands precludes use.

Fish: cm = chum; ck = chinook; co = coho; h = herring. (Based on catch data only.)

III Conservation and Management of the Habitat Base

A. Policies of the Conservation Agencies Relative to the Protection and Management of the Fraser Estuary

The following policy statements have been provided by the respective fish and wildlife agencies. In each case the goals and objectives of the agencies are stated and these are related to habitat management policies in general, and for the Fraser wetlands in particular.

i. Federal Agencies

(a) Canadian Wildlife Service

The federal government is responsible for migratory birds in Canada, having the tasks, in the words of the Migratory Birds Convention, signed with the U.S.A. in 1916, "of saving from indiscriminate slaughter, and of insuring the preservation of, such migratory birds as are either useful to man or are harmless". The role of the Migratory Birds Branch of the Canadian Wildlife Service is to keep Canada fit for birds to live in by fulfilling those federal responsibilities while managing the migratory bird resource for the maximum benefit of existing and future generations of Canadians, and of other peoples having a common interest in the welfare of the birds.

These objectives will be implemented in the Fraser River estuary by the following programmes relative to habitat management:-

1. Monitoring the status, and understanding the requirements of migratory birds living in or visiting the Fraser River estuary so as to ensure that no species or clearly-definable stocks within a species become threatened by destruction resulting, directly or indirectly, from human actions; and to take whatever actions are needed to pre-

serve any threatened group from extinction.

2. Ensuring the preservation and management of important, critical and unique habitats for the primary benefit of migratory birds and other wildlife.

3. Securing adequate enforcement of existing federal legislation relating to migratory birds and their habitat, and by seeking improvements in national and international agreements and legislation for the better conservation of migratory birds and the resources they need.

(b) Fisheries and Marine Service

ii. Provincial Agencies

The provincial Department of Conservation, Ministry of Recreation and Conservation is currently being reorganized. Policy statements have not been formulated for the reorganized department and, therefore, the following statements relate to the two Branches that existed prior to April 31st, 1978.

(a) Fish and Wildlife Branch

The provincial goal of the Branch is:-

"To provide sustained benefits for the people of British Columbia through the management and protection of the fish and wildlife resources."

Consistent with the long-term direction established by this broad management goal, the Branch presently has two objectives for fish and wildlife management:-

1. To maintain optimum abundance and distribution of all native species of fish and wildlife and their habitat.
2. To provide the widest choice of socially acceptable uses of fish and wildlife within the limits of individual species and their habitat.

The provincial goal and objectives provide a framework within which regional objectives can be formulated. The fish and wildlife management objectives for the Fraser estuary and floodplain are:-

1. To maintain existing populations of migratory sports fish and birds.
2. To maintain, and enhance wherever possible, populations of resident and overwintering wildlife, and of resident sports fish.

The habitat management policy adopted by the Branch to achieve these objectives, recognizes the historical losses of estuarine habitat within the Fraser system. Given that only 20-30% of the original wetland system currently exists in a relatively unaltered state, it is assumed, in the absence of quantitative information to the contrary, that the existing area of wetlands is vital to the maintenance of present fish and wildlife populations. Thus the habitat management policy of the Branch for the Fraser estuary can be stated as follows:-

1. That all existing marsh and eelgrass communities in the Fraser estuary and floodplain be protected until quantitative habitat utilization information is available which would indicate those habitat units which could be allocated to other forms of land use without detriment to the fish and wildlife resources.
2. That all proposed modifications to river flow or "unvegetated" foreshore be assessed in terms of their potential effect on those processes of estuary maintenance (i.e. patterns of erosion and sediment deposition, nutrient and energy flow, and the distribution of fresh and saline waters).
3. That water quality in the river and estuary be maintained at a level that is consistent with both preservation of fish and wildlife, and public use of these resources.
4. Certain important tidal and freshwater marshes are in private ownership. These should be purchased by the Crown, consolidated with existing Crown reserves in the study area, and formally dedicated for purposes of conservation and public recreation.

5. That all options for the restoration of marshlands and the enhancement of habitat to compensate for past losses be investigated and, where practical, pursued.

(b) Marine Resources Branch

The Branch functions primarily as an economic development agency for British Columbia fishing and other marine industries. In this capacity it acts as a provincial spokesman for the fishing, shellfish and marine plant industries. It serves these interests by providing representation at international negotiations, and functions as a liason between provincial and federal resource agencies whose activities affect marine resources. Branch administration and enforcement of the provincial Fisheries Act and the Fish Inspection Act provide protection to both the fishery resources and the consumers of fish products.

Consistent with Branch goals, and in recognition of the importance of estuaries in the sustained production of marine resources, the Branch's policy on estuarine management is as follows:-

1. Pristine estuarine environments, where they exist, should be preserved intact.
2. At least the status quo should be maintained in all estuaries subject to industrial use, and any options for habitat rehabilitation should be pursued.
3. As the knowledge of estuarine ecosystems becomes more complete, the policy of the Branch may be subject to modification. Until that time, a stringent policy of preservation is essential to prevent unnecessary losses of fisheries, and recreational use options.

B. Areas Formally Designated for Fish and Wildlife Protection

Lands within the study area have been set aside for conservation purposes under six basic types of tenure (see Map 5). The management status of these tenures is as follows:

1. Federal Government Lands

In 1972 the Canadian Wildlife Service purchased approximately 670 acres (270 ha.) of private land on Reifel Island from the Reifel family. In terms of provincial law the C.W.S. enjoys all of the rights of a private land owner in the management of these lands. These federal lands are supplemented by a provincial wildlife sanctuary, established by Order-in-Council 2595 of 1963, on an adjacant tract of Roberts Bank of approximately 700 acres (285 ha.).

2. Provincial Lands

(a) Crown reserves

Crown reserves are essentially of three types: Order-in-Council, map reserve, and notation of interest. Order-in-Council reserves are the strongest form of tenure and can be considered to legally establish a mandate for fish and wildlife management on a particular area. There is no legal distinction between a map reserve and a notation of interest, however, in practice the former implies a much stronger form of protection. Neither confers management authority since Sec. 10(1) of the B.C. Constitution Act states that one Minister may pass aspects of his authority to another Minister only by Order-in-Council. Both map reserves and notations of interest are legally only reserves from alienation in favour of the Land Management Branch. Notations of interest are usually given by Land Management Branch on areas where they consider the mix of resources to be too complex for an Order-in-Council or map

Table 7. Crown reserves within the study area.

Name of Area	Type of Reserve	Date of Establishment	Area (ha)	Intent
Boundary Bay	Notation of interest	25/2/65	5,905	Wildlife management & recreation
Duck, Barber Islands	Order-in-Council (#2558)	12/11/59	335	Wildlife management
Ladner Marsh	Order-in-Council (#788)	16/4/59	75	Wildlife management
Pitt Lake	Order-in-Council (#1029)	29/4/58	660	Wildlife management
Roberts Bank	Order-in-Council (#2374)	18/9/61	9,675	Wildlife management
Sturgeon Bank	Notation of interest	25/2/65	11,430	Wildlife management
Tsawwassen Beach	Order-in-Council (#2375)	19/9/61	290	Use, recreation and public enjoyment
Woodward Island	Order-in-Council (#2373)	19/9/61	160	Wildlife management

All of the Order-in-Council reserves, with the exception of Tsawwassen Beach, are in the name of the Fish and Wildlife Branch, Ministry of Recreation and Conservation.

reserve, and are also used to effect short-term protection for an area pending more detailed studies.

Crown reserves within the study are outlined in Table 7.

(b) Greenbelt lands

Greenbelt properties were purchased at the request of various provincial and local government agencies through provisions of the Greenbelt Protection Fund Act 1972. Funds were established to implement the Act in 1973, administered in part by both the E.L.U.C. and the B.C. Land Commission. In 1975 all Greenbelt lands were passed to the administration of the Land Management Branch. The Greenbelt Protection Fund Act had no provision either for the delegation of management authority or for the preparation of regulations. A new act, known as the Greenbelt Act, was passed during 1977. It repeals the G.P.F.A., abolishes the Greenbelt Fund, and provides for both regulations and management consignment.

Greenbelt lands are not Crown lands as defined in the Land Act. The Greenbelt Act exempts designated lands from the provisions of any other acts except the Ecological Reserves Act, the Environment and Land Use Act and the Pollution Control Act.

Three Greenbelt properties were purchased within the study area at the request of the Fish and Wildlife Branch. These are:

Name of Area	Date of Purchase	Area (ha)	Management Agency[1]
Pitt Polder	1973	1190	Fish and Wildlife Branch
Mud Bay	1973	190	Ministry of Agriculture
Mud Bay-Lot 495	29/8/74[2]	58	Fish and Wildlife Branch

[1] None of these properties have been formally consigned under the Greenbelt Act 1977.

[2] The National Second Century Fund and the Nature Conservancy contributed approximately 25% of the purchase price for this property.

(c) Consignments from other provincial authorities

The Serpentine Fen property on the south bank of the Serpentine River was consigned for management to the Fish and Wildlife Branch by letter of Ministerial agreement on December 11, 1968, from the Ministry of Highways. This area comprises approximately 115 ha. of riparian marsh and wet meadows.

A small area of marshland (± 65 ha.) exists on the Minnekhada Ranch property at Port Coquitlam. The ranch was purchased in 1974 by Dunhill Developments Ltd. and is now being transferred to the B.C. Land Commission. The Land Commission has indicated that the marshland will be consigned to the Fish and Wildlife Branch.

3. Private Conservation Lands

The primary non-governmental organization purchasing property for conservation purposes is the National Second Century Fund for British Columbia. This fund administered by an appointed board of directors, was established in 1971 by federal "letters patent" from money remaining from federal government centennial grants to the province. The N.S.C.F. purchases land and then leases to government agencies for a period of 99 years at a nominal annual rental rate of one dollar. The lessee has full management rights subject to lease conditions, which are usually drawn up to ensure that operations on the property are consistent with the N.S.C.F.'s letters patent.

Two properties within the study area have been purchased by the N.S.C.F.: Widgeon Creek and Addington Point. The former, comprising 155 ha. of freshwater marsh, was leased to the Canadian Wildlife Service in 1973. Addington Point, approximately 175 ha., was purchased in 1977 and has not as yet been leased.

Conclusion

A significant portion of the existing wetlands of the Fraser estuary and floodplain are designated, at least nominally, for conservation. However, some tenures, particularly Crown notations-of-interest, are not very secure and provide no formal management mandate. Recommendations for improving this situation, and for securing those important wetlands in private ownership, will be explored in the following section.

C. Options for the Management of Habitat

Introduction

The object of this section is to discuss options, and to recommend courses of action, for fish and wildlife habitat management within the study area. Habitat management embraces an array of activities, from outright protection, through restoration, to active enhancement. Habitat protection involves the preservation of valuable pristine areas from alteration or degradation. Habitat restoration is the process by which degraded habitat is either restored to a near-natural condition or improved artificially for the production of designated fish and wildlife species. Habitat enhancement involves the improvement of the quality, productivity and associated public benefits of natural or pristine areas. Given both the degree of alteration that has taken place in the study area, and the present state of knowledge of estuarine ecosystems, options for habitat enhancement are extremely limited.

Options for Habitat Protection

i. Improvements in the Land Planning Processes Within the Study Area

This subject will be discussed in greater detail by the Land Use Working Group, however, some mention must be made here in the context of habitat protection. At the present time the administration of land use within the study area is the responsibility of a bewildering array of agencies, often with overlapping jurisdiction. An estuarine management plan may provide direction for land use, but is unlikely to be successfully implemented unless jurisdiction is given to one or two lead agencies. At present, land-base jurisdiction rests with a number of agencies who are, in fact, development proponents; i.e. National

Harbours Board, Department of National Defence, Transport Canada, Fraser River Harbour Commission, North Fraser Harbour Commission, B.C. Development Commission, and Department of Public Works. If the management plan which will result from the Fraser Estuary Study is to be implemented it is essential that the administration be the responsibility of neutral, un-biased agencies. For this reason it is recommended that:-

1. The jurisdiction of all federal and provincial lands, including those presently administered by Crown corporations, be made the responsibility of the Lands Directorate, Environment Canada and the Land Management Branch, Ministry of the Environment respectively.
2. The two lead agencies would co-chair a permanent committee composed of representatives of the three levels of government. The task of the committee would be to assist the lead agencies in the coordination of both management plan implementation and the collection of information necessary to formulate subsequent plans. Related tasks of this committee would be:-
   - to coordinate the collection, analysis and dissemination of information relating to the study area
   - to assess the potential impacts of regional resource management, human settlement and industrial development objectives on the Fraser estuary and floodplain
   - to prepare guidelines for environmental impact assessments
   - to develop site-specific development regulations
   - to review, reorganize and coordinate referral processes

ii. Maintenance of Water Quality

Though land and vegetation are the most visible components of habitat, water is probably the most important. Water is common to nine of the ten major habitat zones, and plans to preserve the physical habitat will ultimately be futile unless water quality is maintained. Studies by the Westwater Research Centre (Hall, Koch, Yesaki, 1974) indicate that, although the overall water quality in the Lower Fraser River is satisfactory, there are a number of potential problems. "The high levels of micro-organisms, which indicate the potential presence of pathogenic organisms, suggest what may be a major water quality problem in the Lower Fraser River". Moreover, "Occasional high levels of trace metals (zinc, lead and mercury) were detected in the lower reaches of the Fraser. Although the high measured concentrations at present are sporadic in nature and do not appear to be acutely toxic to fish, recommended toxicity criteria as established by the Inland Waters Branch, Department of Environment, are sometimes exceeded, and management of these substances in the lower Fraser River deserves attention."

It is, therefore, recommended that the Inland Waters Directorate, Environment Canada, and the Pollution Control Branch, Ministry of the Environment, be the lead agencies in the development and enforcement of water quality objectives for the Fraser River and Estuary. The objectives must recognize the importance of water quality both to the long-term maintenance of fish and wildlife populations, and to the maintenance of food quality of commercial species.

iii. Acquisition and Designation of Important Habitat Areas

Given that approximately 70-80% of the historic estuarine and freshwater wetlands have been destroyed or irreparably altered, existing wetlands are extremely important if fish and wildlife populations are to be maintained. There are at present in private tenure a number of important marshes which must be maintained in a natural state. Zoning and planning cannot be relied upon to preserve these areas because of the total constraint which would be placed on the development rights of the owners. It is, therefore, recommended that:-

1. All private lands outside the main dykes on Sturgeon Bank, Roberts Bank and Boundary Bay be purchased cooperatively by the federal and provincial Crown. These lands would be incorporated with the existing Crown foreshore reserves (see Map 5) in an Order-in-Council reserve for wildlife, fisheries and compatible uses under joint federal/provincial management authority. The management agencies would be required to prepare a management plan for submission to the Lands Directorate and the Land Management Branch for review by the standing estuary committee.

2. The following areas be purchased by the Provincial Crown, consolidated with existing Order-in-Council reserves (see Map 5) and consigned to the provincial Department of Conservation for management:-

   (a) Rose, Gunn, Williamson and Kirkland Islands
      - approximately 135 ha. of partially dyked marshland and wet meadow in the South Arm of the Fraser River

   (b) Ladner Marsh
      - approximately 75 ha. of natural marshland adjacent to the existing O.I.C. wildlife management reserve

The Fish and Wildlife Branch would be responsible for coordinating the preparation of a management plan for review by the Lands Directorate, the Land Management Branch and the standing estuary committee.

Options for Habitat Restoration

A number of options exists either for the rehabilitation of degraded habitat, or for the restoration of natural processes that have been altered by development structures. These are:-

i. Restoration of water flow through jetties and causeways

A number of causeways and river training structures have been constructed in the study area which have the potential to create significant, long-term changes in patterns of erosion, sediment deposition, and water circulation in the estuary and floodplain. Current plans call for training structures throughout the lower river.

In some areas the effects of these structures may be judged, on balance, to be beneficial, while in others they are almost certain to be detrimental to the long-term maintenance of the marshes and estuarine processes. Studies are currently being carried out to quantify these changes. Future phases of the Fraser Estuary Study should include investigations to determine the feasibility of water exchange structures on jetties and causeways where these are deemed desirable.

ii. Fill Removal

An undetermined area of marshland lying outside of the main flood control dykes has been destroyed in the past by the dumping of land fill and dredgsite. Some such areas have subsequently been used for industrial development, however, many have simply been left in a biologically impaired and aesthetically unattractive state. It is recommended that in future phases of the Fraser Estuary Study areas be identified where fill removal and marsh rehabilitation is feasible and desirable.

iii. Marsh Restoration

Many areas of former marshland have been destroyed by a variety of activities such as dumping of dredge spoil, and excavations for communication lines and transportation corridors. The long-term impact of such activities would be greatly lessened if techniques for marsh rehabilitation could be developed for the wetland species common to the Fraser estuary and floodplain. Research in progress by the U. S. Army, Corps of Engineers (1976) in the Columbia River estuary indicates that a number of common marsh species, such as Carex lyngbyei, are tolerant of transplanting. Preliminary investigations by Moody (1977) in the Fraser estuary found that Scirpus paludosus, Carex lyngbyei, Triglochin maritimum and Salicornia virginica all survived transplanting provided that sufficient attention was paid to factors of site such as salinity, nutrient levels, wane action and elevation. Levings (1977) has proposed an experimental programme of marsh restoration for the study area. It is recommended that consideration be given to funding such a scheme in future phases of the Fraser Estuary Study.

iv. Removal of Log Booms

Extensive areas of the North and Muin Arms of the Fraser River and and the lower reaches of the Pitt River are used for log storage. One of the most comprehensive studies of the environmental impacts of log handling in estuarine waters was undertaken by the Pacific Northwest Pollution Control Council (1971). The study concluded that log debris, bark, and wood leechates from boomed logs can adversely affect water quality and benthic organisms, and the booms themselves can scour and destroy marsh vegetation.

Studies are required to determine where log booming can occur in the Lower Fraser River with no, or minimal, adverse environmental effects.

v. Driftwood Removal

Driftwood removal is a relatively easy method of marsh restoration. Some driftwood is desirable in wetland areas to provide cover for small birds and mammals and perchs for raptors, however, many areas of the Fraser Estuary, particularly the Tsawwassen and Boundary Bay salt marshes, are choked with debris. Heavy accumulations of driftwood reduce the amount of substrate available for the growth of vegetation, and may have effects similar to log booms in reducing benthic production. Mobile logs can also cut tracts through marsh areas destroying marsh vegetation in the process.

vi. Wetland Improvement.

A number of dyked, poorly drained areas of wet pastureland exist in the study area that offer the potential for habitat improvement to compensate for past marshland losses, and as buffer zones to reduce waterfowl/agriculture conflicts. The Alaksen National Wildlife Refuge on Westham Island and the Serpentine Fen Wildlife Management Area at Mud Bay provide examples of the type of habitat developments that might be undertaken on such areas ie. water level control, the creation of ponds and nesting structures, and the provision of food sources.

Two additional areas could be acquired for intensive wetland management (See Map 5):-

(a) Brunswick Point (Lot 187)

This area, composed of approximately 65 ha. of wet pasture, controls access to the forshore and has significant potential for a mixture of waterfowl management and forage production.

(b) Mud Bay

Some properties between the Serpentine and Nikomekl Rivers west of Highway 499 have been purchased as Greenbelt lands. The remaining wet pasturelands in private ownership could be acquired and consolidated with the Mud Bay and Lot 495 Greenbelt properties, and the Serpentine Fen into a single management area for wildlife, recreation and wetland agriculture.

Options for Habitat Enhancement

As stated previously, habitat enhancement is defined as the manipulation of natural communities in order to improve the quality or productivity of specified components of those communities. Given the present state of knowledge of the functional processes of estuarine and wetland ecosystems, it is difficult to predict the effects of such manipulations. Activities designed to improve the habitat of certain species may have serious, perhaps unforeseen, impacts on others. Some suggestions for habitat enhancement include the deposition of dredge spoil in certain areas to raise the level of substrate to that suitable for marsh colonization, and the construction of groins in Boundary Bay to promote the expansion of eelgrass beds and provide shelter to waterfowl during storms (Benson 1964). It is recommended that such habitat enhancement operations be treated as any other development proposal, and require an environmental impact assessment.

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IV Summary of Recommendations

A. Biophysical Information

Some serious gaps exist in the biophysical knowledge of the estuary and floodplain which make it difficult to estimate both the effect of development proposals on the wetlands, and the impact of habitat loss or modification on fish and wildlife populations. Even where the status of knowledge is relatively high, the interpretations of basic information are often not in a form that is easily accessible to managers and planners. Further information and interpretations are required as a first priority in the following five areas:-

i. Fluvial and Oceanographic Processes Affecting the Substrate

Patterns of water circulation and sediment flow, and the resulting processes of erosion and deposition within the Fraser estuary and floodplain are, as yet, incompletely understood. In order to ensure that critical sand flat areas and marsh habitats are not degraded by alterations to the foreshore or river, the following information is required:-

(a) Definition of the major sediment pathways in the estuary and river channels

(b) The rates of sediment supply necessary to maintain the physical integrity and the biota of the foreshore.

Until such information is available the impacts of any structures on the foreshore, or alterations to the flow of the river can not be predicted with any confidence.

ii. Vegetation Zones

Though the distribution and composition of the various wetland communities within the study area are well defined, much remains to be learned about the role of environmental factors in determining community ecology.

Factors such as the frequency and duration of flooding, substrate composition and characteristics, water turbidity, degree of salinity, local currents, and microclimate obviously interact to determine the distribution and abundance of species. Knowledge of this interaction is a prerequisite to both an understanding of the effects of development projects and programmes of marsh restoration or enhancement.

iii. Major Water Zones

Considerable information will be available on salt and freshwater movements in deeper waters upon completion of present studies. It is unlikely, though, that much information will be available on salt and freshwater distribution in shallow areas such as the intertidal marshlands. In view of the fact that even relatively small structures may alter foreshore salinity, resulting in vegetative changes, it is recommended that:-

(a) Baseline salinity information be collected for all of the intertidal marsh communities

(b) That salinity-tolerance of the wetland species be determined in order to predict the effect of salinity changes on the composition of marsh communities.

iv. Primary Productivity and Food Webs

The dynamics of nutrient and energy flow is one of the most poorly understood aspects of the ecology of the Fraser estuary and floodplain. Yet such information is vital to any rational attempt to assess the effects of further habitat destruction on fish and wildlife populations. For this reason it is recommended that a comprehensive research programme be undertaken to systematically estimate the total net primary productivity of all components of the lower Fraser system, and to delineate patterns of nutrient and energy flow through the estuary and floodplain. The basic objective of such a study would be to determine the importance of all major habitat zones, and the vegetation and micro fauna characteristic of them, to the provision of food for fish and wildlife populations of social and economic significance.

v. Habitat Utilization

One of the most critical information requirements in the study area is quantitative information on the type, degree and timing of use of the major habitat zones by important fish and wildlife species. A study designed to provide such information should also address the important question of habitat needs for the major species in order to provide a basis for habitat restoration and management programmes.

Two other data gaps exist but these are somewhat less critical than the five already mentioned.

i. Surficial Geology and Soils

With the exception of a few areas of limited extent, detailed soil and surficial geology information is available for the study area. There is a need for more effective means of communicating this information to urban planners and land managers. It is recommended that:

(a) Steps be taken to fill in the few remaining gaps in soil and surficial geology information

(b) In consultation with urban planners, interpretations of soil and surficial geology information should be developed for a range of land uses and types of development.

ii. Invertebrate Populations

As important primary consumers, invertebrate populations obviously play significant roles in various food webs in the wetland system. Some work has been done on invertebrate populations in the study area, particularly those that are important salmonid foods. Further information is required in the following areas:-

(a) The relationship of invertebrates to aquatic vegetation such as marshes and eelgrass beds

(b) The relationship between invertebrates and types of substrate

(c) The distribution, abundance and biomass of invertebrates in Boundary Bay.

Some of the more important aspects of invertebrate ecology would be included in the primary productivity and food web studies indicated in the list of priority research above.

B. Conservation and Management of the Habitat Base

i. Policy Recommendations

The common management objective of the major conservation agencies is to maintain, and enhance where possible and desirable, present populations of both resident and migratory fish and wildlife. Given that only 20 - 30% of the original estuary and floodplain currently exists in a relatively unaltered state, it is assumed, in the absence of quantitative information to the contrary, that the existing area of wetlands is vital to the attainment of the general management objective. Thus the recommended management policy for the Fraser estuary and flood-plain is as follows:-

(a) That all existing marsh and eelgrass communities be protected until quantitative habitat utilization information is available that would indicate whether any of these habitat units could be allocated to other forms of land use without detriment to the fish and wildlife resource.

(b) That all proposed modifications to either river flow or "unvegetated" foreshore be assessed in terms of their potential effects on those processes of estuary and wetland maintenance (ie. patterns of erosion and sediment deposition, nutrient and energy flow, and the distribution of fresh and saline waters).

(c) That water quality in the river and estuary be maintained at a level that is consistent with both preservation of fish and wildlife, and public use of these resources.

(d) That important habitats in private ownership be purchased by the Crown, consolidated with Crown reserves and dedicated to fish and wildlife habitat management, and compatible uses.

ii. Improvements in the General Land and Water Planning Processes Within the Study Area

At present the jurisdiction over the public land base of the study area rests with a bewildering array of agencies, some of which are development proponents. If a management plan for the study area is to be effectively implemented it is essential that the activities of the agencies with land-base jurisdiction be closely scrutinized and coordinated. Ideally, the jurisdiction of all federal and provincial lands, including those presently administered by Crown corporations, should be passed to neutral lead agencies such as the Lands Directorate, Environment Canada and the Land Management Branch, Ministry of the Environment, It is questionable, however, whether such a step could be taken at the present time. It is therefore recommended that:-

(a) That four leading agencies - Land Management Branch, the North Fraser and Fraser River Harbour Commissions, and Fisheries and Marine Service - be given the responsibility to coordinate and control foreshore land-use in consultation with other agencies of the senior governments, municipalities and regional districts. This coordination and control would take the form of designating land for various uses, and the formulation of site-specific development regulations.

(b) That a standing committee composed of the three levels of government be formed to advise and assist the lead agencies in the coordination of both management plan implementation and the collection of information necessary to formulate subsequent plans. Related tasks of the committee would be:-

- to coordinate the collection, analysis and dissemination of information relating to the study area
- to assess the potential impacts of regional resource management, human settlement, and industrial development objectives on the Fraser estuary and floodplain
- to assist in the preparation of guidelines for environmental impact assessment and to ensure that these cover both site-specific and cumulative impacts
- to assist in the development of site-specific, development regulations
- to review, and assist in the reorganization and implementation of referral processes.

Water is common to nine of the ten major habitat zones in the study area, and plans to preserve the physical habitat will ultimately be futile unless water quality is maintained. It is recommended, therefore, that the Environmental Protection Service, Environment Canada and the Pollution Control Branch, Ministry of the Environment be the lead agencies in the development and enforcement of water quality objectives. The objectives must recognize the importance of water quality both to the long-term maintenance of fish and wildlife populations, and to the maintenance of food quality of commercial species.

iii. Habitat Management Programmes

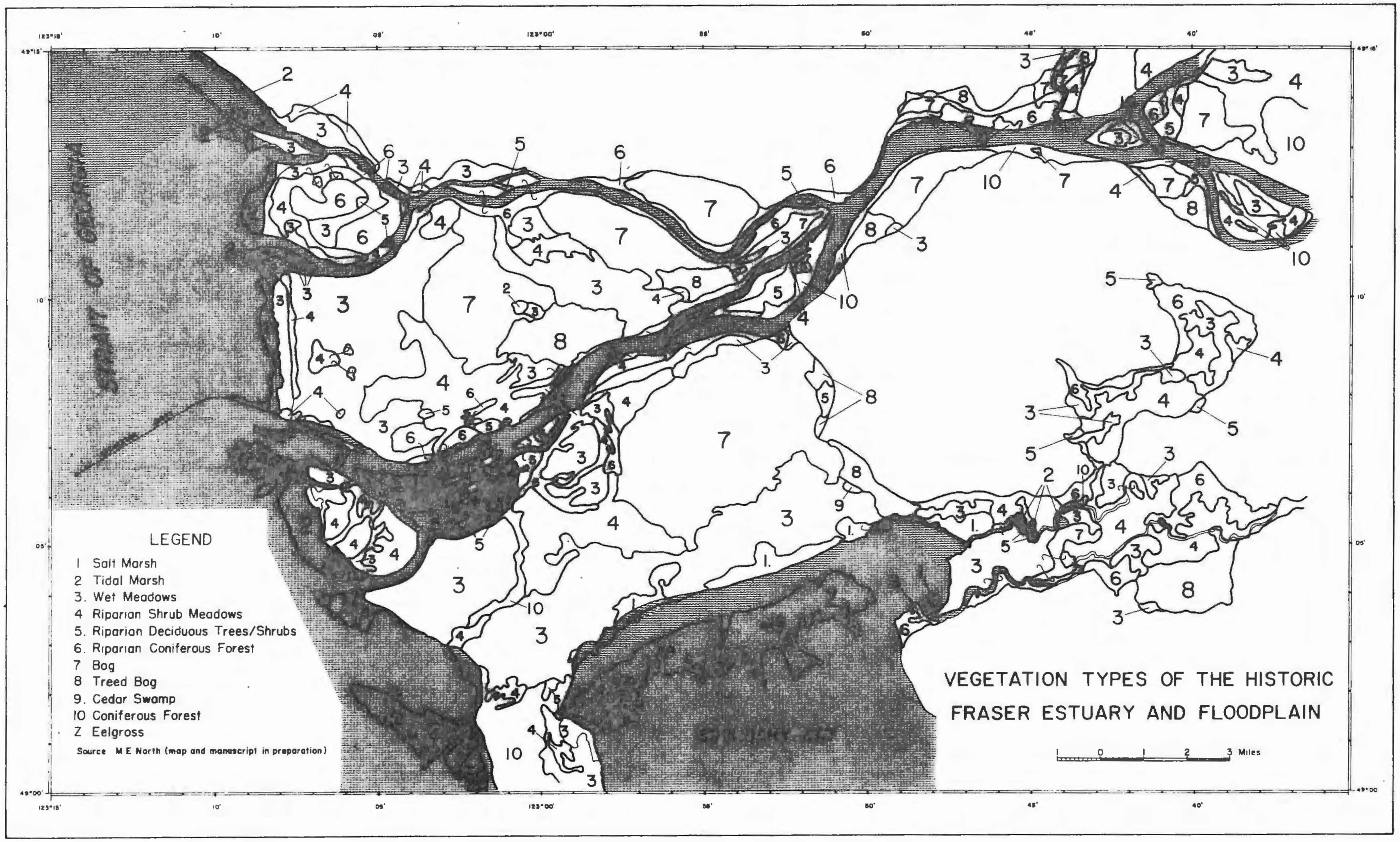
Significant portions of the existing wetlands of the estuary and floodplain are designated, at least nominally, for conservation. Some tenures, however, particularly Crown notations-of-interest, are not very secure and provide no formal management mandate. In addition, there are at present in private tenure a number of important marshes which must be maintained in a natural state. Zoning and planning cannot be relied upon to preserve these areas because of the total constraint which would be placed on the development rights of the owners. It is, therefore, recommended that:-

(a) All private lands outside the main dykes on Sturgeon Bank, Roberts Bank and Boundary Bay should be purchased cooperatively by the federal and provincial Crown. These lands would be consolidated by Order-in-Council with existing Crown reserves for fish and wildlife management and compatible uses under joint federal/provincial management authority. The management agencies would be required to prepare a management plan for review by the Lands Directorate and Land Management Branch (who would retain land-base jurisdiction), other leading agencies, and the standing estuary committee.

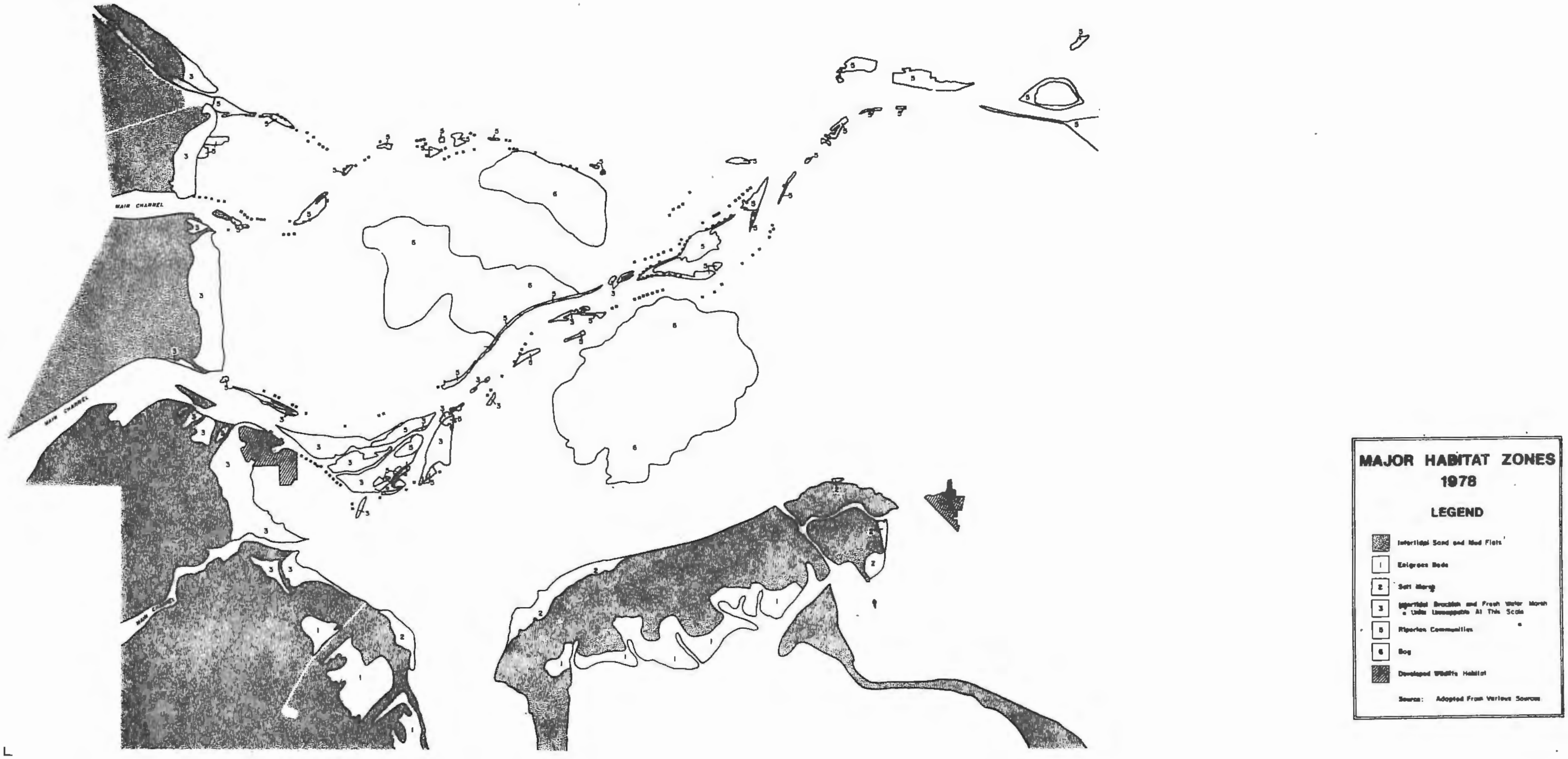
(b) Private lands in Ladner Marsh, and perhaps in the islands of the South Arm, should be purchased by the provincial Crown, consolidated with existing Crown reserves, and consigned to the provincial Department of Conservation for fish and wildlife management, and compatible public uses. The Department of Conservation would be responsible for coordinating the preparation of a management plan for review by the leading agencies, (the Land Management Branch would retain land-base jurisdiction), and the standing estuary committee.

(c) Consideration should be given to the purchase of wet agricultural lands in the vicinity of Mud Bay and Brunswick Point by the federal and provincial Crown for purposes of habitat restoration for migratory and resident birds. The development of such areas would compensate for past habitat losses and relieve the pressure of wildlife use of adjacent agricultural lands. The Canadian Wildlife Service and the Fish and Wildlife Branch would jointly prepare a management plan for review by the leading agencies and the standing estuary committee.

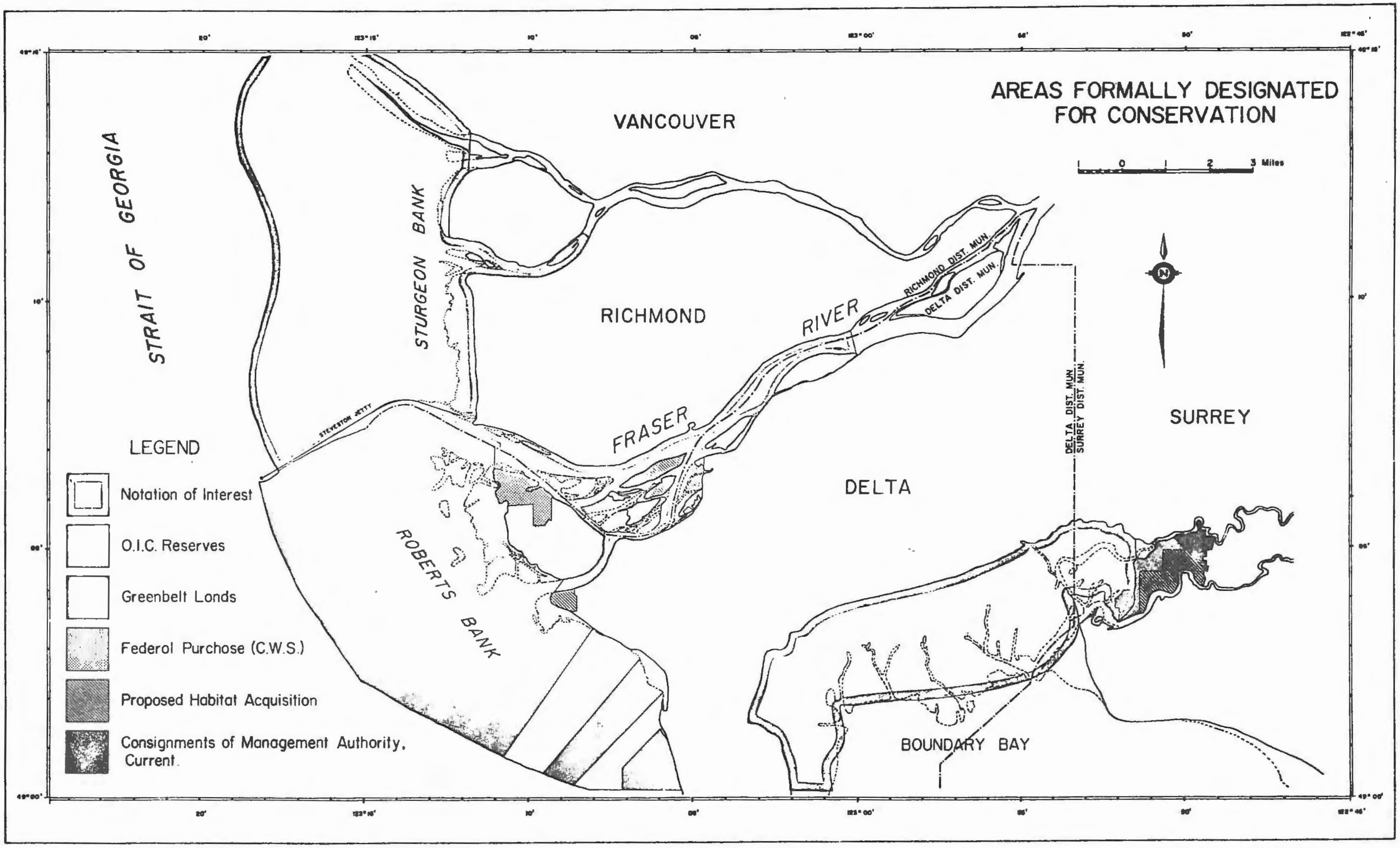
Management plans would identify, or propose studies to identify, the habitat base required to meet fish and wildlife objectives, opportunities for compatible public and commercial use, and options for habitat restoration and enhancement. Habitat enhancement, which is defined as the manipulation of natural ecosystems to meet desired objectives, would require an environmental impact statement.



VEGETATION TYPES OF THE HISTORIC FRASER ESTUARY AND FLOODPLAIN
LEGEND
1 Salt Marsh
2 Tidal Marsh
3. Wet Meadows
4 Riparian Shrub Meadows
5. Riparian Deciduous Trees/Shrubs
6. Riparian Coniferous Forest
7 Bog
8 Treed Bog
9. Cedar Swamp
10 Coniferous Forest
Z Eelgrass
Source M E North (map and manuscript in preparation)
STRAIT OF GEORGIA
0 1 2 3 Miles



MAIN CHANNEL
MAIN CHANNEL
MAJOR HABITAT ZONES
1978
LEGEND
Intertidal Sand and Mud Flats
Eelgrass Beds
Salt Marsh
Intertidal Brackish and Fresh Water Marsh
Units Unmappable At This Scale
Riparian Communities
Bog
Developed Wildlife Habitat
Source: Adopted From Various Sources


AREAS FORMALLY DESIGNATED FOR CONSERVATION
0 1 2 3 Miles
VANCOUVER
STRAIT OF GEORGIA
STURGEON BANK
RICHMOND
FRASER RIVER
RICHMOND DIST. MUN.
DELTA DIST. MUN.
DELTA DIST. MUN.
SURREY DIST. MUN.
SURREY
DELTA
STEVESTON JETTY
ROBERTS BANK
BOUNDARY BAY
LEGEND
Notation of Interest
O.I.C. Reserves
Greenbelt Londs
Federol Purchose (C.W.S.)
Proposed Hobitat Acquisition
Consignments of Monagement Authority, Current.

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THE FRASER ESTUARY AS A FISH HABITAT

Summary/Abstract

The Fraser River and its estuary supports some of the most valuable fishery resources in Canada. The salmon catch alone has been estimated to have a retail gross value of $86 million (1976), and other species (including herring, crab, and shrimp) live in the estuary. Sports fishing and other leisure activities are pursued in the estuary, which is the only large "passive" recreational area close to suburban Vancouver. Several studies have identified the direct and historic interest Native people have in Fraser River fish resources.

Eighty-six species of fish have been reported from the estuary, and their management, utilization, and conservation is of concern to seven provincial, federal and international agencies. In this report, 8 salmonid species, herring, eulachon, surf smelt and white sturgeon are mentioned in relation to estuarine environments. Commercial invertebrates include Dungeness crab and pink shrimp.

A review of published data on juveniles of 3 species of salmon (coho, chum, chinook) showed that these species were more abundant in vegetated areas of the estuary and the offshore Banks (Sturgeon, Roberts). There are no detailed data available on juvenile pinks and sockeye. Returning adults are fished in the estuary with gillnets, and further offshore seine and trolling gear is also used. Recreational fishing for cutthroat trout, dolly varden, coho, and chinook takes place on sand bars in the estuary. Dungeness crabs are caught with baited pots on the Banks and in Boundary Bay.

The permanent fish fauna of the estuary is adapted to rapid changes in water conditions, but migratory salmonids are considered "sensitive" species, adapted to a relatively narrow range of temperature, salinity, and dissolved oxygen conditions. Current velocities are thought to be an important variable affecting the distribution of juvenile salmonids and could influence the energetics of returning adults. Current velocities, sediments, and distribution of vegetation interrelate to provide habitat and food for juvenile salmonids. Vegetation throughout the estuary provides detritus which is used as an energy source for invertebrate prey species of fish. Eel grass on Roberts Bank and in Boundary Bay is used as a spawning substrate for herring.

Fisheries biologists have identified numerous water quality concerns in the Fraser estuary, including local decreases in dissolved oxygen, chlorinated effluents (sewage, forest product industries), leachates (e.g. sanitary landfills), chlorinated

hydrocarbons (e.g. polychlorinated biphenyl), metals, and particulate substances (e.g. coal dust). A number of studies showed the potential problems with changes in distribution of dissolved oxygen and salinity if habitats were modified drastically by river channelization. Habitat alienation (especially of marsh vegetation) by dyking, river training, filling (reclamation), and disposal of dredge spoil has been one of the insidious habitat problems in the estuary. Because of direct mortality due to dredging activities, timing restrictions have been placed on this activity to avoid damage to juvenile salmonids. Dams upstream on the Fraser system have not affected estuarine habitats, as far as can be determined.

Food webs involving juvenile salmonids at the Fraser estuary are complex, because prey species for salmonids graze directly on algae (autotrophs) or indirectly use algae and vascular plants via the bacteria-detritus complex (heterotrophs).

Studies conducted to date show that chum salmon utilized smaller prey (copepods, chironomids) compared to chinook which ate bigger organisms such as mysids and fish larvae. Young coho ate a wide variety of prey including copepods, juvenile eulachon, and chironomids. Representative estuarine habitats for the major prey species were as follows: amphipods and mysids - marshes and shorelines; chironomids - mainstem river; copepods - sloughs and "side channels"; and cumaceans - offshore Banks. Invertebrate biomass reached a peak near the river mouth, corresponding to marsh-midflat habitats.

The Fraser River Geographical Planning Group of the Salmonid Enhancement Program suggested that an additional catch of 10 million fish could be obtained from the Fraser system. Enhancement schemes for salmonids (exclusive of sockeye and pink) are planned on 24 tributaries of the river. Eighteen sites have been selected for chinook enhancement, 8 for chum, 15 for coho, 11 for steelhead, and 6 for cutthroat trout.

Nine categories of new research were identified as critical for improving management of fish habitat in the Fraser estuary. A listing of vital projects is included, and an account of ongoing work, including monitoring, is presented

LIST OF FIGURES

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ACKNOWLEDGEMENTS

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THE ESTUARY AS A FISH HABITAT

- II. Habitat Alienation
  - (i) Dyking and River Training
  - (ii) Dredging
  - (iii) Filling for Construction and Reclamation
  - (iv) Log Storage
- III. Dam Construction Upriver

H. Food Webs and Invertebrate Habitats

- I. "Shellfish"
- II. Salmonids
  - (i) Chum
  - (ii) Chinook
  - (iii) Coho
  - (iv) Herring
- III. Food Sources for Prey Organisms
  - (i) Amphipods and Mysids
  - (ii) Chironomids
  - (iii) Copepods
  - (iv) Cumaceans
- IV. Distribution of Prey in Relation to Habitat

I. Salmonid Enhancement

J. Critical Data Gaps

- I. Fish Communities and Life Histories
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THE ESTUARY AS A FISH HABITAT

A. INTRODUCTION

The Fraser River is one of the last remaining rivers in the world that supports major salmon runs, and a variety of other fish species of both commercial and recreational importance live in or migrate through the estuary. No other Canadian watercourse carries such an important and valuable fishery resource, accentuating need for policies to protect fish habitat in the river and estuary. The only other river in North America which had equivalent historical levels, the Columbia River in the U.S., now has been vastly reduced by extensive damming. Salmon stocks on the Yukon River (upstream fishery pursued by Canadians) approach those on the Fraser but are remote from major population centres, and because of differences in species composition, are valued less in the commercial fishery.

The purpose of this chapter is to describe the estuary of the Fraser River as a fish habitat, with special reference to salmonids. Although a number of other reports have reviewed our present biological knowledge of the lower river and estuary (e.g. Hoos and Packman, 1974; Dorcey, 1976; Romaine et al, 1976), none specifically addressed fisheries in the context of the whole estuary.

The next section of the report deals with the economics of commercial and recreational fishing in the estuary, followed by an enumeration of the agencies involved in the management and protection of the fisheries resource. The next sections describe fish communities harvested by fishermen and briefly describe the technology and strategies used in estuarine fishing. An account of the physical and chemical features of the estuarine waters is presented, together with a description of how deleterious materials and improper engineering practices can modify the "normal" characteristics of the habitats. Recent data from a number of estuaries in B.C., including the Fraser, have underscored the significance of habitat for fish feeding, so the chapter contains a section dealing with estuarine food chains. Finally, information is presented dealing with projected increases in utilization of the river and estuay by enhanced salmon populations.

A listing of data gaps viewed as critical by local research personnel and a summary of ongoing research and monitoring is included.

B. VALUE OF THE FISHERIES RESOURCE

I. DOLLAR VALUES IN THE COMMERCIAL FISHERY

The gross annual value of the Fraser River salmon catch at retail is estimated to be approximately $86 million, expressed in 1976 dollars. Assuming that the real value of salmon as food will increase at 2.7 percent per year, and discounting future values at 6 percent, the present value of this catch, over 70 years, will approximate $2.5 billion. If production increases associated with the Salmonid Enhancement Program are also included, the present value of future salmon catches, over 70 years, are estimated to exceed $3.4 billion.

The Fraser River Estuary is also important for non-salmonid marine species - most noticeably crab and herring. No data exist permitting a definitive statement on the dollar value associated with estuary dependent populations of these species. It is known that the estuary area supports significant stocks of herring - some becoming food for larger fish and some being taken in the commercial herring fishery. In addition in 1976, the commercial crab fishery produced 934,000 pounds of crabs (approximately 43% of B.C.'s total) valued at approximately $1.5 million (DFE, 1976). Care should be taken in interpreting this statistic, as it may be subject to considerable variation.

The fisheries of British Columbia are a common property resource. To control inputs of capital and labour under such circumstances, and to allocate benefits between economic and social goals, a license control plan regulates entry into the various coastal fisheries. Among targetted objectives of the plan are the economic well-being of individual fishing units, employment, native well-being, and the welfare of small coastal settlements. A lower bound estimate of the net potential of these economic and social benefits can be obtained by subtracting from the gross value estimates previously provided, the costs of harvesting and processing under a "most efficient" scheme concerning itself solely with dollar profits. These net values have been previously estimated to be 85 percent of landed value at the catching stage (Fisheries and Marine Service, 1974, Sinclair, 1976), and 50 percent of the wholesale value increment at the processing stage (Fisheries and Marine Service, 1974). Applying this procedure to the values cited previously produces a lower bound net value estimate for economic and social benefits of the commercial fishery of $45 million annually (Table 1). Projecting these values forward over 70 years, they will produce a stream of benefits presently valued at $1.3 billion, and, inclusive of salmonid enhancement at $1.8 billion.

In 1976, the commercial fisheries of British Columbia provided employment for approximately 14,000 persons. While many of these fishermen make their homes in urban areas, they also represent a substantial income earning component for smaller coastal communities (Sinclair, 1971, Burns, 1976). Their fishing efforts range widely from their home port, as they pursue salmon, ground fish and herring according to the time and coastal area in which each "run" is available. Many of these 14,000 fishermen, either because of age, lack of alternative training, or choice, would not easily find re-employment in other industries (Sinclair, 1971, Burns, 1976) - and even where this were possible, social dislocation for individuals and families would often be significant (Burns, 1976).

The contribution of the Fraser River and estuary to the livelihood of these fishermen cannot be precisely estimated from present statistical information. It is known, however, that Fraser salmon represent approximately 25 percent of the total British Columbia catch. Further, as Fraser salmon swim through Queen Charlotte and Johnstone Straits to the north, and the Strait of Juan de Fuca to the south, and as fishermen range coastally with the runs, it is clear that their benefits are shared by the majority of British Columbia's fishermen. In fact, while British Columbians have been well endowed with salmonids and other fish species in many of their coastal waters and rivers, the Fraser system has played a critical role in the past, and will continue to do so in the economic future of the British Columbia fishing industry.

At the processing level, the Fraser is similarly important. The largest fish processing centre in British Columbia - Steveston - is located at the mouth of the Fraser River. In the Lower Mainland as a whole, it is estimated that some 3,000 employees are directly employed in processing and tendering. And again, fish species dependent upon the Fraser River and its estuary are caught at divergent points on the British Columbia coast - thus providing the basis for further processing in smaller communities. These latter communities are usually characterized by a relatively narrow economic base, and fish processing often combines with fish catching (already discussed) to provide a significant percentage of total employment in the area (Sinclair, 1971, Burns, 1976).

THE COMMERCIAL FISHERY AND NATIVE PEOPLE

Approximately 800 native Indians own vessels in the British Columbian salmon fishery (1977). This represents approximately 16 percent of total fleet. In addition, 374 vessels (30 percent) of the British Columbia herring fleet are native owned. An estimated 1,650 persons are directly employed in the commercial catching of fish in British Columbia - many working as families. Further, an estimated 20 percent of total workers are employed in processing. In fact, the commercial fishing industry has historically been the most significant direct employer of native people in British Columbia.

The above statistics must be considered in light of employment levels among native Indians today. It is estimated that unemployment among native Indians stand at about 50 percent of the work force in summer. In winter it increased to about 90 percent (Union of B.C. Indian Chiefs). This is the backdrop against which the significant contribution of Fraser fishes to coastal commercial fisheries must be evaluated from a native point of view. Contribution to native subsistence and culture will be discussed in a following section.

SECONDARY BENEFITS FROM THE COMMERCIAL FISHERY

Auxiliary industries associated with commercial fishery primarily focus their activities in the areas of boat building and repair, engine sales and maintenance, electronics, nets and gear, general hardware, provisions and services. In 1971, it was estimated (Hedlin Menzies, 1971), that their activities grossed approximately $31 million dollars annually on an average investment of 15 million dollars, and employed about 750 persons. Since that time, prices have escalated sharply. Today it is likely that total expenditures are approaching $100 million annually.

II. RECREATION OPPORTUNITIES AND VALUES FOR RESIDENTS

In a recent federal-provincial study of urban recreation in British Columbia (Meyer, 1978), Greater Vancouver residents identified "getting rid of tensions and frustrations", "maintaining close contact with nature", and "maintaining health" as those attributes of recreation "most needed" in the urban future. Activities found in the study to contribute most strongly to these satisfactions are listed below.

Getting Rid of Tensions and Frustrations	Close Contact with Nature	Physical Health
Reading	Hiking	Swimming
Hiking	Camping	Hiking
Fishing	Fishing	Skiing
Beach Activities	Gardening	Tennis
Travel	Beach Activities	Individual Sports

It can here be observed that sport fishing and beach activities play a key role in the recreational aspirations of Vancouver residents. The study concludes:

> "The shoreline has traditionally served as a line of demarcation, shielding things "natural" and "quiet" from the typical urban inundation of land. Relatively natural and quiet recreational opportunities are still available off metropolitan shores, saving the urban resident the stresses of prolonged accessing travel. The continued viability of the Fraser River and of other major coastal streams in southern British Columbia - and their consequent ability to funnel recreational salmon and steelhead literally past the urban doorstep - combines with marine access opportunities to provide a major recreational asset for city residents on the coast."

This ocean shore opportunity is, of course, provided by nature. But access to it for public, and particularly public recreational purposes is controlled and can be foreclosed by man. Such foreclosure would, it is believed, accelerate the pace and pressures of living for urban Vancouver residents, with attendant impact upon physical and mental health and upon traditional social instabilities. Direct public use of the estuary and near estuarine areas extends through sport fishing on streams or sand bars (Eddie, 1973), crabbing, hunting, nature study and appreciation, strolling, picnicking and swimming to salt water sport fishing and boating (Mos and Harrison, 1974).

Fishery resources dependent upon the Fraser river and its estuary have recreational importance well beyond that associated with residency in the Lower Mainland. A report undertaken in 1974 (Meyer, 1974) and recently updated (Meyer, 1978) identified mean annual household values for Fraser River salmon and steelhead, associated with recreational opportunities. Analysis of study data showed that residents of the Fraser River drainage basin, living from river mouth to headwaters, placed a recreational activity value of $90 million annually on the river's salmon and steelhead (Table 2). It is estimated that this value, if extended over the next 70 years, would amount, in present terms, to $6.3 billion. In addition, residents associated an additional $111 million annually with <u>preservation</u> of salmon and steelhead stocks on the river.

RECREATION AS A BUSINESS

In addition to the direct satisfactions and values enjoyed by British Columbians due to the recreational opportunities provided by a viable riverine and estuarine environment on the Fraser River, there are significant business opportunities associated with nature based recreation. It is estimated that resident boaters spent $104,000 on capital items during 1975 (Fisheries and Environment Canada, 1978). Sport fishing was indicated as a primary boating motivation by 86 percent of residents (Mos and Harrison, 1974) - and most of these residents live and recreate in areas proximate to the migratory path of Fraser River salmon and steelhead. Further, it is estimated that the B.C. residents spent $83 million on sport fishing directly in 1975 (Fisheries and Marine Service, 1977).

Tourists are also attracted to British Columbia by her comparative advantage in natural amenities - scenery, fish and game. A major recent national survey (Fisheries of Environment Canada, 1978) estimated that a further $27 million was spent directly on sport fishing in British Columbia in 1975 by tourists visiting the province. Because Fraser fishery stocks traverse the rivers and coastal waters of the south-western portion of British Columbia - where both residents and tourists are found in greatest concentrations, a significant part of tourist effort and expenditure would be directed toward them.

III. FRASER RIVER SALMON AND STEELHEAD AND THE NATIVE INDIAN

There are ninety-one Native Bands with an on-reserve population of 11,800, and a full population of 17,900 located on the Fraser River area. This represents 48 percent of the total bands and 37 percent of the total population of Native people in British Columbia (1972).

There is no accurate method of measuring in dollars the losses to the Native peoples of the Fraser River Basin resulting from degradation of salmon stocks. In 1973, a study of the cultural relationship between Native peoples and the salmon of the Fraser River - jointly sponsored by the Department of Fisheries and Environment and the Union of British Columbia Indian Chiefs was completed (Bennett, 1973). The following excerpt summarizes the cultural and subsistence role identified by Fraser River bands.

> "The fishery resource provides part of the food supply for a very high proportion of Indian families. If the fishery were adversely affected, a large number of Indians would be without sufficient food. It is doubtful whether

> alternative forms of sustenance would be acceptable. Most of those sampled said they would not substitute other foods in place of fish in their diet. Furthermore, because of the fact that fishing is a fundamental part of their lives, the loss of the fishery would detach the Indian people from the culture which they have developed throughout the centuries."

The Native peoples of the Fraser River have a direct and historic interest in the salmon stocks of the Fraser River system, and can be identified as possessing a major vulnerability with regard to negative impacts upon the system. To the degree that said stocks are also taken for food and for ceremony by other native peoples in British Columbia - they will also be similarly vulnerable.

A SUMMARY - ECONOMIC AND SOCIAL VALUES OF THE FRASER RIVER FISHERY

The preceding sections have outlined in general terms the multitude of benefits, economic and social, provided by the fisheries of the Fraser River system. Its $86 million annual salmon catch, and its undetermined contribution to herring and other fishery species render it critical to the economic survival of the British Columbia fishing industry, 17,000 fishermen and shoreworkers, and their families. It also provides badly needed economic opportunity for native peoples, and for the residents of remote communities. Because of its importance to the commercial fishery, it occupies a critical position in dictating the profitability of a <u>$100 million</u> support industry. On the recreational side, it plays a large part in support of private boating expenditures of about $187 million annually - and sport fishing expenditures by tourists estimated at <u>$27 million</u>.

An overall dollar value figure for Fraser River salmon on steelhead cannot be precisely determined - for while some of the values presented here are system specific, others relate to the whole of British Columbia. However, in noting that Fraser stocks contribute 25 percent of British Columbia's total salmonid production, that these benefits are broadly dispersed, and that most of resident and non-resident recreational activity is concentrated in areas adjacent to the salmon's migratory path, it appears likely that the system's fishes may directly support economic activities in excess of <u>$200 million</u> annually.

The above figures are substantial. They do not, however, represent the only important benefit area provided by the river. The Fraser River estuary and foreshore, in combination with the marine life they sustain, provide the types of recreational satisfactions deemed "most needed" in the future by Vancouver residents. More broadly, residents of the Lower Mainland have joined with those from upriver communities to describe their satisfaction from the river's salmon and steelhead as "worth" $90 million and $111 million for participation and preservation respectively. These estimates thus provide an additional $200 million to the dollar measures of importance reached previously.

Finally, and most importantly in terms of impact on individual rather than group, the salmon and steelhead of the Fraser River have been interwoven into the subsistence and cultural patterns of Indian peoples for centuries. The Indian people view salmon as part of their "Indianness". It is highly unlikely that they would view substitutes as even remotely satisfactory.

THE VALUE OF THE FRASER FISHERY, AND CHANGES IN THE ESTUARY

The final concern of this study is not the aggregative economic and social values that are associated with the fishes of the Fraser system. Rather, it is the value of one component of that system - the estuary - and more importantly, what effect changes in the amount of estuarine habitat available may have on the values noted above. It will be discovered in this report that these answers are only generally known. It is known that the estuary is an important and often critical component of required habitat for salmonids and several other species. But the complexities of the biological system, its variability, its dynamic nature - both in terms of its own evolution, and of the impacts upon it by man - difficulties of empirical observation, and the only recent focussing of scientific attention in this area, mitigate against precise estimates of biological "capacity" or impact results from enhancing or deleterious actions. The direction of result can be suggested, together with the judgement that marginal improvements to the estuary will likely have less economic and social impact than marginal decrements (Meyer, 1974). But exact cause and effect estimates of impact are unlikely, and even where obtained, will not prove broadly applicable.

Resource management on the estuary is thus an exercise in decision making under risk. The results presented in this section indicate that these risks, when applied to future development of the Fraser foreshore in a manner deleterious to estuarine habitat, are of major proportion.

It is also relevant to know how the people resident in the Fraser River basin view such risks. In a recent random sampling of households in Greater Vancouver and Prince George (Meyer, 1978), residents were asked, in light of other potential uses for Fraser waters, some of which could be deleterious to fish, at what level future salmonid stocks should be maintained. Ninety-nine percent of residents called for salmonid stocks to be protected or increased. Fifty-two percent of those replying called for the strongest possible increase in salmon and steelhead stock levels.

In considering this public sentiment, and the major value estimates earlier identified, a number of socio-economic strategies for management of the Fraser estuary can be identified.

<u>To Maximize the Probability of Benefit</u>

1. Foreshore uses that are compatible with continued estuarine viability should receive favourable treatment. In particular, the recreational potential of the foreshore has been identified.

2. Where possible, available estuarine area should be increased, and degraded estuary area should be restored.

<u>To Safeguard the Values Already Dependent Upon the Estuary</u>

1. Uses that are clearly harmful to estuarine habitat should not be permitted.

<u>To Minimize the Risks of Economic and Social Costs Where Alternative Uses May be Harmful</u>

1. Uses which <u>may</u> harm the estuary should <u>only</u> receive consideration where it is demonstrably clear that the benefits to British Columbians and to Canadians will be significantly greater and of longer durability than potential values risked by the development.

2. Potentially harmful uses should not be considered if reasonable alternative locations exist for siting.

3. If the possibility of estuarine damage is suspected, smaller scale uses should be given preference over larger scale uses.

4. Uses which may be harmful, and which are clearly irreversible, should not be permitted.

It is considered that such strategies will, under conditions of uncertainty, permit more effective use of the Fraser River estuary and/or adjacent areas, but also protect the major economic, social and cultural interests presently dependent on it.

C. AGENCIES INVOLVED IN MANAGEMENT AND PROTECTION

The management, utilization, and conservation of fish and fish habitats in the estuary is of concern to seven provincial, federal, and international agencies or offices (Table 3). Because of the biological complexity of the estuarine ecosystems, a host of environmental factors relate directly or indirectly to fish habitat. In the present paper, however, we have only listed agencies who actually handle fish or are concerned with food webs which supply fish with energy.

D. FISH COMMUNITIES

The species composition of fish communities in the estuary apparently varies with the penetration of saline water in the salt wedge from the Strait of Georgia. Because physical conditions in the estuary apparently change rapidly with time and space (see below), it is difficult to set exact boundaries for the biological communities. It should also be understood that the communities overlap as a continuum exists between them.

Eighty-six species of fish have been reported from the study area (Levings, 1973; Northcote, 1974; Goodman, 1975; Birtwell, unpublished). When the species lists generated for Sturgeon and Roberts Bank and for the lower mainstem river are compared, 29 species (Table 4) have been reported from the Banks and the river and hence might be arbitrarily declared estuarine species because of either residence or migratory features. No systematic sampling of fish has been conducted in Boundary Bay so species composition data are not available for that area. Of the estuarine taxa, 5 species of salmon, 2 trouts, 1 char, herring, eulachon, surf smelt, and white sturgeon are of direct commercial and/or aesthetic significance and hence will be discussed in detail. It should be pointed out that even though the other 56 species do not rate detailed mention here, they may be of major importance ecologically. For example, the staghorn sculpin (*Leptocottus armatus*) may be a significant predator on young salmonids (Dunford, 1975). There are few data, however, on such interspecific interactions within the estuary.

Over 300 different taxa of invertebrates have been reported from the estuary (Levings and Coustalin, 1975; Northcote et al., 1976). Most are important for their role in food chains (see below) leading to species of economic interest. The invertebrates of direct commercial concern within our study area are relatively few: Dungeness crab (Cancer magister), pink shrimp (Pandalus jordani), 6 species of bivalves (oysters, Crassostrea gigas; butter clams, Saxidomus giganteus; little necks; Venerupis japonica, Protothaca staminea; the heart cockle, Clinocardium nuttallii), and the soft-shell clam (Mya arenaria). The Dungeness crab is fished along the drop-off of Sturgeon and Roberts Bank (see below). Bivalves in Boundary Bay are not utilized because of sewage pollution. Ghost shrimp (Callianassa californiensis) are harvested on Roberts Bank and Boundary Bay for fishbait.

E. LIFE HISTORY AND MIGRATIONS OF "SIGNIFICANT" FISH IN THE ESTUARY

Many of the existing data on this topic, mostly from Fisheries and Marine Service (Environment Canada) files (Fig. 1) have been brought together by Northcote (1974) on which the following account is based.

"Numerically, usage of the lower mainstem river is dominated by the several million eulachon adult and several billion juvenile migrants confined largely to spring months (March to June). Next in numerical importance are the pink salmon, averaging over 5 million adult migrants (only on odd-numbered years) and some 220 million migrants (only on even-numbered years). These are widely separated in time, both seasonally as well as yearly, since there are virtually no adults or juveniles on the respective "off" years. Usage of the river by sockeye adult migrants is somewhat greater and later on a 1902 cycle year compared to other years which are roughly similar, at least in timing if not in numbers. Recent output of sockeye juveniles (smolts) average some 45 million annually, migrating down the lower river between March and June. Some half million chum salmon adults move up the river between September and December, much later than most other species of salmon, whereas their young (about 27 million) move downstream in the spring at about the same time as the other young salmon. Coho and chinook salmon usage is similar in numbers, both for juveniles and adults, although upstream passage of chinook adults is much more spread out over the year. Usage of the river by steelhead trout migrants includes an extended period of upstream adult movement (summer and winter steelhead) and a downstream passage of both juveniles (smolts) and adult post-spawners (kelts). The numbers involved are not large, compared to salmon, but recreationally this species has considerable importance. Too little is known of the timing or magnitude of cutthroat trout runs to present even an approximation of their migratory usage of the lower river. Roughly their timing should follow that of the steelhead, with perhaps a third as many fish involved."

I. DISTRIBUTION OF JUVENILE SALMONIDS IN THE ESTUARY

Juveniles of three salmonid species (coho, chinook, chum) have been found in "significant" numbers in the estuary, and are considered to be estuarine residents. The effort dedicated to sampling, however, has been minimal to date considering the size of the area. Useful data on the timing, migration, and population size of the various species have been obtained through sampling programmes at Mission (e.g. Todd, 1966), but no concerted effort has been directed to obtaining these data downriver. Dunford (1975) and Goodman (1975) have presented the only published data on catches of juvenile salmonids in the estuary, and their reports were utilized in preparation of the following discussion.

Millions of pink and sockeye juveniles move down through the estuary, but because surveys were conducted in years when pinks were not moving (Figure 1) through the estuary, few have been recorded to date. Beach seine catches for juvenile chum and chinook were significantly higher at sites characterized by well-developed marshes (e.g. Duck-Barber-Woodward Island complex) compared to shorelines where vegetation was reduced because of natural or man-made disruption (e.g. several North Arm stations) (Table 5). There were no differences in tow-net catches for these two species when slough catches (e.g. Deas Slough) were compared with mid-channel (lower mainstem river, e.g. Woodward Reach) tows (Table 6). There were no marked spatial differences in catches of coho juveniles in tow net samples (Table 6).

Sampling for juvenile salmonids on Sturgeon and Roberts Banks showed that chum catches in tow nets are similar to those from the lower mainstem river (Table 7). Differences between "nearshore" (marsh) and open-water (mid-tide) habitats were not marked. Coho and chinook, however, were approximately twice as abundant in nearshore habitats (Table 7).

II. UPSTREAM MIGRANTS AND FISHING

Adults destined for Fraser spawning areas are taken outside the estuary, of course, in waters off Vancouver Island, in the Strait of Georgia, and the Strait of Juan de Fuca.

The following table shows the magnitude of adult fish populations caught in or passing through the estuary. These data do not include Fraser River fish caught elsewhere or fish caught for recreation.

Species	Catch in Estuary and[1] Adjacent Strait of Georgia	Escapement to Spawning Grounds
Sockeye	805,000	1,284,000
Pink	364,000	1,657,000
Chum	110,000	488,000
Coho	37,000	58,000
Chinook	92,000	72,000

All of the commercial fishing for salmonids in the estuary is with gillnets, and in recent seasons approximately 600 boats/ year have fished in the lower river. About 80% of the fishing effort occurs in the lower mainstem river (South Arm) and the remainder is expended in the Ladner-Sea Reach and North Arm Channels. After setting nets in the South Arm, gillnetters often drift downstream and out into the Strait of Georgia (past Sand Heads). Physical features, both natural and man-made, can influence fishing success in the river. For example, after construction of the Surrey Docks near New Westminster, salmon aggregated in the "box" formed by the structures. The seasonal course of fishing follows patterns established by the biology of the various species involved (see above). Timing and management of the fishing is shared by the Fisheries and Marine Services, Environment Canada (FMS), and the International Pacific Salmon Fisheries Commission (IPSFC). Strategies for management (e.g. numerical strength of the various races or stocks) are determined primarily by test fishing in the estuary (Cottonwood Reach-Deas Island area), patterns of catches in the commercial fishery, and "offshore" (Juan de Fuca, Strait of Georgia, and Johnston Strait) catches. The fishing season usually opens mid-April and focuses on chinook. Usually one day per week of fishing is allowed by FMS until about mid-June when pink (odd years only) and sockeye begin to enter the river. Control of fishing then shifts to IPSFC which usually allows two or three days per week until mid-September. The use of large mesh nets is controlled so that chinook catches are minimized. After mid-September, control of the estuarine fishing reverts to FMS which manages the autumn fishery for coho and chums. The fall fishery can persist as late as December, and effort is regulated by the number of fish returning. Steelhead trout are caught incidentally in the commercial fishery, primarily in late summer and fall (Ogus and Andrews, 1977).

Footnote: 1. Data are long-term (>20 yr.) averages for cycle years of sockeye; for coho, chum, chinook 1972 to 1977; and for pink 1969 to 1977 (odd years only). Data are updated and supersede those cited by Northcote (1976) (see above).

Eulachon are caught in the estuary by gillnetters during April and May and in recent years about 45 boats were involved in this fishery. Recreational gillnetting and dipnetting is conducted from shore for both eulachon and smelt. White sturgeon are taken in the estuary incidentally during salmon gilnetting, and a sport fishery for the species is pursued further upriver.

Recreational fishing for cutthroat trout, dolly varden, coho and chinook takes place on sand bars in the estuary. Usually the "jacks" (precocious males) of the latter two species are caught with baited pots and usually about ten boats, with about 30 pots per boat, are engaged in the fishery. Crab fishing is usually at its peak in summer. Recreational crabbing occurs in Boundary Bay and Roberts Bank. Beam trawling for shrimp (Pandalus jordani) takes place close to the "drop off" of Sturgeon Bank, at the mouth of the North Arm.

F. FEATURES OF THE AQUATIC ENVIRONMENT RELEVANT TO FISH ECOLOGY

I. TEMPERATURE, SALINITY, OXYGEN

The permanent fish fauna of the estuary, in common with other estuarine assembages, is adapted to rapid changes in salinity and temperature. The migratory salmonids, however, are generally considered "sensitive" species, and are adapted to a relatively narrow range of temperature, salinity, and oxygen conditions. Data from the lower mainstem river (Fig. 2) are used to show the range of conditions that fish in the upper layers of the mainstem river are exposed to. In mid-winter, with low flow conditions, saline water from the Strait of Georgia penetrates under the fresh upper layer in a typical "salt wedge" configuration, and traces of sea water have been recorded upstream as far as Annacis Island. In 1973, surface salinities decreased from approximately 10 $^{o}/oo$ to 0 $^{o}/oo$ as the spring runoff became more intense (Fig. 2). Dissolved oxygen values fluctuated within the range 10 to 12 mg l^{-1}. Temperature values ranged from a low of 2^{o}C in February to 14^{o}C in June. Considerable year to year fluctuations in these variables might be expected as timing and magnitude of changes are very dependent on river runoff. Conditions in the North Arm and sloughs such as Tilbury Slough, which receive less runoff than the mainstem river, would also display quite different seasonal changes in properties. (See below).

Available information from Sturgeon and Roberts Banks shows that channel configuration, both natural and constrained by man, can influence the distribution of fresh water as it flows seaward over the Banks (Levings and Coustalin, 1975). During freshet in 1973, surface salinities over Sturgeon Bank were generally less than 15 ^{o}/oo, and ranged down to zero. Surface waters are usually saturated with dissolved oxygen because of mixing with air on rising tides (Otte and Levings, 1975).

Surface salinities in Boundary Bay are not dramatically influenced by Fraser River runoff. The few data available show that salinities are higher than over Sturgeon Bank. Fresh water from the Serpentine, Nikomekl, and Little Campbell Rivers can modify conditions near the mouths (Fig. 3).

II. CURRENTS AND TIDES

Current speeds in the estuary are extremely variable because of fluctuations in tidal amplitude, river runoff, and the effects of nearshore features (e.g. docks, sandbars). Surface speeds in the lower mainstem river reach their maximum (up to 360 cm s^{-1}; B.C. Pilot) when the river is in full freshet (usually in June), when most of the downstream migrants have presumably passed through the mainstem river (Fig. 1). Stronach (1977) recorded surface currents in the order of 150-200 cm s^{-1} at Sandheads during the 1976 freshet. An analysis of Water Survey of Canada data showed that during May (1976), when juvenile salmon of all species were migrating downriver, current speeds in the mainstem river were in the range 90 to 100 cm s^{-1} on falling tides (these data are based on values averaged through the water column of the river and absolute surface values were probably much higher). Speeds in Williamson Slough were approximately 60 cm s^{-1} (Levings and Chang, 1977).

When adults are migrating upstream in autumn, surface speeds at low water are in the order of 100 to 150 cm s^{-1}. Migrating fish may also travel in the salt wedge (when present) where speeds are probably much lower and currents in fact may be predominantly upstream on rising tides. Gillnet catches are usually higher on rising tides, suggesting that returning adults capitalize on reduced currents on flooding tides or follow these tides through behavioural preferences. Currents over Sturgeon and Roberts Banks are also extremely variable but are very reduced compared to those in the river channels. Tidal currents over the Banks flood north and ebb south, parallel to the bottom contours. Average speeds are in the range 5 to 10 cm s^{-1} (Thomson, 1976).

From this review of current regimes in the estuary, it is obvious that migratory salmonids are well adapted to temporal and spatial changes in velocities throughout the estuary. More juveniles were observed in areas characterized by low current speeds (backchannels, marshes) where food is presumably most abundant and "available" (see above). The migration of adults of almost all salmonids reaches its peak after freshet. It is possible this is an adaption so that energy reserves for upstream swimming are conserved for movements further upriver.

III. CORRELATIONS OF FEATURES WITH VEGETATION

Current speeds, sediment distribution, and distribution of vegetation all interrelate to provide habitat and food for juvenile salmonids. This topic is addressed in some detail below. In certain sectors of the lower mainstem river and on the Banks, at sites where current speeds are decreased, fine sediments accumulate and marsh vegetation (especially sedge) is able to colonize and spread. The marsh plants produce detritus which can be used as food by invertebrates which in turn are utilized by fish.

On more saline sectors on the offshore banks (e.g. south Roberts Bank) and in Boundary Bay, eel grass beds (primarily *Zostera marina*) are found in the intertidal and subtidal zone. These plants, which are more typical of marine embayments than estuaries, provide habitats for very productive and diverse invertebrate communities. The eel grass beds are also important spawning substrates for herring, which deposit eggs during late winter through early spring. Over the period 1967 to 1973, Boundary Bay contributed to between 1% and 57% of the herring spawn in the southern Strait of Georgia (Webb, 1974).

G. IMPACT OF ENVIRONMENTAL CHANGE ON FISH ECOLOGY

I. WATER QUALITY CONCERNS

(i) Dissolved Oxygen

The dissolved oxygen requirements of fish and invertebrates have been thoroughly reviewed by Davis (1975). He devised "levels of protection" of dissolved oxygen levels which would protect major fish groups. For example, the minimum dissolved oxygen level designated as "more or less ideal" for freshwater salmonid populations is 7.75 mg O_2 l^{-1} (85% saturated at 20°C). Salmonid larvae and mature eggs of salmonids require dissolved oxygen levels of 9.75 mg l^{-1} (100% saturation at 20°C).

Studies in the lower mainstem river indicate that dissolved oxygen levels in the mainstem river are generally above 90% saturation (see above). Lower dissolved oxygen levels have been recorded in the North Arm (Hall *et al.* 1974) which could be attributed to discharges of untreated domestic, industrial and stormwater effluents. Significantly lower dissolved oxygen values have been recorded in some backwater areas of the Fraser. Dissolved oxygen levels as low as 0.5 mg 1^{-1} were recorded in Tilbury Slough in 1976, and anoxic conditions were recorded in deep water pockets in Deas Slough in 1976 and 1977 (FMS unpublished data). The BOD and total organic carbon (TOC) levels in the mainstem Fraser are also generally low (1 to 4 mg 1^{-1} BOD and from 1 to 11.2 mg 1^{-1} TOC; Hall et al. 1974) but in backwater areas can be considerably greater. Total organic carbon levels, for example, as high as 700 mg 1^{-1} were recorded in Tilbury Slough in 1976 (FMS unpublished data) compared with values of 2 to 14 mg 1^{-1} in the Fraser River. Such low dissolved oxygen levels and high carbon content indicate that certain backwater habitats may be considerably less than optimal for salmonids and other aquatic organisms. The alteration of flow and flushing patterns so the discharge of effluents to these areas could act to further degrade and alienate these habitats. Unless mitigative measures are taken, alterations of flow patterns such as would occur with the installation of river training walls could modify flow regimes in some of these habitats and possibly create additional poorly-flushed backwater areas which could also experience reduced dissolved oxygen problems.

(ii) Chlorinated Effluents

Over 25 outfalls discharge large volumes of chlorinated effluent into the Fraser River downstream of Hope, and are of concern since the toxic effects of this effluent are well documented (Brungs, 1973; Mattice and Zittel, 1976). The toxic nature of chlorinated water is primarily related to the amount of total residual chlorine which is equivalent to the amount of free residual chlorine plus the combined residual chlorine (Mattice and Zittel, 1976). Brungs (1973) suggested that residual chlorine levels should not exceed 0.002 mg 1^{-1} in receiving waters in most aquatic organisms are to be protected.

Martens and Servizi (1974) found that chlorination of effluent from the Lulu Island sewage treatment plant increased the toxicity of the effluent to sockeye salmon fingerlings. In a later study, Martens and Servizi (1975) demonstrated that dechlorination of the Lulu Island effluent reduced the chlorine-induced toxicity. Recently, Servizi (1977) determined that effluent from the Annacis Island treatment plant was highly toxic to fish despite dechlorination which suggests that factors other than chlorine contributed to the observed toxicity.

As part of a field program designed to measure the effects of chlorinated sewage effluent from the Iona Island sewage treatment plant, a series of in situ bioassays with juvenile chinook salmon were carried out in 1976 (FMS, unpublished data). Bioassay cages were placed at the following selected distances downstream from the sewage outfall: 0 m (outfall), 500 m, 915 m, 2,400 m, and 4,025 m. The results of the bioassays are illustrated in Table 9.

TABLE 9. Results of in situ bioassays with juvenile Chinook salmon; August 16-20, 1976, Iona Island

Distance from outfall (m)	No. of Fish	% Mortality at Time				
		0	24	48	72	96 (hr)
0	10	0	100	100	100	100
550	10	0	100	100	100	100
915	10	0	100	100	100	100
2,400	10	0	0	0	100	100
4,025	10	0	10	10	*	100

*Not determined

These data illustrate the toxic nature of the waters receiving sewage from the Iona Island sewage treatment plant. The exact cause of the mortalities, however, is unknown. Residual chlorine levels between 0.1 and 0.3 mg l^{-1} were recorded in effluent collected at the outfall.

Sub-lethal effects of residual chlorine have also been documented in the literature as well as avoidance and preference reactions in fish to chlorinated water. Buckley (1977) observed sub-lethal stress in fingerling coho salmon exposed to fluctuating levels of total residual chlorine averaging 0.003 to 0.012 mg l^{-1}. Symptoms of hemolytic anemia were noted along with other specific blood chemistry changes. Sprague and Drury (1969) noted avoidance reactions in rainbow trout to chlorine concentrations between 0.01 and 1.0 mg l^{-1} and a preference to lethal concentrations of 0.1 mg l^{-1}.

Although much attention has been given to the toxic effects of residual chlorine it is only recently that concern has been raised about the formation of stable organochlorinated compounds via the chlorination process. These compounds may be acutely toxic and could accumulate in fish tissues. Gehrs *et al.* (1974) found that two chlorinated compounds, 5-chlorouracil and 4-chlororesorcinol caused a significant decrease in the "hatchability" of carp (*Cyprinus carpio*) eggs at concentrations as low as 0.001 mg l^{-1}. Many toxicants can be formed spontaneously during chlorination. For example, in the presence of "excess" chlorine, benzene can form endrin, terpene can be transformed into toxophene, and phenol can react with chlorine to yield pentachlorophenol (Katz and Cohen, 1976).

(iii) Leachates

Leachates from sanitary landfills and woodwaste or hogfuel deposits can be very toxic and can contribute substantial quantities of contaminants to the Fraser River. The problems associated with woodwaste landfills include "toxicity, metal content, colour, pH, TOC, BOC, gaseous emissions and aesthetic, such as 'oil' films and black deposits" (Econotech Services Limited, 1976). Leachates from one hogfuel deposit adjacent to a tributary of the Fraser River were found to be highly toxic (96 hr. LC 50 = 10%) in a laboratory bioassay with juvenile rainbow trout in 1977 (FMS unpublished data). The leachate was darkly coloured with a pH of 4.4 and a TOC level of 2,400 mg l^{-1}. Leachates from a sanitary landfill adjacent to the Brunette River, a tributary of the Fraser River, were toxic in a bioassay carried out in 1976 with coho salmon fry (96 hr. LC 50 = 24%) (FMS unpublished data).

(iv) Chlorinated Hydrocarbons

Albright et al. (1975) collected samples of fish, crab and shellfish from the lower Fraser River and Georgia Strait in 1972 and 1973 and analyzed them for chlorinated hydrocarbon content. They determined that PCB and p, p'-DDE were of major importance in the samples analyzed and found that "...the average PCB and p, p'-DDT residues in fish species from the estuary... were significantly greater than those from the upper portion... of the Fraser River". The authors suggested that the most likely source of PCB's was from surface runoff and domestic and industrial effluents. In a more recent study, Johnston et al. (1975) measured chlorinated hydrocarbon levels in muscle tissue from 12 species of fish in the Fraser River downstream from Hope. Levels in most fishes from the lower Fraser River were "...either below limits of detection or, if present, were very low". Levels of PCB were the highest of all organochlorine compounds measured with a maximum of 3.69 ppm recorded in a large scale sucker and an overall mean of 140.7 ppb for all samples. Levels of PCB were higher in several species of fish in the lower river than those from upstream stations implying that the large urban-industrial greater Vancouver area is a source of these compounds. Bawden et al. (1973) recorded a PCB level of 2.72 ppm (dry wt.) in an oyster from Roberts Bank in 1972.

(v) Metals

Northcote et al. (1975) determined the concentrations of 11 heavy metals in selected species of fish in the Fraser River and stated that "...the levels of most trace metals detected in lower Fraser fishes do not suggest that...there is serious contamination from these materials at least in the mainstem river". However, the occurrence of mercury levels as high as 2.19 ppm (wet wt.) in prickly sculpin and 1.99 ppm (wet wt.) in northern squawfish is of concern and suggests that considerable quantities of mercury are entering the Fraser River.

A recent study by Lorz (1977) illustrates the possible serious consequences to salmonids of exposure to sub-lethal levels of specific metals. Lorz found that short-term exposure of yearling coho salmon in freshwater to total copper levels of 5 to 30 ug l^{-1} "...caused a reduction in percentage of downstream migrants compared to controls when the coho yearlings were exposed to a natural stream" in Oregon. In addition, he found that the percent survival of yearling coho when placed in seawater decreased in proportion to the concentration of copper the fish were exposed to in fresh water and demonstrated osmoregulatory problems resulting from copper exposure. Although direct comparison cannot be made, the possible implications of these results for the Fraser River system are worthy of consideration. Levels of acid extractable copper in some affluents discharged to the Fraser River far exceed the 5 to 30 ug l^{-1} copper levels used by Lorz. Hall et al. (1974) for example, found copper levels in Fraser River water samples which ranged from <1 to 14 ug l^{-1}.

(vi) Particulate Substances

Particulate material enters the Fraser River and estuary in forms such as suspended sediments, coal dust, fly ash, sawdust, and wood debris.

A preliminary study by Pearce and McBride (1977) indicated that the coal content in sediments around the Roberts Bank coal terminal had increased slightly since 1971. In laboratory experiments, coal particles were found to accumulate in the spaces between gill lamellae of Dungeness crabs exposed to higher concentrations of coal (Pearce and McBride, 1977).

Discharges of effluent containing high suspended sediment levels can pose severe problems to fish and other aquatic organisms. In the Coquitlam River, a major tributary to the Fraser River, drastic declines in salmon runs are believed to have resulted from suspended sediment discharged from gravel mining operations. Wood and bark debris from booming and sawmilling operations can smother benthic invertebrates, and because of the high BOD associated with bark deposits (Pease, 1975) can lower dissolved oxygen levels. This problem could be most serious in sloughs and poorly flushed areas (e.g. Deas Slough).

(vii) Training Walls and Channelization

Based upon the probability that particular estuarine and riverine characteristics would change as a result of the installation of training walls, Fisheries and Marine Service, in cooperation with the Department of Public Works, initiated a number of studies between spring, 1976 and September, 1977. These studies were to provide some baseline biological and chemical data that would be used in assessing the effects of the proposed training walls and hence assist management decisions.

Emphasis was focused upon those areas of reduced water velocity where water and sediment quality may change after placement of the training walls. Tilbury Slough and Deas Slough were chosen as the main study areas, and for comparative purposes, adjacent areas in Tilbury Reach, Ladner Reach and in the Fraser River were also selected. An area behind the training wall in Woodward Channel was studied and compared to a similar area at the entrance to Ladner Reach.

The studies of fish in Tilbury and Deas Slough included the determination of species composition, age structure, abundance, distribution, growth rates of juvenile age classes and gut content analysis. Differences in these factors between river and slough habitats as well as temporal changes were monitored for one year. The survival of fish, and their vertical distribution in relation to water quality changes were also examined in Deas Slough. Furthermore, a laboratory study was initiated in relation to the salinity tolerance of fish and invertebrates.

(a) Fish utilization of the intertidal zone

Salmonid utilization of the intertidal slough habitats differed between 1976 and 1977, perhaps reflecting the cooler summer in the former year. In Deas Slough, juvenile chinook salmon were consistently found in this area until December 10 in 1976, but only to July 8 in 1977. In the adjacent Fraser River areas, the same species of fish were present until September 17 in 1976 and July 8 in 1977, perhaps indicating the importance of Deas Slough as a rearing area. The last sockeye fry (fish less than 1 year old) were recorded in Deas Slough on October 8, 1976 and September 2 in 1977, and in the adjacent Fraser River, to September 17 in 1976 and September 2 in 1977.

Fish population changes in the littoral zone of the sloughs were often significant with respect to numbers of individuals and species composition, reflecting the seasonal changes in populations.

Deas Slough was divided into an upper and lower section for comparative purposes. Population size estimates were derived for the littoral zone of these sections based upon beach seine catches. This was done for each species independently, at the point in time when its population size reached a maximum in each particular section. Table 9 indicates the maximum population size of each species that was observed to utilize the littoral zone of the particular section in the Deas Slough study area: population size estimates (for 4.95 ha.) along the adjacent Fraser River shoreline are also included for comparative purposes.

There were significant differences in the number of species of fish utilizing the sloughs and adjacent shoreline areas in the Fraser River. Only 14 species of fish were recorded in Tilbury Slough and 27 in Deas Slough, whereas 24 species were recorded in the mainstem of the Fraser River. These differences probably relate not only to the methods of capture but also to the differing water quality conditions between the sloughs and the Fraser River. For example, in Deas Slough, which is permanently flooded (cf. Tilbury Slough), white sturgeon, black crappie, brown catfish and longnose dace were captured. These species of fish were not caught at the proximal riverine sampling sites. The warmer water in upper Deas Slough was probably the predominant factor influencing the presence or absence of certain species in this location. Significant differences were found in the relationship between the length and weight of particular species of fish utilizing slough and riverine area; for example, peamouth weighed more for a given size in Tilbury Slough than in the adjacent riverine area. Further computations are being carried out to determine differences in the growth rates of age 0+ and 1+ fish between slough and riverine habitats.

(b) Fish utilization of mid-water zones

Fish were collected using gill nets at mid-water sites in the Deas Slough study area. Only 19 species of fish were caught, and marked differences in catches between sampling occasions were primarily associated with changes in the populations of migratory fish. Of particular note was the relative lack of use of the sloughs by migratory adult salmonids. However, cutthroat trout and dolly varden char were caught by gill net in the Slough, but not in Ladner Reach. Sturgeon were also captured in the Slough, but not in the river, and similarly, large scale suckers, redside shiners, prickly sculpins and black crappies were only present in the gill nets that were set within the slough.

In general, the data illustrated the relative importance of slough habitats for many species of fish in contrast to the riverine areas.

(c) Water and sediment quality

Water quality changes between the slough and riverine areas were frequently marked, especially in the Deas Slough study area where both vertical and horizontal changes occurred. Quite frequently, the waters of upper Deas Slough were warmer by 4°C than the adjacent waters of Ladner Reach Dissolved oxygen levels were frequently at air saturation in the surface waters, but in depth, oxygen depletion was a common phenomenon. During stratified conditions, dissolved oxygen depletion occurred, frequently creating anoxic conditions in the deeper waters of Deas Slough. Similar depressions of dissolved oxygen levels, though not as severe as in Deas Slough, were occasionally found in Tilbury Slough. Whereas dissolved oxygen, temperature, pH, oxidation-reduction potential, salinity and water clarity were determined at each fish capture site on every occasion in Deas Slough, in order to relate to fish population changes, growth, etc., a more detailed water and sediment quality study was also undertaken in both Tilbury and Deas Slough.

To date, the water chemistry data have not been thoroughly analyzed.

(d) In-situ bioassays

In view of the vertical changes in water quality in Deas Slough, experimental techniques were used to determine if the water quality conditions at different depths affected certain species of fish. In-situ bioassay experiments were performed with juvenile chum and chinook salmon and starry flounder at 1 m, 5 m and 8.5 m depth. Survival of the salmon appeared to be primarily related to dissolved oxygen levels; greater mortalities occurred at depth where dissolved oxygen levels were depressed.

(e) Laboratory Bioassays

Bioassays were carried out in 1976 at the Pacific Environment Institute. The salinity tolerance of 5 species of fish and two species of crustaceans was determined as a preliminary step towards the identification of any problem which might arise if salinity and temperature changes were to occur as a result of the installation of training walls. Large-scale suckers and brassy minnows, were killed by salinities of about 12^{o}/oo, while crayfish were killed at salinities between 12 and 16^{o}/oo. Prickly sculpins were euryhaline tolerating salinities from freshwater to 29^{o}/oo. The staghorn sculpin tolerated salinities down to between 1.0 and 0.5^{o}/oo whereas the starry flounder tolerated salinities down to 1.0 - 2.0 ^{o}/oo. Mysids appeared to have the capacity to be euryhaline. When acclimated to fresh water, the lethal salinity was between 7 and 17^{o}/oo but rose to between 24 and 26^{o}/oo when they were acclimated to waters of 1^{o}/oo salinity.

The results implied that certain species had the capacity to accommodate salinity changes while others (the "freshwater" forms) were relatively intolerant of high salinities. Results corresponded with the field water quality and fish catch data collected during the study.

(f) In-situ preference experiments

On the assumption that the vertical changes in water quality may affect the vertical distribution of fish populations and hence their opportunity to fully utilize the slough habitat, preference experiments were employed. The procedure used was that of Birtwell (1977), wherein a column of water 6.0 x 0.5 x 0.5 m was enclosed in a buoyed mesh container, intersected at 1 m intervals with a gate mechanism. An artificial distribution of fish was placed in the apparatus, the gates were opened, and the fish permitted to select that part of the water column which they preferred. Experiments were carried out with salmonids and non-salmonids. All the species of fish showed a preference for the shallower waters, and on those occasions when the deepest section of the apparatus penetrated waters of reduced dissolved oxygen, the fish avoided this section. However, it was observed that during these experiments, March to August 1977, only a minor portion of the test animals utilized the lower part of the water column on any occasion.

II. HABITAT ALIENATION

Although estuarine factors affecting survival of salmon were recognized by earlier workers (e.g. Royal, 1962), the significance of habitat loss in the Fraser delta has been identified only within the past decade. As discussed in some detail below, fish in the estuary utilize food species which are directly or indirectly dependent on vegetation. The demand for riverine marshes and intertidal foreshore to facilitate development of industrial sites, residential housing, and marinas has been a continuing activity for many years. Generally such proposals involve small areas but the cumulative effects of small projects spread over many years can be substantial. Some activities related to development (e.g. dredging) lead to direct mortality of fish. In the late 19th century, dyking effectively removed major portions of regularly flooded habitat from the aquatic ecosystem of the estuary.

(i) Dyking and River Training

The selection of dyke alignment is of great significance considering the present status of fish habitat in the estuary. Improper alignment may result in the disruption of fish-rearing habitat or such habitat that either contributes, or has the potential for contributing, to the food web or rearing juvenile salmonids. At the Fraser estuary, dyking has confined the river to low flow channels, and substantial areas of previously-flooded vegetation are now agricultural, industrial or residential lands (see habitat sub-chapter).

River training structures now confine some reaches of the Fraser's channels (e.g. trifurcation at New Westminster). Estuarine fish populations were presumably subjected to temporaty increases in current velocities before a new equilibrium between depth, area, and speed was attained in this portion of the river.

Secondary effects related to dyke construction and river training include effects of armouring the structures with "rip-rap" (irregular blocks of stone) and damage to habitat during construction (e.g. work-space corridors). Dykes or training structures that are lined with rip-rap are usually not colonized by streamside vegetation (willows, alder), which can provide food indirectly via detritus. In some instances, streamside vegetation can provide shade and maintain moderate water temperatures.

(ii) <u>Dredging</u>

Dredging operations in the Fraser estuary can lead to direct mortality of migrating salmon fry or to indirect effects due to alienation and destruction of estuarine habitats.

Reports documenting the destruction of salmon fry by suction dredging in the estuary have been published by several authors (Dutta and Sookachoff, 1975; Tutty, 1976; Tutty and McBride, 1976; Tutty and Morrison, 1976). Guidelines for dredge operations in the estuary were published in 1975 (FMS) - losses from fish populations can be avoided by timing restrictions so that work is not conducted when fry are migrating through the estuary. Dredging activities may destroy eulachon spawning beds if such activities are conducted during the spawning season (Samis, 1977).

Removal of bottom substrates by dredging can lead to indirect effects, if species or habitats significant in fish food webs are lost. In Boundary Bay, natural turbidity levels are not high and sedimentation rates are presumably lower than at habitats closer to the mainstem Fraser. Therefore, dredging in Boundary Bay could result in smothering of food web species and localized decreases in primary production due to turbidity effects. Disposal of dredge spoil poses problems if significant habitats (e.g. marshes) are severely modified by the dumped waste. Dredged material has been commonly used as fill in the construction of jetties and causeways in the estuary. Since 1914, six such structures have been built - the Steveston jetty (completed in 1932), the North Arm jetty (1935), the breakwater at the mouth of the North Arm (1951), the Tsawwassen causeway and ferry terminal (1960), the Iona Island jetty (1961), and the Roberts Bank superport causeway and loading area (1970).

(iii) <u>Filling, for Construction and Reclamation</u>

A large number of incidents have occurred (approximately 100 in the past 5 years) involving habitat alienation by dumping of waste rock, sand, dirt, or concrete rubble on marsh habitats in the Fraser estuary. Except for those involving relatively large landfill projects (e.g. B.C. Development Project at Tilbury Island; Entech 1974, 1975) few have been documented in available literature. The immediate effect of such activities is the gradual reduction of the total available marsh habitat in the estuary. There may be secondary effects of such activities depending on the type of material used, as leachates from certain fill material may degrade water quality.

(iv) Log Storage

The industrial waterfront of the North Arm of the Fraser River is dominated by log conversion industries with 60% being alienated for this use. Total water acreage presently leased for log handling and storage including the "Point Grey Booming Grounds" is 1,051 acres (425 hectares) or approximately 47% of the total acreage leased. There are 81 separate leases and they are held by 26 different companies. MacMillan Bloedel Ltd. is the major lessee, holding 492 acres (100 hectares). Under an agreement with the Provincial Lands Branch, the North Fraser Harbour Commission is responsible for administering the leases.

Little biological data are available for benthic populations, vegetative communities or salmonid utilization of the areas. K. Yamanaka (1975) and R. Bell-Irving(1976) have described, respectively, the productivity and in found and vegetative communities of the Musquam Marsh but detailed correlation to industrial impact was not made. Logs which ground on vegetation probably have deleterious effects on the plants.

III. DAM CONSTRUCTION UPRIVER

Several dams have been constructed in the Fraser River system. The most notable of these in terms of hydraulic changes in the lower Fraser are the Kenney dam on the Nechako River, constructed by the Aluminum Company of Canada in 1952, and the Seton-Bridge River dams constructed by B.C. Hydro in 1955 and 1956. Each of these developments is operated primarily for power, but is also used to reduce flood peaks in the lower Fraser when the need arises. During the 1972 freshet, the storage available in the two systems was used to reduce the flood peak by approximately 40,000 cfs, or the equivalent of about 8 per cent of the peak flow at Hope. While the Seton development results in a slight modification of the hydrograph in the Fraser River, it is not a diversion project and would therefore not alter the mean annual flow. The Kemano development currently involves an annual diversion of approximately 4,000 cfs from the Fraser River Drainage. If B.C. Hydro proceeds with their plans for expansion of the Kemano generating facilities, this diversion could increase to about 11,300 cfs or about 8 per cent of the long-term mean annual flow in the Fraser River at Hope.

It is not known what environmental changes may have taken place in the Fraser River or its estuary as a result of these developments. High sedimentation levels occurred in the Nechako River as a result of channel scouring during the initial years of spillage from the Nechako reservoir. This sediment would eventually have reached the Fraser estuary, but it would have been distributed over a number of years and was probably insignificant relative to natural concentrations. The most significant change resulting from the developments has probably been with regard to increased water temperatures in the lower Fraser River. In hot, dry summers, natural temperature levels in the river near Hell's Gate Canyon approach what is considered to be the upper tolerance limit for migrating adult salmon. Any diversion of water from the Fraser drainage during these periods would aggravate the situation.

A series of alternative proposals for flood control and hydro-electric generation (System E) on the upper Fraser River has been examined by fisheries biologists (FMS 1974) and potential effects were documented. Engineering feasibility studies of one of the prime possibilities of such dual purposes developments, the McGregor Diversion project, have been suspended by B.C. Hydro.

H. FOOD WEBS AND INVERTEBRATE HABITATS

Pathways of energy flow from primary producers (plants) to consumers (fish), are complex in estuaries because certain species use "detritus" as an energy source and others graze directly on plant material. Detrital systems involve heterotrophic production whereas direct grazing on plants involves autotrophy. Bacterial production is an integral part of heterotrophy in estuaries, and these organisms utilize decomposing plant material from both vascular plants and algae. The relative importance of the heterotrophic vs autotrophic pathways for almost all of the estuarine invertebrates at the Fraser estuary has not been assessed. The following account, therefore, can only provide a partial review of data on the energy exchange at higher trophic levels, with special reference to exchanges from invertebrates to fish. Existing knowledge on the habitat requirements, feeding behaviour and general biology of certain invertebrate species, however, provides information on their presumed nutritional sources.

A schematic figure of energy flow relationships for the offshore banks of the Fraser estuary is presented in Fig. 4.

I. "SHELLFISH"

Detailed data on feeding habits of Dungeness crab (C. magister) are not available for the Fraser estuary, but they are known bottom feeders, utilizing a wide variety of benthic invertebrates especially bivalves, gammarid amphipods, mysids, and polychaetes (Mayer, 1973; Gotshall, 1977). Bernard (1975) pointed out that infaunal communities near the "dropoff" at the seaward edge of Sturgeon Bank were characterized by juveniles of short-lived, productive species of bivalves and polychaetes. Crabs are harvested along this part of the delta front, and it is likely the crabs are using these invertebrates as a food source. Juvenile C. magister may utilize eel grass beds (Zostera marina and Z. americana) on southern Roberts Bank and in Boundary Bay but there are no available data. Filter feeders such as the cockle (Clinocardium nuttallii) and butter clams (Protothaca staminea) are abundant in the sandy sediments at Boundary Bay. These filter feeders utilize phytoplankton directly as an energy source, drawing water across their gills which trap phytoplankton cells. Except for some extremely hardy forms (e.g. the soft shell clam, Mya arenaria), filter feeding bivalves are uncommon on Sturgeon Bank and on the northern sectors of Roberts Bank (Swinbanks and Murray, 1976). At these portions of the delta, sediments are muddier and phytoplankton productivity of adjacent waters is lower compared to Boundary Bay. Presumably both differences are related to proximity to the river mouth and the accompanying heavy silt load.

II. SALMONIDS

Except for steelhead, cutthroat, and dolly varden, adult salmonids apparently do not feed in the estuarine phase of their life history. There are no published data on diet analysis of the three species mentioned above from the Fraser estuary, but data from the nearby Squamish River estuary showed that dolly varden and cutthroat fed primarily on estuarine crustaceans (Levy and Levings, 1978). Adult eulachon, another of the commercially important species, do not feed in the estuary. White sturgeon prey on juvenile lamprey in the lower river (Northcote, 1974).

The diet of juvenile salmonids, however, is of particular relevance to estuarine management of the lower Fraser, since juveniles of all salmonids reside in the estuary for a finite length of time. Migrating coho, chinook, and chum are most abundant in the estuary (see above) and presumably reside there appreciably longer than do sockeye and pinks. Barraclough (1967, a, b, c) and Barraclough and Fulton (1967) showed that pinks were more abundant at stations offshore of Sturgeon Bank compared to "inshore" (Table 10). Stomach contents of sockeye smolts caught at Mission showed the fish had been feeding primarily on insect larvae (Goodman, 1964). It is evident that sockeye and pink do eat while passing down the lower river and estuary, and also are dependent on estuarine habitats. However, there are no data enabling comment on the "residence time" of the various juvenile salmonid species.

The following section deals in some detail with the food habits of coho, chinook, and chum juvenile salmon and herring. Subsequently, life history, food sources, and habitats of selected food species are discussed.

(i) Chum

Juvenile chums are all less than 1 year old when residing in the estuary, so this species utilizes smaller prey items compared to coho and chonook juveniles. All chums spawn in tributaries of the lower River (below the Fraser Canyon), so juveniles of relatively uniform age and size might be expected in the estuary. Because of their relatively (compared to coho and chinook) small size (50 mm), these predators utilize small prey organisms such as harpacticoid copepods (Goodman, 1975; Dunford, 1975). As noted by Dunford (1975), chum fry at the Fraser estuary tend to be "pelagic" in their feeding habits, and hence utilize prey at or near the water surface. The diet of chum caught in "side channels" (tidal creeks penetrating marshes) was dominated by copepods, whereas those from sloughs had ingested mainly chironomid larvae (Table 11a). Fish caught up to 18 km offshore from the dropoff at the edge of the Banks (Barraclough, 1967, a, b, c) were feeding on winged insects in almost equal proportion to copepods (Table 11b). Chum caught over Sturgeon and Roberts Bank ingested a wide variety of prey, including larval fish, calanoid copepods, cumaceans, gammarid amphipods, and fresh water and terrestrial insects (Goodman, 1975).

(ii) Chinook

Chinook juveniles caught in the estuary are representatives of races of fish spawned in rivers close to (e.g. the Harrison) and far removed (e.g. the McGregor) from the sea. Fry remain in different rivers for varying time periods (up to 2 years) and hence the age (and size) structure of fish utilizing the estuary is variable. In general, however, chinook are the largest of the juvenile salmonids, and hence utilize larger food items than do chum or coho. Smolts up to 10 cm in length were obtained by both Dunford (1975) and Goodman (1975) at several locations in the estuary. In Dunford's study (1975) chinook from the slough habitat had been feeding mainly on chironomid pupa and mysids (Neomysis mercedis), whereas chironomid pupa dominated stomach contents from side channels. Goodman's (1975) data show that chinook caught in the lower mainstem river (tow nets) ingested more chironomid larvae than chinook caught closer to shore in beach seines (data on counts; (20.8% (133 stomachs) vs 4.5% (351 stomachs)). Chinook caught on Roberts and Sturgeon Banks had been feeding primarily on larval and juvenile fish, especially herring (Clupea harengus pallasi).

(iii) Coho

Like chinook, coho juveniles in the lower river represent a variety of races, and hence ages and sizes. Diets are therefore correspondingly diverse, and the data show that this species utilizes a wide variety of prey, ranging in size from cyclopoid copepods to juvenile eulachon, chum salmon and herring. Fish larvae accounted for 17.2% of the stomach contents from 160 coho caught in beach seines in the lower Fraser, but no fish were observed in stomachs of 96 fish caught in tow nets. Chironomid larvae were slightly more abundant in fish caught in beach seines compared to those caught in tow nets (19.6% vs 13.6%). Coho were not reported by Goodman (1975) or Dunford (1975) from slough or "side channel" habitats at the Duck-Woodward-Barber Island complex. Coho caught over Sturgeon Bank had been feeding primarily on juvenile fish (mostly herring), marine plankton (e.g. hyperiid amphipods - Parathemisto pacifica) and estuarine epibenthos such as mysids (Neomysis mercedis) and amphipods (Anisogammarus confervicolus).

(iv) Herring

Herring were reported by Goodman (1975) at most stations over Sturgeon and Roberts Bank. This species is known to utilize eel grass beds on Roberts Bank for spawning (see above). Goodman (1975) reported that most juvenile herring caught over the Banks had been feeding on marine planktonic invertebrates. At five sub areas reported, diet items were as follows (average percentage biomass): marine calanoid copepods (41%), euphausiids (21%), larval fish (21%), harpacticoids (3%), and mysids (3%).

III. FOOD SOURCES FOR PREY ORGANISMS

(i) Amphipods and mysids from marshes and shorelines

Amphipoda and Mysidacaea are two orders of Crustacea that are common in most estuarine environments. The amphipod Anisogammarus confervicolus and the mysid Neomysis mercedis are distributed widely in the Fraser estuary. For example, Neomysis mercedis has been recorded from off Sturgeon Bank to slightly upstream of Mission (Northcote et al., 1976; Levings and Coustalin, 1975). Both species seem to be associated with nearshore substrates, and the abundance of A. confervicolus can be directly related to the presence of vegetative cover (Levings, 1976)

River currents can transport mysids and amphipods in estuaries. In laboratory tests, Levings and Chang (1977) found that A. confervicolus could only withstand currents up to approximately 10 cm s^{-1}. As noted above, in nature the animals cling to vegetation and hence may avoid displacement by slightly stronger currents if plants are present.

It is likely that both the mysid and the amphipod can utilize detritus, in addition to directly grazing on algae. Feeding and growth experiments with Anisogammarus confervicolus showed the species grew best on filamentous green (Enteromorpha linza) and brown (Pylaiella littoralis) algae, while sedge debris (Carex lyngbyei) produced an equal or intermediate growth rate (Levings and Pomeroy, unpublished). The diet of Neomysis mercedis has not been documented locally. However, in San Francisco Bay gut analyses showed this species had fed on a wide variety of estuarine algae (Angela and Knight, 1975).

(ii) Chironomids from mainstem river

The family Chironomidae is one of the largest groups of Diptera (two-winged flies) among the insects. Except for a few brackish-water genera (e.g. Saunderia) most chironomids in the lower Fraser are members of genera found in fresh water. Northcote et al. (1976) reported that chironomid larvae were most common at stations upriver from Steveston. Levings and Coustalin (1975) reported these forms from only a few stations on Sturgeon and Roberts Bank. Immature chironomids (larvae, pupae) are benthic, and are usually found in mud or in association with microbenthic algae on rocks, stumps, and pilings (Pomeroy and Levings, unpublished). Morley and Ring (1972) found that Saunderia larvae were primarily associated with the alga Enteromorpha and grew best on this diet. Adult chironomids may feed on vascular plants such as sedges but as the winged adults have very short life spans, consume little food. Chironomids may be utilized as fish food when immature (larvae, pupae) or as winged adults (see above). Chironomids form one of the major food groups among the "drift" organisms, which are animals carried by river currents and thus become available to fish.

(iii) Copepods from sloughs and "side channels"

Copepods compose a very diverse subclass of crustaceans, occupying marine, brackish water, and freshwater habitats. In the Fraser estuary, three orders of Copepods (Calanoida, Cyclopoida, and Harpacticoida) feature in fish diets. Because calanoids and cyclopoids are predominantly pelagic, they will be discussed together. The Harpacticoids are epibenthic and hence require separate treatment.

Northcote *et al*. (1976) and Levings and Coustalin (1975) found that calanoid and cyclopoid copepods were almost ubiquitous throughout the estuary, but they are probably more abundant in "quiet" water. Speed and "residence time" of water in the lower river are probably key factors in determining the establishment of estuarine copepod populations (Ketchum, 1954). The importance of river speeds and tidal exchange in the maintenance of copepod populations in sloughs is evident, since their availability to fish is ultimately dependent on population dynamics of the prey organism. There are no local data on the feeding ecology of cyclopoids but Heinle *et al*. (1977) found that estuarine calanoids used detritus as a food source, as well as phytoplankton, which is their "usual" food. Since the turbid conditions of the Fraser prevent significant production of phytoplankton, it is likely that cyclopoids and calanoids in our study area are also part of the detrital food web.

Harpacticoid copepods live in association with the substrate, and hence this taxon can be considered part of the epibenthos. Harpacticoids have not been adequately surveyed to date on the Fraser estuary, partially because of sampling difficulties associated with their small size. For example, harpacticoids were rarely obtained by Northcote *et al*. (1976) but juvenile salmon, especially chum and sockeye, used them extensively as food (see above). Sibert *et al*. (1977), working at the Nanaimo River estuary, showed that harpacticoids use detritus as food sources, so these organisms are indirectly dependent on autotrophic production from algae and vascular plants. Harrison (1977) found the distribution of harpacticoids on sand flats at Sturgeon Bank was dependent on small-scale features.

(iv) Cumaceans from Sturgeon and Roberts Banks

Cumaceans, another order of Crustacea, are abundant in the sand habitats at the outer edge of Sturgeon and Roberts Bank (Levings and Coustalin, 1975), and are utilized as prey by juvenile salmonids (see above). Male cumaceans are presumably more available as prey for salmonids, as they are better swimmers than females. Cumaceans use microbenthic algae living in sand as a food source, as they browse these plants from individual grains. Detritus from algae, eel grass, and other plant material might also be important, but there are no local data on this topic.

The sand habitat near the "dropoff" is naturally unstable, so these organisms live in transitory conditions. The abundance and distribution of cumacean populations can be modified by radical change in sediment type, e.g. from sand to mud (Wieser, 1959).

IV. DISTRIBUTION OF PREY IN RELATION TO HABITAT

A detailed review of the distribution and habitats of organisms potentially available as food for fish in the Fraser estuary is clearly beyond the scope of this paper. Data that have been gathered shows that invertebrate biomass from two habitats, namely sediments and the water close to the sediments, reached a peak near the river mouth, at sites corresponding to marsh-mud flat habitats (Fig. 5). These observations, although they lend support to the importance of the marshes seaward of the dykes on Sturgeon and Roberts Banks, must be viewed with caution as they do not reflect production of food but rather measure potentially available food at one instant in time. There are no data on secondary productivity available from the Fraser estuary.

At other sectors of the estuary where eel grass beds (primarily *Z. marina*) were present (i.e. southern Roberts Bank), biomass of invertebrates was highest in or adjacent to these features (Fig. 6). No data are available from Boundary Bay, but it is likely eel grass beds there also harbour more invertebrates than adjacent sandy shores.

I. SALMONID ENHANCEMENT

The Salmonid Enhancement Programme (SEP) of the Fisheries and Marine Service has a stated goal of increasing the commercial and recreational catches of salmonids (includes the 5 species of *Oncorhynchus*, in addition to cutthroat and steelhead trout) in British Columbia.

The Fraser River Geographical Planning Group of the Salmonid Enhancement Program suggested that an additional catch of 10 million fish, on an average annual basis, could be obtained from this river system. This figure includes the goals of the IPSFC whose enhancement schemes for sockeye and pink are subject to international agreement. Assuming a juvenile to adult survival rate of 5%, the enhanced populations will be sending 200 million additional juveniles through the estuary. Since a portion of the estuarine habitat has been degraded (see above) the impact of the increased number of juveniles on the production systems is of major concern. Adequate water quality must be maintained for all species so that their aquatic life-support system is not impaired.

The present section reviews the SEP proposals for species other than pink and sockeye, which are subject to international implications. Discussion will be centered on chum, chinook, coho, cutthroat and steelhead. These species are particularly relevant to the present paper because they are thought to utilize estuarine environments more completely than sockeye or pink.

Enhancement schemes for salmonids (exclusive of sockeye and pink) are planned on 24 tributaries of the Fraser River (Table 12). Eighteen sites have been selected for chinook enhancement, 8 for chum, 15 for coho, 11 for steelhead, and 6 for cutthroat trout. Techniques to be utilized in these schemes include incubation boxes to improve egg-to-fry survival, spawning channels, rearing ponds, and hatcheries.

Water quality effects in the Fraser are expected to be of a chronic nature (see above) and pollution from sewage and other effluents would be expected to be most severe for species which reside in the estuary longest. On the basis of existing data enhanced chinook, coho, and chum stocks would be more susceptible to water quality degradation compared to sockeye and pink. Sea-run cutthroat trout also tend to "wander" less than other species, suggesting they are more reliant on their inshore environment (Swiatkiewicz, pers. comm.).

Restoration of estuarine habitats, especially marshes, may be examined in the context of salmonid enhancement initiatives. Rehabilitation of marsh habitat has a very real potential for success in the Fraser estuary but available techniques simply have not been tried, except on a very localized basis (Moody, 1978). On the lower Columbia River re-vegetation efforts, primarily transplanting of sedge (Carex lyngbyei), have been apparently successful (Anon, 1976). Construction of backchannels and sloughs to provide extra rearing habitat could be harmonized with certain kinds of engineering activities (e.g. channel dredging) and research on this topic is also badly needed (see below).

Enhancement of stocks will possibly increase the commercial fishing pressure in the estuary. Commercial interception of steelhead trout (primarily a recreational species and managed by the B.C. Fish and Wildlife Branch) has been investigated by Ogus and Andrews (1977). They found that approximately 1,000 steelhead (± 200) were taken each season in the Fraser estuary by gillnetters and suggested that careful timing of fishing effort might be the only technique available to reduce incidental steelhead catches.

J. CRITICAL DATA GAPS

I. FISH COMMUNITIES AND LIFE HISTORIES

Much of the descriptive work dealing with fish communities at the western part of the Fraser estuary has been completed or is in progress (see below). Information is, however, totally lacking from Boundary Bay. Except for herring spawn surveys (Webb, 1974), and studies of cutthroat trout in the Serpentine and Nikomekl Rivers (Swiatkiewicz, pers. comm.), there are no quantitive data on fish catches from Boundary, Mud, or Semiahmoo Bay.

New data are needed on the crab population (C. magister) of the estuary, as the life history of the local stocks (migrations, growth rates, etc.) have not been documented.

II. "RESIDENCE TIME" ESTIMATES

One of the major deficiencies in our knowledge involves the "residence time" of juvenile fish in the estuary. Since some fish are continually passing through the river mouth, catches may not necessarily indicate the degree of utilization exhibited by the various species. Mark and recapture studies are required to determine how long juveniles stay in the estuarine habitats. However, each major tributary produces a separate "run" (or race) of downstream migrants, and considerable overlap in timing probably occurs. Therefore, marking studies need to be carefully designed. Such tagging studies could also determine the migration routes used by the juveniles. For example, do juvenile chinook and coho go around the training walls at Steveston, or do they penetrate them at breaks in the structure?

III. ONSHORE-OFFSHORE USAGE

Allied to the question of residence time is the problem of offshore-onshore habitat usage by the salmonids. Previous studies (Barraclough et al., 1967, a, b, c; Barraclough and Fulton, 1967) have shown that juveniles of all five species (chum, sockeye, pink, chinook, coho) are found offshore of Sandheads. Few sockeye and pink have been found on Sturgeon and Roberts Bank but presumably chum, chinook and coho can move between the Banks and offshore feeding sites. The consequences of feeding at the two habitats has yet to be determined.

Interactions between enhanced populations of salmonids could increase the significance of the remaining estuarine habitat. For example, if juveniles from enhanced sockeye and pink stocks were competing with chum, chinook and coho offshore populations, the latter three species might be "forced inshore" and hence obliged to use estuarine habitats more completely. Goodman (1975) lumped coho, chinook, chum, sockeye, and herring stomach content data from Sturgeon Bank and examined temporal changes in the data. He found that diet composition shifted about June 1, when the fish began utilizing more estuarine benthos than "offshore" zooplankton. In years when pinks are very abundant, marine zooplankton might be grazed excessively by sockeye and pink and the other salmonid species would presumably be reliant on estuarine benthos for six months rather than three, as observed in 1973.

IV. MARSH PROGRADATION

Marsh habitats are dynamic, since plant communities are building seaward or increasing in elevation. Unfortunately, the rate at which such progradation occurs is not yet known. These data are of interest since natural growth at certain sectors might compensate for habitat lost by industrial activity. Accompanying data on colonization rates by invertebrates of "new" marsh are also required.

V. DATA ON TIMING AND PRODUCTIVITY

More data on the timing of biological events at the estuary are required, especially fluctuations in food supply as related to fish migration. Basic data such as seasonality in biomass of drift, epibenthic or plankton organisms are not available but are needed to examine the synchrony of food availability in relation to physical events such as river run-off. This work should be done in collaboration with fry and smolt enumeration studies at Mission Bridge.

Secondary production estimates should be obtained from population studies using material from the field collections.

VI. REVIEW OF SURVIVAL RATES IN RELATION TO HABITAT LOSS

A detailed review of available data on escapements is required, especially for species which may have been affected by habitat degradation at the estuary. Historical data on dyking and land use patterns are available (Forrester *et al.*, 1975) and there may be correlations with declines or changes in survival in certain races or species of fish. Correlation analysis has been successfully applied to survival data and environmental factors from oceanographic data (Blackbourn, 1976).

VII. ECOSYSTEM MODELLING

The virtue of numerical models to help predict the ecological processes involved in salmonid feeding in the estuary have been recognized by a number of authors (e.g. Parsons *et al.*, 1969;

Takahashi et al., 1973). A group of fisheries workers attended a recent workshop (organized by Westwater Research) and recognized the value of modelling. The present authors further advocate its use. Data pertinent to submodels (e.g. timing, productivity, "residence time"), should be tested as it becomes available to ensure their utility in larger system models.

VIII. WATER QUALITY

The tremendous dilution capacity of the Fraser River is not sufficient to protect aquatic biota from persistent contaminants such as heavy metals and chlorinated hydrocarbons. Water quality characteristics of the mainstem river do not necessarily reflect water quality conditions of sloughs and side channels. The implications of any major flow variation or water diversion proposal on water quality must be closely assessed. The following research activities should be encouraged and coordinated:

- Routine monitoring of aquatic biota for metals and persistent contaminants. Monitoring programmes must be designed to act as "early warning systems" so that potential, as yet unidentified, contaminants can be readily screened. Analytical capabilities for complex organic and inorganic compounds must be enhanced. Studies of the relationships between suspended sediments, salinity, and the distribution, toxicity and absorption-resorption processes of heavy metals are required. The quantification of bioaccumulation and biomagnification processes in lower Fraser River food chains is necessary.

- Sensitive *in-situ* bioassay techniques for assessing acute and chronic toxicity, and sub-lethal effects on fish must be developed. The sub-lethal effects on fish of chronic exposure to low levels of pollutants must be assessed. Increased attention should be directed at the water quality problems of sloughs and backwater areas.

- Emphasis must be placed on the control of all toxic substances presently being discharged to to the Fraser River.

IX. BASIC ECOLOGICAL QUESTIONS

There are a number of issues relating to the fisheries ecology of the estuary which cannot be solved without "breakthroughs" relating to certain basic ecological questions. One of these problems is: What are the "common properties" of food species that can be used to simplify food web models? Modelling energy flows and transfers through the estuarine system is extremely complex on a species basis; therefore some property enabling simplification must be located before significant progress can be made from the models. Another important issue involves the cycling of nutrients in the estuary and the relative importance of sea water, marsh regeneration, leaf litter, and river water as nutrient sources for primary production (algae, vascular plants) at the estuary. Such biogeochemical problems must be resolved before an understanding of production in the Fraser estuary can be achieved.

K. STUDIES IN PROGRESS

I. ESTUARINE RESEARCH SPONSORED BY OR PERTINENT TO FISHERIES AGENCIES
(major projects in progress as of April 1978)

Topic	Principal Investigators	Comments	Expected Completion
Fish ecology and water chemistry in sloughs related to proposed training wall construction.	I. Birtwell, M. Nassichuk (FMS, Vancouver)	Partially reported in present document	late 1978
Training walls as artificial substrates for algae/invertebrates	C. Levings, M. Pomeroy, (FMS, Vancouver)		mid 1978
Drift fauna in major channels (South Arm, Sea Reach, Canoe Pass)	C. Levings (FMS, West Vancouver)	Complements Westwater work in Duck-Barber Woodward area; contributes to training walls project	1979
Residence time, fish ecology mysid ecology in Duck-Barber-Woodward	T. Northcote, D. Levy (Westwater, UBC)	Complementary work with marsh productivity being conducted by K. Hall, R. Kistricz, Westwater	1980
Re-analysis of stomach content data obtained by Goodman (1975)	J. Sibert B. Hillaby (FMS, Vancouver, Nanaimo)		1980
Re-vegetation studies on Sturgeon Bank	J. McNally (FMS, Vancouver)	Initiated in January, 1977	ongoing

Topic	Principal Investigators	Comments	Expected Completion
Algae-eel grass detritus interactions	P.G. Harrison, UBC, Botany	Field work in Boundary Bay	ongoing
Contaminants in sewage and fish toxicity	I. Rogers (FMS, W.V.) J. Servizi (IPSFC, Cultus Lake)	Some contaminants from BCFP hard-board plant at New Westminster	ongoing
Ecology of harpacticoid copepods at Iona Island foreshore	B. Harrison, IOUBC	Ph.D. thesis work	1981
Sediment-organism relationships on Sturgeon, Roberts Bank	D. Swinbanks, UBC Geology	Ph.D. thesis work	-
Introduction of cutthroat trout to Brunette River for recreational fishing	V. Swiatkiewicz, B.C. Fish and Game, Burnaby		ongoing
Analysis of PCB's in stored salmonid tissues	O. Langer, EPS	Using tissues from fish caught in 1973 by T.G. Northcote	1980
Studies related to EIS for proposed river training structures	Beak Consultants Ltd. under contract to DPW	Guidelines issued by EARP	1979

II. ONGOING MONITORING RELATED TO FISH POPULATIONS AND HABITATS

Topic	Agency	
Commercial catches in the estuary	FMS, IPSFC	- mainly via "fish tickets" i.e. receipts issued to fishermen from buyers; tallies from buyers by IPSFC - some biological data such as scale samples for racial analysis obtained
Test fishing	FMS, IPSFC	- mainly in Cottonwood Reach
Fry and smolt enumeration at Mission	FMS, IPSFC	
Surveillance of fish habitats and reporting damage to same	FMS; Fisheries Officers	- in support of the Fisheries Act: Continual observation
Recreational bar-fishing activities	FMS; Fisheries Officers	- observations conducted along with regular duties
Herring Spawn Surveys	FMS; Fisheries Officers	- annual inspections

M. PERSPECTIVE ON INFORMATION

It is apparent that a large bulk of knowledge is currently available concerning certain fisheries aspects of the Fraser estuary. The information must be viewed in perspective, however, especially with regard to more recent data on the functioning of estuarine ecosystems. Most available fisheries data are for population management rather than habitat management, reflecting the past emphasis of earlier workers on single species ecological studies. The following recommendations and suggested studies were developed with due regard to the quality and utility of the available data, many of which are unsuitable for habitat management.

Furthermore, scientific management of fisheries habitat must operate in an iterative fashion; that is, when new local data or generalizations from other areas become available, management strategies should change to take the new facts into account. New data result in additions or removal of selected problems from the present long list of data gaps. For example, recent work (spring 1978) by investigators from the Westwater Research Institute has documented the fact that juvenile coho and pink salmon utilize marshes in the Duck-Barber-Woodward Island. For a variety of technical reasons, the significance of this area for pink and coho was not appreciated previously. The information reinforced generalizations concerning the importance of marsh habitats to juvenile salmonids.

N. RECOMMENDATIONS

1. That marsh and eel grass habitats in the Fraser estuary recognized as fish-rearing areas and as such must be protected.

2. Because of the ecological complexities and the benefits of inter-agency work, it is suggested that studies and analyses be conducted in two "pilot study areas" (e.g. Garry Point to Annacis Island; Southern Roberts Bank). These pilot areas should also provide focal habitats for developing mitigation procedures (e.g. recolonization on dredge spoil).

3. That water quality adequate for successful rearing of juvenile salmonids and other fish species be maintained in the Fraser estuary (including tributaries). New efforts are needed to determine if effluents presently discharged are influencing the survival, migration, and distribution of all estuarine fish species. Waters utilized by fish food species should not be degraded.

4. That detailed ecological studies be conducted to determine the significance to fisheries of: (a) non-vegetated, intertidal habitat (mud, sand flats) in the estuary in the total productivity, ecological balance and estuarine dynamics (b) terrestial habitat adjacent to the high tide or high water mark, especially the contribution of leaf litter from trees and shrubs to food webs leading to fish.

5. That existing foreshore industries manufacturing, receiving, or shipping toxic materials be subject to special guidelines to prevent spills, and those involved in highly toxic chemicals and specific activities be located in less sensitive non-estuarine sites.

O. SUBMISSIONS FOR FURTHER RESEARCH ON FISH HABITAT ISSUES IN THE FRASER ESTUARY

SUMMARY

MAJOR TOPICS	ESTIMATED COST
Fish communities, life histories, residence time, onshore-offshore questions, outmigration, food timing, secondary production.	$500,000.00
Water quality.	$665,000.00
Marsh progradation, vegetation units as suppliers of fish food, marsh construction, survival vs habitat loss.	$235,000.00
Modelling; ecological basics.	Initial funding: $100,000.00 Difficult to predict further level as this work is at a frontier of knowledge.

Because of funding and timing uncertainties related to further studies in the framework of a Federal-Provincial study of the Fraser estuary, proponents felt it would be premature, at this time, to describe in detail needed work. Particulars could be obtained from individual investigators.

I. WATER QUALITY (J.C. DAVIS, I.K. BIRTWELL, M. NASSICHUK, G.L. GREER, I.H. ROGERS)

The following projects are grouped according to priority. "A" items are high priority projects requiring a start early in the program. "B" items are somewhat dependent upon the outcome of "A" projects with regard to program design, sampling sites, species investigated, etc. These items are of high concern but should be initiated later in the program.

Priority	Project	Estimated Cost
"A"	Toxic Hazards of Sewage Discharged to the Fraser Estuary To investigate the toxic hazard to aquatic life from sewage discharged from Iona & Annacis Island by: - determining the heavy metal contamination in resident and transient biota and sediments to study the magnitude of impact on the estuary and its recources. - to document the area of the estuary contaminated by metals in relation to use of the area by fish. - to conduct water quality studies in the vicinity of the Annacis & Iona outfalls at various times to document impacts on water quality in receiving waters and seasonal variation in water quality in relation to river and sewer flow characteristics. - to conduct chemical studies on Annacis & Iona effluent and organisms and sediment samples to identify persistant and bio-accumulative organics such as PCB's and organohalogen compounds and determine the potential hazards of chlorination practices. (I.K. Birtwell, M.D. Nassichuk, J.C. Davis, I.H. Rogers)	$145,000

Priority	Project	Estimated Cost
"A"	Roberts Bank - Coal Port Impact on Benthos To investigate and document the effects of operation and expansion of the coal port terminal on benthos in the area. Studies would include surveys of benthos, crab respiration in coal dust and contaminated sediments, crustacean physiology and toxicity bioassays and a survey of crab fishermen in the area. (I.K. Birtwell, M.D. Nassichuk)	$50,000
"A"	Adult Salmon Migratory Pathways - Sonic Tagging It is important to understand the timing, migratory pathways and use of the Fraser estuary and lower reaches of the river by migrant adult salmon. Movements in relation to these factors and in relation to discharge of industrial wastes and sewage would be studied by tracking adults with implanted sonic tags. Information on duration of exposure to toxicants, avoidance behaviour and migratory routes of importance would be obtained. (G.L. Greer)	$40,000
"A"	Hog Fuel Leachates - Hazards to Aquatic Life Large quantities of hog fuel are currently stored or transported along the lower Fraser River. Chemical studies would be done to characterize toxic constituents in leachates from wood mixtures, coupled with biological experiments to study the acute and sub-lethal toxicity of these leachates to important aquatic organisms. (I.K. Birtwell, M.D. Nassichuk)	$30,000

Priority	Project	Estimated Cost
"B"	**Monitoring Program for the Lower Fraser** Annual or more frequent surveys would be carried out to determine the level of inorganic and organic contaminants in fish, sediments and waters of the lower Fraser River. Emphasis would be placed on establishing regular sampling sites and species to be examined, standardizing methods of sampling, preservation and analysis, and establishing a tissue bank of representative organisms to obtain a historical record of persistant contaminants of new and unknown character such as pesticides and haogenated organics. (I.K. Birtwell, M.D. Nassichuk)	$200,000
"B"	**Contaminant Toxicology and Sub-lethal Studies** In view of the industrialization of the lower Fraser River, volume of shipping traffic and proximity to oil refineries, it is important to study the lethal and sub-lethal effects of major pollutants upon a variety of estuarine biota in the laboratory and field. Pollutants to be examined would include halogenated organics, metals, PCB's, as well as fuel oils and heavy crude oils and their water soluble components. Attempts would be made to determine acutely toxic concentrations, no-effect sub-lethal response threshold, potential for bioaccumulation and possible health hazards caused by contamination of estuarine organisms. (I.K. Birtwell, J.C. Davis, M.D. Nassichuk, G.L. Greer)	$200,000

II. HABITAT ALIENATION-FOOD WEBS (B. Hillaby, C.D. Levings, W.J. Schouwenberg, J. McNally)

Topic	
A. Ecology of juvenile salmonids in eel grass beds (residence, feeding, growth, migration); Roberts Bank, Boundary Bay (B. Hillaby, W.J. Schouwenberg)	$ 75,000
Ecology of juvenile salmonids in Ladner slough (residence, feeding, migrations (B. Hillaby, W.J. Schouwenberg)	$ 58,000
Juvenile crab studies on Roberts Bank, Boundary Bay (residence, feeding, migrations (B. Hillaby, W.J. Schouwenberg)	$ 25,000
Completion of Fisheries Resource Inventory of the Lower Fraser (W.J. Schouwenberg)	$ 20,000
Vegetation units as suppliers of fish food: comparison of fresh water, bullrush, and salt marshes, eel grass beds, and riparian communities (C.D. Levings)	$ 85,000
Feasibility of developing fish food communities on dredge spoil; investigating the potential role of training structures as creators of fish habitat (e.g. backwaters behind walls as holding areas) (C.D. Levings, J. McNally)	$150,000
B. B.C. Ministry of Recreation and Conservation, Fish and Wildlife Branch, Regional Fisheries Biologist (V. Swiatkiewicz)	
<u>Cutthroat trout</u>: adult movement studies: marine creel census of cutthroats (and other stocks); assessment of cutthroat harvest incidental to herring fishery.	$ 65,000

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Species	Average Commercial Catch	Net Value Per Pound	Total Net Value
	lbs.	¢/lb.	$
SHINOOK	2,378,300	$1.36	3,234,488
SOCKEYE	23,523,200	1.15	27,051,680
COHO	1,141,800	1.13	1,290,324
PINK	13,327,500	.64	8,529,600
CHUM	5,604,600	.82	4,595,772
			$44,701,864

TABLE 1: Total net economic value of Fraser River commercial salmon catch by species ($ 1976). From FMS (1974).

	Number of Households[3]	Value per Household	Regional Salmon Related Recreation Value
		$ annual	$ '000
Lower Mainland[1]	397,181	$182	$72,287
Upriver Communities[2]	64,344	$279	$17,952
Total			$90,239

	Number of Households[3]	Value Per Household	Annual Preservational Value
		$ annual	$ '000
Lower Mainland[1]	397,181	$225	$ 89,366
Upriver Communities[2]	64,344	$340	$ 21,877
			$111,243

1 Defined as referent area between Hope and the Strait of Georgia.

2 Defined as all other areas of Fraser River Basin.

3 1976 Census data, figures were divided by 3.2 to get the total number of households.

TABLE 2: Upper panel: Annual value of Fraser River salmon and steelhead related recreation ($ 1976). Lower panel: Annual preservation value associated with the salmon and steelhead stocks of the Fraser River and estuary.

AGENCIES	LOCATION OF OFFICE, GEOGRAPHIC AREA OF INTEREST: SPECIES
Resource Services Branch, FMS	Vancouver; Nanaimo, West Vancouver; entire estuary; all species in tidal water
International Pacific Salmon Fisheries Commission (IPSFC)	New Westminster; entire estuary; sockeye, pink
Marine Resources Branch, B.C. Recreation and Conservation	Victoria; entire estuary; steelhead, oysters
Fish and Wildlife Branch	Burnaby; tributaries; sport fish
Fisheries Officers, New Westminster, (Field Services Branch, FMS)	New Westminster, entire estuary all species
Fish Inspection Laboratories Vancouver (Industry Services Branch, FMS)	Vancouver; entire estuary; all commercial species
University of B.C. (Westwater, IOUBC)	Vancouver, Ladner marshes/Iona; salmonids; Dungeness crabs

TABLE 3: Agencies and offices involved in fisheries management (including research activities) in the Fraser River estuary.

Herring (*Clupea harengus pallasi*)

Chinook (*Oncorhynchus tshawytscha*)

Sand lance (*Ammodytes hexapterus*)

Starry flounder (*Platichthys stellatus*)

Coho (*Oncorhynchus kisutch*)

Longfin smelt (*Spirinchus thaleichthys*)

Surf smelt (*Hypomesus pretiosus pretiosus*)

Staghorn sculpin (*Leptocottus armatus*)

Three spine stickleback (*Gasterosteus aculeatus*)

Peamouth chub (*Mylocheilus caurinum*)

Chum (*Oncorhynchus keta*)

Shiner perch (*Cymatogaster aggregata*)

Sockeye (*Oncorhynchus nerka*)

Dolly Varden char (*Salvelinus malma*)

Steelhead trout (*Salmo gairdneri*)

River Lamprey (*Lampetra ayresi*)

Sand sole (*Psettichthys melanostictus*)

Prickly sculpin (*Cottus asper*)

Large scale sucker (*Catostomus macrocheilus*)

Eulachon (*Thaleichtys pacificus*)

Pacific lamprey (*Lampetra tridentatus*)

Pink salmon (*Oncorhynchus gorbuscha*)

Cutthroat trout (*Salmo clarki clarki*)

Northern squawfish (*Ptychocheilus oregonense*)

Green sturgeon (*Acipenser medirostris*)

Black bullhead (*Ictalurus melas*)

White sturgeon (*Acipenser transmontanus*)

Flathead sole (*Hippoglossoides elassodon*)

Pacific tomcod (*Microgadus proximus*)

TABLE 4: Species of fish common to offshore banks and mainstem river. (Data from Goodman, 1975; Northcote, 1974; and Birtwell (this report).

	COHO	CHINOOK	CHUM
Marsh Remnant or Non-existent	6.3	4.5	1.8
Moderate Marsh	2.6	4.2	0.5
Well-developed Marsh	4.0	9.6	4.1

TABLE 5: Mean catch per haul (beach seines) of juvenile salmonids in the lower mainstem river (New Westminster to Sandheads). "Marsh remnant" data from stations BS 3, 6, 7, 8, 10, 17, 22, 40, 42 (59 hauls); "moderate marsh" from BS 1, 5, 9, 39, 41 (30 hauls); "well-developed marsh" from BS 2, 12, 13, 14, 15, 16, 21, 30, 31, 32, 33, 34, 35, 36, 37, 38, 43, 44 (127 hauls). Note that maximum catches during May to June were in the order 50 to 100 fish per set. All samples obtained during April to July 1973 and 1974. Data from Goodman (1975).

	COHO	CHINOOK	CHUM
Slough	2.7	2.2	<1
Open water/ Mid-channel	2.3	2.5	<1

TABLE 6: Mean catch per haul (tow nets) of juvenile salmonids in the lower mainstem river (New Westminster to Sandheads). "Open water" data from stations TN 1, 2, 4, 5, 8, 9, 13, 14, and 52 tows during April to July 1973. "Slough" data from stations TN 3, 7, 10, 11, 12, 15, 16 and 48 tows during April to July 1973. Note that maximum catches during May to June were in the order 50 to 100 fish per set. Data from Goodman (1975).

	COHO	CHINOOK	CHUM
Nearshore-Marsh	11.4	24.5	<1
Open Water	4.2	10.8	<1

TABLE 7: Mean catch per haul (tow nets) of juvenile salmonids at Sturgeon and Roberts Bank. "Open water" data from Sturgeon Bank TN 4, 5, 6, 7; Roberts Bank TN 1, 2 and 46 tows during April to July 1973. "Nearshore-marsh" data from Sturgeon Bank TN 1, 2, 3; Roberts Bank TN 3, 4, 5, 6, 7, 8 and 65 tows during April toJuly 1973. Note that maximum catches during May to June were in the order of 50 to 100 fish per set. Data from Goodman (1975).

UPPER DEAS SLOUGH

		Mo. of Max. Abundance
3-spine stickleback	249.0×10^3	AUG
peamouth chub	205.2×10^3	AUG
large-scale sucker	70.9×10^3	AUG
sockeye salmon (0+ juv)[1]	24.0×10^3	JUL
chinook salmon (0+ juv)	19.7×10^3	APR
brassy minnow	17.8×10^3	AUG
chum salmon (0+ juv)	14.9×10^3	MAR
prickly sculpin	6.1×10^3	JUL
unident. fish larvae	4.0×10^3	JUL
redside shiner	3.5×10^3	AUG
black crappy	3.0×10^3	SEP
northern squawfish	2.0×10^3	AUG
starry flounder	1.5×10^3	MAY
longfin smelt	870	MAR
chinook salmon (1+ juv)[2]	400	APR
carp	400	SEP
sockeye salmon (1+ juv)	100	APR
cutthroat trout	100	---
mountain whitefish	100	AUG
Dolly Varden	80	---
staghorn sculpin	60	JUN
brown catfish	60	MAY

[1] 0+ juv represents juvenile fish less than one year old.
[2] 1+ juv represents juvenile fish in their second year.

...cont.

TABLE 9: Rank order of population estimates at the time of maximum abundance for species of fish utilizing the intertidal zone of Deas Slough and Ladner Reach (equivalent areas of 4.95 hectares)

LOWER DEAS SLOUGH

		Mo. of Max. Abundance
peamouth chub	23.5×10^3	AUG
3-spine stickleback	22.5×10^3	AUG
longfin smelt	8.7×10^3	FEB
chinook salmon (0+ juv)	8.3×10^3	APR
large-scale sucker	5.3×10^3	AUG
starry flounder	4.5×10^3	MAY
chum salmon (0+ juv)	3.3×10^3	APR
sockeye salmon (0+ juv)	3.1×10^3	JUL
unident. fish larvae	2.7×10^3	AUG
prickly sculpin	1.5×10^3	SEP
redside shiner	930	AUG
chinook salmon (1+ juv)	740	APR
brassy minnow	600	AUG
carp	500	APR
staghorn sculpin	400	APR
black crappy	400	AUG
sockeye salmon (1+ juv)	200	MAY
northern squawfish	100	JUL/AUG
steelhead trout (adult)	60	AUG
cutthroat trout	60	---
Dolly Varden	60	---
mountain whitefish	60	---
coho salmon (adult)	60	NOV
brown catfish	60	JUL

...cont.

LADNER REACH (Fraser River)

		Mo. of Max. Abundance
unidentified fish larvae	53.8×10^3	AUG
longfin smelt	18.7×10^3	JAN
chum salmon (0+ juv)	8.6×10^3	APR
chinook salmon (0+ juv)	6.6×10^3	APR
peamouth chub	4.4×10^3	AUG
chinook salmon (1+ juv)	4.0×10^3	APR
starry flounder	2.7×10^3	MAY
prickly sculpin	1.6×10^3	JUL
3-spine stickleback	1.1×10^3	FEB
redside shiner	1.1×10^3	AUG
large-scale sucker	1000	AUG
sockeye salmon (0+ juv)	500	JUN
sockeye salmon (1+ juv)	200	MAY
staghorn sculpin	200	NOV/APR
mountain whitefish	200	AUG
northern squawfish	100	JUN/AUG
coho salmon (0+ juv)	100	DEC
steelhead trout (adult)	100	AUG
Dolly Varden	100	---
carp	100	---
brassy minnow	100	SEP

<4.6 km off Sandheads

SPECIES	TOTAL NUMBER OF FISH	NUMBER PER TOW (23 HAULS)
Pink	91	3.9
Chum	12	<1
Chinook	40	1.7

>4.6 km off Sandheads

SPECIES	TOTAL NUMBER OF FISH	NUMBER PER TOW (39 HAULS)
Pink	378	9.6
Chum	51	1.3
Chinook	27	< 1

TABLE 10: Catch per haul of pink, chum, and chinook juveniles from two boat surface trawls adjacent to and distant from offshore banks of the Fraser estuary. Data from Barraclough (1966 a, b, c) and Barraclough and Fulton (1967).

Prey	Mean Percent in Diet in Slough Habitat	Mean Percent in Diet in Side Channel Habitat
Copepoda	8.7	39.3
Cladocera	14.4	15.0
Collembola	0.0	3.3
Chironomid larva	13.9	6.0
Chironomid pupa	30.6	8.4
Adult diptera	3.8	9.3
Homoptera	1.2	7.7
Ephemeroptera, Plecoptera	1.4	2.7
Anisogammarus	13.7	0.7
Corophium	4.8	0.0
Tabanid	0.3	0.0
Neomysis	1.1	0.0

TABLE 11a: Mean percent (numerical data) of various taxa in stomachs of juvenile chum salmon from slough and side channel habitats in the Duck-Barber-Woodward Island complex. Slough data from 191 fish obtained at 5 time periods (March to late May) in 1973 and 1974. Channel data from 81 fish obtained at 3 time periods (early April to late May) in 1973. Data from Dunford (1975).

Prey	Percent Number	Percent Frequency
Insects	28.8	63.3
Copepods	40.8	50.0
Euphausids	0.1	3.3
Eggs and Larvae	4.4	13.3
Amphipods	15.2	23.3
Fish larvae	1.0	0.1
Oikopleura	9.6	13.3

TABLE 11b: Percent number and percent frequency of occurence of various taxa in juvenile chum salmon stomachs in the Strait of Georgia (>4.5 km off Sandheads). Data from 30 fish and 1377 diet items. Data from Barraclough (1967 a, b, c) and Barraclough and Fulton (1967).

TRIBUTARY	CHUM	COHO	CHINOOK	STEEL-HEAD	CUT-THROAT	COMMENTS
Lower Fraser						
Blaney Creek	60	7.5	-	0.3	3	Incubation boxes
Chilliwack-Vedder River	75	50	10	7	-	Hatchery
Coquitlam River	50	150	-	2	10	Hatchery
Harrison River	200	50	250	5	20	Hatchery
Inches Creek	90	25	-	-	4	Incubation boxes and rearing
Nicomen Slough	50	10	-	-	10	Incubation boxes and rearing
Stave River	210	25	-	1	10	Incubation boxes and rearing
Squakum Creek	28	-	-	-	-	Streambed Improvement
Total	1,063	318.5	260	15.3	57	
Lillooet						
Birkenhead	-	30	25	2	-	Incubation boxes and rearing
Thompson - Shuswap						
Bessette Creek	-	30	15	-	-	Hatchery
Deadman Creek	-	40	50	2	-	Incubation boxes and rearing
Eagle River	-	30	50	1	-	Hatchery
Middle Shuswap River	-	10	16	-	-	Colonization
Nicola River	-	3	37.5	1.2	-	Rearing pond
Nicola River	-	3	5	0.3	-	Water Storage
Undetermined	-	30	50	1	-	Hatchery
Total	-	146	223.5	5.5	-	
Middle Fraser						
Chilko-Chilcotin River	-	-	50	5	-	Rearing pond
Cottonwood River	-	-	50	-	-	Hatchery
Quesnel River	-	-	100	-	-	Hatchery
Total	-	-	200	5	-	
Upper Fraser						
McGregor River	-	-	100	-	-	Hatchery
Nechako River	-	-	100	-	-	Hatchery
Stuart River	-	-	150	-	-	Hatchery
Tete Jaune	-	-	100	-	-	Hatchery
Undetermined	-	-	100	-	-	Hatchery
Total	-	-	550	-	-	
GRAND TOTAL	1,063	494.5	1,258.5	27.8	57	

TABLE 12: Proposed increases in stocks of salmonids (thousands of adults) (excluding sockeye and pink) for the Fraser River system.

Approximate Migration Timing of Salmon in the Lower Fraser River 1901-1981 Cycle

SOCKEYE ESCAPEMENT (Five Year Average)

Birkenhead	65,000
Chilko R.	55,000
Early Stuart Run	154,000
Horsefly R.	348,000
Late Stuart Run	238,000
Lower Adams Run	62,000
Stellako R.	38,000
Upper Pitt R.	15,000
Weaver Cr.	36,000
Miscellaneous	67,000
Total	1,078,000

COHO ESCAPEMENT (1973-77 Average by Subdistrict)

Lower Fraser	13,500
Mission-Harrison	11,300
Chilliwack-Vedder R.	12,100
Lillooet	9,300
Kamloops	11,100
Total	57,300

PINK ESCAPEMENT (1969-77 Average)

EARLY RUN	
Fraser R. Mainstem	726,000
Thompson R.	450,000
Seton Cr.	266,000
Misc. Streams	54,000
Total	1,496,000
LATE RUN	
Harrison R.	135,000
Chilliwack-Vedder R.	119,000
Misc. Streams	15,000
Total	269,000
Grand Total	1,765,000

CHUM ESCAPEMENT (1973-77 Average)

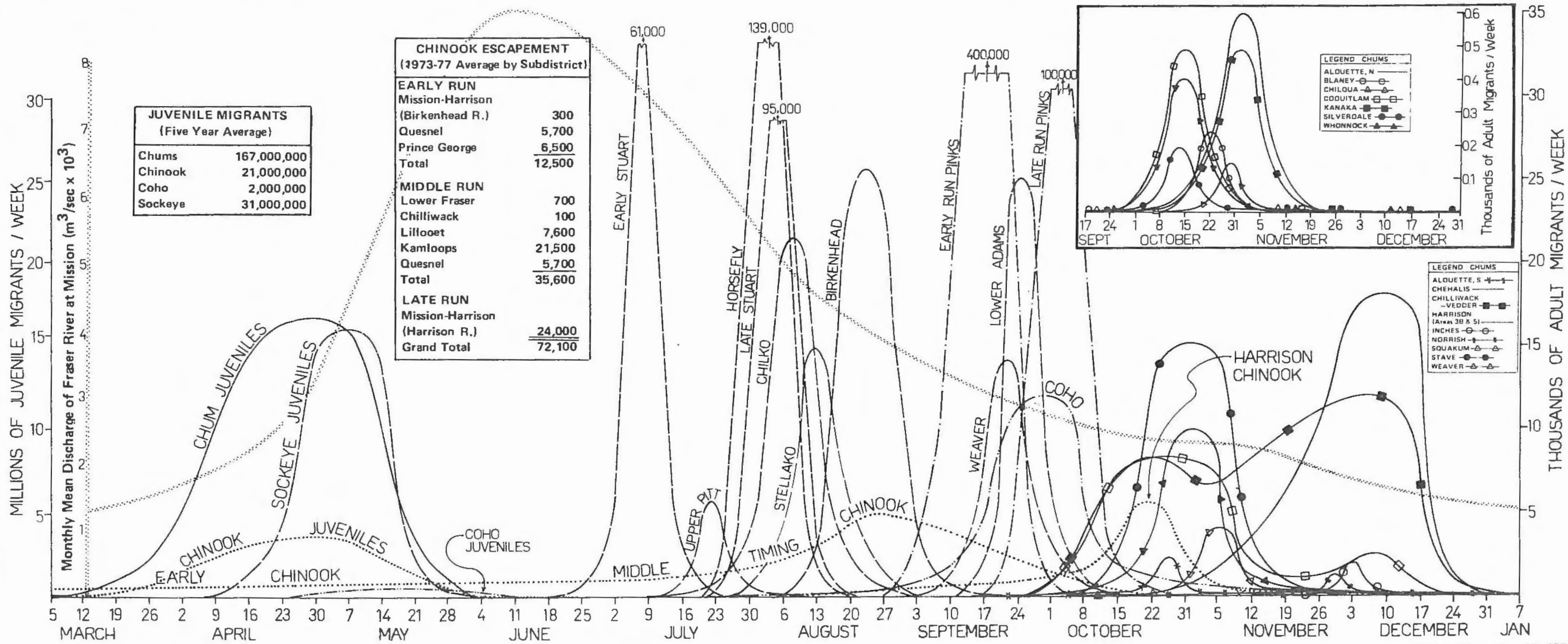
Alouette, N. R.	2,100	Mainstem Fraser R.	161,400
Alouette, S. R.	5,900	Nicomen Sl.	3,700
Blaney Cr.	1,100	Norrish Cr.	3,000
Chehalis R.	53,000	Silverdale Cr.	500
Chilliwack - Vedder R.	85,600	Squakum Cr.	11,000
Chilqua Cr.	700	Stave R.	26,400
Coquitlam R.	1,100	Weaver Cr.	24,200
Harrison R.	85,000	Whonnock Cr.	1,500
Inches Cr.	6,000	Miscellaneous	1,700
Kanaka Cr.	1,400	Total	475,300

JUVENILE MIGRANTS (Five Year Average)

Chums	167,000,000
Chinook	21,000,000
Coho	2,000,000
Sockeye	31,000,000

CHINOOK ESCAPEMENT (1973-77 Average by Subdistrict)

EARLY RUN	
Mission-Harrison (Birkenhead R.)	300
Quesnel	5,700
Prince George	6,500
Total	12,500
MIDDLE RUN	
Lower Fraser	700
Chilliwack	100
Lillooet	7,600
Kamloops	21,500
Quesnel	5,700
Total	35,600
LATE RUN	
Mission-Harrison (Harrison R.)	24,000
Grand Total	72,100



Revised November 17, 1978

Approximate Migration Timing of Salmon in the Lower Fraser River 1902 - 1982 Cycle

SOCKEYE ESCAPEMENT (Five Year Average)	
Birkenhead R.	83,000
Chilko R.	146,000
Early Stuart Run	31,000
Lower Adams R.	1,479,000
Seymour R.	45,000
Stellako R.	85,000
Upper Pitt R.	15,000
Weaver Cr.	30,000
Miscellaneous	331,000
Total	2,245,000

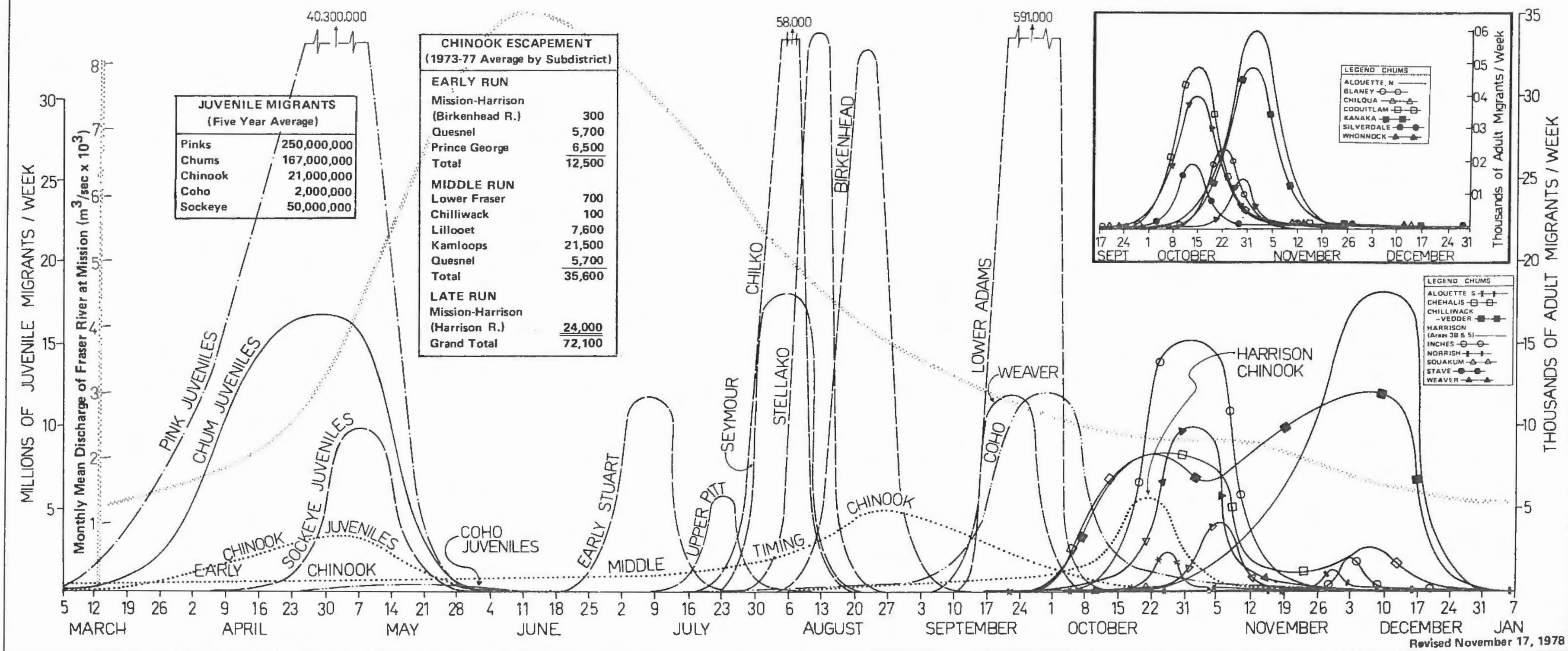
COHO ESCAPEMENT (1973-77 Average by Subdistrict)	
Lower Fraser	13,500
Mission-Harrison	11,300
Chilliwack-Vedder R.	12,100
Lillooet	9,300
Kamloops	11,100
Total	57,300

CHUM ESCAPEMENT (1973-77 Average)

Alouette, N. R.	2,100	Harrison R.	85,000	Squakum Cr.	11,000
Alouette, S. R.	5,900	Inches Cr.	6,000	Stave R.	26,400
Blaney Cr.	1,100	Kanaka Cr.	1,400	Weaver Cr.	24,200
Chehalis R.	53,000	Mainstem Fraser R.	161,400	Whonnock Cr.	1,500
Chilliwack - Vedder R.	85,600	Nicomen Sl.	3,700	Miscellaneous	1,700
Chilqua Cr.	700	Norrish Cr.	3,000	Total	475,300
Coquitlam R.	1,100	Silverdale Cr.	500		

JUVENILE MIGRANTS (Five Year Average)	
Pinks	250,000,000
Chums	167,000,000
Chinook	21,000,000
Coho	2,000,000
Sockeye	50,000,000

CHINOOK ESCAPEMENT (1973-77 Average by Subdistrict)	
EARLY RUN	
Mission-Harrison (Birkenhead R.)	300
Quesnel	5,700
Prince George	6,500
Total	12,500
MIDDLE RUN	
Lower Fraser	700
Chilliwack	100
Lillooet	7,600
Kamloops	21,500
Quesnel	5,700
Total	35,600
LATE RUN	
Mission-Harrison (Harrison R.)	24,000
Grand Total	72,100



Revised November 17, 1978

Approximate Migration Timing of Salmon in the Lower Fraser River 1903 - 1979 Cycle

SOCKEYE ESCAPEMENT (Five Year Average)	
Birkenhead R.	50,000
Bowron R.	28,000
Chilko R.	440,000
Early Stuart Run	42,000
Lower Adams R.	318,000
Seymour R.	39,000
Stellako R.	105,000
Upper Pitt R.	19,000
Weaver Cr.	17,000
Miscellaneous	80,000
Total	1,138,000

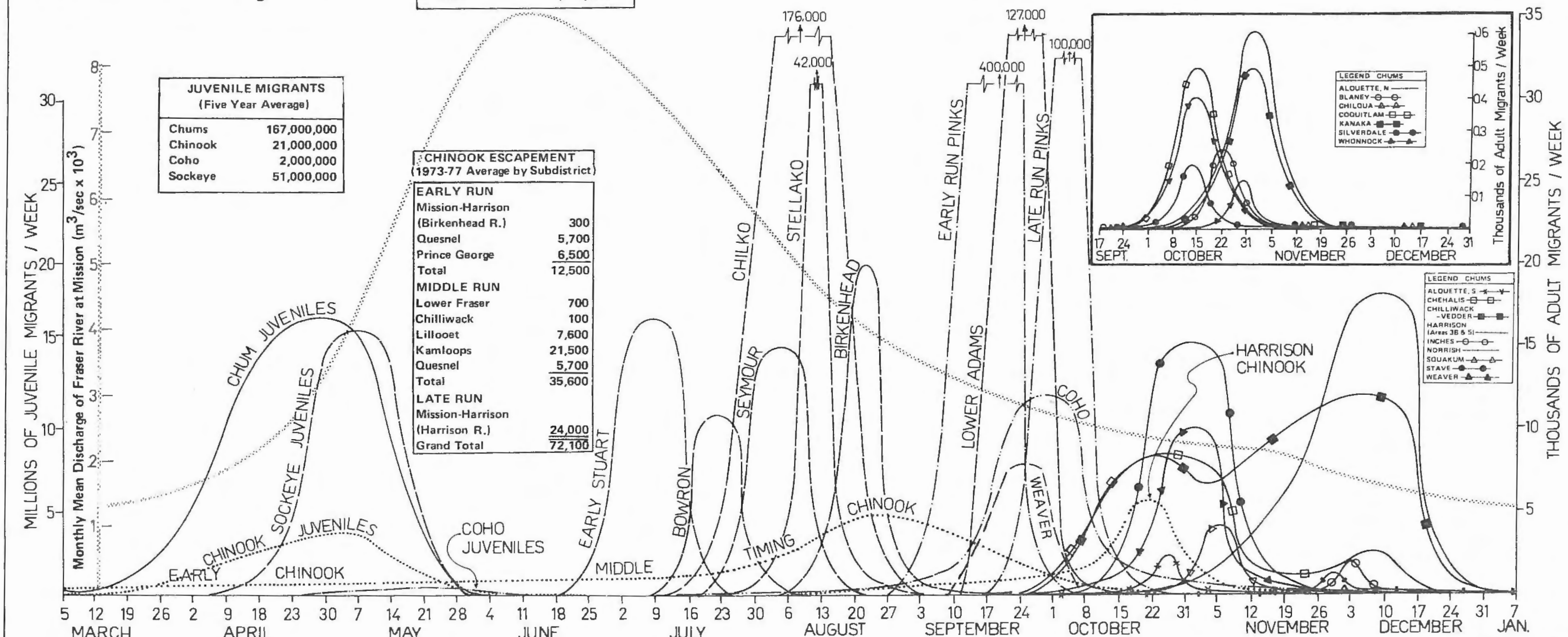
COHO ESCAPEMENT (1973-77 Average by Subdistrict)	
Lower Fraser	13,500
Mission-Harrison	11,300
Chilliwack-Vedder R.	12,100
Lillooet	9,300
Kamloops	11,100
Total	57,300

PINK ESCAPEMENT (1969-77 Average)	
EARLY RUN	
Fraser R. Mainstem	726,000
Thompson R.	450,000
Seton Cr.	266,000
Misc. Streams	54,000
Total	1,496,000
LATE RUN	
Harrison R.	135,000
Chilliwack-Vedder R.	119,000
Misc. Streams	15,000
Total	269,000
Grand Total	1,765,000

CHUM ESCAPEMENT (1973-77 Average)			
Alouette, N. R.	2,100	Mainstem Fraser R.	161,400
Alouette, S. R.	5,900	Nicomen Sl.	3,700
Blaney Cr.	1,100	Norrish Cr.	3,000
Chehalis R.	53,000	Silverdale Cr.	500
Chilliwack - Vedder R.	85,600	Squakum Cr.	11,000
Chilqua Cr.	700	Stave R.	26,400
Coquitlam R.	1,100	Weaver Cr.	24,200
Harrison R.	85,000	Whonnock Cr.	1,500
Inches Cr.	6,000	Miscellaneous	1,700
Kanaka Cr.	1,400	Total	475,300

JUVENILE MIGRANTS (Five Year Average)	
Chums	167,000,000
Chinook	21,000,000
Coho	2,000,000
Sockeye	51,000,000

CHINOOK ESCAPEMENT (1973-77 Average by Subdistrict)	
EARLY RUN	
Mission-Harrison (Birkenhead R.)	300
Quesnel	5,700
Prince George	6,500
Total	12,500
MIDDLE RUN	
Lower Fraser	700
Chilliwack	100
Lillooet	7,600
Kamloops	21,500
Quesnel	5,700
Total	35,600
LATE RUN	
Mission-Harrison (Harrison R.)	24,000
Grand Total	72,100



Revised November 17, 1978

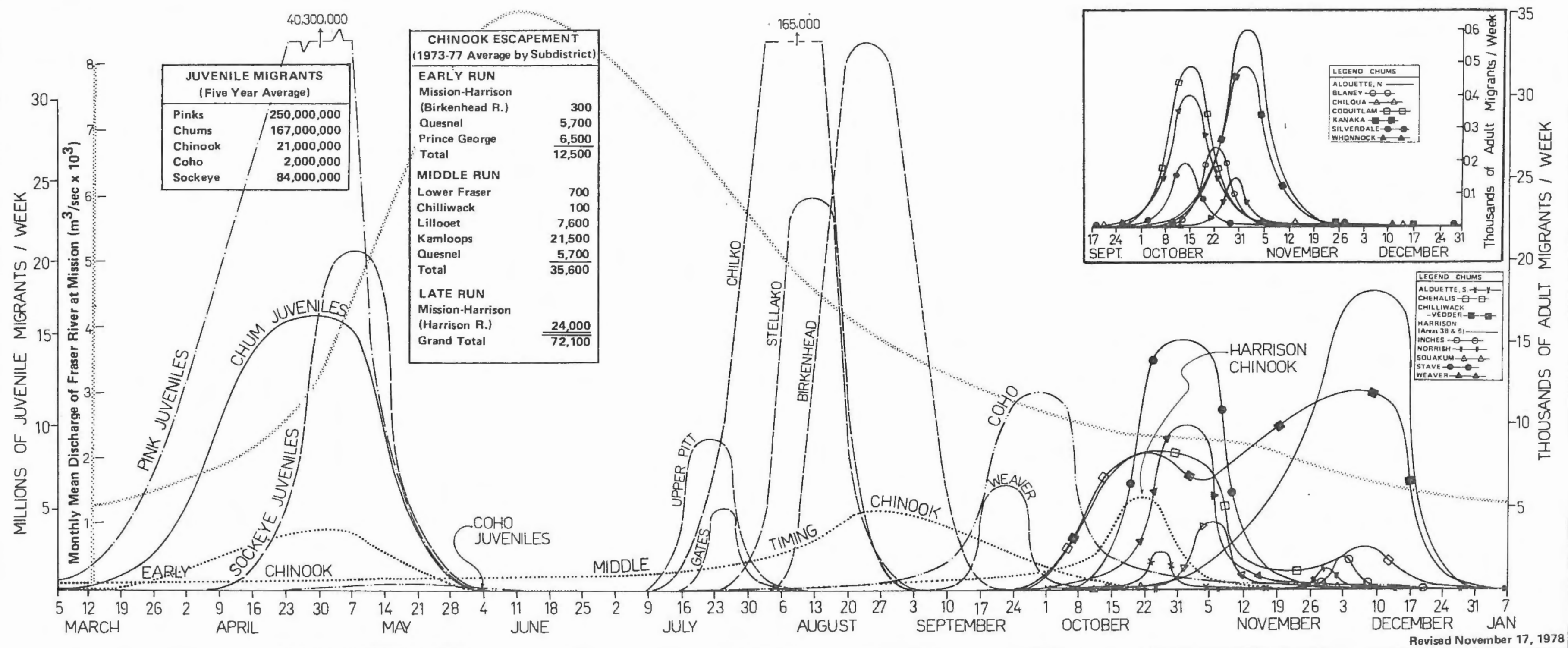
Approximate Migration Timing of Salmon in the Lower Fraser River 1904 - 1980 Cycle

SOCKEYE ESCAPEMENT (Five Year Average)	
Birkenhead R.	83,000
Chilko R.	413,000
Stellako R.	58,000
Upper Pitt R.	21,000
Weaver Cr.	18,000
Gates Cr.	9,000
Miscellaneous	78,000
Total	680,000

COHO ESCAPEMENT (1973-77 Average by Subdistrict)	
Lower Fraser	13,500
Mission-Harrison	11,300
Chilliwack-Vedder R.	12,100
Lillooet	9,300
Kamloops	11,100
Total	57,300

CHUM ESCAPEMENT (1973-77 Average)

Alouette, N. R.	2,100	Harrison R.	85,000	Squakum Cr.	11,000
Alouette, S. R.	5,900	Inches Cr.	6,000	Stave R.	26,400
Blaney Cr.	1,100	Kanaka Cr.	1,400	Weaver Cr.	24,200
Chehalis R.	53,000	Mainstem Fraser R.	161,400	Whonnock Cr.	1,500
Chilliwack - Vedder R.	85,600	Nicomen Sl.	3,700	Miscellaneous	1,700
Chilqua Cr.	700	Norrish Cr.	3,000	Total	475,300
Coquitlam R.	1,100	Silverdale Cr.	500		

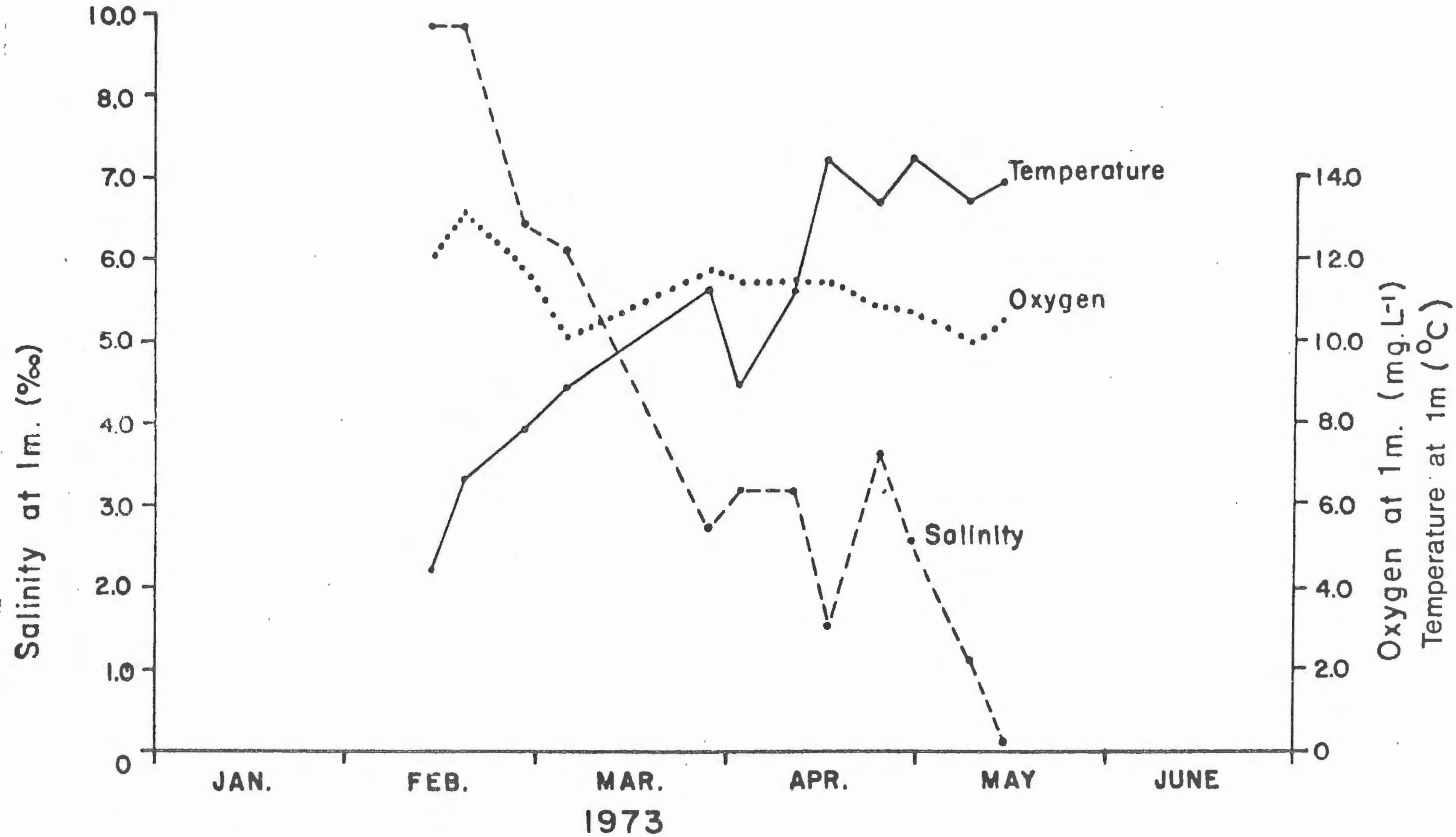


JUVENILE MIGRANTS (Five Year Average)	
Pinks	250,000,000
Chums	167,000,000
Chinook	21,000,000
Coho	2,000,000
Sockeye	84,000,000

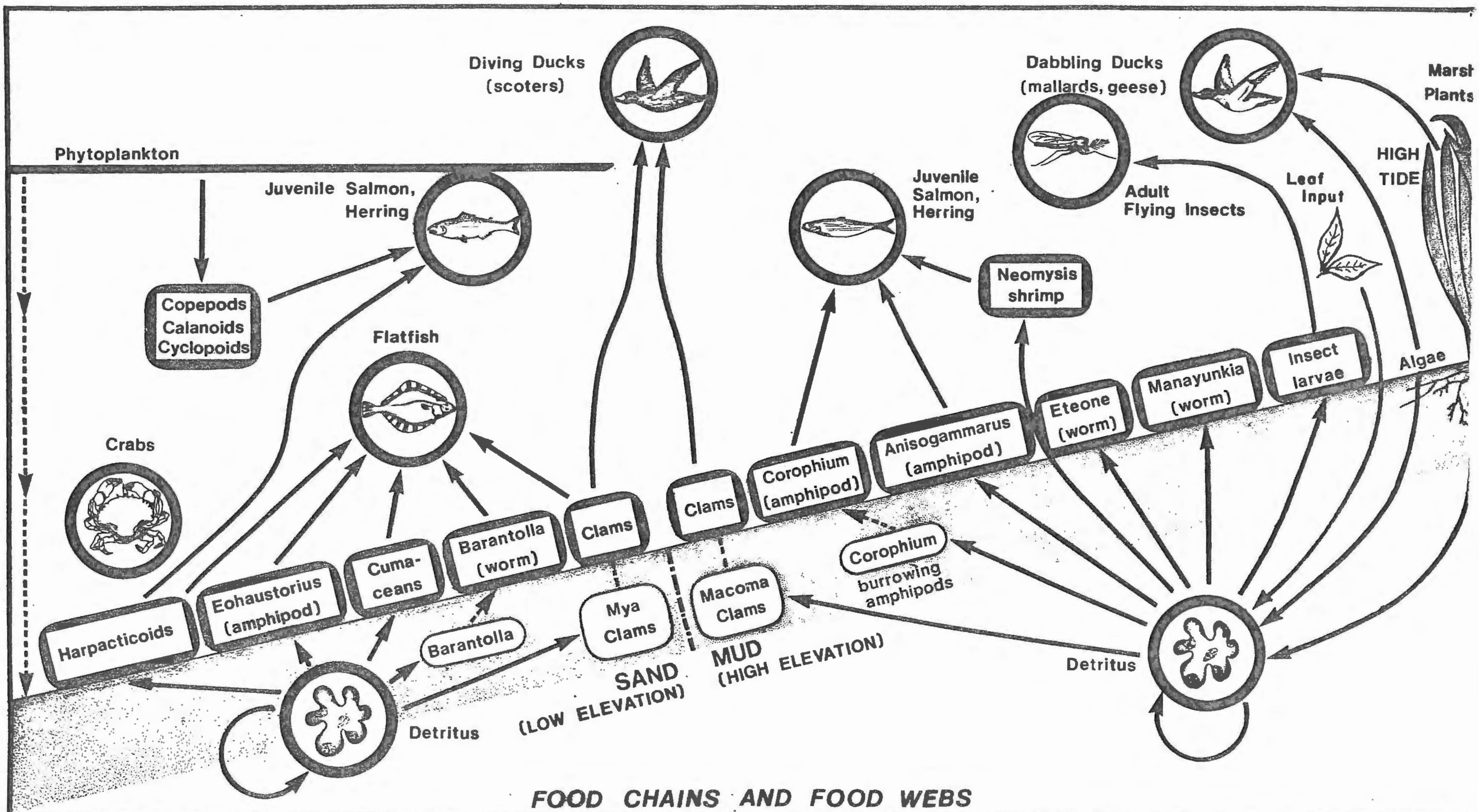
CHINOOK ESCAPEMENT (1973-77 Average by Subdistrict)	
EARLY RUN	
Mission-Harrison (Birkenhead R.)	300
Quesnel	5,700
Prince George	6,500
Total	12,500
MIDDLE RUN	
Lower Fraser	700
Chilliwack	100
Lillooet	7,600
Kamloops	21,500
Quesnel	5,700
Total	35,600
LATE RUN	
Mission-Harrison (Harrison R.)	24,000
Grand Total	72,100

Revised November 17, 1978

FIG. 2 TEMPERATURE, SALINITY & OXYGEN at 1m
(South Arm, Garry Point)



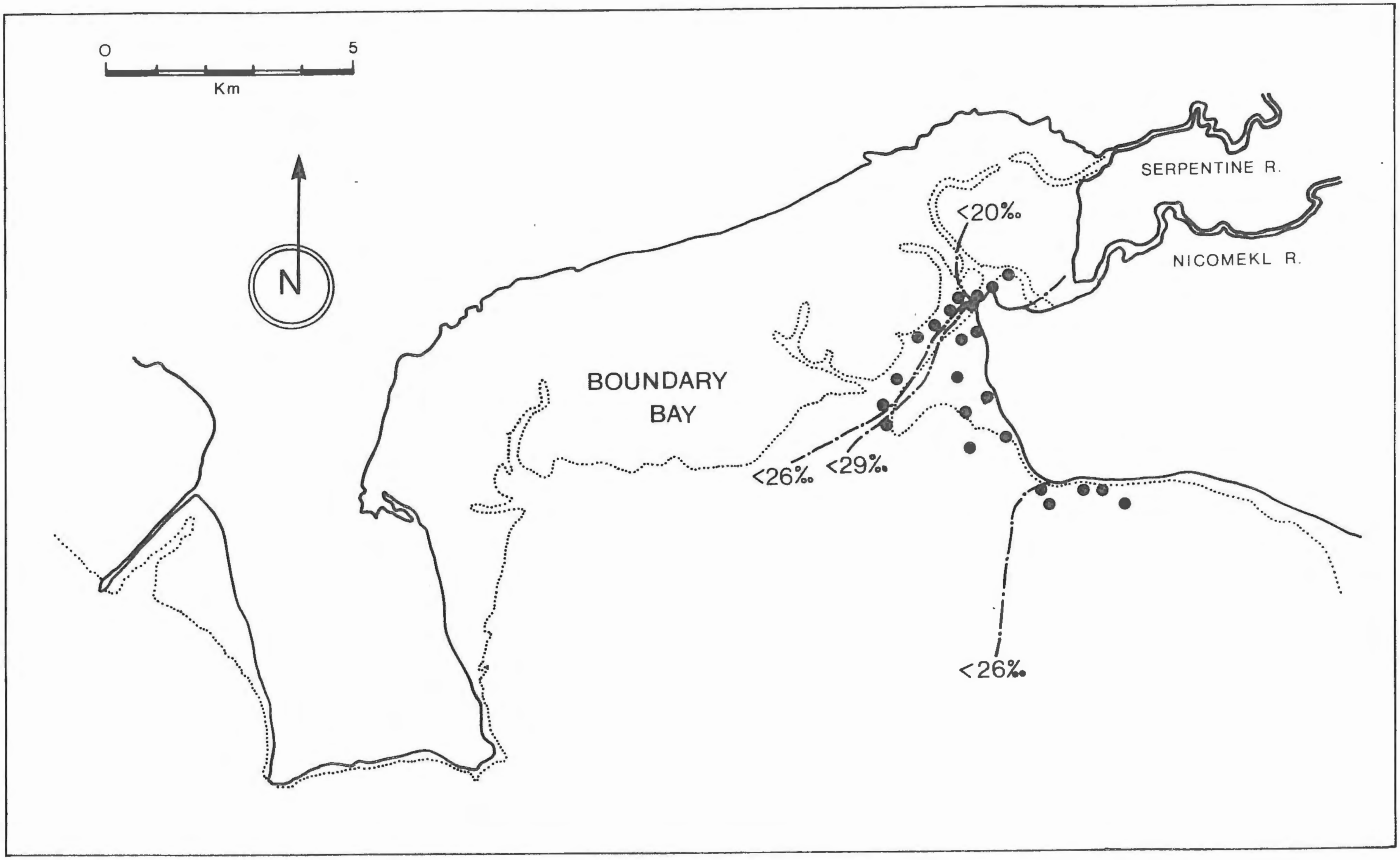
FRASER RIVER ESTUARY STUDY

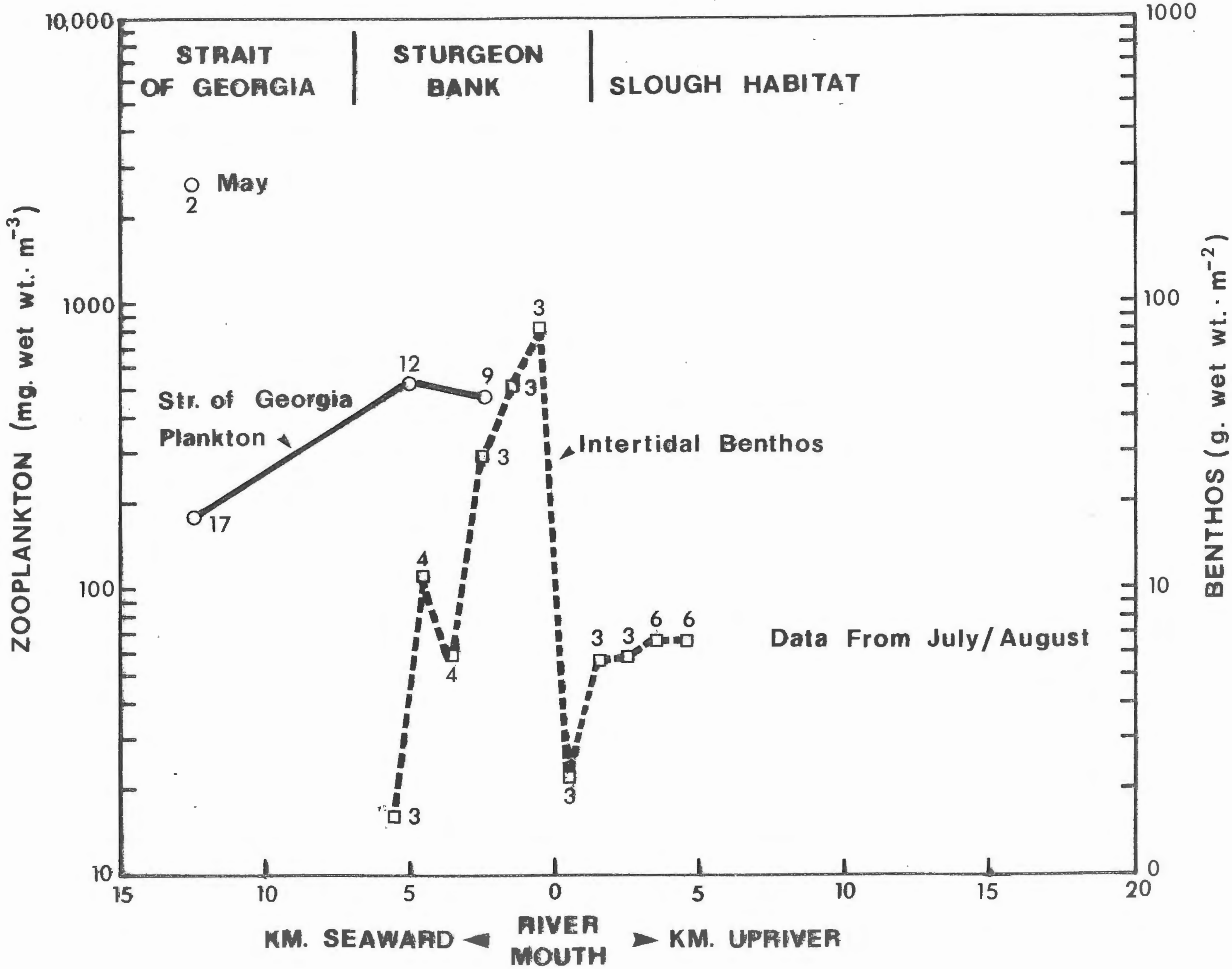


FOOD CHAINS AND FOOD WEBS

Source: Fisheries and Environment Canada

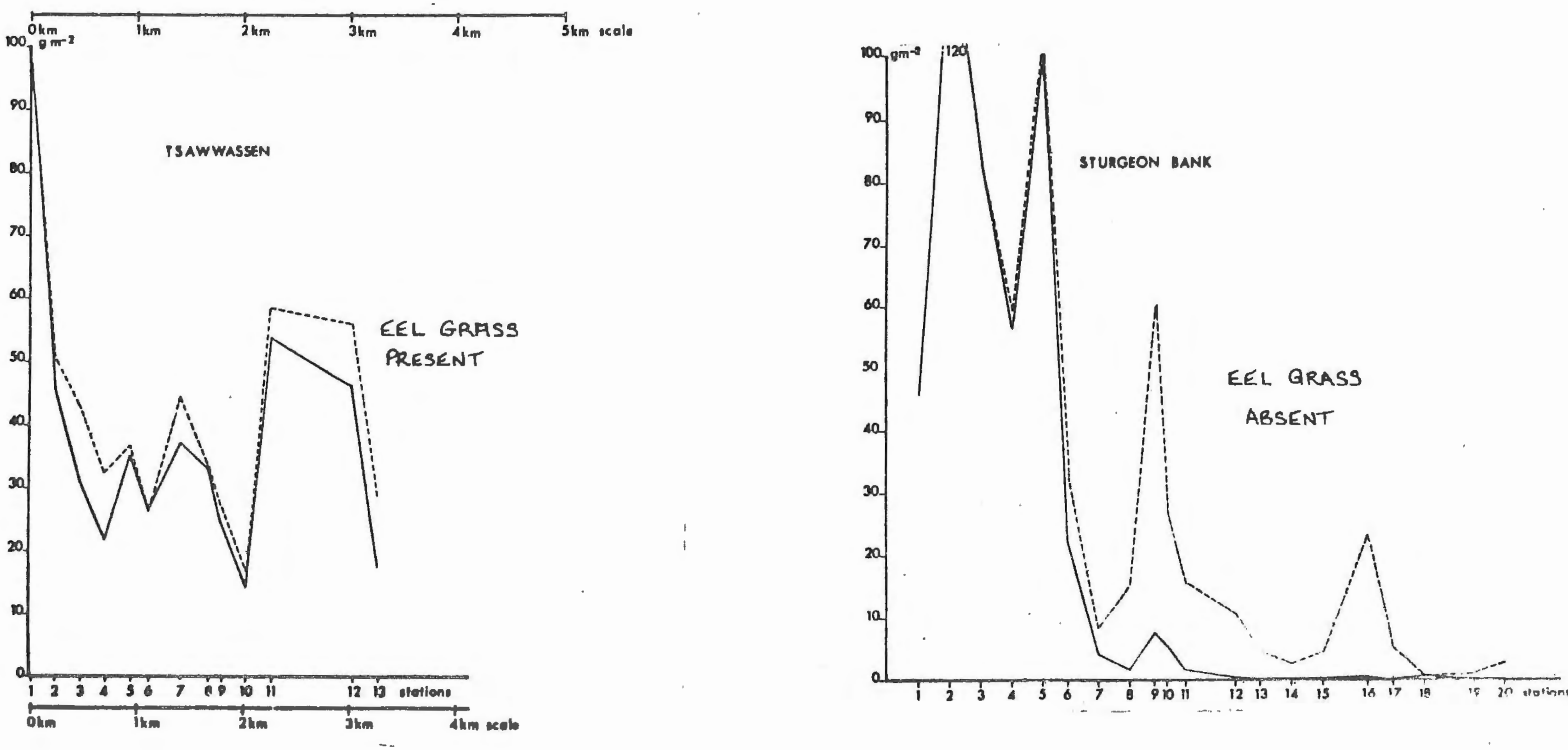
FIG. 3 DATA FROM KAY 1976





STRAIT OF GEORGIA
STURGEON BANK
SLOUGH HABITAT
May
Str. of Georgia Plankton
Intertidal Benthos
Data From July/August
ZOOPLANKTON (mg. wet wt. · m-3)
BENTHOS (g. wet wt. · m-2)
KM. SEAWARD
RIVER MOUTH
KM. UPRIVER
10,000
1000
100
10
15
5
0
20

FIG. 6 CHANGES IN BIOMASS OF BENTHOS AT SECTIONS OF STURGEON AND ROBERTS BANKS IN THE PRESENCE OR ABSENCE OF EELGRASS BEDS



WILDLIFE RESOURCES OF THE FRASER RIVER ESTUARY

A Report to the Fraser Estuary Study

by the Wildlife Sub-group of the Habitat Working Group

August 1978

Members of the Wildlife Sub-group

1) Department of Fisheries and the Environment (Canada)

   a) Canadian Wildlife Service, Delta
      D. E. C. Trethewey, Chairman (report compiler/editor)
      E. W. Taylor

   b) Fisheries and Marine Service
      M. Bigg, Nanaimo

2) B. C. Ministry of Recreation and Conservation,
   Fish and Wildlife Branch
   T. Burgess, Burnaby
   W. Munro, Victoria

Acknowledgements

Additional contributions to the Wildlife Sub-group report were made by: J. Kelsall, K. Simpson and N. Perret, Canadian Wildlife Service, Fisheries and the Environment Canada, Delta; P. Meyer, Fisheries and Marine Service, Fisheries and the Environment Canada, Vancouver; D. Lowe, Fish and Wildlife Branch, Ministry of Recreation and Conservation, Province of British Columbia, Burnaby.

J. Kelsall, R. McKelvey, G. Kaiser and L. Retfalvi, Canadian Wildlife Service, Delta also reviewed the manuscript of the Wildlife Sub-group report.

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A. INTRODUCTION

Wildlife has been an important part of the Fraser River lowlands since the days of the pioneer. It has provided food, revenue through trapping, and recreation for native Indians and white settlers alike. However, growing agricultural, industrial, residential and social needs have already changed the estuary considerably and promise an uncertain future for wildlife. Approximately 70 percent of the original estuarine and floodplain wetlands were removed by early dyking programs (Forrester, Squire and North 1975). Pressures for development of more estuarine lands still exist with presently at least 12 major projects involving further reduction of estuarine habitat proposed.

Although wildlife losses resulting from past habitat reduction are difficult to quantify, there is no doubt that they have occurred with some species. Such a relationship is indicated by accounts of game abundance by early European visitors.

Despite habitat losses, the wildlife of the estuary still is numerous and varied reflecting the diversity and productivity of remaining habitat. Not only is the Fraser estuary the most important single area of aquatic bird habitat in British Columbia (Halladay and Harris 1972), it also supports the largest population of wintering waterfowl in Canada.

In early 1977, the governments of Canada and British Columbia realized the seriousness of environmental and developmental conflicts in the estuary, and established a joint study with the overall objective of "The formulation and recommendation of a management plan for the Fraser River Estuary/Delta by means of joint federal-provincial actions" (Fraser River Estuary Study 1977). However, before such a management plan could be formed, an inventory of natural resources and land uses within the estuary was required.

The purpose of this report, therefore, is to describe the Fraser River estuary as wildlife habitat by:

- describing the Wildlife Resource Base;
- identifying the agencies involved in the management and protection of the resources;
- describing the level of habitat utilization, the distribution, periodicity and significance (as applicable) of use by wildlife populations;
- outlining habitat requirements by major species or groups and identifying the level of habitat-oriented dependency in terms of food, space, water quality, etc.;
- identifying present and proposed land use practices, industrial and urban developments and activities which have potentials to decrease or increase the productive capacity of terrestrial and aquatic wildlife environments;
- describing commercial and recreational resource use;
- identifying information gaps.

The literature relating to the wildlife of the Fraser River estuary was summarized by Hoos and Packman (1974), Northcote (1974) and Taylor (1974). The following is based mainly on those three reviews and the files of governmental wildlife agencies. An attempt also was made to incorporate the results of more recent studies.

Although many forms of living creatures might be classed as wildlife, this report discusses only mammals, birds, amphibians and reptiles.

Boundaries of the wildlife study area are as defined in the Fraser River Estuary Study Information Package, July 1977. This includes the land-water interface outside the boundary of the dykes between Kanaka Creek and the outlet of Pitt Lake in the east, the estuary drop-off in the west, Point Grey to the north and the international boundary to the south. The study area also includes Boundary Bay and Simiahmoo Bay.

B. AGENCIES RESPONSIBLE FOR WILDLIFE IN THE STUDY AREA

Jurisdiction over wildlife in the study area is divided between the federal and provincial governments.

1. Federal Jurisdiction:

The Department of Fisheries and the Environment is responsible for the management and protection of marine mammals and migratory birds throughout the study area and for other forms of wildlife on the one National Wildlife Area within the study area.

(a) Marine Mammals:

Harbour seals and killer whales are managed and protected from harrassment or killing under the federal Fisheries Act as given in the B. C. Fisheries Regulations. The responsible agency within the department is the Fisheries and Marine Service.

(b) Migratory Birds and Wildlife on National Wildlife Areas:

The Canadian Wildlife Service is responsible for migratory birds throughout the study area and for all wildlife on the Alaksen National Wildlife Area in Delta. Appropriate acts are the Migratory Birds Convention Act and the Canada Wildlife Act. Migratory birds are defined in the Migratory Birds Convention Act.

2. Provincial Jurisdiction:

The Fish and Wildlife Branch, Ministry of Recreation and Conservation, has responsibility for all other wildlife.

C. THE WILDLIFE RESOURCE BASE - - ITS HABITAT REQUIREMENTS AND UTILIZATION OF THE FRASER ESTUARY

The purpose of this section is to:

- identify the forms of wildlife which use the Fraser estuary;
- identify habitat requirements for major species or groups in terms of food, space, water quality, etc.;
- describe distribution, periodicity and significance as applicable, of habitat utilization by wildlife;
- identify key breeding, feeding, resting and migratory sites and pathways.

Habitat capability for wildlife and details of habitat zones in the study area are discussed in the Habitat Sub-group report.

1. MAMMALS:

Relatively little work has been done on mammals of the Fraser estuary beyond recording incidental information on species occurrence and distribution. Mammals were grouped into four categories: marine mammals, furbearers, game animals and non-game animals.

a) Marine Mammals

The only marine mammals which regularly frequent the estuary are harbour seals, and killer whales.

(i) Harbour Seals:

At least 700 harbour seals occur all year in the estuary with nearly two-thirds of these in Boundary Bay (Table 1, Fig. 1). This is the largest concentration of the species in B. C. During the year the greatest number haul out on tidal sandbars and grassy hummocks during the birth season of July-August. Births occur mainly at the haul out sites. The usual daily movement cycle is to gather at the haul outs on falling tides and disperse individually to feed on rising tides. An unknown (although probably relatively small) number of seals also inhabit the Fraser River upstream to Hope and in Harrison and Pitt Lakes. The species is non-migratory.

Harbour seals need daily haul out areas in undisturbed localities. The species is wary and will not tolerate persistent human activity nearby. The most favoured haul out localities are sandbars with easy access to deep water channels. The main food is fish of all types. Foraging occurs only in the shallow waters of the estuary or in the river.

Table 1 Summary of a photographic census of harbour seal haul outs in the Fraser River estuary, 22 August, 1976, near the end of the pupping season. All age groups, including pups, are represented (M. Bigg, Pacific Biological Station, Nanaimo unpublished data).

Location	Number of seals*		
	Hauled Out	Swimming	Total
Sturgeon Bank	87	5	92
Roberts Bank	165	0	165
Boundary Bay	462	11	473
Total	714	16	730

*Additional seals probably were not hauled out and were not seen swimming.

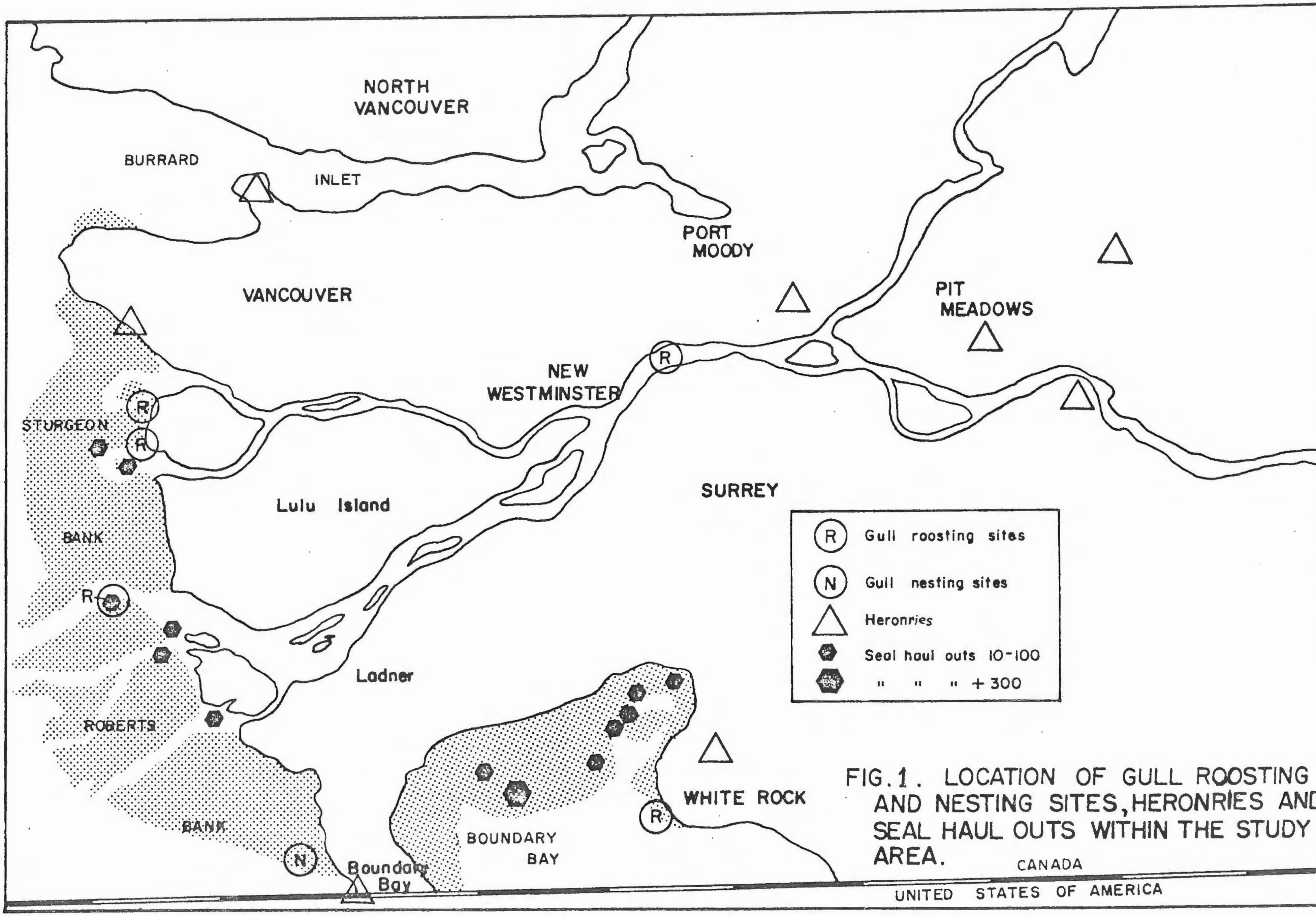

FIG. 1. LOCATION OF GULL ROOSTING AND NESTING SITES, HERONRIES AND SEAL HAUL OUTS WITHIN THE STUDY AREA.

(ii) Killer Whales

About 70 killer whales comprising four family groups frequently visit the estuary for feeding, usually along the deep water edge off the delta front between Point Grey and Point Roberts. They do not ascend the river as do seals although they occasionally do use the shallow areas of the estuary. These animals are present most often during summer and fall when salmon are preparing to enter the river to spawn. They generally remain for short periods of perhaps a few days at a time.

It is unknown if mating or calving occurs in the estuary, but is thought unlikely that the area is of special importance in that regard.

The main food of killer whales while in the estuary is salmon which apparently is taken as the whales travel back and forth along the deep water edge and offshore.

b) Furbearers

Eleven species of furbearers occur in the Fraser River estuary study area: muskrat, beaver, red fox, coyote, mink, river otter, striped skunk, spotted skunk, raccoon and bobcat. Population sizes are not known, but it is believed that muskrat and beaver are the most abundant furbearers.

Furbearers are year-round residents, generally found wherever suitable habitat occurs.

(i) Beaver

Beaver are dependent upon mixed bog-forest-freshwater riverine habitat. Generally, the freshwater marshes and riparian plant communities have highest capabilities for sustaining beaver, with bog rating slightly lower.

Two areas of specific importance for viable beaver populations are Surrey Bend, and the Pitt River with its associated Sturgeon Slough.

Beaver activity along the lower Fraser River appears widespread. Both old and fresh transient beaver activities can be found along the river banks and on the numerous islands within the study area. It is not known where most of the beaver originate, but Surrey Bend and the Pitt Meadows area are well-known beaver producing areas.

(ii) Muskrat

Muskrat are well adapted to estuarine and river marsh habitats. Areas of greatest abundance are from Deas Island westward throughout the entire Ladner marsh and Westham Island areas, and throughout the upper stretches of the Pitt River and associated marshes.

Muskrat populations are dependent upon stable water levels. It is evident from direct observation and from communication with trappers that muskrat populations utilize the dykes and ditches (outside the study area) rather than the Fraser River/dyke interface.

Present information on muskrat populations is restricted to fur harvest data collected by the B. C. Fish and Wildlife Branch. Population estimates are unavailable as is the utilization and importance of the salt marsh or riverine areas for healthy muskrat populations.

Major habitat zones having high capability ratings for muskrat are freshwater marshes, riparian plant communities, cattail/sedge marshes and bogs.

(iii) Mink

Mink, a major predator of muskrat, are found wherever stable muskrat populations exist. They do, however, have a wide distribution along the Fraser River banks and non-tidal areas where crabs or other crustaceans are readily available (i.e. Westham Island, Ladner Marsh, Pitt River Marshes).

(iv) River Otter

River otters usually are associated with river banks and ocean shorelines. They are not considered numerous throughout the study area. Known areas of otter habitation are Westham Island and the Pitt River where they feed on crustaceans, fish, small birds and mammals.

Habitat zones most important for otter are similar to those for muskrat and mink.

(v) Red Fox

Red fox, primarily an upland wildlife species, prey mainly on birds and small mammals. Douglas Island is the only area within the study perimeter that has a small population of foxes. Generally, fox populations have declined drastically within the last five years throughout the lower Fraser Valley. The cause of the decline is unknown.

(vi) Raccoon

Raccoons are adaptable omnivores that exploit a variety of habitats, particularly riparian communities, bogs, and agricultural areas where they search for food such as birds, small mammals, fish and crustaceans.

(vii) Other furbearers

Skunks (striped and spotted), coyotes and bobcats are the least encountered furbearers in the Fraser River estuary area. All four species exist in greater numbers in the eastern and southeastern parts of the lower Fraser Valley where they are more closely associated with the upland farms and forested areas such as Langley, Chilliwack or Pitt Meadows.

The coyote, a recent addition to the fauna of the lower Fraser Valley, has increased in numbers over the past several years.

c) Game Animals

Blacktail deer, cougar and black bear are known to occur in the study area but are not believed to be numerous.

(i) Blacktail deer

Blacktail deer are found in isolated populations wherever heavily wooded sections of land occur (generally of the bog habitat zone) such as: Douglas Island, Annacis Island (western half), Surrey Bend, Burns Bog.

(ii) Cougar

Cougar usually are associated with rocky or mountainous terrain and in close association with their primary food item, deer. Cougar are rare within the study area, the closest sighting of the species near the study area being in the Municipality of Coquitlam.

(iii) Black Bear

Black bears generally inhabit heavily wooded areas that provide an omnivorous diet of fish, small mammals, berries and other vegetation. Although bears have been almost eliminated throughout the Fraser estuary, Burns Bog is known to support a few and Surrey Bend may also have some. Elsewhere throughout the estuary area black bears are rare or absent.

d) Non-game Animals

Hoos and Packman (1974) listed 27 species in this category which include shrews, moles, opossum, bats, rats and mice, squirrels and rabbits. Most of the species in this group are a valuable source of food for raptors and carnivores.

All of the non-game species, except squirrels, have a general distribution throughout the entire Lower Mainland and occur within or near the study area wherever woodlots, bogs, riparian communities and adjacent agricultural lands provide suitable habitat. Squirrels usually are associated with coniferous stands (Douglas fir) where there is an abundance of seeds, fruits and berries. Although not numerous, squirrels are found in small numbers within the study area.

In spite of the fairly widespread occurrence throughout the study area of many species in this group, little or no research has been done on most species and information about their abundance is unavailable.

2. BIRDS

Species lists compiled by Hoos and Packman (1974) indicated 203 species representing 45 different families of birds frequent the estuary and adjacent water and upland areas. Taylor (1974) stated: "The avian component of the estuary wildlife resource is still both varied and abundant and no season of the year is without its regular visiting groups or species. Some arrive in spring to nest, rear young and depart in the fall as other groups arrive to spend the winter. Many are spring, summer or fall migrants, seen only briefly in passing".

The estuary and adjacent areas play host to a number of species that are either local in occurrence (such as the crested mynah) or are rare in Canada (such as the house finch) or in North America. During the summer of 1978, an Asiatic species, the spoon-billed sandpiper (only the third sighting of this species for North America), attracted bird watchers from all over the continent to the Iona sewage lagoons. Also, the rare Ross's gull was reported from the estuary during early 1978.

Birds are grouped into five general categories, waterbirds, songbirds, marshbirds and shorebirds, birds of prey and upland game birds.

a) Waterbirds

Waterbirds include waterfowl (ducks, geese and swans) plus several groups of birds that obtain their food primarily from the water (e.g. gulls, loons, grebes, cormorants, and alcids).

(i) Waterfowl

"The waterfowl of three continents converge at the Fraser wetlands on their way to and from breeding and wintering areas that extend from eastern Russia to South America. By nature of its size, climate, geographic location and the nutrient supply in its waters and delta lands, the Fraser River delta is the most important single area of aquatic bird habitat in British Columbia" (Hallady and Harris 1972) (Fig. 2).

It also supports the largest population of wintering waterfowl in Canada (Taylor 1974). Leach (1972) listed 36 species of waterfowl (of which 27 species either breed in the

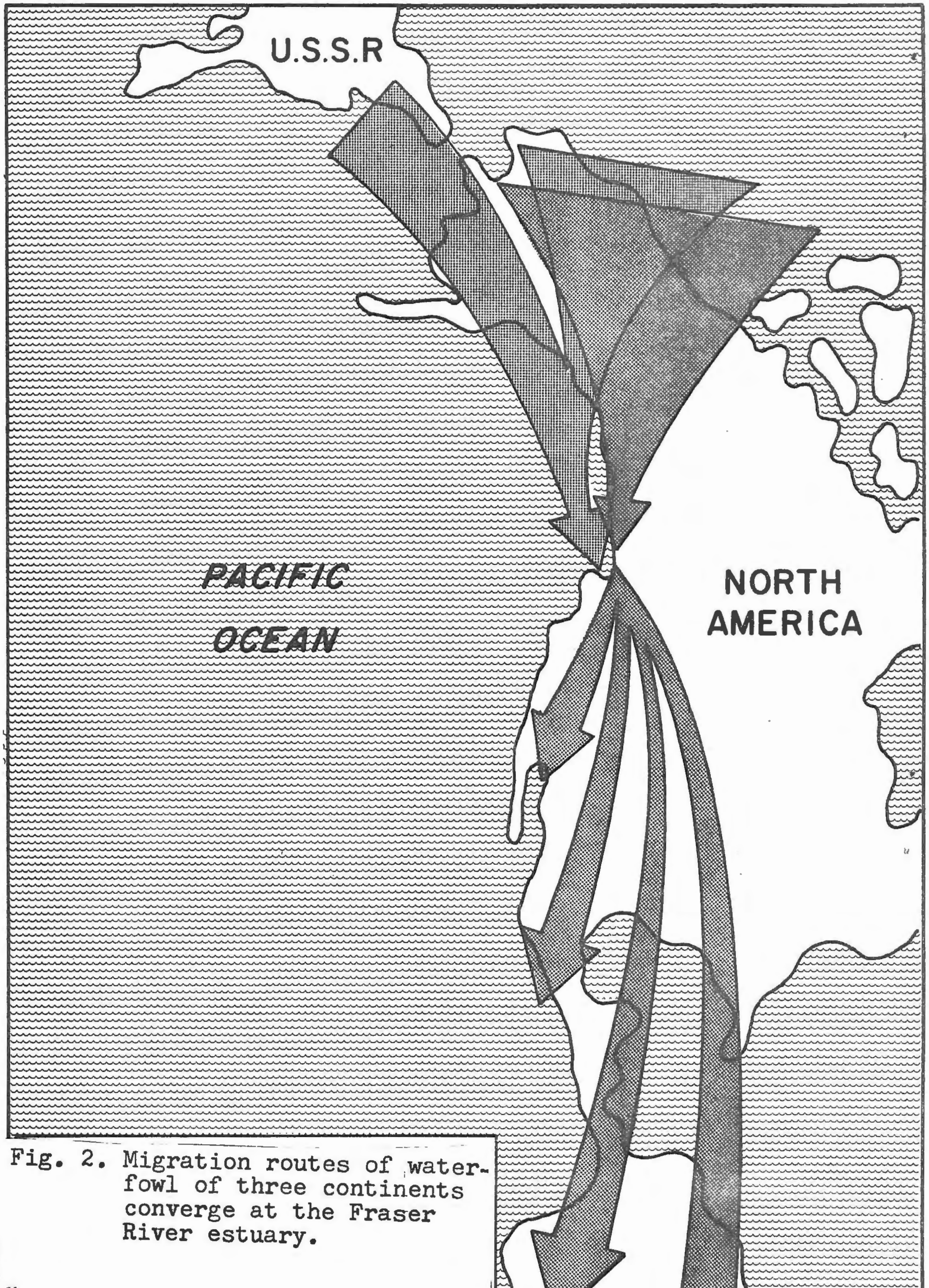

Fig. 2. Migration routes of waterfowl of three continents converge at the Fraser River estuary.

Source: Halladay and Harris, 1972.

area or occur as a significant part of the wintering population) as having been recorded on the Fraser delta. In addition, an estimated two million waterfowl migrate annually along the Pacific Flyway and it is believed at least one-half of these pass through the Fraser delta (Burgess 1970 , Halladay and Harris 1972).

About 200,000 ducks use the estuary as wintering habitat (Halladay et al. 1970). The first migrants arrive at the estuary in late August, build to peak numbers in November and December, then decline with the onset of the mating season. By May, most have migrated north again to the breeding grounds. This trend has been well documented by Canadian Wildlife Service aerial surveys (Burgess 1970, Taylor 1970, Sverre 1974).

The Fraser estuary is used mainly by waterfowl as migratory and wintering habitat. The estuary is not noted as a production (nesting) area, but with the establishment of wildlife management areas on Westham Island and at the Serpentine Fen, some increased local nesting is occurring, especially among Canada geese.

Dabbling ducks (such as mallard, pintail and teal which typically obtain their food on dry land or by "dabbling" or tipping-up in shallow water), geese and swans mainly eat vegetation which they obtain in the foreshore marshes and mudflats, riparian meadows, bogs, or from adjacent upland agricultural lands. Habitat zones of highest capability for dabblers are the freshwater marshes and wet riparian meadows followed closely by mud flats, agricultural lands and bogs.

Early in the fall, before low-lying fields in the lower Fraser Valley become flooded by fall and winter rains, dabbling ducks are attracted to the estuarine marshes and other permanently wetted or frequently wetted areas. When the fields become flooded, many of the dabbling ducks leave the estuary to feed in the fields. Those birds feed mainly on unharvested waste crops and weeds. Although the entire agricultural area is important to dabblers, an assessment of the year-to-year value to them of an individual parcel of farm land is difficult due to a number of factors such as crop rotation, changing farming techniques, etc. which may alter a particular area's attraction to the birds.

During the hunting season, many dabblers use Boundary Bay as a daytime loafing area, then fly inland under cover of darkness to feed in flooded fields.

During periods of prolonged cold weather when the fields become frozen or snow-covered, field-feeding ducks are forced to move back to the estuarine marshes which, because of their saltwater influence, and resulting lower freezing point, remain relatively ice-free. It is during periods of such crisis that the estuarine marshes are especially important to dabbling ducks.

Swans and snow geese feed primarily on the rhizomes of bullrush (Scirpus sp.) on Roberts Bank and Sturgeon Bank. Snow geese also feed on Woodward Island in the South Arm of the Fraser River and to a limited degree on agricultural lands near the foreshore marshes. Snow geese are most numerous during spring and fall migrations, but a sizeable population (up to 20,000 birds) often overwinters. These birds move between the Fraser estuary and the Skagit River estuary 100 km to the south in the State of Washington.

Canada geese, primarily grazers, utilize mainly agricultural areas, particularly pasture lands and other locations where short grass is available. Nesting concentrations of Canada geese are located at Westham Island, Serpentine Fen and Stanley Park. Some nesting also occurs at scattered locations throughout the study area.

Black brant rely heavily on eelgrass (Zostera sp.) as a source of food. Consequently portions of the estuary which produce eelgrass (i.e. Boundary Bay and parts of Roberts Bank) rate highest as brant habitat. Boundary Bay also provides good gravelling beaches for brant.

Although large numbers of brant (16,000 plus) migrate northward through the area each spring (Hoos and Packman 1974), perhaps only a few hundred southward migrants use this route in the fall. Only a few small flocks remain to winter in the area.

Diving ducks (such as goldeneye, scaup and scoters, which typically obtain their food by diving, often to considerable depths) occur throughout the estuary. Largest concentrations of diving ducks occur in Boundary Bay (Vermeer and Levings 1977). Mitchell (1951) reported that most diving ducks wintering in southwestern B. C. apparently preferred to feed in water no deeper than 6-8 fathoms (11-15 meters). The intertidal mud and sand flats and shallow sub-tidal portions of Sturgeon Bank, Roberts Bank and Boundary Bay provide extensive areas which meet these depth requirements.

While in the estuary, diving ducks eat mainly animal matter such as small fish, bivalves, snails and crustaceans which occur in the intertidal and shallow sub-tidal areas (Vermeer and Levings 1977). Some eelgrass is eaten by diving ducks, but eelgrass beds are of most value to diving species as habitat for food species.

The seasonal pattern of waterfowl use and distribution over the four major estuary components and Boundary Bay, is summarized for the eight-month period of winter and migrational use in Fig. 3 and Table 2.

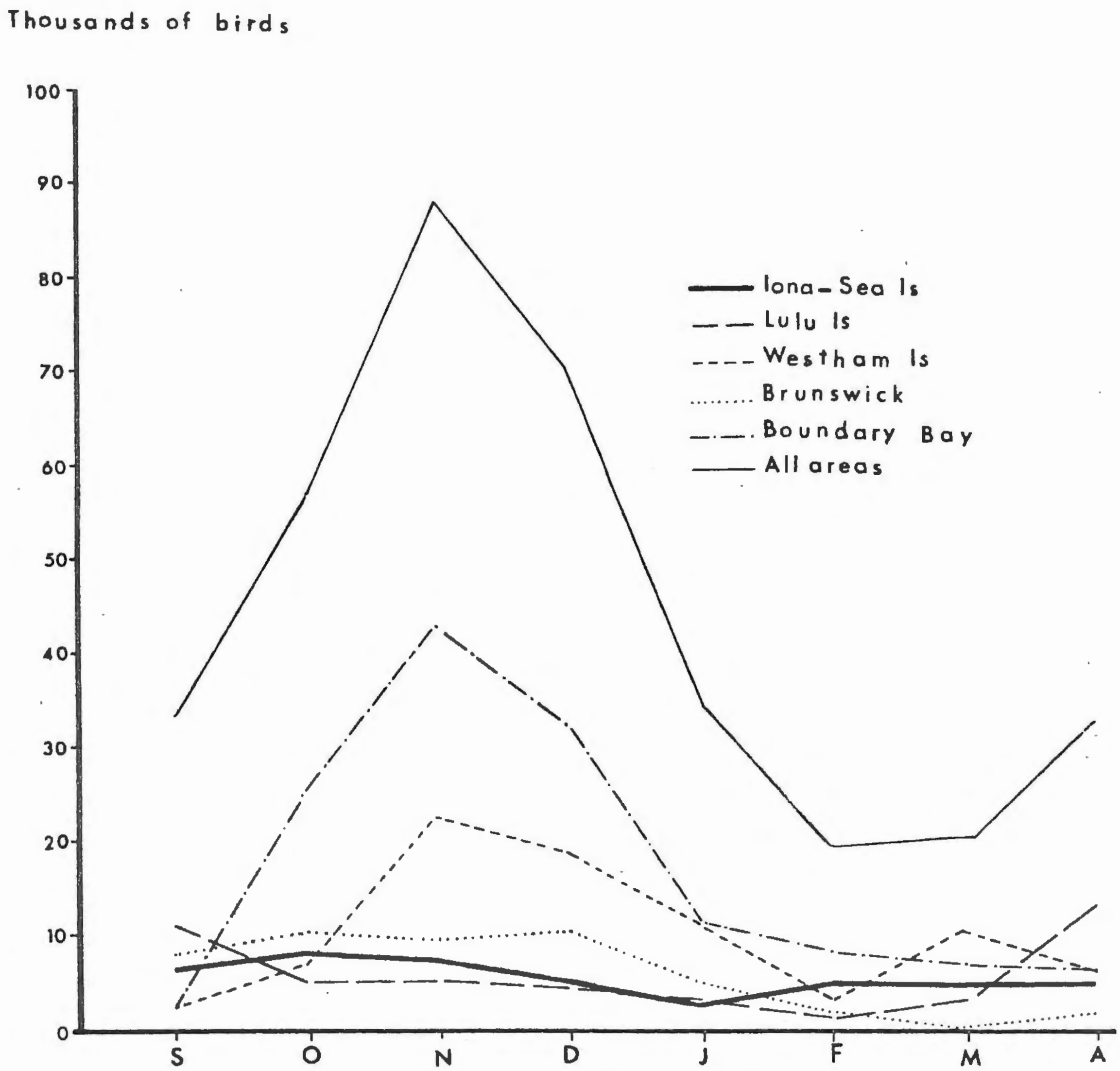

Fig. 3. Waterfowl per census day, aerial count averages by month, 1966 to 1974, Fraser Estuary, B. C. (From Taylor 1974).

Table 2. Average Monthly Waterfowl Counts for Period 1966 to 1974
(Average number of birds counted per aerial census-day)
From Taylor (1974).

	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	Total
Iona - Sea Island									
Ducks	6634	7723	7227	5275	2594	4284	4284	4648	42669
Ducks & geese	6634	8278	7701	5354	2594	5284	5284	5066	46295
Lulu Island									
Ducks	11032	5177	3881	3376	2845	647	2066	4571	33595
Ducks & geese	11032	5269	5490	4214	3011	1614	3300	13637	47567
Westham Island									
Ducks	2437	7036	20505	17341	10062	2872	5748	3786	69787
Ducks & geese	2437	7064	22872	19342	12412	3539	10415	6186	84267
Brunswick-Tsawwassen									
Ducks	8632	9093	8899	9788	3346	1963	157	1044	42922
Ducks & geese	8632	10580	9098	10727	5349	1964	275	1976	48601
Boundary - Mud Bay									
Ducks	2375	25663	43597	32212	11730	8457	6679	4535	135248
Ducks & geese	2379	25669	43691	32214	11743	8505	6982	6378	137561
Total Ducks	31110	54692	84109	67992	30577	18223	18934	18584	324221
Total Ducks & Geese	31114	56860	88852	71851	35109	20906	26256	33343	364291

For more details regarding the numbers of individual species of waterfowl, one is referred to Hoos and Packman (1974), Northcote (1974) and Taylor (1974), and the appropriate original literature references cited in those documents.

(ii) Gulls

The Vancouver and Fraser estuary area has the second largest gull population on the west coast (next to San Francisco Bay). Some gulls breed locally, but peak numbers of over 70,000 birds in the study area are reached during winter when Strait of Georgia birds are joined by gulls from as far away as south-eastern Alaska (Drent et al. 1971).

Wintering gulls are mainly glaucous-winged gulls (65-70 thousand) and mew gulls (5-8 thousand)(Drent et al. 1971). In addition, Campbell et al. (1972) have identified at least 14 other species of gulls and terns which visit the delta.

Most gulls feed regularly around garbage dumps, meat plants, and other sites where man provides food. According to Drent et al. (1971), 70% of all glaucous-wings are found at such places in winter. However, many gulls do forage, as the opportunities arise, on natural food items on the intertidal areas (marine organisms), at upriver tributaries such as the Harrison River (carcasses of spawned-out salmon) and on agricultural areas adjacent to the study area (insects, field mice, earthworms, etc.)(Drent and Ward 1970, Hoos and Packman 1974, Ward 1973).

According to Ward (1973), several of the major gull roosting sites in the Vancouver area are located within the study area on:

- mud flats and sand flats adjacent to the main channel of the Fraser River west of Steveston (3-year max. 30,500);
- log booms in the Fraser River near Sapperton, between the Pattullo Bridge and Port Mann Bridge (3-year max. 17,000);
- mud and sand flats in Boundary Bay off Ocean Park (3-year max. 26,000).

Small numbers of gulls are reported also to roost on Sturgeon Bank off the front of Sea Island (Environment Canada 1976). See Fig. 1 for locations of gull roosting sites.

Gull nesting colonies are scattered throughout southern Georgia Strait and adjacent waters (Drent and Guiget 1961), but only one is located within the study area, on man-made structures adjacent to the Tsawwassen ferry terminal (Fig. 1)(Environment Canada 1976).

(iii) Other Waterbirds

Other waterbirds include diving species such as: loons (3 species), grebes (5 species), cormorants (3 species), and alcids (5 species). Relatively little work has been done on these species' utilization of the Fraser estuary beyond recording incidental information on species occurrence and distribution (e.g. Campbell et al. 1972). Taylor (1974) stated:

"Grebes are common in the waters of the region and the western grebe, which is present all year except during the nesting season in July and August, is most abundant. The red-necked, horned and eared grebes are in much fewer numbers and present only in the winter and early spring.

The double-crested cormorant is absent from the region only during the nesting season in June and July. Prior to that period, usually in April, it gathers in numbers along the jetties in the river mouth where it feeds on the run of oolichans".

Canadian Wildlife Service surveys in 1976 reported large individual flocks of western grebes and arctic loons, containing an estimated 50,000 and 30,000 birds respectively, off Roberts Bank during the spring northward migration (G. Kaiser, personal communication).

Generally, diving species feed on small fish and invertebrates such as would typically be expected to occur in association with the intertidal and shallow subtidal portions of the estuary. Major habitat dependencies of this group are similar to those for diving ducks.

In addition, the various areas of primary production such as the eelgrass beds, the benthic algae, the salt marshes, the bullrush marshes, the cattail/sedge marshes and some of the freshwater marshes all contribute indirectly to the support of all the diving species (and some of the dabblers) by playing a critical role (through the provision of detritus) in the food chain supporting these species.

b) Marshbirds and Shorebirds

The marshbird and shorebird group includes: long-legged, shallow-water waders such as herons, coots, rails and bitterns which favour sloughs and marshes; and the smaller shorebirds such as the sandpipers, plovers and numerous other species that run along the beaches and wet fields in search of food.

Generally, great blue herons and the smaller shorebirds utilize similar feeding habitat, being found most often on the broad intertidal areas such as the mud and sand flats, the marshes (salt, bullrush, cattail/sedge and freshwater) as well as the wet riparian meadows.

(i) Herons

Although Campbell et al. (1972) reported three species of herons and one species of bittern occurred in the Fraser delta, the great blue heron is the largest and most numerous and makes widest use of estuarine habitat (Taylor 1974).

Recent counts of active nests in known heronries by the Canadian Wildlife Service in 1977 indicated that great blue herons appear to be thriving in the study area (J. P. Kelsall and K. Simpson, personal communication).

Counts of active nests indicate both the health and numerical strength of the birds, when compared with counts and comments on herons from past investigators. However, such comparisons are not straightforward since numbers of heronries have been destroyed over the years and others have moved position (some several times) as industrial or urban development has destroyed or modified their habitat.

From the vicinity of Kanaka Creek westward, seven heronries were found and observed by Kelsall and Simpson (Table 3, Fig. 1). It is possible that one or two more small ones remain to be discovered. In addition, a small, well-known colony in Stanley Park, just outside the area of present interest, contained 19 active nests in Douglas-fir trees in 1977.

Table 3 Locations of heronries, numbers of active nests per heronry and tree species in which nests were built in or near the Fraser River estuary west of Kanaka Creek in 1977 (J. Kelsall and K. Simpson, personal communication)

Location	Number of active nests	Tree species used
Crescent Beach	37	Douglas-fir
University of B. C.	82	Red alder
Point Roberts (U.S.A.)	216	Red alder
Port Coquitlam	169	Sitka spruce (predominately)
Edgewater Bar	16	Black cottonwood
U.B.C. Research Forest (Maple Ridge)	9	Douglas-fir
McIvor (Pitt Meadows)	10	Sitka spruce
	539	

The 539 active nests recorded represent a minimum 1078 herons of breeding age. In 1977, they produced a weighted mean number of fledgling birds of 2.63 percent (range 1.88 - 2.94 in the seven colonies involved). Judging from the literature, that is typical of healthy populations.

The numbers of active nests located in 1977 represent a four-to-five-fold increase over the most recent numbers reported by Mark (1976). However, there is no doubt that destruction of large tree groves, concurrent with urban sprawl in the lower mainland has much reduced the nesting options for herons in the area.

According to Taylor (1954):

" (Herons) may often be seen fishing well spaced out along the tideline of the exposed intertidal mud flats, marshes, or on the ditches and fields within the dyked lands of the estuary. The birds frequently travel some distance from the nesting sites to obtain fish, amphibians or small rodents with which to feed their young. The colony sites are usually associated with tall, mature ....trees, well removed from human disturbance. These situations are limited in the region and the future of the heron as a part of the delta fauna is vulnerable to change in both the upland and lowland portions of its range".

(ii) Shorebirds

One of the largest aggregations of birds frequenting the delta is the shorebird group. The importance of the delta for both migrating and wintering shorebirds was indicated by Halladay and Harris (1972) who estimated that the many species involved (at least 30 according to Campbell *et al.* 1972) number approximately five million during migration with about one million remaining to winter. Individual flocks of up to 9,000 birds are not uncommon in winter (Taylor 1974).

Information on most aspects of the biology of shorebirds in the Fraser River estuary is lacking. It is known, however, that depending on tidal conditions, shorebirds feed on both the intertidal foreshores and the agricultural lands within the dyked areas (Taylor 1974).

The food of most shorebirds consists mainly of small invertebrates (Bent 1927 and 1929) and although food habits studies are unavailable for shorebirds in the Fraser estuary, Levings and Coustalin (1975) reported the availability, on Sturgeon and Roberts Banks, of large numbers of potential food organisms for shorebirds.

Shorebirds choose their roosting sites according to tidal conditions and may roost on the high beach zone, partially flooded fields, causeways or on the rocky breakwaters of jetties (Drent et al. 1971).

The Canadian Wildlife Service began shorebird banding studies in 1977, but at the time of writing, reports of the first year's work were still in press (G. Kaiser, personal communication).

c) Songbirds

The most varied of the groups of birds of the delta are the passerines, or perching birds, more commonly referred to as songbirds. More than 80 species of songbirds are associated with the estuary (Hoos and Packman 1974).

Many species of songbirds are seen only during migration, while others such as starlings, house sparrows, robins, juncos, crested mynahs and Brewer's blackbirds are present throughout the year. The songbird group contains many species which are widespread throughout a variety of habitats, are seldom seen except by those who actively seek them, and are difficult to assess in terms of their numbers and use of the estuary (Taylor 1974).

It is unlikely that many species of songbirds visit the exposed intertidal mud-sand flats, but any areas of emergent vegetation and riparian tree/shrub communities are extensively used by those species adapted to the particular type of available habitat.

d) Birds of Prey (Raptors)

Birds of prey consist of hawks, eagles, falcons and owls. They are most common in the study area during the fall and winter months, but seldom in large numbers (Taylor 1974).

At least 21 species of raptors are found in the Fraser delta area as follows (those species marked with an asterisk (*) are major users of estuarine habitat):

Year 'round residents	Residents summer or winter	Transients
Bald eagle*	Rough-legged hawk	Gyrfalcon
Red-tailed hawk*	Peregrine falcon*	Golden eagle
Marsh hawk*	Kestrel	Snowy owl
Cooper's hawk	Merlin	Turkey vulture
Short-eared owl*	Goshawk	
Long-eared owl	Sharp-shinned hawk	
Barn owl	Osprey	
Great horned owl		
Saw-whet owl		
Screech owl		

Birds of prey require abundant prey species, large open areas for easy hunting and vegetation for perching, nesting and cover. Raptors use the upper reaches of the intertidal area, meadows and fields primarily as hunting grounds, being attracted to such areas by the availability of prey species. For example, peregrine falcons, gyrfalcons, goshawks and merlins are attracted by the large numbers of waterfowl and shorebirds. Other hawks and most owls are attracted by the abundant supply of small rodents which occurs on the upper fringes of the foreshore and the fields nearby. Bald eagles are attracted by fish and crippled birds.

Some birds of prey such as marsh hawks and short-eared owls use the vegetated areas adjacent to high tide as nesting areas and cover. Trees adjacent to estuarine areas often are used by raptors for nesting and as lookout perches. Birds such as goshawks, Cooper's hawks and sharp-shinned hawks prefer treed areas from which to launch surprise attacks on prey.

Although birds of prey are widespread throughout the Lower Mainland in appropriate habitat, areas where greatest concentrations of these wintering birds occur are the Pitt Meadows region, the Westham and Reifel Islands area and the Sea and Iona Islands area (Grass and Grass 1978, Taylor 1974).

e) Upland Game Birds

Upland game birds of the study area include ruffed grouse, ring-necked pheasants and California quail. Of the three species, ring-necked pheasants are most abundant. Only ruffed grouse are native to British Columbia.

Pheasants require shrub cover, cereal grains or other seeds for food and tall grass for nesting. Large open agricultural areas are not as attractive to pheasants as small areas fringed with heavy cover along ditches and fence rows. Cattail marshes are important cover areas during hunting season.

Quail, uncommon in the study area, prefer much the same sort of cover (especially the smaller agricultural units) as pheasants. However quail do not appear to be as well adapted as pheasants to the local climate.

Ruffed grouse prefer the edges of wooded areas. They require a forest in which to nest but use the edges for feeding. Winter food of grouse is primarily buds of deciduous trees.

3. AMPHIBIANS AND REPTILES

Apparently there have been no specific studies of these two groups in the study area and consequently little is known of their respective roles in the estuarine ecosystem. On the basis of distributions given in Carl (1944 and 1966), Hoos and Packman (1974) listed 12 species of amphibians and four species of reptiles in the estuary.

D. LAND USE IMPACTS ON WILDLIFE

Land use impacts on estuarine wildlife may be detrimental, beneficial, or neutral depending on the type of land use and the species involved.

1. DETRIMENTAL IMPACTS

Estuarine land uses having greatest detrimental impact on wildlife are those which alienate or degrade important habitat. Wildlife species are dependent upon habitat and because they use suitable habitat to the limits of its carrying capacity (i.e. the maximum number of animals of a given kind that a given unit of habitat can support), a reduction in amount or quality of available suitable habitat will result in a reduction in the number of animals.

Detrimental impacts on estuarine habitat may be brought about by its total destruction (alienation) such as that from dredging and filling or from degradation, often more subtle and less easily detected, such as alterations to freshwater flow, salinity or water quality. In addition, activities adjacent to critical habitat (but which do not actually encroach onto the habitat) may create disturbances that influence the animals' behavior so they make less efficient use of the area. Airports are one example.

Impacts also may be described as short-term or long-term depending on their duration. However, these terms are relative since the duration of impacts on habitats varies depending on the nature of individual developments or activities, types of habitat and species involved. Durations of impacts may range from those that last only a few hours, to those that still are in effect many years later, to those that essentially are irreversible.

Generally, activities which result in land "reclamation" by landfill, dyking and dredging have resulted in most of the adverse impacts. These three types of activities, either individually, or more often, in combination, usually are the impact-causing agents common to most other more specific classes of activities.

A detailed assessment of detrimental land use impacts on wildlife habitat is presented in the report of the Habitat Sub-group. Therefore, further discussion of detrimental impacts in this report will be confined mainly to impacts on the animals themselves.

Typical examples of detrimental impacts associated with seven types of land use are presented below.

a) Industrial Land Use

Industry located on or adjacent to wildlife habitat presents a constant threat of spills of oil or other toxic substances which may have serious adverse direct effects on wildlife. Additional lesser impacts may result from harassment due to industrial noise or from industry-related service activities.

b) Urban Land Use

Typical problems for wildlife associated with urban development are:

(i) Domestic Predators

Dogs and cats usually increase with urban housing. Conversely, numbers of natural predators such as hawks and owls are reduced as their feeding habitat vanishes. However, prey species in areas of remaining natural habitat adjacent to urban areas are subjected to increased levels of harassment and predation by dogs and cats, particularly the latter.

(ii) Insect Control

During warm summer weather urban areas adjacent to marshes often are plagued by mosquitoes. This usually results in demands by urban dwellers for the spraying of the marshes with insecticides. The main impact of such spraying is a reduction in numbers of beneficial insectivorous birds, amphibians or reptiles in the sprayed and adjacent areas due either to insecticide poisoning or reduced food supply since all insect populations, not just those of the target species, are reduced.

(iii) Increased Human Use of Habitat

Undeveloped natural areas adjacent to urban areas tend to attract unstructured so-called "non-consumptive" human recreational activities which may result in the destruction of sensitive habitat through trampling and picking of vegetation or in the disturbance of wildlife species due to noise, exercising of pets, etc. (Edwards 1976, Wilkes 1977).

c) Commercial Land Use

Detrimental impacts of commercial land uses are associated mainly with marine-related activities such as marinas, houseboat tie-up areas and boat servicing areas. Typical potential impacts of such activities are: pollution due to oil and sewage; disturbance of waterbirds due to heavy boat traffic in the vicinity of marinas and on main routes to and from such facilities.

d) Transportation Land Use

Transportation activities may affect wildlife. For example:

(i) Port Development

Associated with port development such as the Roberts Bank Superport and existing and proposed ferry terminals are the ever present threats of pollution and harassment during the construction and operation of such facilities.

(ii) Airport Development, Expansion and Use

Airports usurp large amounts of potential wildlife habitat. Additionally, the ever present threat of bird strikes dictates that areas between and adjacent to runways, although not paved, be maintained in a condition as unattractive as possible to as many species as possible (Solman 1978). Other impacts on wildlife associated with airports potentially are related to chemical pollutants such as de-icers, spills of petroleum products, noise disturbance and bird strikes, which not only reduce the number of birds in the area but also are a hazard to human lives.

(iii) Roads, Highways and Railroads

Where roads, highways and railroads dissect wildlife habitat, a considerable number of animals are killed annually by motor vehicles and trains (Sargent and Forbes 1973). Also, pollution of roadside habitat by lead and other toxic substances from automobile exhaust and tires and by salt used to de-ice roads in winter are detrimental.

(iv) Navigational Aids and Radio Transmission Towers

Towers and their support wires used as navigational aids and for radio transmission are hazards to birds at night (Avery 1976).

e) Utilities Land Use

Utilities such as electrical and telecommunications transmission lines, gas and oil lines, sewers and sewage treatment plants have potential direct impacts on wildlife.

(i) Navigational Hazards

Overhead electrical and telecommunications lines and towers are navigational hazards to birds (Cornwall and Hochbaum 1970; Avery *et al*. 1976; Miller and Kaufman 1978);

(ii) Contamination

Heavy metals and other toxic substances from sewage treatment plant outfalls or leaks or spills of insulating oil from buried or underwater electrical lines may contaminate food or the animals themselves.

(iii) Harassment

Harassment may be a problem during construction of utilities, especially where helicopters are used to aid construction across waterfowl habitat during periods of bird use.

f) Recreational Land Use

Recreational activities which may have direct impacts on wildlife include:

(i) Harassment

Harassment may result from unrestricted use of wildlife habitat by recreationists for such activities as:

- horseback riding
- driving motorbikes and all-terrain vehicles
- hunting
- fishing

- nature study
- walking and hiking

(ii) Lead Poisoning

Concentration of waterfowl hunting in certain areas may result in lead poisoning of waterfowl. The potential severity of the lead poisoning problem will vary with factors such as the concentration of hunting, the type of bottom on which the shot lands, the rate at which it is covered by sedimentation and the depth into the sediment that an individual species forages.

g) Agricultural Land Use

The agricultural use of herbicides and insecticides (biocides) also presents a potential direct threat to wildlife which use fields where those chemicals have been improperly used or where they have not broken down according to manufacturers' predictions. Such were the causes of at least four duck kills (over 1000 birds in one instance) in fields in Richmond and Delta between 1973 and 1977.

Less obvious impacts of agriculture on estuarine wildlife may result from the run-off and/or wind-drift of biocides and fertilizers onto adjacent wildlife habitat or from a reduction in the food supply of insectivorous birds as a result of the use of broad spectrum insecticides.

2. BENEFICIAL IMPACTS

Although most land use impacts on wildlife are detrimental, some are beneficial or neutral. Beneficial impacts usually are not planned by the developer and occur accidentally and incidentally as a result of development.

Most beneficial impacts are restricted to only a few specialized species and probably occur at the expense of (i.e. a net loss to) the total ecosystem.

Also, the species composition of wildlife adapted to the use of developed areas usually is different from and/or less varied than that which used the areas in their natural state. For example, a golf course or a cow pasture may provide excellent grazing conditions for wigeon and Canada geese, but if a productive estuarine marsh was destroyed to provide the golf course or the pasture, the detrimental impacts on the varied forms of wildlife that formerly used the area combined with the lost value to the fisheries resource would probably far outweigh the benefits to wigeon and geese.

Amounts and kinds of benefits derived by wildlife from human land use depend upon the type of land use and the species involved. Some species may derive benefits without causing any damage (e.g. gulls loafing on log booms); others may derive benefits and themselves provide benefits to humans (e.g. insectivorous birds); and still others, in the process of deriving benefit, may cause damage or otherwise create a nuisance which puts them into conflict with human interests (e.g. pre-harvest depredations of farm crops). The problem of wildlife conflicts will be discussed in a subsequent section.

The following list provides some examples of the types of benefits which may accrue to wildlife from various forms of land use. However, because the net environmental impact of each development should be assessed independently, the benefits listed must be viewed with caution since no attempt has been made to appraise the potential detrimental impacts of the development on the total ecosystem. The list is not meant to be extensive or complete, but rather to provide representative, typical examples of beneficial spin-offs from development within the estuary.

a) <u>Industrial Land Use</u>

(i) <u>Buildings</u>

Buildings may provide nesting or roosting sites for birds. However, birds attracted to such sites usually are undesirable introduced alien species such as rock doves, starlings, crested mynas or weaver finches (English sparrows). Some native insectivorous birds such as swallows and robins also nest in or on buildings.

Buildings potentially are common to all of the other activities discussed in this section and therefore will not be included in discussions of the other activities.

(ii) <u>Landscaping</u>

Landscaping may provide habitat for a wide variety of birds depending on vegetation types cultivated. As with buildings, landscaping potentially is common to most other activities discussed in the industrial section and will not be discussed hereafter.

(iii) <u>Food Processing Plants</u>

Food processing plants often provide food for scavenging birds such as gulls, crows and starlings.

(iv) <u>Log Booms</u>

Log booms may provide loafing areas for gulls, herons, crows and waterfowl.

(v) <u>Peat Mining</u>

Peat mining, for example in Burns Bog, may provide open-water areas for waterfowl.

b) Urban Land Use

(i) Bird Feeders

Urban dwellers often encourage wild bird use of their property by setting out bird food in artificial feeding devices.

(ii) Sanitary Landfills

Sanitary landfills (garbage dumps) provide food for scavenging birds such as gulls, crows and starlings.

c) Commercial Land Use

Golf courses may provide potential grazing areas for wigeon and Canada geese and feeding and resting areas for gulls and shorebirds.

d) Transportation Land Use

(i) Bridges

Bridges may provide nesting and roosting sites for some species of birds.

(ii) Jetties and River Training Walls

Jetties and river training walls may provide roosting and loafing sites for gulls, shorebirds and waterfowl. Some nesting by gulls occurs on a breakwater at the Tsawwassen ferry terminal.

It also has been suggested (Beak Hinton Consultants Ltd. 1977) that eelgrass (an important food of black brant, and an important habitat for prey species of diving birds) has increased in the intercauseway portion of Roberts Bank because of construction of the Roberts Bank superport facility.

e) Utilities Land Use

(i) Overhead wires

Overhead wires provide loafing sites for perching birds.

(ii) Sewage Lagoons

Sewage lagoons may provide habitat for some species of waterfowl and shorebirds.

f) Agricultural Land Use

Of the types of land uses discussed, agriculture probably is most compatible with wildlife interests. However, it also presents one of the major areas for potential wildlife and human land use conflicts in crop depredation.

As discussed in the Habitat Sub-group report, the initial dyking at the turn of the century eliminated much natural marshland and as a result reduced the numbers of many forms of native wildlife which used them. Some forms of agriculture provided waterfowl and upland game bird habitat where none existed previously. Other agricultural activities may even have provided better quality habitat for some species of waterfowl than was provided by the naturally-occurring vegetation communities.

The value to wildlife (particularly wintering waterfowl and shorebirds) of the agricultural lands of the Lower Fraser Valley is, in general, well recognized. Large numbers of wintering dabbling ducks rest during the day on the waters of Boundary Bay and the outer marshes of Roberts and Sturgeon Banks and then fly inland in the evening to feed, for the most part, on unharvested waste farm crops and weeds in flooded fields.

However, it is difficult to assess the long-term value to wildlife of a particular parcel of agricultural land. Whether a given parcel of agricultural land is improved for wildlife by agriculture depends upon the type of agriculture which replaces the natural habitat. Similarly, agricultural land that was good wildlife habitat one year may not be attractive to the same species under different cropping practises in succeeding years. This is particularly true for wintering waterfowl.

Because of the large numbers of wildlife species which inhabit the lower Fraser Valley and the fairly wide range of crops grown, a detailed list of potential benefits provided to wildlife by agriculture would be too long to include here. Therefore, the following list is meant to provide a few samples of the general sorts of benefits enjoyed by wildlife as a result of agricultural practices.

Feature of agricultural landscape	Potential benefits to wildlife
(i) Pasture lands:	- grazing area for Canada geese and wigeon.
	- feeding area (worms, insects, etc) for gulls, shorebirds and some insectivorous birds.
(ii) Standing crops:	- food for many wildlife species attracted to the crop, or to weeds growing among the crop species.
	- nesting cover for some species of ground-nesting birds.
	- escape cover for many species.
(iii) Unharvested waste crops:	- winter food for various species, particularly waterfowl.
(iv) Uncultivated fields:	- may be good habitat for small rodents.
	- feeding area (insects, weed seeds, etc.) for a number of bird species.
	- nesting cover for ground-nesting birds.
	- escape cover for some species of birds.
	- hunting area (abundant prey species) for predatory mammals and raptors.

(v) <u>Uncleared fence rows, dykes and ditches</u>:	- escape and nesting cover for many species. - seeds of some species (e.g. weeds, blackberries, roses, choke cherries, etc.) may provide a variety of wildlife foods.
(vi) <u>Cultivation practices</u>:	- ploughing may expose large numbers of earthworms, insects, etc., to gulls and insectivorous birds. - run-off of manures and fertilizers may provide nutrient input to adjacent habitat, but if excessive, may be more detrimental than beneficial.

It is important to re-state that although wildlife may receive benefits from various land uses, the initial destruction of natural habitat to provide for those uses probably results in a net loss to the wildlife resource. Consequently, although a few species may derive benefits, when the total wildlife resource is considered, such benefits are only relatively minor mitigating factors.

3. CONFLICTS

The most significant conflicts between wildlife and man in the Fraser River estuary involve the alienation of wildlife habitat. However, while deriving benefits from certain types of established human land uses, wildlife may cause damage or otherwise create a nuisance and thus come into conflict with human interests. Examples of such conflicts follow:

a) Crop Depredation

The crop depredation problem spans many types of commercial and private crops and many species of birds and mammals. The problem usually is slight but can be extreme when large numbers are involved (as with starlings swarming on berry patches). Usually there is no simple solution to the problem and each situation must be evaluated separately. A solution may be as simple as a scarecrow or as drastic as not growing a particular crop in a particular location.

b) Bird Hazards at Airports

Birds at airports are a potential hazard to planes and human lives. The first recorded human fatality caused by a collision between an aircraft and a bird (a gull) occurred in 1912 (Solman 1978). Turbine-powered aircraft are more susceptible to bird damage than propellor-driven craft because the former travels faster and thus birds are less able to avoid collisions with them.

Ideally, airports should not be built in areas such as estuaries (e.g. the Fraser) which are traditional wintering and staging areas for migratory birds. Unfortunately, this cannot always be avoided. For human safety, the airport and as much of the adjacent area as feasible, should be made as unattractive as possible to as many species of birds as possible (Solman 1978). However, to do so in an area such as the Fraser River estuary, which has extremely high ecological value to both fisheries and wildlife resources, would further disrupt natural habitat outside the boundaries of the airport and may be unacceptable to other regulatory agencies and the public.

Also, garbage dumps should not be situated where they will create major flyways of scavenging birds across aircraft flight paths.

c) Wildlife as a Potential Health Hazard

Wild animals may serve as reservoirs of diseases for humans and domestic livestock.

Concentrations of birds in public places, roosting or nesting on buildings, under bridges etc., may not only create a nuisance with their noise and droppings, but may also represent a health hazard to humans and domestic stock (Davis, _et al_. 1971).

The problem of wildlife as a source of human disease also is habitat-related in that suitable types of habitat attract the birds. It may be related to people feeding pigeons in city parks and squares. It also may be related to an abundance of ledges, holes and niches in man-made structures which create ideal roosting and/or nesting sites. Elimination of the features which attract the birds will significantly reduce this type of conflict.

E. RECREATIONAL VALUES FOR WILDLIFE OF THE FRASER RIVER FORESHORE

No studies exist that have directly measured the recreational value of the wildlife of the Fraser River foreshore. Nor does a consistent body of data exist that can indicate even the magnitude of recreational use. The purpose of this section will, therefore, not be to establish an exact magnitude of value - for such an estimate will not be possible pending further explicit data collection in the subject area. Rather, inferences will be drawn from both partial user data, and studies conducted elsewhere to provide an order-of-magnitude first indication of dollar worth.

It was assumed that most wildlife-related recreation in the study area is directed toward birds. Therefore, bird-related activities were selected for this evaluation. Recreational values of other forms of wildlife not considered will further increase the values provided herein.

1. CATEGORIES AND MAGNITUDES OF USE

The birds of the Fraser foreshore provide recreational enjoyment for a variety of users. Hunters, strollers and beachgoers, local residents, and even persons driving the Tsawwassen causeway all enjoy the pursuit, or the sight of bird life to some degree. In addition, some local species of birds range beyond estuarine environs to bring pleasure to more distant residents and recreationists while migratory species bestow value upon persons in other regions, provinces and countries. It is beyond this task to document these latter two sources of value across the complete range of each species' flight path. Rather, this statement will estimate on-site user values only. In so doing, it will considerably understate the full value of these wild species.

a) <u>Hunters</u>

In 1976-77, 5,350 hunters bought Fraser Valley Special Hunting Licenses. It was further estimated (Recreation Work Group 1978) that these hunters hunted 77,160 days in the Fraser estuary and related lowlands (Table 4) for an average of 14.4 days per hunter.

Table 4. Estimated numbers of hunter-days spent in various portions of the Fraser River estuary during the 1976-77 hunting season.

Area	Hunting days
Iona Island	2816
Sea Island	2864
Lulu Island	5560
Westham Island	9688
Brunswick Point	4296
Tsawwassen	1568
Duck-Barber-Woodward Islands	8352
Ladner Marsh	6416
Centennial Beach	2504
Inner Boundary Bay	8104
Outer Boundary Bay	1184
Mud Bay	5776
Pitt Polder	5832
Pitt Lake	1112
Upper Serpentine	5536
Nikomekl-Serpentine Lowlands	5552
	77,160

In addition, it is estimated that in British Columbia, each hunter spends an additional 7 days in associated activities such as dog training, shooting practice, care of equipment, etc. (Quadra 1977). For the 5,350 license holders identified previously, this would add a further 37,450 recreation days to estuary-related hunting activity.*

*Not all this activity would necessarily be dependent solely upon the Fraser estuary.

b) George C. Reifel Migratory Bird Sanctuary

It was estimated that 75,200 persons visited the Reifel Sanctuary in 1976 (Recreation Work Group 1978). These persons can be considered as attending explicitly to view birds, and will be so treated in the value section.

c) General Recreational Use

Few data exist on general recreational use across the estuary foreshore. However, the Greater Vancouver Regional District has produced a single-day estimate for a summer weekend day. Further, seasonal participation patterns for marine boating, by weekday and weekend were estimated in another study (Meyer and Harrison 1976). If relative recreational patterns on the foreshore are assumed not too dissimilar, it may then be possible to prorate the GVRD estimate to an annual figure utilizing the boating estimates. This is done in Table 5.

Table 5. Estimated numbers of people, by period, who visit the Fraser estuary for general recreational purposes.

	July and August		June and Sept.		Oct. to May	
	Week	Weekend	Week	Weekend	Week	Weekend
Proportion of day participation estimate to Peak Weekend participation rate *	.26	1	.09	.4	.02	.09
Recreationists per day	8,900	34,400	3,100	13,800	700	3,100
Number of Days	44	18	43	17	173	70
Total Recreationists	391,600	619,200	133,300	234,600	121,100	217,000

*From Meyer and Harrison (1976).

These recreationists will not, of course direct their effort solely at birds. This problem will be discussed in the value section to follow.

d) Residency Adjacent to the Estuary

Meyer and Phillips (1977) reported that amenities such as birds, small animals and natural areas are important factors in living style. It is estimated that 175,000 persons live within one mile of the Fraser foreshore. For these persons, the birds of the estuary area are part of their lifestyle. It is assumed in this analysis that the value such a resident obtains from watching birds over a year will be at least equal to that of the recreational hunter who makes 14 trips annually to specifically seek waterfowl.

e) Travellers on the Tsawwassen Causeway

In 1976, an estimated 900,000 automobiles used the B. C. government ferries at Tsawwassen. About 50 percent of these were British Columbians, 50 percent tourists. During such trips, it is usual to see birdlife along the causeway, and over the estuary. Therefore, it seems reasonable to assume that this experience enhances the automobile trip to some degree. A value will arbitrarily be assigned "per automobile" in the following section.

2. UNIT VALUES ASSOCIATED WITH USE

No explicit study of wildlife values of the Fraser estuary has been conducted. Further, as in most instances participation requires either minimal license or entry fees, or no fee at all, valuation must be by hypothetical enquiry. Further, previous empirical work with non-priced goods has identified at least three possible approaches to valuation:

1) a demand-related user "willingness to pay" approach, useful in evaluatory "additions" to the quality and quantity of wildlife recreation;
2) an offer-related "requirement for compensation" approach, useful in evaluating the losses suffered by present or potential users should wildlife opportunities decline;
3) some attempt at an intermediate value based upon relative governmental expenditures and priorities.

In this analysis, the "willingness to pay" approach is relevant for enhanced wildlife opportunities in the estuary, while "requirements for compensation" pertain to losses associated with estuarine degradation. Therefore, both will be discussed. Theorists point out that the difference between these two value estimates may not be great where the "product" being evaluated plays a relatively less important role in the material, social, psychological and cultural style of living of the individual.

Conversely, where the product (in this case, hunting or viewing birds of the Fraser estuary) is considered "relatively important", compensation required for losers can be considerably greater than willingness to pay for further recreational opportunity. An extreme case that is clearly not applicable to the estuary - but one that makes the point very well, has been outlined by Mishan:

> "The maximum sum (a person) will pay for something valuable is obviously related to, indeed limited by, a person's total resources, while the minimum sum he will accept for parting with it is subject to no such constraint. To take an extreme example, a man may be ready to sacrifice every penny he can spare in order to pay for an operation that will save his life. This may amount to a present value of $10,000 or $10,000,000, but will be a finite sum. On the other hand, there may be no

> sum large enough to compensate him for going without the operation, and so parting from his life."
>
> (Journal of Economic Literature, 1971, pp. 1-19)

It is therefore necessary to determine what inferences regarding willingness to pay for enhancement, and requirements for compensation for reductions in estuarine wildlife, may be drawn from existing empirical work.

The most geographically proximate estimate of wildlife values on the demand site (willingness to pay) is obtained from a 1977 update of 1970-71 seasonal data obtained by questionnaires mailed to hunters in British Columbia (Quadra 1977). This report provides an estimated hunter-day value of $8.90 for upland birds and waterfowl. It is likely, however, that such an estimate represents an extreme lower bound of day value. For, in fact, data on upland birds and on waterfowl were not gathered. Rather, they were "judgmentally" derived by the consultant, and interpolated with data on caribou, mountain goat, mountain sheep and grizzly bears.

Actual data were derived for wetland and waterfowl resources in Washington State by Hammack and Brown (1974). They developed a "willingness to pay" value of $247 per year - again based upon a mailed questionnaire. Day values would, of course, depend upon the number of "days hunted". Utilizing our earlier figure of 14.4 days per year would result in a day value of $17, but could obviously vary with effort.

The U. S. Fish and Wildlife Service (Brown et al. 1978) has recently published the "willingness to pay" results from its 1975 National Survey of Hunting, Fishing and Associated recreation. These data provide the most contemporary and complete estimate to date of user willingness to pay. Per day values appropriate to estuarine birds are:

Waterfowl	$ 33
Migratory Birds	$ 39

The lower of these two numbers - $33 per day - will be utilized as a willingness to pay estimate for hunters in the present study. The higher value was developed in the context of more generalized recreation, and will be utilized in that section of the analysis.

Requirements for compensation will exceed willingness to pay by a factor dependent upon relative importance of the recreational amenity under consideration. Thus, for the Fraser estuary, differences may be greater for large-scale proposed alternatives than for small-scale ones. Work in fishery recreation suggests that where "whole systems" are at stake, required compensation can exceed willingness to pay estimates by 20 times (Meyer 1975). Conversely, where product is relatively unimportant, the two value estimates can be close (Bohm 1971).

For intermediate products, such as park sites or recreational site-related activities, empirical work suggests a differential of perhaps 3 or 4 to 1 (Romm 1969, Hammack and Brown 1974, Eby 1975, Banford 1977, Gordon and Knetsch 1977).

The only direct data derived on compensatory requirements from bird losses came from the Hammack-Brown (1974) study, and from Horvath (1974). Hammack and Brown estimated a value of $1,044 per year per hunter, 4.2 times their estimate for willingness to pay. Horvath, in his study of the American Southeast, estimated compensatory requirements of $67.24 per day for hunters of waterfowl, and $81 per day for non-consumptive recreationists generally enjoying birds.

If Horvath's figures are related to the willingness to pay estimates previously selected ($33 and $39 respectively), they provide compensatory estimates in excess of willingness to pay by ratios of 2.0 and 2.1 respectively. This difference seems reasonable for a "generalized" display of compensatory requirements". Consequently, the Horvath estimates were utilized in the present study.

3. ORDER OF MAGNITUDE ESTIMATES FOR RECREATIONAL VALUE OF THE BIRDS OF THE FRASER ESTUARY

a) Specific User Values

Combining the data of the previous two sections, annual user estimates were obtained for the Fraser estuary area (Table 6).

Table 6. Value estimates for bird-related recreation, Fraser River estuary

		Value Per Day		Total Annual Value	
	No. of User days	Willing-ness to pay	Compensa-tion req-uired	Willing-ness to pay	Compensa-tion req-uired
		$	$	$'000	$'000
Hunting Values	77,160	33	67.24	2,546	5,188
Associated Values	37,450	33	67.24	1,236	2,518
Reifel Sanctuary	75,200	39	81	2,933	6,091
				6,715	13,697

b) General Recreational Values and the Birds of the Fraser Estuary

The estimates for general recreational use developed in Section 1c do not, of course, refer exclusively to birds - but range the full gamut of recreational use on the foreshore. Further, it is likely that birds play a somewhat more prominent role for the winter recreationist than for those present in summer.

To gain a better understanding of the "bird" component of general recreation, it was assumed that while individual recreation day values would range between a complete focus on birds, and no concern for birds at all, the proportionate focus on birds across all users could generally be described by a probability curve. (For a full discussion of probabilistic applications in such problems, see Meyer and Dolphin, 1977.) Further, it was assumed that this probability distribution would "peak" at 10 percent of the user population in July and August, at 15 percent of the user population in June and September, and at 25 percent of the user population, October through May. The case for July is presented graphically in Fig. 4.

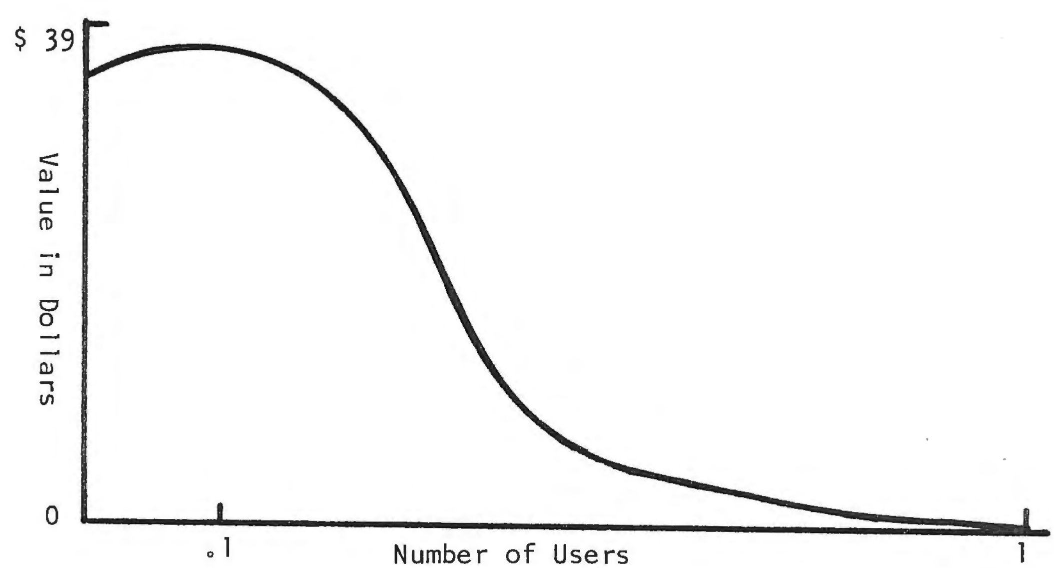

Fig. 4. Probability estimate - importance of "bird" values for general recreationists.

From the curve it can be seen that the probability of all users assigning their full value to birds is only 10 percent. the probability of other values between 0 and $39 being assigned can likewise be read from the curve. Of course, as the curve is arbitrarily selected, a different peak value, or a different curve shape will yield a different result. However, such results are surprisingly insensitive to moderate changes in assumption, and those selected do not seem *a priori* unreasonable. Results, based upon those assumptions, and obtained by integrating under the curve follow in Table 7.

Table 7. Estimated general recreation value for birds of the Fraser River estuary

		Total Recreation Unit Value		Value for Birds	
Period	No. of Recreation Days	Willing to pay	Compensation required	Willing to pay	Compensation required
	'000	$	$	'000	$'000
July & Aug.	1,011	39	81	14,394	29,174
June & Sept.	368	39	81	5,283	10,698
Oct. to May	338	39	81	5,139	10,407
				24,816	50,279

Other analysts may, of course wish to alter underlying assumptions, according to their own judgement. Under present assumptions, estimates of bird-related value associated with recreation on the estuarine foreshore, are $25 million and $50 million annually, respectively. And under any foreseeably reasonable set of assumptions, these values would appear to be of major significance.

c) Resident Values

Residents living adjacent to the estuary will also gain pleasure from the existence of plentiful bird life in the immediate area. If it is arbitrarily assumed that this value is, over a year, at least equal to the value received by the hunter in 14 trips to the estuary, the value estimates in Table 8 would pertain.

Table 8. Estimated amenity values from bird life for residents of the Fraser estuary

	Value of 14 Days Hunting		Aggregate Annual Value	
No. of Residents	Willing to Pay	Compensation required	Willing to Pay	Compensation required
	$	$	$'000	$'000
175,000	462	941	80,850	164,675

d) Travellers on the Tsawwassen Causeway

It was arbitrarily estimated that travellers on the Tsawwassen causeway, an area frequented by estuarine birds, have their trip enhanced by $1 per automobile by such experiences. This adds an annual value of $900,000 to those values previously identified.

e) Summary of Estimates of Dollar Values Associated with Birds of the Fraser Estuary

As noted initially, no comprehensive data source exists upon which to base specific estimates of the dollar value of the birds of the Fraser estuary for recreation. Based upon inference and assumption, it is estimated that as a first order magnitude, existing flocks may return local user values in the order of $112 million annually if viewed as a base for enhancement, and $229 million annually if considered under threat. Although these values are based on inference, such inferences and assumptions are considered reasonable.

Further, no values on the path of migratory species outside the immediate area have been calculated, nor have resident values for Greater Vancouver associated with local flocks which range inland for part of the day.

Finally, no preservation values have been estimated. Evidence collected on Fraser River salmon and steelhead suggest that preservation values may be equal in magnitude to values associated with use (Meyer 1978). Valuation of particular incremental changes in flock levels must, of course, be proposal specific - and an explicit survey of bird-related recreational values in the estuary would be beneficial.

Even if the order of magnitude estimates inferred here changed considerably, the results are such that it can safely be concluded that the birds of the Fraser River estuary make a major contribution to the recreation and living style of residents of Greater Vancouver, and a significant contribution to the enjoyment of visitors.

F. WILDLIFE MANAGEMENT POLICIES WITHIN THE STUDY AREA

1. FEDERAL POLICIES

a) Marine Mammals

(i) Harbour Seals

Harbour seals were hunted in B. C. during 1914-1964 for bounty to reduce interference with salmon fisheries and during 1962-70 for hides. The Fraser River-Boundary Bay region was always regularly hunted with 50-200 pups killed annually during the 1960's. In 1970, the species was protected with provisions for some to be captured for zoos and aquaria. Each year 5-10 deserted pups are claimed from this region.

(ii) Killer Whales

Prior to 1964 there was no specific management policy for killer whales as they had no commercial value. However, because they sometimes frighten spring salmon and thus interfere with sport and commercial salmon fishing, the Department of Fisheries encouraged their harassment away from important fishing areas.

During 1964-70, killer whales were captured in increasing numbers for zoos and aquaria, with 20 taken in southern B. C. Permits were required for live capture although no quotas were imposed. One was accidentally drowned in a net off Steveston in July 1966. In 1970, the species was protected and quotas imposed. In 1970-77, six whales were taken. The current policy, established in 1976, is to issue permits to replace killer whales which die in Canadian zoos and aquaria; none are to be captured for export to other countries.

b) Migratory Birds

The federal government is responsible for migratory birds in Canada, having the tasks, in the words of the Migratory Birds Convention signed with U.S.A. in 1916 "of saving from indiscriminate slaughter and of insuring the preservation of such migratory birds as are either useful to man or are harmless".

The role of the Migratory Birds Branch of the Canadian Wildlife Service is to keep Canada fit for birds to live in by fulfilling those federal responsibilities while managing the migratory bird resource for the maximum benefit of existing and future generations of Canadians and of other peoples having a common interest in the welfare of the birds.

Such policy will be implemented in the Fraser River estuary by:

(i) Monitoring the status and understanding the requirements of migratory birds living in or visiting the Fraser River estuary to ensure that no species or clearly definable stocks within a species become threatened by destruction resulting, directly or indirectly, from human actions; and to take whatever actions are needed to preserve any threatened group from extinction;

(ii) Ensuring the preservation and management of important, critical and unique habitats for the primary benefit of migratory birds and other wildlife;

(iii) Encouraging and making possible the appreciative use of birds by ensuring their diversity and abundance at appropriate seasons, particularly in places within reach of large numbers of people;

(iv) Managing the use of those migratory birds the stocks of which may at present be safely exploited by people in need of food or recreation;

(v) Devising ways of preventing or diminishing effects of birds detrimental to society and providing advice on how to minimize damage by birds;

(vi) Securing adequate enforcement of existing national legislation relating to migratory birds and their habitat and by seeking improvements in national and international agreements and legislation for the better conservation of migratory birds and the resources they need.

G. DATA GAPS AND RECOMMENDATIONS

1. ECOLOGICAL INFORMATION

Site-specific data are lacking for most species of wildlife in the study area. Although sufficient data exist for many species to document their dependency on the estuary, in many cases the data are not detailed enough to identify habitat types of special importance. For still other species, little is known beyond the incidental recording of information about their occurrence and general distribution.

Before wildlife management agencies can develop comprehensive management plans or quantify their goals for wildlife populations in the study area, the following information (which for the most part presently is lacking) is required:

- Numbers of each species using each habitat throughout the year;
- Turnover among migratory species;
- Relationships between habitat units and wildlife species which use them.

Further, present ecological data exist mainly as isolated pieces of information. That is, wildlife data have been collected by wildlife agencies, fisheries data by fisheries agencies, etc. with little attempt at co-operative ecological studies to investigate the inter-relationships of the total ecosystem.

Therefore, the wildlife sub-group recommends that:

a) Because wetland portions of the study area are recognized as essential wildlife habitat, they must be protected;

b) The following be quantified by species and habitat type in more detail than presently exists:

   - numbers of wildlife using the study area;

- turnover among species which migrate;
- relationships between habitat units and wildlife species which use them;

c) Because of the ecological complexities of the estuary, a co-operative, detailed examination (taking advantage of inter-agency work) should be conducted in one or two "pilot study areas" to determine the inter-dependency of the total system;

d) Existing foreshore industries manufacturing, receiving, or shipping toxic materials be subject to special guidelines to prevent spills, and those involved in highly toxic chemicals and specific activities be located in less sensitive non-estuarine sites and any new industries or activity that may have direct detrimental effects on wildlife not be allowed to locate near the foreshore area. For example: a helicopter training centre on Westham Island;

e) Undeveloped land (Habitat zones 8, 9, 10 of Table 6, Habitat Sub-group report) not included in (a) above should be zoned to preclude its value as wildlife habitat from being destroyed;

f) A concentrated public education campaign be undertaken to inform the public of the ecological importance of the Fraser River estuary.

2. ECONOMIC EVALUATION

As stated elsewhere in this report, wildlife of the Fraser estuary provides recreational enjoyment and thus bestows value to many people locally, nationally and internationally. Estuarine habitat, critical to the survival of wildlife, also is valued by portions of society for development. Any reduction in quantity or quality of habitat will result in a reduction in the numbers of wildlife it can support and thus lower its wildlife-related value to society.

In justifying the use of estuarine lands for development, developers typically emphasize the economic contributions to society of such developments. However, preliminary investigation for this study have shown that the recreational value of wildlife in the study area also potentially is very high.

Therefore, because no studies exist that have directly measured the recreational value of the wildlife in the study area, it is recommended that:

- The economic value of wildlife be determined through intensive studies as part of a larger program to determine and publicize the economic value to the people of British Columbia of the total ecological resources of the Fraser River estuary.

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