FISHERIES RESEARCH BOARD
OF CANADA

MANUSCRIPT REPORT SERIES

No. 1275

A Discussion of the Impact of the Proposed Nanaimo Harbour Development on the Aquatic Environment and its Fishery Resources

prepared
by

Research and Development
Fisheries and Marine Service

Pacific Biological Station, Nanaimo, B. C.

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INTRODUCTION

Proposals to enlarge the capability of Nanaimo Harbour facilities to handle large Pan-Max carriers and serve as a trans-shipment centre have been proposed by the Nanaimo Harbour Commission. While their first proposal was to enlarge the present facility, several alternate sites have since been proposed. These are detailed in Fig. 1. It is seen that the original plan would occupy 165 acres and reduce by one half the width of the estuary's edge. A second site (Jack Point) would level the existing land with a loading dock on the outside (eastern edge) and a dredged barge channel on the adjacent tide flats. A third alternative would locate the facility at Duke Point with the option of a large sawmill and a dredged barge and log channel on the adjacent tide flat. A fourth site would occupy the area east of Harmac toward Dodd Narrows. In this report the living marine resources of this area and their historical and present uses are first discussed. This is followed by a short examination of their ecological relationships and a discussion of the probable impact of the development on the resources and their utilization.

Much of the ecological information included has been recently acquired and incompletely analysed. The study is continuing and will provide a much more comprehensive and detailed understanding of the interactions among the various flora and fauna and between them andthe physical and chemical environment. This report is, then, a progress report and preliminary to a full reporting at a later date.

PHYSICAL ASPECTS

The Nanaimo River rises in the southern Vancouver Island mountains and drains eastward into Nanaimo Harbour (Fig. 2). The river is about 35 miles long and has a drainage area of approximately 320 square miles. The system has several lakes including First, Second, Third and Fourth Lakes. Important tributaries are Sadie Creek, Green Creek, North Nanaimo River, South Nanaimo River, and Haslam Creek. The flow of the Nanaimo River is affected by operation of storage dams at the outlet of Fourth Lake and on the South Nanaimo River. From May 1965 to December 1969 the daily discharge of the Nanaimo River near the Trans-Canada Highway Bridge has varied between 15,200 and about 37 cfs with a mean daily discharge about 1,500 cfs. In the estuary area the Nanaimo River is joined by three streams, Hong Kong Creek and Chase River, which drain into the main (westernmost) channel of the Nanaimo River, and Holden Creek which drains from Quennel and Holden Lakes to the southeast corner of the Nanaimo River flats. Another stream, the Millstone River, empties into Nanaimo Harbour north of the Nanaimo River. The Millstone River, which drains Westwood, Brannan, Diver and Long Lakes, has an impassable fall about three-quarters of a mile upstream from the mouth. The estuary is about 2,000 acres, including the saltmarshes, in total area. It is bounded on the southwest by the coast of Vancouver Island and on the east by a peninsula and an elongated island (Fig. 1). The Northumberland Channel shore from Jack Point to Dodd Narrows is generally steep and of wave-worn sandstone. A major exception is a tidal lagoon emptying at Duke Point.

The first official chart of Nanaimo Harbour is dated 1862. It reveals a convex portion of the delta front bulging into Nanaimo Harbour on the southwest side, and a concave portion of the northeast half, with the mean axis

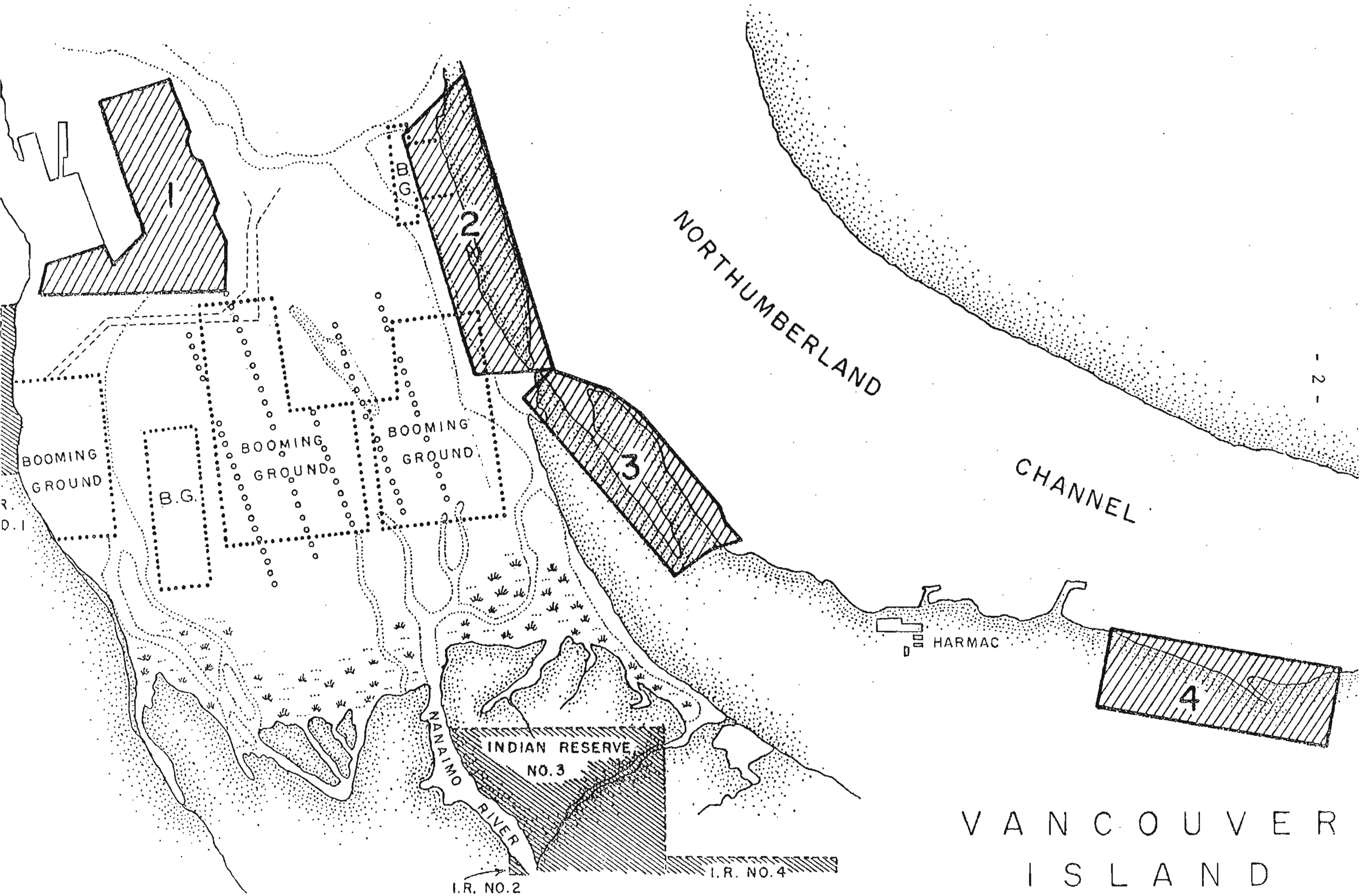

Fig. 1. Map showing Nanaimo estuary and Northumberland Channel with approximate locations of alternate port facility sites.

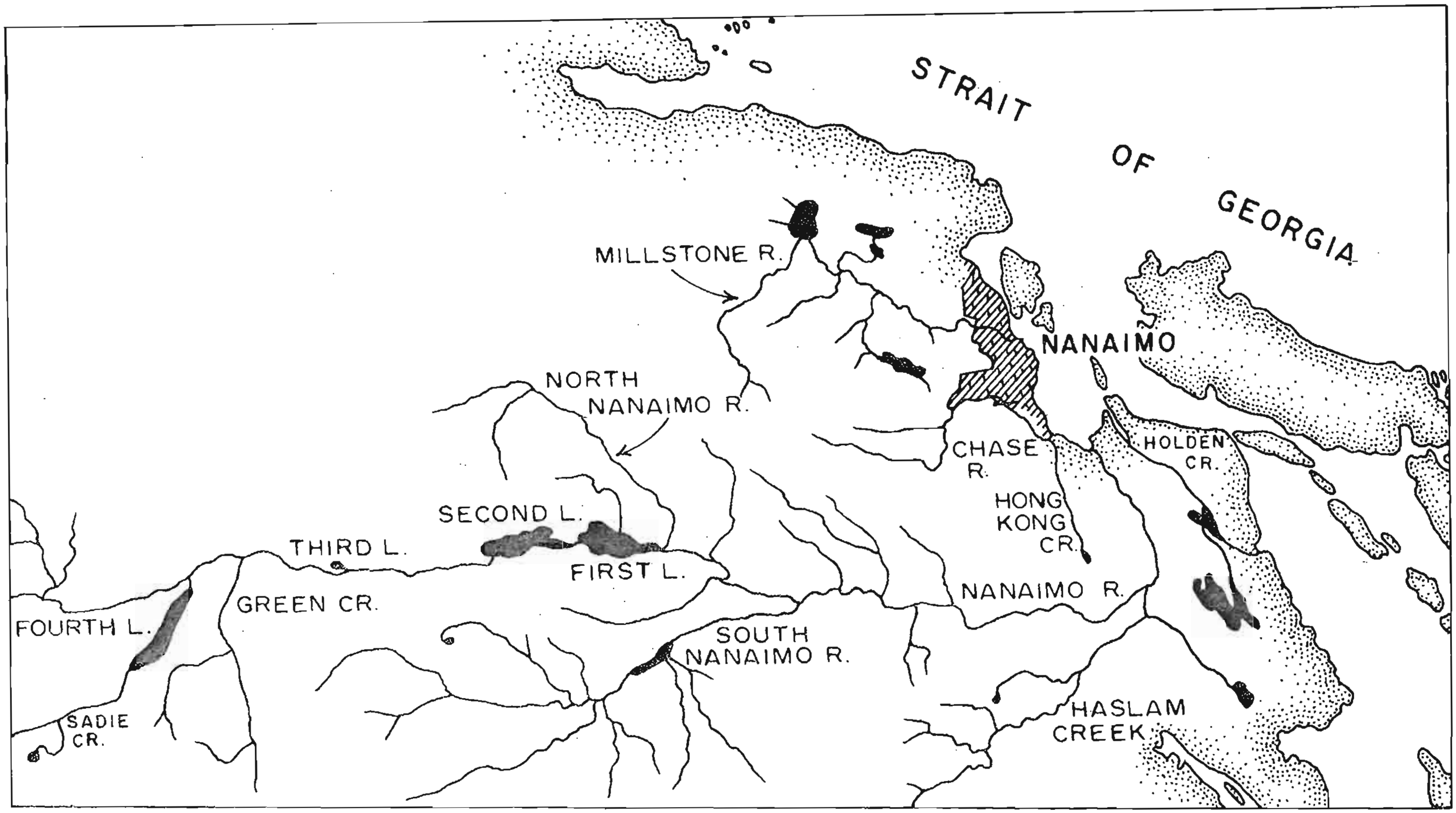

Fig. 2. Map showing streams draining into Nanaimo estuary.

of the delta front roughtly in line with Jack Point and extending southwest from it. Subsequent charts and recent survey data (Canadian Hydrographic Service) suggest little change in the position of the main delta front between 1862 and the present, or in the foot of the delta front. The main changes since 1862 have involved fill to form much of the present area of downtown Nanaimo and alterations associated with construction of the present Assembly Wharf. Formerly, dredging for gravel in the mouths of the rivers took place, but effects are difficult to evaluate.

The relatively stable configuration of the delta front indicates an approximately steady state between supply and deposition of sediment from the rivers and its removal by effects of current and wave action. The convex extension into the harbour and the concave bight toward Jack Point may reflect two factors. First, the main deltaic channel occurs on the southwest side. Thus deposition on the delta face would be greater there. The northeast section is much more exposed to wave action and hence is more subject to suspension and removal of sediment. The configuration of the delta front thus appears consistent with distribution of sediment supply and exposure to wave action. Currents in Nanaimo Harbour would be expected to exit to Northumberland Channel on the ebb tide, where a net flow to the southeast occurs in the upper 3 m and below 10 m. Thus sediments suspended along the delta face could be effectively removed from the locality.

The sequence of charts and sounding data suggest that the elevation of the outer portion of the intertidal flats has increased since 1862. This could, at least in part, be due to changes in the datum for soundings.

There are suggestions of qualitative changes in the sediment of the estuary since historical time. Indians report that prior to logging and coal mining in the region, the estuarine tidal flats were much more sandy than at present. The increase in silt would be expected from logging activities, especially below the series of lakes. The Indians also state that the region adjacent to Indian Reserve No. 1 is only now recovering from accumulated coal washings in nearby watersheds.

Another qualitative change commenced with log storage on the flats in 1948. Since that time bark has been accumulating on the flats and in some areas is mixed with sediments forming thick deposits. Log rafts stored on the estuary can be clearly seen in the area photograph (Fig. 3).

Residents of Nanaimo No. 1 Indian Reserve report a local increase in mudiness of sediments between the Reserve and the river channel after the construction of the present assembly wharf. This might be expected from the effect of the wharf in sheltering this portion of the estuary from sediment suspension due to wave action under northwesterly winds, and possible retention of sediments in eddies behind the wharf.

While the above qualitative changes cannot be quantified, there seems little reason to doubt the reports themselves, and the changes are consistent with known events.

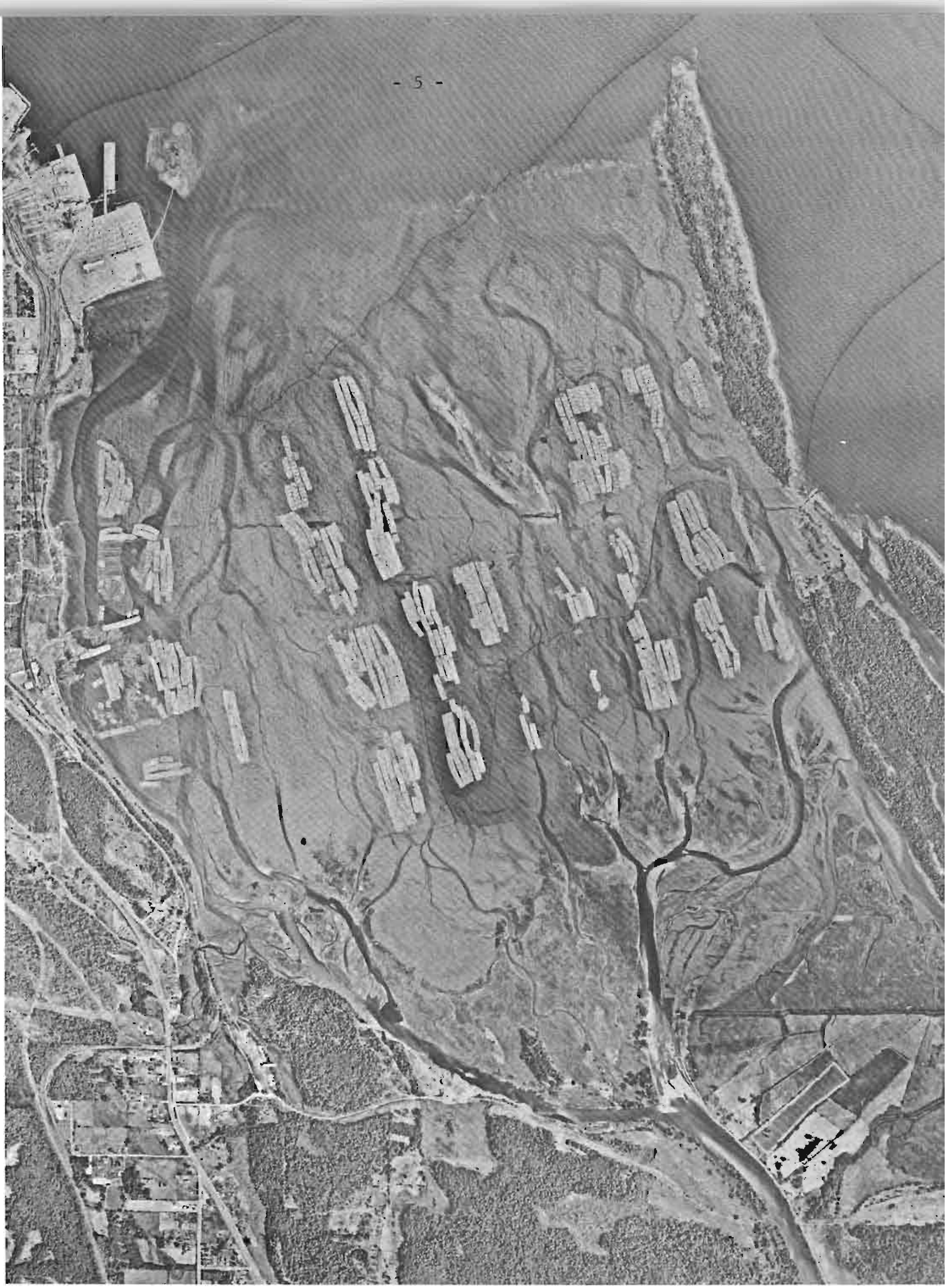

Fig. 3. Aerial Photograph of Nanaimo River Estuary, 1968.
Mosaic from British Columbia Government Photographs,
Courtesy of Lockwood Survey Corporation Ltd., Vancouver.
Scale: 1" equals 1580 feet.

FISHERY RESOURCES

Estimates of the annual spawning populations of Pacific salmon in the Nanaimo River, including those in Chase River, Hong Kong and Holden Creeks, are presented in Table 1 and discussed below.

Table 1. Fishery officers' estimates of escapements of Pacific salmon to the Nanaimo River, 1949 to 1972.

Year	Chum	Coho	Chinook	Pink	Sockeye
1949	20,000	1,200	800	1,500	0
1950	>100,000	2,00-5,000	500-1,000	300-500	0
1951	50,000-100,000	5,000-10,000		1,000-2,000	1-50
1952	20,000-50,000	2,000-5,000		500-1,000	0
1953	20,000-50,000	5,000-10,000	1,000-2,000	500-1,000	0
1954	50,000-100,000	5,000-10,000	1,000-2,000	100-300	0
1955	10,000-20,000	2,000-5,000	2,000-5,000	100-300	0
1956	20,000-50,000	5,000-10,000	2,000-5,000	1-50	0
1957	20,000-50,000	10,000-20,000	5,000-10,000	500-1,000	1-50
1958	50,000-100,000	2,000-5,000	2,000-5,000	100-300	1-50
1959	5,000-10,000	1,000-2,000	2,000-5,000	1-50	0
1960	2,000-5,000	1,000-2,000	500-1,000	1-50	0
1961	5,000-10,000	500-1,000	500-1,000	0	0
1962	5,000-10,000	1,000-2,000	500-1,000	0	0
1963	2,000-5,000	1,000-2,000	1,000-2,000	0	0
1964	10,000-20,000	2,000-5,000	500-1,000	0	0
1965	10,000-20,000	1,000-2,000	2,000-5,000	0	0
1966	50,000-100,000	2,000-5,000	1,000-2,000	0	0
1967	22,000	6,000	1,200	0	*
1968	26,000	800	1,500	0	*
1969	26,000	1,200	1,100	0	0
1970	30,000	4,750	1,500	0	0
1971	17,500	4,250	850	0	0
1972	70,000	2,250	1,950	0	1

*Few caught in native subsistence fishery.

Since 1950, five species of Pacific salmon (chum, coho, chinook, pink and sockeye) and two species of migratory trout (steelhead and cutthroat) have been reported to occur in the streams draining into Nanaimo Harbour. All seven species occur in the Nanaimo River, whereas only steelhead and cutthroat are reported in the Millstone River, Hong Kong and Holden Creeks, and chinook, chum, coho, steelhead and cutthroat in Chase River. No estimates are available of the total contribution of the salmon runs originating from these streams to the commercial and sport fisheries. These runs contribute not only to catches in the local area but also to catches in other parts of the Strait of Georgia and its approaches. Nanaimo River chum salmon are caught in the commercial gillnet and seine fisheries in the Strait of Georgia and Johnstone Strait. Coho and chinook salmon from Nanaimo Harbour streams may be caught in the troll fisheries off the west coast of Vancouver Island as well as in the Strait of Georgia troll and sport fisheries, and in the commercial net fisheries in Johnstone Strait, and the Straits of Georgia and Juan de Fuca.

Prior to, and in the early days of settling by white immigrants, the Nanaimo area probably fed, clothed and housed in the order of 2,000 Indians, wholely dependent on local and largely marine resources. A native food fishery still occurs in the Nanaimo River close to its mouth. In the years 1968 to 1972, an average of 28 native food fishery permits were issued for the Nanaimo River to an average of 30 families consisting of about 150 persons (see Table 2). During this period, the average annual catch was about 1,700 chums, 350 coho, and 150 chinook. Some steelhead were also taken but no estimates of the numbers caught are available for all years. The fish are taken mainly with gillnets operated in the Nanaimo River from its confluence with the Chase River up to the Cedar Road Bridge. A few salmon are taken by spears.

Table 2. Native food fishery statistics, Nanaimo River, 1968 to 1972.

Year	Number of fish caught				Number of		
	Chum	Coho	Chinook	Steelhead	Permits	Families	People
1968	680	300	255	30	17	17	85
1969	760	65	10	-	25	26	130
1970	2,450	750	150	-	34	40	200
1971	1,800	545	175	-	32	37	165
1972	2,975	60	50	-	30	28	175

The local sport fishery in tidal waters takes place mainly outside the confines of Nanaimo Harbour and therefore can be expected to contain fish of mixed origin. However, during late July and early August, a sport fishery develops in Northumberland Channel near Jack Point for maturing chinook bound for the Nanaimo River. The fish caught in this fishery average less than 25 pounds but have been taken up to 55 pounds. Up to 40 or 50 boats, containing visiting as well as local fishermen, may fish in this area at any one time. The average seasonal catch has been about 50 fish. In addition, coho and a few chinook are taken by anglers in non-tidal portions of the Nanaimo River. The Nanaimo River is a popular steelhead stream not only for local anglers but also for Lower Mainland fishermen. During the period 1966 to present, estimated catches in the river ranged between 664 and 2,573, and the river ranked between the fifth and the fourteenth in size of anglers' catches among the over 300 streams fished by steelhead anglers in British Columiba. Unknown numbers of migratory cutthroat are taken by anglers in the Nanaimo River and adjacent streams.

Chum

Early diaries and log books of trading ships suggest that Nanaimo was a major source of dried salted chum salmon, and it remained a significant but probably reduced producer of chum salmon until the coast-wide decline in this species occurred in the 1960's.

Since 1949 the annual escapement of chum salmon has varied from a high, in excess of 100,000 to a low, between 2,000 and 5,000. In the 10-year period from 1962 to 1972, the average escapement was about 28,000 chum annually. Chum salmon spawn in the Nanaimo River from its confluence with the Chase River upstream as far as Haslam Creek. Most of the spawning takes place in the main channel up to and adjacent to Indian Reserve No. 3 and above the Cedar Road Bridge in Polkinghorne's Slough and Side Channel and in Maffeo's Side Channel. Some chum also spawn in the lower reaches of Haslam Creek. Returning chum salmon begin arriving in the river from late August to late September. Spawning commences shortly after arrival in the stream, reaches a peak in mid to late October, and ends by late November or early December.

Coho

Annual estimates of coho spawners have varied since 1949 from a high of about 15,000 to a low of about 1,000. From 1962 to 1972 the estimated escapements averaged about 2,800 coho annually. Earlier running coho spawn in the Nanaimo River and its tributaries upstream as far as Second Lake. Later running coho spawn in the lower part of the river in the same areas as do the chum. As mentioned earlier, some coho spawn also in Chase River and in Hong Kong and Holden Creeks. Coho commence arriving in the river in late August and in September. Spawning takes place from late September to late December or early January with the peak in late October to early November.

Chinook

The annual escapements of chinook since 1949 have varied from a few hundred to about 7,500. From 1962 to 1972 the average escapement was about 1,400 chinook annually. The Nanaimo River chinook run has a small spring and a larger fall component. The spring chinook enter the river from early April to late June and spawn in the Nanaimo River below First Lake. The fall chinook enter the river in late August and September and spawn in the river mainly below the Trans-Canada Highway Bridge downstream as far as Cedar. Generally, spawning commences in September, reaches a peak in October and ends in November and December.

Pink

In the fifties, small numbers of pink salmon were reported in the Nanaimo River in both even and odd numbered years. None have been reported since 1960. The pinks spawned in the lower three miles of the Nanaimo River and lower quarter mile of Haslam Creek. According to long time residents of the area, substantial numbers of pinks spawned in Haslam Creek.

Sockeye

Sockeye salmon have been reported in the Nanaimo River in 1951, 1957, 1958 and 1972. These sockeye either were strays from other river systems, or were the descendants of sockeye which may have resulted from the introduction of eyed sockeye eggs and fry into the Nanaimo River system in 1886, 1887, 1889, 1902, 1903, 1904 and 1933, or resulted from kokanee which may have migrated to the sea as juveniles. The kokanee present in the Nanaimo Lakes are known to have been there prior to the introduction of sockeye eggs to the system in 1933. It is not known if kokanee were present in the system before the earlier introductions.

Trout

No estimates are available of the number of steelhead and migratory cutthroat spawners in the Nanaimo River. From studies of the ratio of catch to escapement of steelhead in other systems it is likely that annual catches represent less than one-third of the total steelhead run. The steelhead catch in the Nanaimo River has been estimated to be between 664 and 2,573 steelhead annually in the years 1966 to 1971. The Nanaimo River steelhead run occurs from November to April. Steelhead spawn in the Nanaimo River to a point slightly upstream from its confluence with Sadie Creek, and in many of its tributaries. Spawning occurs between February and May. Migratory cutthroat also occur in the Nanaimo River and its tributaries as far upstream as Sadie Creek.

Other fishes

Many other species of fish are found either on or immediate to the Nanaimo estuary. Five or six species taken in this area within the past two years by Environment Canada personnel fishing with a variety of nets are listed in Table 3. Salmonids are included in this table and were, with the exception of chums, entirely juveniles. Some of these fishes, like the stickleback, cutthroat trout and starry flounder, may occupy the estuarine habitat throughout much of their life. Others like chinooks, chums, and several other flatfishes, utilize the estuarine flats during their juvenile stages. Others are more occasional visitors, e.g. herring and lingcod. Herring are a dominant fish in Northumberland Channel throughout most of the year, and anchovy, dogfish and Pacific salmon are usually present.

Table 3. List of fishes occurring in the Nanaimo estuary area.

1.	Pacific lamprey	Lampetra tridentatus
2.	Dogfish	Squalus acanthias
3.	Herring	Clupea harengus pallasi
4.	Northern anchovy	Engraulis mordax mavdax
5.	Pink salmon	Oncorhynchus gorbuscha
6.	Coho	Oncorhynchus kisutch
7.	Chinook	Oncorhynchus tshawytscha
8.	Chum	Oncorhynchus keta
9.	Sockeye	Oncorhynchus nerka
10.	Steelhead trout	Salmo gairdneri
11.	Cutthroat trout	Salmo clarki clarki
12.	Surf smelt	Hypomesus pretiosus pretiosus

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Table 3. (cont'd)

13.	Capelin	Mallotus villosus
14.	Plainfin midshipman	Porichthys notatus
15.	Walleye pollock	Theragra chalcogramma
16.	Pacific tomcod	Microgadus proximus
17.	Threespine stickleback	Gasterosteus aculeatus
18.	Tubesnout	Aulorhynchus flavidus
19.	Bay pipefish	Syngnathus griseolineatus
20.	Shiner perch	Cymatagaster aggregata
21.	Pile perch	Rhacochilus vacca
22.	Pacific snake prickleback	Lumpenus sagitta
23.	Black prickleback	Xiphister atropurpureus
24.	Penpoint gunnel	Apodichthys flavidus
25.	Crescent gunnel	Pholis laeta
26.	Saddleback gunnel	Pholis ornata
27.	Pacific sandlance	Ammodytes hexapterus
28.	Blackeye goby	Coryphopterus nicholsi
29.	Copper rockfish	Sebastes caurinus
30.	Kelp greenling	Hexagrammos decagrammus
31.	Rock greenling	Hexagrammos lagocephalus
32.	White spotted greenling	Hexagrammos stelleri
33.	Lingcod	Ophiodon elongatus
34.	Padded sculpin	Artedius fenestralis
35.	Smooth head sculpin	Artedius lateralis
36.	Silver spotted sculpin	Blepsias cirrhosus
37.	Roughback sculpin	Chitonotus pugetensis
38.	Pacific staghorn sculpin	Leptocottus armatus
39.	Grunt sculpin	Rhamphocottus richardsoni
40.	Tidepool sculpin	Oligocottus maculosus
41.	Great sculpin	Myoxocephalus polyacanthocephalus
42.	Cabezon	Scorpaenichthys marmoratus
43.	Saddleback sculpin	Oligocottus rimonsus
44.	Sharpnose sculpin	Clinocottus acuticeps
45.	Prickly sculpin	Cottus asper
46.	Longsnout prickleback	Lumpenella longirostus
47.	Tidepool snailfish	Liparis florae
48.	Sturgeon poacher	Agonus acipenserinus
49.	Pacific sandab	Citharichthys sordidus
50.	Speckled sandab	Citharichthys stigmaeus
51.	Flathead sole	Hippoglossoides elassodon
52.	Rock sole	Lepidopsetta bilineata
53.	Slender sole	Lyopsetta exilis
54.	Starry flounder	Platichthys stellatus
55.	Sand sole	Psettichthys melanosticus
56.	English sole	Parophrys vetulus

The list is almost certainly not complete. Green sturgeon (Acipensor medirostris) have been taken occasionally by the native food fishery. Additional fishes, particularly shore and demersal forms would probably be found with additional sampling. Squid were also taken occasionally.

From the point of view of human use, the Pacific salmon, trout, herring and lingcod are the most important. The others, however, interact with these "target" species in a number of ways.

Crabs

Early reports suggest that Nanaimo was one of three major B.C. crab producing areas prior to World War I. While it seems to have lost its eminence in this respect, a commercial fishery persists and the resource forms the base of an important recreational fishery. During the series of low tides in late spring and early summer it is common to see 30 to 50 people on week days and 100 on weekends crabbing on the flats. The commercial fishery has supplied local markets with fresh crab valued at about $4,500 (landed value) annually for the past 10 years. The recreational catch has been estimated to range between 1,800 and 6,000 crabs annually during the past 4 years. This is an especially valuable recreational resource in that it is enjoyed by whole families and, at present, can be pursued without specialized equipment such as a boat or fishing gear.

Shell fish

The local Indians have referred to past abundance of clams in the estuary which declined in response to sediment from coal washings. Substantial populations of clams of various species and of oysters are now evident. These are utilized recreationally despite the fact that the area is closed due to marginally high coliform bacteria counts. Since the removal of the sewer outfall to Northumberland Channel, these counts have been reduced and present pollution probably originates from poor sanitary facilities in waterside homes. The oysters are presently harvestable under permit with subsequent relaying to an unpolluted area. An upgrading of local sewage disposal systems and the prevention of sewage discharge by vessels using the port facilities would lead to a meeting of sanitary criteria. The Nanaimo estuary would then be an important recreational source of shell fish.

SIGNIFICANCE OF THE ESTUARY TO FISHERY RESOURCES

Estuaries in general are known to be biologically rich areas, forming important breeding, nursery and feeding areas for a variety of organisms important to man. The juveniles of Dungeness crabs spend much of their early life on the shallow sandy bottom of the Nanaimo estuary. Cutthroat trout inhabit the estuary throughout much of their life, seldom straying far from the influence of fresh water. A significant portion of the chum and chinook fry entering estuarine waters spend several weeks on or near the estuary during their first year of life. Chinook and coho inhabit the estuary and adjacent shore environment for several months after their seaward migration as smolts.

At almost any season a variety of waterfowl and shorebirds can be observed on the estuary. Insectivorus songbirds fly the shores and sedge meadows during the summer months. As many as 20 harbor seals can be seen in the estuarine channels in early summer. Obviously the estuary is supporting a large faunal biomass. Why? Surveys of the estuary in July and August 1973 have demonstrated that the seaward and upper delta portions support a healthy benthic biota, one that would normally be expected for this area. A benthic species list is given as Table 4. This list, undoubtedly very incomplete, contains 45 species.

Table 4. List of benthic invertebrates observed on the Nanaimo estuary, August 1973.

Protozoa (single cell animals)	
Foraminifera spp.	Abundant on Zostera and superficial deposits.
Porifera (sponges)	
Haliachondria panicea	On rocks and oysters in central estuary.
Platyhelminthes (flatworms)	
Polyclad worm (?Freemania litoricola)	In gravel and sand.
Nemertea (ribbon worms)	
Cerebratulus sp.	In mud, general.
Emplectonema cf gracile	Among oysters and mussels.
Annelida (sand worms)	
Axiothella cf rubrocincta	Sandy mud.
Hemipodus borealis	In mud and sand, general.
Mesochaetopterus sp.	Small colonies.
Nereis virens	In mud and sand near low water.
Echinodermata (star fishes)	
Piseaster ochraceus	Rare, on south shore Duke Point and elsewhere.
CRUSTACEA	
Cirripedia (barnacles)	
Balanus glandula	Common barnacle on rocks, pilings, oysters.
Chthamalus dalli	Common barnacle, with above.
Isopoda (pill bugs)	
Exosphaeroma oregonensis	Near meadowland.
Pentidotea wosnosenskii	At base of Duke Point shore.

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Table 4. (cont'd)

Amphipoda (beach fleas)	
Corophium spinicorne	In sandy mud, forming small delicate tubes.
Anisogammarus confervicolus	Among Zostera and benthic algae.
Decapoda	
Callianassa californiensis	Mud shrimp, abundant in sandy mud near sea edge.
Callianassa gigas	Mud shrimp, one specimen.
Cancer gracilis	Crab, several.
Cancer magister	Dungeness crab, small mounted exo-skeletons common, a few live individuals.
Cancer productus	Red crab, buried among Zostera.
Hemigrapsus oregonensis	Small shore crab, ubiquitous.
Upogebia pugettensis	Mud shrimp, very common.
MOLLUSCA	
Amphineura	
Mopalia ciliata	Rare, on larger rocks and Duke Point.
Gastropoda (snails)	
Collisella pelta	On rocks, Duke Point.
Haminoea vesicula	Spawning on Zostera.
Lacuna porrecta	On Zostera.
Litorina scutulata	High intertidal rocks.
Litorina sitkana	On oysters and Duke Point.
Notoacmea scutum	Rare, on rocks.
Thais lamellosa	Not frequent.
Bivalvia (clams, oysters)	
Clinocardium nuttalli	Cockle.
Crassostrea gigas	Pacific oyster.
Cryptomya californica	With Upogebia.
Hiatella arctica	Nestling among rocks, old shell, etc.
Macoma inconspicua	Very abundant.
Macoma nasuta	Bent nosed clam.
Macoma secta	Fairly common near water edge.
Mya arenaria	Abundant, high on beach.
Mytilus edulis	Common on rocks, piles, etc. (blue mussel).
Protothaca japonica	Manilla clam, abundant.
Protothaca staminea	Little neck clam, fairly rare.
Solen sicarius	Jacknife clam, rare.
Tresus capax	Horse clam, very abundant.
Saxidomus nuttalli	Butter clam.

Adjacent to the Assembly Wharf the substrate has been recently disturbed and contains no large infauna. However, an abundant settlement of several species of clams has occurred. These sediments are mixed with coal particles. The central portion of the estuary has suffered from propeller wash and subsequent channeling, caused by tugs dragging log booms, but nevertheless contains numbers of cockles, horseclams, polychaetes, burrowing crustaceans, and patches of Zostera. The eastern side of the estuary is less disturbed and contains a rich infauna, particularly crustaceans (mud shrimp) and horseclams, and also a few jacknife clams (Solen) which are very susceptible to oxygen deprivation. Except for the substrate disturbance mentioned above, the seaward edge of the flats show little evidence of stress. The area upstream (south) of the present Assembly Wharf is covered by very find silt overlaying sand. A tangle of half-buried old logs may be contributing to sediment entrapment but fill for the Assembly Wharf has likely altered water flow causing deposition of the fine silt. These silts are barren except for an enormous population (300+ m^2) of Upogebia (mud shrimp), consisting of young individuals. It is possible that this population is ephemeral.

The central portion of the estuary is much damaged by the log booms, which also churn out the substrate during low tide groundings and degrade the sediments due to bark accumulation. The booming ground is peripherally occupied by Zostera, and it may be speculated (supported by local lore) that originally this plant occupied the entire central and lower estuary. The middle of the flats bears a slightly elevated ridge of coarse gravel that houses a large population of Pacific oysters, which demonstrate sporadic recruitments. The oysters were spawned out in August, but appeared healthy. The gravel also contains a very few butter clams and large numbers of horseclams, manillas and Mya clams. The encrusting sponge Haliachondria was abundant, as was the shore crab Hemigrapsus oregonensis.

The upper estuary does not contain a significant salt marsh. The transition between meadowland and the intertidal is fairly abrupt. The general appearance suggests that deposition and washout of sediments on the Nanaimo delta is in equilibrium, i.e. it is neither advancing nor retreating.

The biota of the lagoon at Duke Point is essentially that of a surf-protected shore. The steep rocky shore with small tide pools provides habitats for many invertebrates. The central portion of the lagoon consists of an extensive Zostera bed, which is permanently submerged. The mouth and head of the lagoon consist of sediments with large populations of clams and mud shrimps, while the rocks and any solid substrate support many oysters. An incomplete list is provided in Table 5.

The rocky foreshore fronting on Northumberland Channel is wave-worn sandstone with little growing on the surface. Patches of Mytilus edulis occur, but most of the biota is confined to small rockpools andto fissures. An incomplete species list is provided in Table 6.

Table 5. List of benthic invertebrates found in the lagoon at Duke Point, August 1973.

Nemertea	
Paranemertes cf. peregrina	Under rocks.
Annelida	
Amphitrite robusta	Under rocks, in sand and shell.
Hydrozoa	
Plumularia sp	In and on Zostera.
Obelia longissima	On Zostera.
Echinodermata	
Dermasterias imbricata	Rare.
Pisaster ochraceus	Abundant.
Cucumaria miniata	Rare.
Eupentacta quiquesemita	Common under rocks.
Ophiopholis aculeata	Brittle star, under rocks.
Strongylocentrotus drobrachiensis	Sea urchin, fairly abundant between rocks.
CRUSTACEA	
Cirripedia	
Balanus cariosus	
Balanus glandula	
Chthamalus dalli	
Isopoda	
Idothea resecata	On Zostera.
Decapoda	
Cancer oregonensis	Under rocks.
Hemigrapsus nudus	Under and on rocks.
Hippolyte clarki	Small green shrimp on Zostera.
Pagurus granosimanus	Small hermit crab.
Pugettia gracilis	Kelp crab.
Upogebia pugettensis	Common.
Amphipoda	
Caprella cf. californica	On Sargassum weed.
MOLLUSCA	
Amphineura	
Cyanoplax dentiens	Rare, under rocks.
Mopalia ciliata	Common, on rocks.
Tonicella lineata	Not abundant, in tide pools.
Gastropoda	
Bittium cf. challisae	
Collisella pelta	
Haminoea vesicula	

...

Table 5. (cont'd)

Gastropoda (cont'd)	
Lacuna porrecta	On Zostera.
Littorina scutulata	
Littorina sitkana	
Nassarius mendicus	Among Zostera roots.
Polinices lewesi	One specimen.
Searlesia dira	Very few.
Tachyrhynchus lacteolus	Among Zostera roots.
Thais lamellosa	Rare.
Nudibranchiata	
Anisodoris nobilis	A few spawning.
Chioraea leonina	Among Zostera.
Corambe pacifica	Among Zostera.
Bivalvia	
Crassostrea gigas	One specimen.
Entodesma saxicola	Among rocks.
Hiatella arctica	
Macoma secta	
Mya arenaria	
Pododesmus macroschisma	One specimen.
Protothaca japonica	
Protothaca staminea	
Psephidia lordi	Among Zostera roots.
Transenella tantilla	Under rocks.
Mytilus edulis	

The distribution, size and sex composition and density of Dungeness crab (Cancer magister) populations associated with the Nanaimo Estuary was studied during the period June to October 1973. Traps, trawls and tangle nets were used. In addition, cast shells were collected from the estuary at low water and live crabs were observed. These studies have revealed that the upper estuarine flats, particularly the east (Holden Creek) and west (Nanaimo River) channels are utilized by yearling crabs during June and early July as moulting sites. Adult males and females utilize the lower estuary, particularly the eel grass beds as sites for moulting and breeding, in May and June.

Dungeness crabs are relatively more abundant in the Nanaimo estuary than in the local areas. Legal males are more abundant on the ground adjacent to the present Assembly Wharf and breeding females appear to prefer the area immediately west of Jack Point. The smaller individuals of both sexes congregate off the Assembly Dock. The two channels, one on each side of the estuary appear to play an important role in the early life of juveniles. These are not likely to be discrete populations; rather, the entire area probably contains one single intra-breeding population.

Table 6. List of benthic invertebrates found on the western shore of Northumberland Channel, August 1973.

Porifera	
Mycale sp.	Rare.
Brachiopoda	
Terebratalia transversa	Common in low intertidal in fissure and under overhangs.
Bryozoa	
Bugula pacifica	
Annelida	
Serpula vermicularis	Common in fissures.
Echinodermata	
Pisaster brevispinus	Rare.
Pisaster ochraceus	Common.
Strongylocentrotus drobrachiensis	Not common.
Strongylocentrotus purpuratus	In tide pools.
CRUSTACEA	
Cirripedia	
Balanus glandula	
Chthamalus dalli	
MOLLUSCA	
Gastropoda	
Acmea digitalis	Very high on shore.
Ceratostoma foliata	One species.
Littorina scutulata	
Searlisia dira	In fissures.
Bivalvia	
Crassostrea gigas	Sporadic.
Mytilus edulis	
Pododesmus macroschisma	
Protothaca japonica	
Saxidomus nuttalli	

During the period 21 July 1972 to 24 August 1973 various types of nets were fished over the estuarine flats and in the adjacent deep waters. These nets included a beach seine fished in shallow water, several purse seines, the largest about 500 m in length and 30 m deep fished in deep water, and tow nets towed between two boats at both locations. Many species of fish were caught as have already been listed (Table 3). However, the main catches were herring and salmonids.

Coho and chinook juveniles were equally abundant in beach seine hauls at the river's mouth in April and May reflecting the seaward migration of smolts and fry. Numbers increased along the beaches in the harbour in late May and June. Chum salmon appeared to have moved through the area during the spring and early summer whereas chinook and coho were found broadly distributed in the area during virtually any month. A secondary immigration of juvenile chums into the intertidal estuary occurred in July. These were probably not Nanaimo River stock as judged from their size composition. Herring were present in large numbers as young of the year from May to mid-October.

Samples of fish catches (Table 3) were examined to ascertain the food items utilized. Food items were arbitrarily classified into four types:

1. Organisms brought to the estuary by fresh water or air borne which originate in streams or on the land.

2. Organisms which originate in or on the estuary bed.

3. Organisms which normally live in the water column over the estuarine flats.

4. Pelagic marine organisms which are brought into estuarine waters by the tides or by estuarine circulation.

The first category includes insects, spiders, mites and ticks, earthworms and cladocerans. The second category includes estuarine amphipods and isopods, crabs and shrimp, cladocerans, cumaceans, mysids, ostracods, polychaetes, nematodes, and harpacticoid copepods. The third category includes estuarine copepods (calanids, cyclopoids) and pelagic larvae of estuarine animals. The fourth category includes marine pelagic copepods, amphipods, larval fishes, euphausiids, barnacle larvae, chaetognaths, and pteropods. The results of this examination are presented as Table 7.

Data presented in Table 7 immediately demonstrate the value of food items generated on the estuary to a variety of fishes living there. Overall, groups 2 and 3 taken together form more than twice the instances of fish utilizing food imported from the land (group 1) or food imported from the sea (group 4). Some species, e.g. chinook, show a heavy reliance on aquatic insects carried into the estuary by freshwater transport, while the herring seem to lean toward food items imported from the sea. No species appears to be restricted in diet to food organisms produced in only one habitat.

Recent studies have shown that some young chums live for several weeks as residents of the upper intertidal zone of the estuary. In that habitat they exploit fresh water, estuarine, and marine food chains as offered by the diurnal tidal changes. Relatively rapid growth may result from lower energy costs of obtaining food, since food items are concentrated by the physical estuarine mechanisms. In addition, food items ingested were of a more ideal size than was observed in the adjacent purely freshwater and marine habitats.

Table 7. Numbers of fish caught containing food species originating from four production systems (see text for details of food items and origins).

Fish	Land-freshwater	Estuarine-benthic	Estuarine-pelagic	Marine-pelagic
Dog fish	0	1	0	3
Herring	9	186	269	290
Northern anchovy	0	2	2	0
Cutthroat trout	5	5	0	2
Coho	66	65	20	146
Chinook	463	296	41	232
Chum	487	880	226	846
Sockeye	0	0	0	2
Threespine stickleback	224	684	176	239
Tubesnout	0	2	0	0
Bay pipefish	0	9	1	1
Shiner perch	31	339	33	13
Pacific sandlance	1	60	28	65
White spotted greenling	0	3	0	2
Lingcod	0	0	0	4
Pacific staghorn sculpin	13	86	1	2
Tidepool sculpin	3	23	2	0
Sharpnose sculpin	0	1	0	0
Saddleback sculpin	15	3	6	1
Prickly sculpin	47	288	5	10
Crescent gunnel	0	1	0	0
Saddleback gunnel	0	9	0	0
Speckled sandab	0	12	0	0
Starry flounder	20	59	2	4
Totals	1384	3014	812	1862

A series of stations off, but adjacent, the Nanaimo estuary were fished, using purse seines, during the period July 1972 through February 1973. The main species examined and found with recognizable food in their stomachs are listed in Table 8. All except the shiner sea perch were entirely juveniles. An examination of the food items found in their stomachs revealed much heterogeneity, both among and within species of fish. Types of food utilized most were copepods, amphipods, decapods, euphausiids, insects, and fish. Average usages, as percentages of total bulk of food present, are shown in Fig. 4.

Herring were abundant only until October. Their average diet (by bulk) included 15% copepods, 16% amphipods, 7% decapods, 8% euphausiids, 15% larval fishes. Chinook, while most abundant in the fall months, were present throughout the winter. Their average diet included 2% copepods, 4% amphipods, 8% decapods, 12% euphausiids, 5% insects, and 69% small and larval fishes. Chums were caught as fingerlings only in July. Their diet included 92% copepods, 1% amphipods, 3% euphausiids and 3% insects. One juvenile chum was taken in November but contained no food. Three hundred adult chums were taken

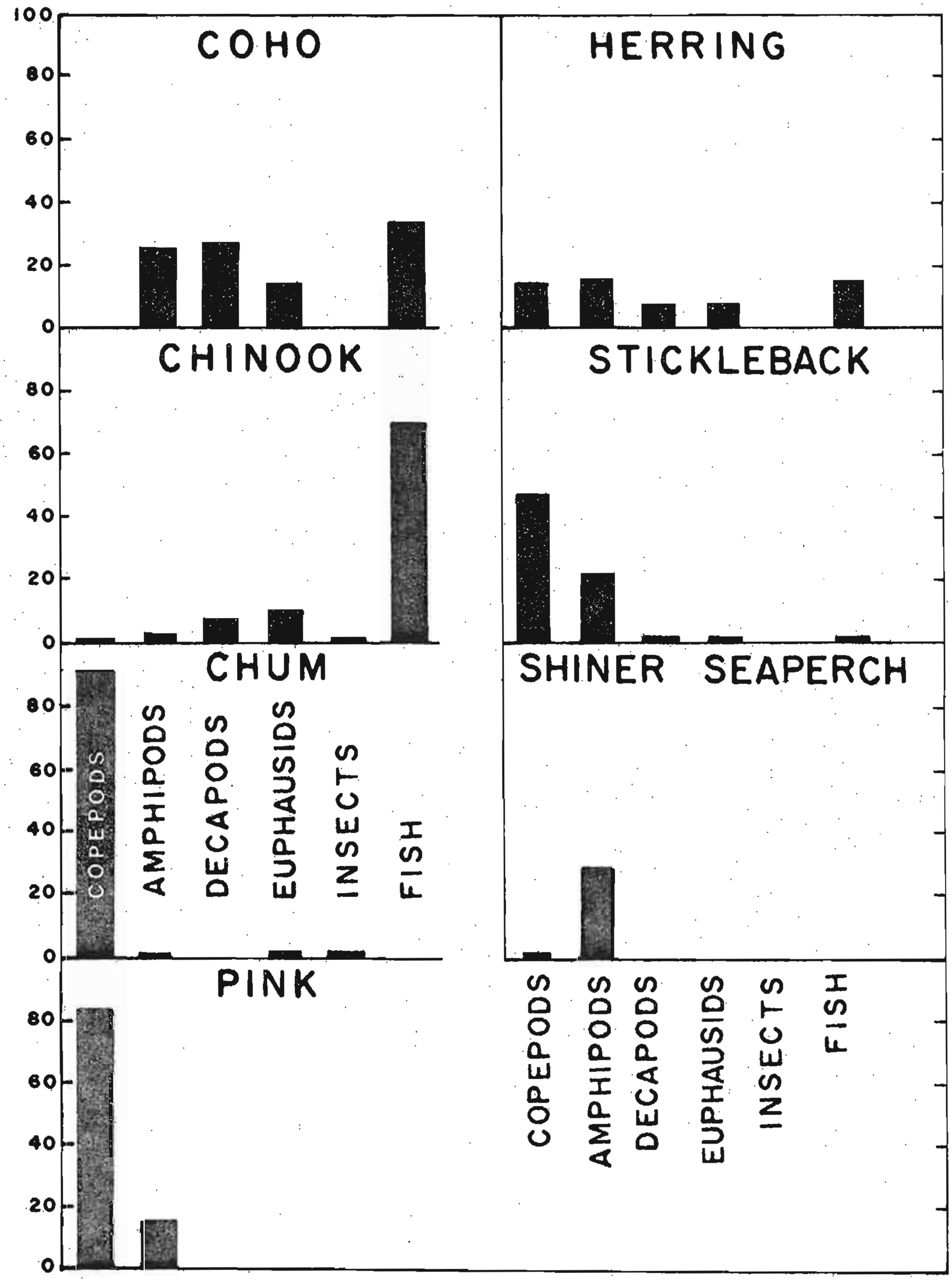

Fig. 4. Average percentage that specified food type formed of total mass of food eaten.

in October, 3 in November and 400 in December. These were released without further examination. Pinks were obtained in the July, September and November samples as juveniles. Their diet included 20% copepods, 54% amphipods, and 7% decapods. Coho were taken in most samples as fish in their first sea year. Their average diet included 25% amphipods, 27% decapods, 14% euphausiids and 33% fish. Threespined stickleback were usually taken in all samples. Their diet included 47% copepods, 22% amphipods, 2% decapods, 2% euphausiids and 2% fish. Shiner sea perch were taken only in August. Their diet included copepods (1%) and amphipods (29%).

Table 8. Numbers of fish containing food sampled off the Nanaimo estuary July 1972-February 1973.

	Herring	Chinook	Chum	Pink	Coho	Stickleback	Shiner
25-26 July 1972	72	23	6	15	5	21	0
8-9 August 1972	1	7	0	0	6	4	15
18-23 August 1972	125	41	0	0	15	21	3
25-26 September 1972	88	34	0	13	1	14	0
16-26 October 1972	26	35	0	0	8	32	0
14-17 November 1972	0	18	0	1	3	8	0
12-14 December 1972	1	7	0	0	2	2	0
9-10 January 1973	0	0	0	0	2	5	0
24-25 January 1973	0	4	0	0	1	0	0
5-7 February 1973	0	16	0	0	0	13	0

Much of the food types listed above are habitually found in estuarine waters. Roughly one half of the bulk of amphipod material utilized by the salmonids originated within the intertidal estuary as benthic fauna. Two genera, Anisogammarus and Corophium, are typically estuarine and a third, Caprella, is usually associated with benthic littoral algae. We do not know whether these fish had fed on the estuary previous to their capture or whether the food items were carried off the estuary to the fish. The important point is that fishes captured near the estuary used, in significant part, food material originating within the intertidal estuary.

The richness of the estuary is due to several factors. Chief among these are the following:

1. Organic material escaping from the land mass is concentrated in the drainage system and enters the estuary as a source of energy. This contribution may be in the form of detritus--decaying terrestrial plant material--or as organisms collectively known as drift--largely a flowing water insect community. This material is used either directly as fish food or forms the base of a food chain utilized by "target" resource species.

2. The grass and sedge community of the marsh and wetland surrounding the estuary is highly productive and exports detritus into the estuarine waters. Except under extreme flood conditions most of this material is retained in the estuary and enters the estuary food chains.

3. When fresh water flows out over sea water it entrains sea water from below, thus forming a brackish layer, mixed by the wind, which increases in volume and salinity seaward. This "estuarine" system results in a constant supply of sea water to the estuary, with a constant replenishment of dissolved inorganic nutrients beneficial to marine plants.

4. The intertidal "flats" of the estuary are populated by attached algae and benthic diatoms which, because of the shallow water characteristics and exposure to adequate solar radiation, are highly productive in terms of the amounts of CO_2 fixed into organic carbon and O_2 produced per unit area per day. Toward the lower edge of the estuary and extending to about 30 ft in depth, dense beds of eelgrass are similarly productive and also provide shelter and spawning sites to many invertebrate and vertebrate forms.

Thus the various physical systems associated with the estuary--land drainage, shallow water, and estuarine circulation--all serve to concentrate nutrients produced over much wider geographical areas into the estuary, resulting in a highly productive habitat. The mechanisms responsible for nutrient enrichment also concentrate fish food organisms produced to seaward into areas in which they are utilized by estuarine species and estuarine stages of transient species such as salmon and steelhead. The same mechanisms are no doubt responsible for the observed concentration on the estuarine area of ducks and geese, shore birds and seals.

The estuary also exports the results of its production processes. Phytoplankton produced in the water column are borne seaward with the brackish water component. Many of the animals living on the estuary produce aquatic larvae which are temporary members of the plankton community. Many larval and juvenile fish move offshore as they grow in size and maturity. With these processes and migrations, the estuary makes significant contributions to the standing crops of marine resources of both adjacent and more distant areas.

These findings have been related together in a simplified food chain diagram presented in Fig. 5.

EFFECTS OF THE PROPOSED DEVELOPMENTS

Site 1 (Inner Harbour)

Changes in configuration of an estuary result from changes in supply, distribution, deposition and erosion of sediments. These processes are influenced by current velocity, current pattern, wave action, and protective cover, e.g. vegetation.

Water movements in Nanaimo estuary are determined by tides, river discharge and wind action. Effects of wave action will be most pronounced during northwest winds and as the tide rises and falls across the flats. The effects of wave action is to place fine sediments into suspension, facilitating their transport by currents. The relationships between current velocity, wave action and movements of sediment of different sizes are not simple, but in general, the higher the currents and the greater the exposure to wave action, the greater the capacity to remove and redistribute sediment.

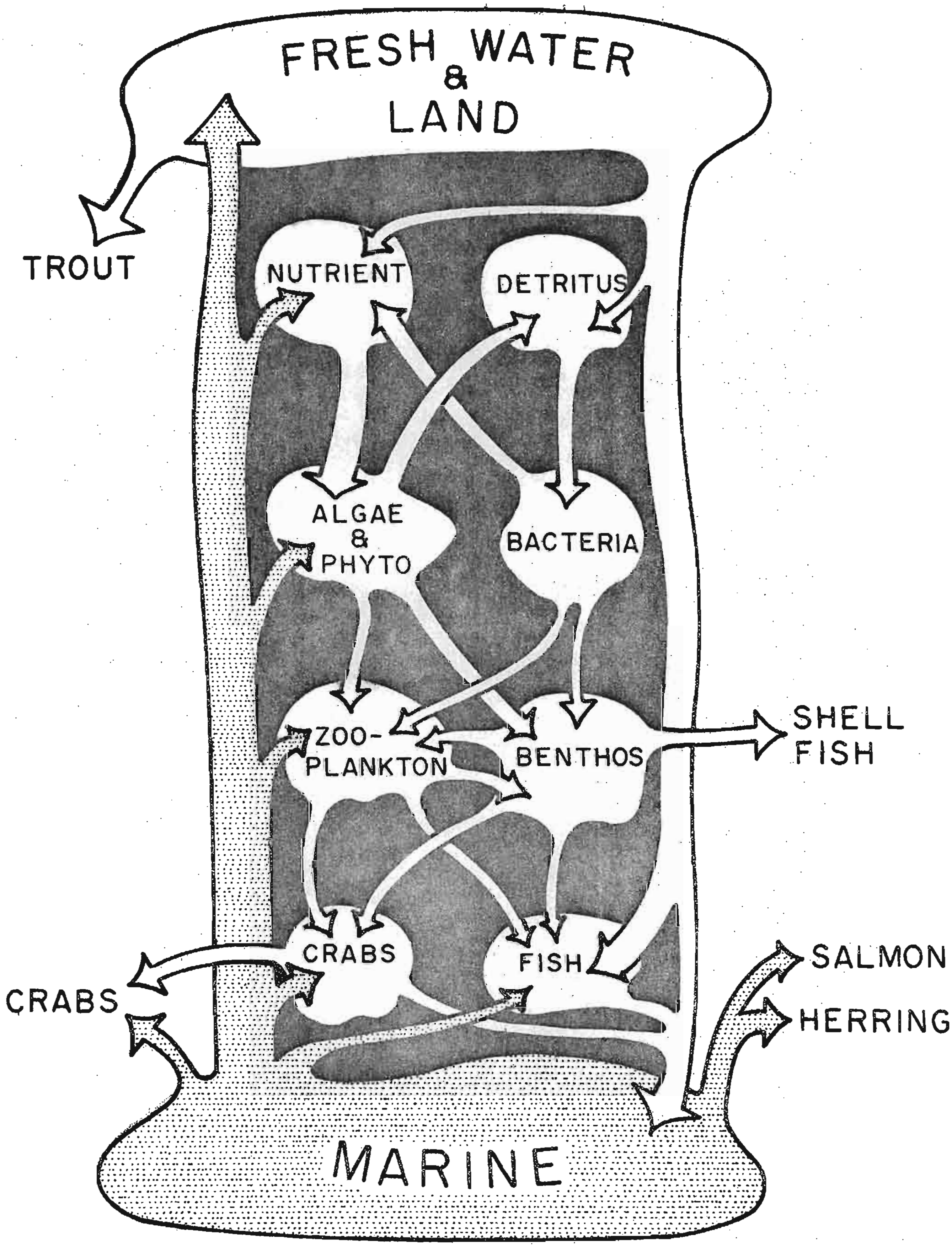

Fig. 5. Diagramatic representation of biological interaction between land and sea through the estuary.

The proposed Nanaimo Harbour Commission development at Site 1 would cover less than 10% of the present area of tidal flat. However, it would include virtually one half of the width of the entrance to the flat.

The volume of water entering and leaving the estuary with the tide can be used to approximate the velocities which would occur in the entrance if restricted by the port development at Site 1. The intertidal area of the flats may be taken as 2400 m $\times$ 2300 m, or about $5.5 \times 10^6 m^2$. Since it is the recurring maximum velocities (spring tides) rather than the averages that will determine erosion, a tidal height of 5 m is assumed with a range of 0-5 m; it is assumed that the mean elevation of the flats above zero tide level is 2 m, giving a mean depth of 3 m and a volume of about $16.5 \times 10^6 m^3$ of water at high tide. The development would reduce the entrance to 1300 m in width. The mean height of the bottom in the entrance is about 1 m above the zero sounding datum. The mean depth of water in the entrance during a postulated tidal cycle would be (5 m - 1 m)/2 = 2 m, and the mean cross-sectional area through which the volume of water would pass is thus 2600 m^2. Further, assuming that the tide falls or rises in six hours, the velocity either in, during flood tide, or out, during the ebb tide, averaged for the period of ebb or flood would be about 0.30 m/sec. However, tidal velocities in general vary sinusoidally with the maximum velcoity occurring near mid-tide. Given a sinusoidal variation, the maximum current can be estimated at 1.57 times the mean, or about 0.47 m/sec. However, during peak river discharge an additional 290 or more m^3/sec will be leaving the estuary. Taking this into account, maximum velocity becomes about 0.57 m/sec on the ebb tide. Flood velocities above some threshold tidal height would be reduced due to effects of river flow.

A current of about 0.5 m/sec (1 knot) is capable of eroding sediments in the size range 0.15 mm to about 3.5 mm in diameter. A 0.5 m/sec current will also transport any material kept in at least partial suspension, by wave action for instance, of less than 7 mm in diameter. These size ranges, including the sand fraction, dominate the sediment on the Nanaimo tidal flats. It must be concluded that the relative stability of the intertidal estuary is in fact a delicate and precarious posture in large part due to the stabilizing influence of the eelgrass beds occupying the outer estuarine edge. It may take but little physical perturbation to precipitate far-reaching degradation processes.

Wave action in the entrance to the estuary would be little affected during northwesterly winds, whereas wave energy density would be lowered over the remainder of the flat due both to the sheltering effect of the port facility and wave diffraction inside the entrance. Under southeasterly winds the direct effect of wave action in suspending sediment would be little affected by the development. However, wind-induced current patterns and entrance velocities would be affected.

The net effects of the above changes are likely to be erosion of the delta front in the eastern section, coarsening of sediments there and deepening of the entrance with an ultimate decrease in the extent of the flat in addition to the 8% to be covered by the development. The effect of the development in sheltering the western section of the estuary, coupled with the likely formation of an eddy or backwater would probably cause an initial increase in the deposition and decrease in erosion of fine sediments there. The construction of the present Assembly Wharf is stated to have caused local increases in muddiness behind it. The much larger structure proposed at Site 1 could have a correspondingly larger effect. However, as erosion and channel deepening occurred in the entrance and adjacent to it, the steepness of seaward slopes in the tidal flat could increase, resulting in a slow long term loss of sediment from areas away from the entrance. At the new equilibrium, a further decrease in intertidal area, and a decrease in the height of that remaining seems likely. The long term changes would also threaten the extent of highly productive saltmarsh and possibly the dyked meadowlands. If gradients are significantly changed, additional dredging might be required to maintain the main river channel in the position required by the proposal.

The marked constriction of the entrance would also affect salinity and temperature regimes within the estuary and alter the present outer estuarine circulation. Thus, in addition to Site 1 occupying a major portion of the lower estuarine eelgrass habitat, it would precipitate an instability which would lead to significant changes in the remaining portion of the estuary. The physical changes could not be prevented from altering many of the biological features of the estuary which support its present resources, and would not maintain the option of their enhancement. One direct effect would be to obliterate one of the major crab nursery areas in the Nanaimo area, and lead to the decline of the commercial and recreational fisheries based upon this resource.

Site 2 (Jack Point)

Development at Site 2, in extending about 500 feet westward into the estuary would impinge upon one of the major low water channels of the estuary, cover one of the major crab and eelgrass beds, and initially disrupt an area utilized by juvenile salmonids. However, the configuration of the project is such that the channel, crab and eelgrass beds and salmonid nursery area would probably be rapidly re-established along the new shoreline. Because of its elongated configuration and the smaller encroachment upon the estuary, Site 2 would have a markedly smaller effect on the wave-current-sediment-ecological equilibrium. If a barge channel and log access were required on the estuarine side of this development, a proportionally greater disruption of the ecosystem would occur, particularly to the area utilized by juvenile crabs.

There are two effects of development at Site 2 which are related to the question of how the resource is utilized. Presently the majority of recreational crabbing is pursued at low tide and the area is approached on foot from roads end at Duke Point. Development of Site 2 would prevent public access to the water's edge and even if this were provided, a barge channel would prevent access to the flats by that route. Thus, with access from the western shore limited by the present Assembly Wharf, the development at Site 2 would effectively close the estuary's edge to access from land.

The sports fishery for Nanaimo chinook salmon is centred in the early season (last half of July) on the northeastern edge of Jack Point. Later (early August) it moves to the northwestern edge of Jack Point and extends along the face of the estuarine flats half way to the Assembly Dock. The development at Site 2 would undoubtedly, because of physical alteration and barge traffic, impair or prevent the recreational use of this area.

Site 3 (Duke Point)

If the project were built at Site 3 with the estuarine barge channel and log storage option, the effects to the present ecosystem and utilization of the resources would be similar to that at Site 2. In addition, the lagoon area is an almost unique feature of the marine environment and valuable as a recreational area to the people of greater Nanaimo. Without the barge channel the present estuarine ecosystem would be little affected. The lagoon would be irretrievably lost.

Site 4 (Harmac south)

The project built at Site 4 would have little if any effect on the estuarine ecosystem, upon presently utilized marine resources or upon present recreational use.

CONCLUSIONS

Considering the factors as herein discussed, the various sites may be classified according to their probable impact on the present estuarine ecosystem. Proceeding from the most deleterious to the least, these are:

1. The inner harbour site (1).

2. The Jack Point site (2).

3. The Duke Point site with barge channel (3a).

4. The Duke Point site without barge channel (3b)

5. The Harmac south site (4).

This rating takes into account the loss of the nearshore environment along Northumberland Channel which sites 2, 3 and 4 would occasion. There are two points apropos to this argument.

(1) This type of rocky intertidal environment is, in itself, productive, however, there are miles of this available in the Nanaimo area. On the other hand, estuarine environment is relatively scarce. From this argument alone it would be far better to site the development on rocky shore habitat and leave the estuary alone.

(2) The large and valuable industrial complex already in existence on Northumberland Channel has demonstratably affected the flora and fauna in its proximity, and it is not likely that it can be moved. It would seem advantageous to add further development to that site (either by development at Site 3b or 4) than to further degrade the estuary which, environmentally, is recoverable.

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V. Aro	- Salmon fisheries	C. McAllister	- Physical processes
E. Barraclough	- Larval fishes	H. Mundie	- River food chains
F. Bernard	- Benthic invertebrates	D. Narver	- Stream biology
T. Butler	- Crabs and shrimp	N. Nishio	- Recreational fisheries
D. Goodman	- Estuarine fishes	J. Sibert	- Systems ecology
B. Kask	- Fish food chains	H. Smith	- Juvenile salmonids
R. LeBrasseur	- Zooplankton	K. Stephens	- Chemical processes
J. Mason	- Estuarine ecology	D. White	- Historical

R. Parker - Fisheries member, Nanaimo Steering Committee.