SEASONAL USE OF NEARSHORE INTERTIDAL HABITATS BY JUVENILE PACIFIC SALMON ON THE DELTA-FRONT OF THE FRASER RIVER ESTUARY, BRITISH COLUMBIA

by

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ABSTRACT

Seasonal occurrence, relative abundance, and distribution of juvenile salmon populations on the delta-front of the Fraser River (outer) estuary were examined for the periods June - August 1981 and April - August 1982. In 1981, the latter part of the chinook (*Oncorhynchus tshawytscha*) migration was observed. In 1982, juvenile pink (*O. gorbuscha*), chum (*O. keta*), and chinook were abundant in nearshore intertidal zones between April and August. The absence of the juvenile coho (*O. kisutch*) and sockeye (*O. nerka*) populations (except for incidental catches), despite substantial adult escapements to the Fraser River, indicates the nearshore region of the outer estuary was not utilized as nursery habitats by these species. Pink, chum, and chinook juveniles were distributed between intertidal zones independent of fish size, and seasonal salinity and temperature patterns. Significant seasonal increases in average length occurred for pink and chum (1982) and for chinook (1981 and 1982), and were the result of growth on the delta-front of the Fraser estuary as indicated by comparisons with previously studied life history patterns, migration timings, seaward migration routes, and size distributions of juveniles in the Fraser River and Strait of Georgia. Residency periods, for at least part of the juvenile populations in 1982, were estimated to be 8 to 15 days for pinks, 15 to 25 days for chum, and 60 to 75 days for chinook.

Stomach analyses of chinook revealed that epibenthic, pelagic and surface drift invertebrates, and larval and juvenile Pacific herring (*Clupea harengus*) were fed upon. Dietary differences between intertidal zones were relatively minor except for herring, which were taken more frequently in the offshore zone. Herring were the most important prey as indicated by an index which incorporates frequency of occurrence, numerical abundance, and volume of organisms in the stomach. Most members of a resident herring population appeared to outgrow their vulnerability to chinook predation as the season progressed, which may have produced the observed temporal variations in the kinds of prey taken.

Results of this study showed nearshore intertidal zones of the outer Fraser estuary comprise important rearing habitats for salmon juveniles, and thus expand the known limits of estuarine nursery areas which previously included primarily the marshes of the inner Fraser estuary.

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INTRODUCTION

Juveniles of anadromous Pacific salmon (genus *Oncorhynchus*) frequent estuaries and coastal marine areas each year before migrating into the open ocean. Both pink salmon (*Oncorhynchus gorbuscha*) and chum salmon (*O. keta*) fry enter estuaries soon after emerging from spawning gravels (Neave 1966a;1966b). Pinks migrate through estuaries and rapidly disperse to nearshore marine nursery areas (LeBrasseur and Parker 1964; Healey 1967). Chum fry either reside in estuarine habitats (Mason 1974; Healey 1979) or disperse, like pinks, to high salinity nursery sites (Healey 1980a). Chinook (*O. tshawytscha*) juveniles that migrate downstream as recently emerged fry usually reside in estuaries for protracted periods (Reimers 1973; Healey 1980b). Chinook that spend approximately 90 days in freshwater before migrating to the ocean may also rear in estuaries (Argue *et al.* 1979). Seaward migrating chinook, coho salmon (*O. kisutch*) and sockeye salmon (*O. nerka*) smolts that have reared in freshwater systems for one year or more apparently use the estuary just for migratory passage.

The Fraser River system in British Columbia supports large spawning populations of pink, chum, chinook, coho, and sockeye (Aro and Shepard 1967). Each year between March and May chum and chinook fry and additionally in even numbered years pink fry are abundant in the Fraser River estuary in the marsh-island complex (Levy *et al.* 1979) and on Sturgeon and Roberts Banks (Conlin *et al.* 1982; Gordon and Levings 1984). Chum and chinook fry are temporary estuarine marsh residents whereas pinks migrate quickly through the estuary to the Strait of Georgia (Levy and Northcote 1982).

The Fraser estuary can be divided into two major areas: an inner marsh-island complex and an outer tidal flats delta-front region. A number of observations suggest the outer area of the Fraser may serve as salmonid nursery habitat: (1) juvenile salmon occur seaward of the Fraser River mouths (Goodman 1975; Greer *et al.* 1980) in unvegetated mudflat and sandflat, vegetated sandflat, and salt marsh areas which comprise Sturgeon and Roberts Banks; (2) benthic and planktonic invertebrate surveys (Levings and Coustalin 1975) and forage fish surveys (Greer *et al.* 1980; Conlin *et al.* 1982) on these banks indicate the presence of potential food organisms for salmon, and (3) both chum and chinook juveniles reside on tidal flats of delta estuaries in other coastal river systems in B.C. (Mason 1974; Healey 1979; Healey 1980b).

Juvenile salmon that rear in the Fraser estuary are potentially more sensitive to changes and losses of estuarine habitats than transients which use these areas only for migratory passage (Levy and Northcote 1982). Changes of delta morphology and in some areas, losses of naturally occurring vegetation have taken place within the Fraser estuary. The original marsh area has been greatly reduced by dyking for flood control and land reclamation (Romaine *et al*. 1976). Sediment deposition patterns across the delta-front have been changed by dredging of the river channels (Luternauer and Murray 1973) and the construction of structures including the Steveston north jetty, the North Arm jetty, the breakwater at the mouth of the North Arm, the Iona Island causeway and sewage outfall channel, the Vancouver International Airport approach lights causeway, the B.C. Ferries Tsawwassen terminal causeway and the Westshore Terminals coalport causeway (Hoos and Packman 1974).

This study was designed to evaluate whether nearshore regions of the outer Fraser estuary are nursery areas for juvenile salmon. The quantity and quality of such estuarine nursery areas may influence salmonid production of juveniles in the Fraser estuary. The work complements that of Dunford (1975) and Levy and Northcote (1982) who determined that marshes of the inner estuary serve as nursery sites.

The use of delta-front intertidal zones by salmonids was assessed by an examination of: (1) seasonal occurrence and relative abundance of juveniles; (2) distribution of juveniles between nearshore zones, and (3) seasonal size changes and length of residency periods of juveniles.

Since chinook reside for longer periods and grow to larger sizes in estuaries than juveniles of other salmon species (Healey 1980a), a diet analysis of chinook was performed to examine the relationships between food resources and habitat use.

METHODS AND MATERIALS

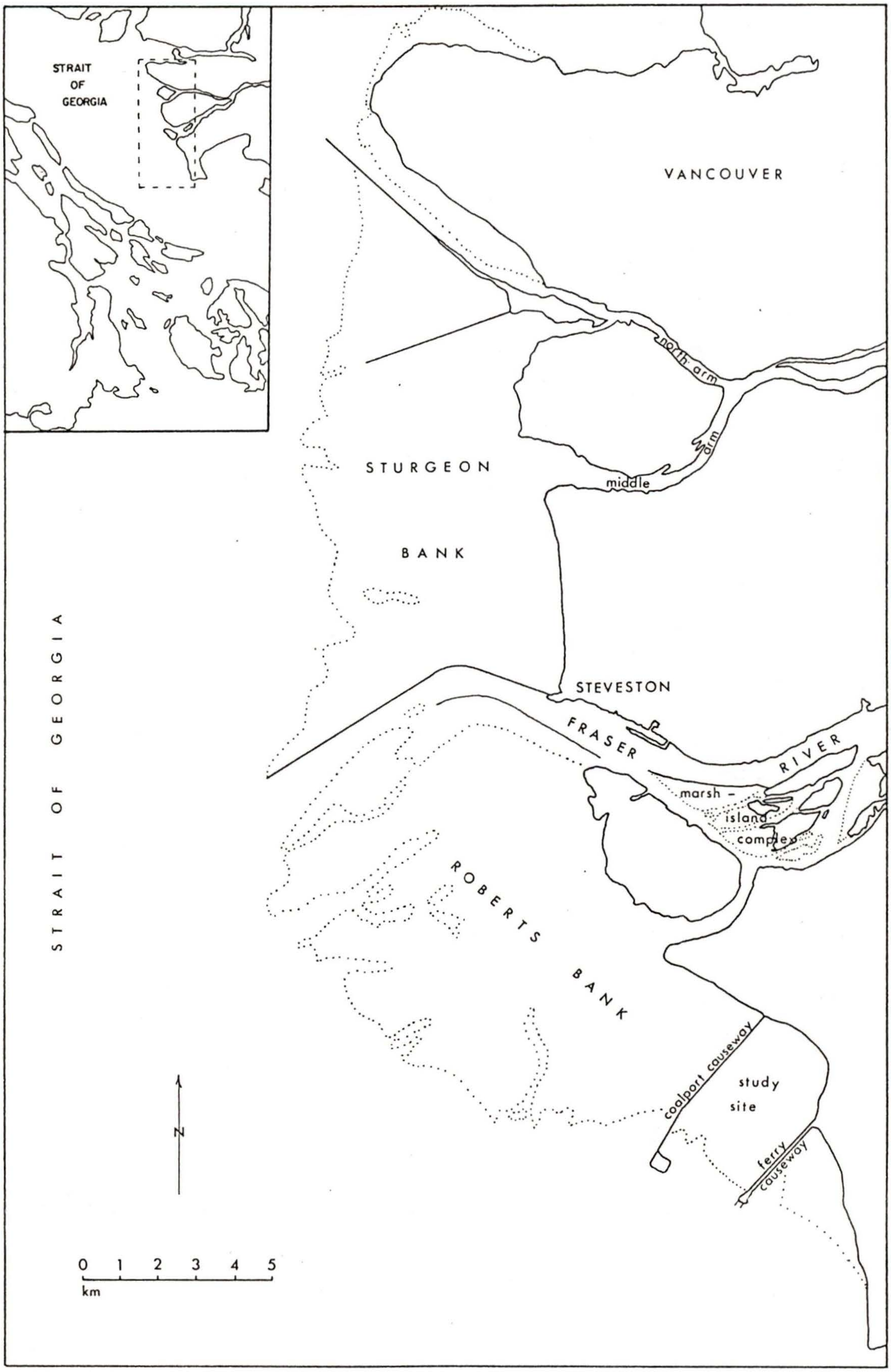
Description of Study Area

The study area was located on southern Roberts Bank of the Fraser River delta (49° 1'N, 123° 2'W)(Fig. 1). The delta forms the outer zone of the Fraser estuary and is exposed to the Strait of Georgia. The study site was an approximately rectangular area (~1340 ha) of gently sloping tidal flats bounded by the Westshore Terminals coalport and B.C. Ferries Tsawwassen terminal causeways, the landward edge of a foreshore salt marsh, and an imaginary line extending between the seaward ends of the two causeways.

Five major zones identified and sampled within the study area (Fig. 2) were: an offshore zone, a causeway beach zone, an eelgrass bed (*Zostera* sp.), an unvegetated sandflat, and a salt marsh. The criteria used to distinguish between these zones were distance from the shoreline, topography of the intertidal and subtidal flats, and intertidal and foreshore vegetation.

The offshore zone is an area sampled at the terminus of each causeway and at the exposed (at low tide) edge of a dredge borrow pit (Fig. 2). The depths of water at these coalport terminal, ferry terminal, and borrow pit sampling sites were respectively 15.0 m, 3.0, m and 5.0 m below chart

Fig. 1. The Fraser River estuary, British Columbia, showing the locations of the marsh-island complex and the tidal flats of the delta-front. The inset map includes the location of Roberts Bank in Georgia Strait.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OF
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Fig. 2. Southern Roberts Bank of the Fraser delta depicting the offshore zone (O) including the borrow pit (B), causeway beaches (C) and tide channels (T) of the causeway beach zone, eelgrass bed (E), sandflat (S), foreshore salt marsh (M), coalport terminal expansion areas (e), and the locations of the following sample sites: (1) coalport, (2) ferry terminal, (3) borrow pit, and (4) salt marsh. (This figure is a reproduction from an aerial photograph that was taken on 24 July 1982 at 1432 PST).


C
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datum. *Fucus* sp., *Laminaria* sp., and *Sargassum* sp. occurred in the lower intertidal zone on the rocky substrate (riprap) around both causeway terminals. No submergent vegetation was observed on the slope of the borrow pit.

The causeway beach zone is intertidal, borders both causeways shoreward of the delta-foreslope, and includes tide channels adjacent and parallel to each causeway extending from the offshore zone to approximately the midway point along the causeways. The banks of the unvegetated channel system adjacent to the ferry causeway are exposed at low tides but the bottoms of the channels do not drain completely at 0.0 m chart datum. The adjacent beaches of both causeways are a composite of gravel, cobble, and boulders with coarser substrates occurring at exposed sites adjacent to subtidal areas.

An eelgrass bed of ~460 ha extends across the delta front from 1.0 m below to 1.0 m above chart datum. The bed is separated from each causeway by the tide channels. In addition, several channels flow through the eelgrass into the borrow pit in the north-west section of the bed. Two species of eelgrass are found in the study area. *Zostera marina* is the dominant species and *Z. japonica* is a recent introduction (Harrison and Bigley 1982). *Z. japonica* was found in the highest intertidal part of the eelgrass bed.

An unvegetated sandflat of ~516 ha occupies the upper (>1 m above chart datum) intertidal area. *Ulva lactuca*, an unattached algae, occurs over the sandflat and partially overlaps the eelgrass. At 0.0 m chart datum part of the eelgrass bed and all of the sandflats are exposed.

An ~78 ha salt marsh along the foreshore has a plant community dominated by *Distichlis stricta*, *Salicornia virginica*, *Grindelia integrifolia*, and *Atriplex patula* (Beak-Hinton 1977; Hillaby and Barrett 1976). The marsh is drained by a dendritic system of tide channels. The common mouth of these channels, ~14 m wide and located at the south-east corner of the marsh (Fig. 2), begins to flood at tide levels of ~3.0 m above chart datum. A drainage ditch containing runoff from farmland enters the main arm of the tide channel system ~100 m upstream from the channel mouth.

Activities associated with expansion of the coalport (beginning in the summer of 1981 and continuing throughout 1982) had changed some features of the area while the study was in progress. Boulder size rip-rap was deposited along the beaches of the coalport causeway, in a U-shape around the borrow pit, and on the perimeter of the terminal expansion areas (Fig. 2). The morphology of the borrow pit described by Conlin *et al.* (1982) changed from dredging. The tide channel adjacent to the coalport causeway was filled in by erosion from a sand stockpile that was deposited partly in the intertidal zone.

The Fraser estuary is influenced by mixed, mainly semi-diurnal tides (Canadian Hydrographic Service 1982). Salinities on the Fraser delta vary with respect to positions in the intertidal zone and distance from the Fraser River channels (Levings and Coustalin 1975). On Roberts Bank a transition from a brackish to a marine environment occurs (Swinbanks 1979). Salinities are generally higher between the two causeways than to the north-west of the coalport (Levings and Coustalin 1975) because the coalport tends to isolate brackish surface waters of the Fraser plume on ebb tides (Beak-Hinton 1977). During flood tides the intercauseway area receives pulses of lower salinity water (Beak-Hinton 1977) causing short term variations of salinity. In the offshore zone of the study site, salinities of surface waters ranged from 28‰ in the winter months of 1980-81 to 14‰ in June 1981, and surface water temperatures in the offshore zone in 1980 ranged from highs of 21°C in July to lows of 2°C in December (Conlin *et al.* 1982).

The fish community of the study area comprises 40 species (Table A-1). Abundance and frequency of occurrence for most of these species are documented by Greer *et al.*

(1980) and Conlin *et al.* (1982) from beach seines they performed at the terminus of the coalport and on the perimeter of the borrow pit. Gordon and Levings (1984) provide a comparison of species composition between Roberts and Sturgeon Banks.

Measurement of Environmental Parameters

The areas of eelgrass, unvegetated sandflats, and the foreshore salt marsh were determined from a 1:30,000 aerial photograph (BC82012-157) of the Surveys and Mapping Branch, B.C. Ministry of the Environment, taken on 24 July 1982 at 1432 PST (see Fig. 2). Temperatures of surface waters (at all sample sites) were measured with a hand-held thermometer (±0.5°C). Salinities from hand-collected samples of surface water (at all sample sites) were measured in the laboratory with a Beckman (model no. RS7-C) inductive conductivity salinometer (±0.1‰). Temperatures (±0.5°C) and salinities (±0.1‰) of subsurface water were measured with a Beckman (model no. RS5-3) portable salinometer.

Sampling Methods

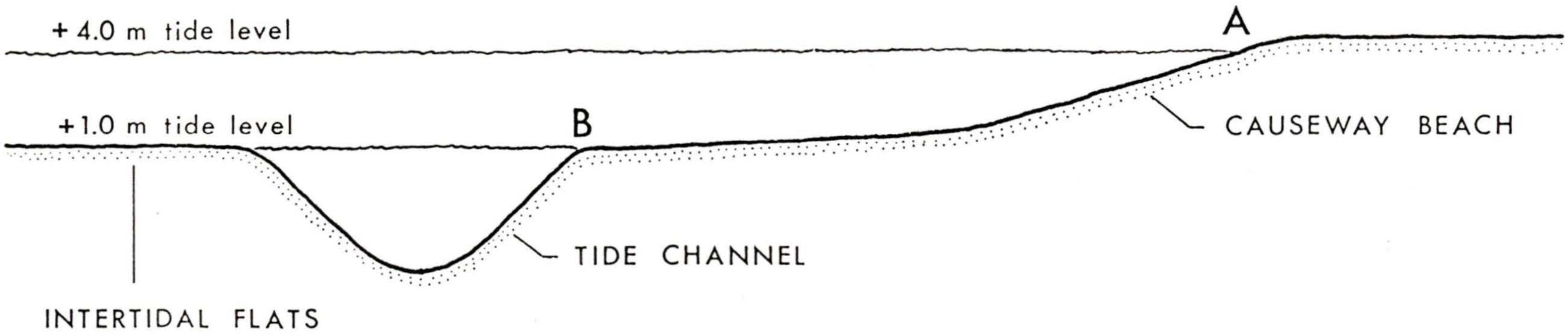
Beach seines

Sampling was performed between 16 June and 27 August in 1981 and between 9 April and 19 August in 1982 using a beach seine (15 m long by 3 m deep of 6 mm mesh). The location and time of each set are included in figs. A-1,A-2 and tables B-1,B-2 respectively. The net was deployed 15 m off the beaches by a 3.0 m inflatable rubber boat powered with a 10 hp outboard motor. Two sampling sites (1 and 2) were established at the terminus of each causeway (Fig. 2) because these offshore areas could be sampled at all tide levels. The borrow pit was sampled mainly at site 3 (Fig. 2) at tide levels of +0.5 m and less when a beach was exposed. Sampling locations along the beaches of each causeway and in the tide channels varied according to tide levels on each sampling date. For example, at tide levels of +4.0 m, water depths permitted sampling along the entire length of the causeway but below +1.0 m sampling was performed only in the tide channel (Fig. 3). In 1981 both causeways were sampled but in 1982 sampling was performed only along the ferry causeway because the rip-rap deposited on the coalport beach was too large to seine on and the adjacent tide channel was filled in. The salt marsh was sampled at the mouth of the tide channel system only at tide levels of +3.5 m or greater.

Seines with a portable ramp assembly

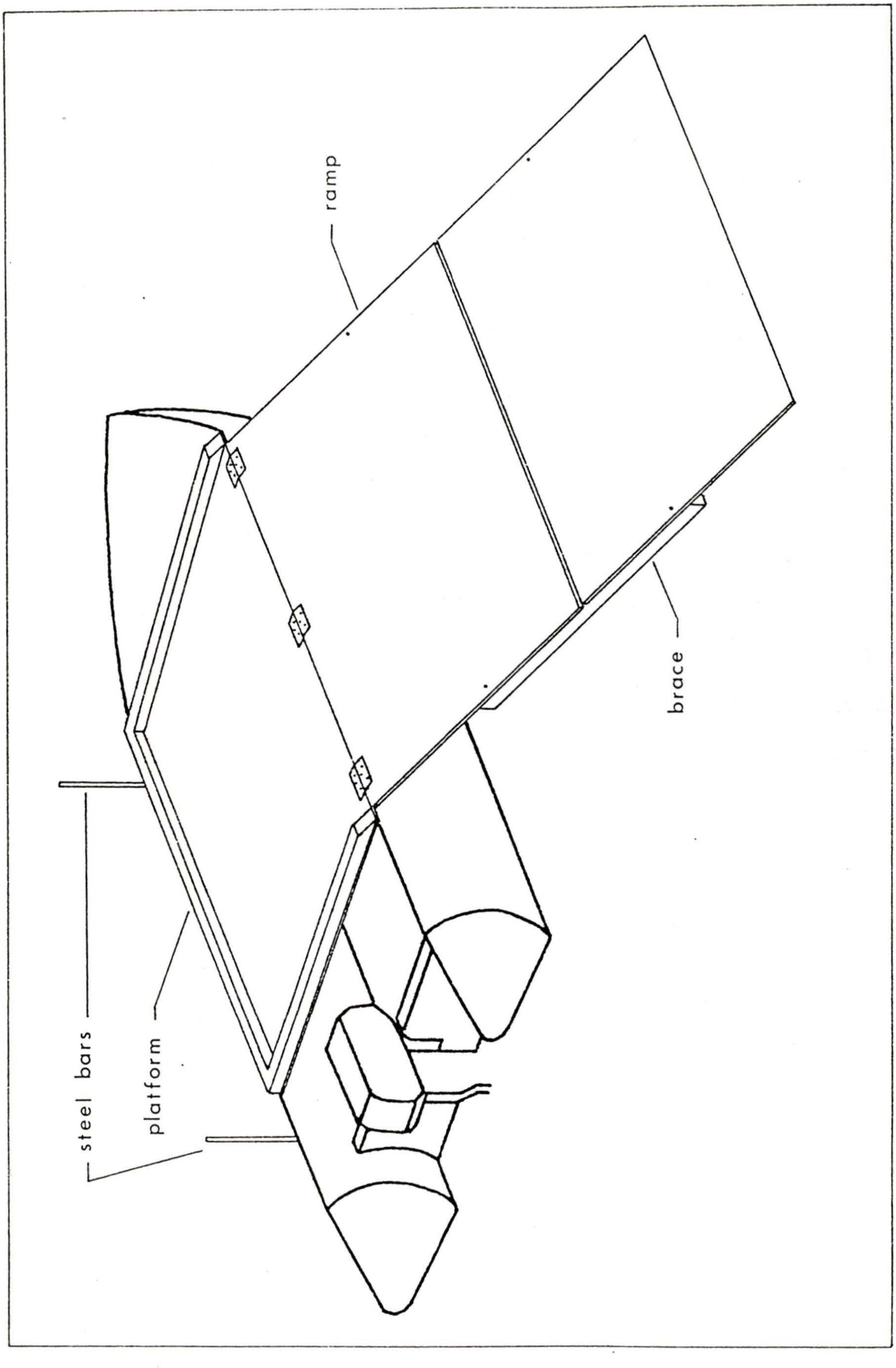
The gentle slope of the tidal flats imposed constraints on the effective use of the beach seine. Shallow depths (i.e. 1.5 m) precluded the use of trawls and other seine

Fig. 3. Cross-section (not to scale) of the causeway beach zone showing locations of beach seines at (A) high and (B) low tides.


+4.0 m tide level
A
+1.0 m tide level
B
CAUSEWAY BEACH
TIDE CHANNEL
INTERTIDAL FLATS

methods. To sample in these areas a portable ramp assembly (Fig. 4) was constructed and attached to the top of the same boat used for deployment of the beach seine. Three plywood sections, connected to each other by hinges, were arranged so they could be either collapsed to rest on top of one another or unfolded to an extended position. The ramp assembly was transported on the boat in the collapsed position. At a sampling site, the boat was anchored by sinking two 2.5 m long steel bars into the bottom substrate by hand pressure after placing them through the front and rear handle loops on one side of the boat. Such anchoring permitted the boat to freely slide on the bars in response to wave action or tide changes while remaining in a fixed position. The ramp sections were extended to form an inclined access from the water bottom to the platform section on top of the boat. A set was performed by positioning the beach seine (described above) parallel to, and at a distance of 15 m from, the submerged edge of the ramp. The net was hauled by hand to the boat where the two ends of the seine were drawn against the ramp. The set was completed by pulling the net up the ramp and onto the platform. This new sampling technique enabled me to capture fish in water depths of 1.5 m and less throughout the eelgrass and sandflats (Figs. A-1,A-2) with sampling times varying according to tide height. The eelgrass bed was

Fig. 4. Portable ramp assembly designed to capture fish occurring in the eelgrass and sandflat zones. Each of the two ramp sections and the platform are 1.3 cm by 122.0 cm by 243.0 cm plywood. A 5.0 cm by 5.0 cm fir lip is attached to the unhinged edges of the platform. The 5.0 cm by 5.0 cm by 91.0 cm braces are held in place with 1.0 cm by 7.0 cm carriage bolts (in the extended position).


ramp
brace
steel bars
platform

sampled within the range of low tide to +2.0 m chart datum. The sandflat was sampled within the range of +2.0 m to high tide. Sampling locations were chosen at depths in the range of 1.2-1.5 m.

Sample Analysis

All fish in each catch were identified, enumerated and either released or retained for analysis. Fish kept for analysis were killed immediately after capture with an overdose of the anaesthetic 2-phenoxyethanol to prevent regurgitation of stomach contents and then preserved in 10% formalin. Fork lengths and wet weights were measured from preserved fish. Scale analysis was used to determine the age of chinook juveniles. An individual was classified as either: (1) a yearling or older fish if an annulus was detected, or (2) a young of the year fish if there was no annulus. The processes of scale growth and annulus formation have been reviewed by Tutty and Yole (1978).

A detailed taxonomic analysis of stomach contents of juvenile chinook salmon was performed. Only stomach contents were examined since the contents of the intestinal tract were well digested and unidentifiable. For prey of chinook captured in 1981, frequency of occurrence and numerical abundance were tabulated. In 1982, three parameters were measured: frequency of occurrence, numerical abundance, and effective area. Effective area of a prey item, a rectangle with dimensions equal to the maximum length and greatest width of the animal (Yoshiyama 1980), provided an approximate measurement of prey size or volume. Since effective area represents the largest surface area of the prey, measurements were taken of amphipods or fish from the lateral aspect and crabs or isopods from the dorsal aspect. Measurements did not generally include appendages (i.e. legs of insects or dorsal fins of fish).

An index of relative importance (IRI) (Pinkas *et al.* 1971) was used to determine dominant prey items. This index is based on an equal contribution of percent numbers, volume (effective area), and occurrence. Use of the index avoids bias in calculations of prey importance based on only one of these parameters (Macdonald and Green 1983). For example, if just numerical abundance was considered, numerous small organisms would mask the importance of a few large ones. Although Macdonald and Green show that measurements for each of these variables in the IRI equation may be redundant if sizes of prey species do not differ, chinook prey sizes may vary considerably. Therefore IRI was calculated as follows:

$$IRI = (NA + EA)FO$$

IRI = index of relative importance

where NA = percent numerical abundance

EA = percent effective area

FO = percent frequency of occurrence

Percent IRI was calculated to compare IRI values between groups of fish with different sample sizes.

RESULTS

Seasonal Occurrence and Abundance of Juvenile Salmon

Juveniles of all five species of salmon were caught between June 1981 and August 1982. Chum, chinook, coho, and sockeye were caught in 1981 and 1982 as well as pinks in 1982. Chinook catches for each sample site in 1981 (Figs. A-1a,b,c) are given in table B-1. Pink, chum, and chinook catches for each site in 1982 (Figs. A-2a,b) are given in table B-2.

The seasonal pattern of pink occurrence and abundance in 1982 is illustrated in Fig. 5. From very low numbers in early April the catch in all zones peaked in early to mid-May and then rapidly declined. The highest average catches per set (200-300) were obtained along the causeway beaches and offshore sample sites during the first half of May. The last catch of pinks was on 16 June.

Since sampling in 1981 began in mid-June, most of the year's chum migration was missed and catches contained only a few remaining stragglers (Table 1). In 1982, chum juveniles were abundant between mid-April and mid-June (Fig. 6). During April chum penetrated the tide channels of the salt marsh. Peak abundance in the offshore zone on 20 May was followed by a rapid decline over the next month. The last date of capture in 1982 was similar to that of 1981.

Fig. 5. Average catch of pink salmon juveniles per beach seine set in four zones on southern Roberts Bank during 1982.

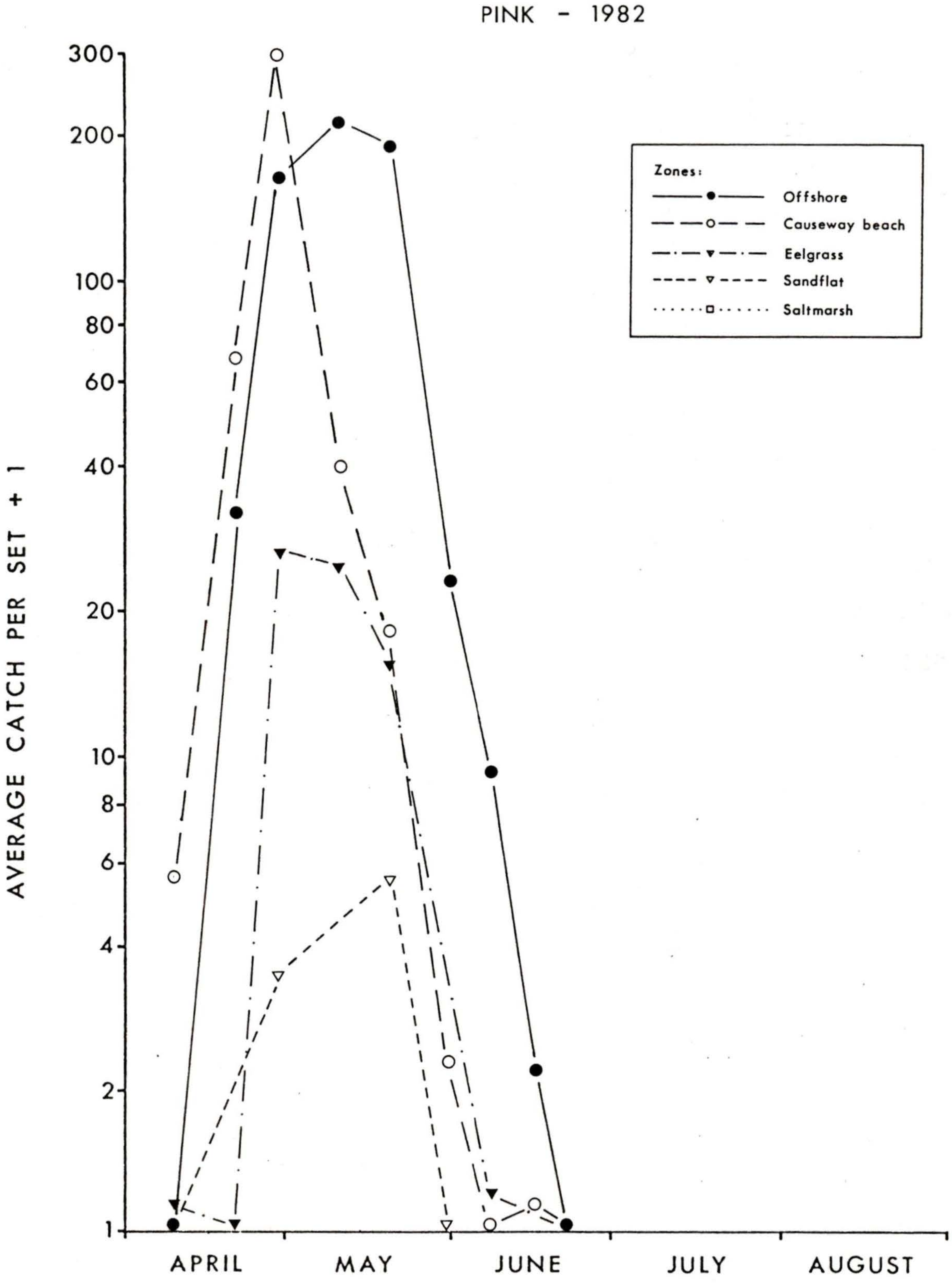
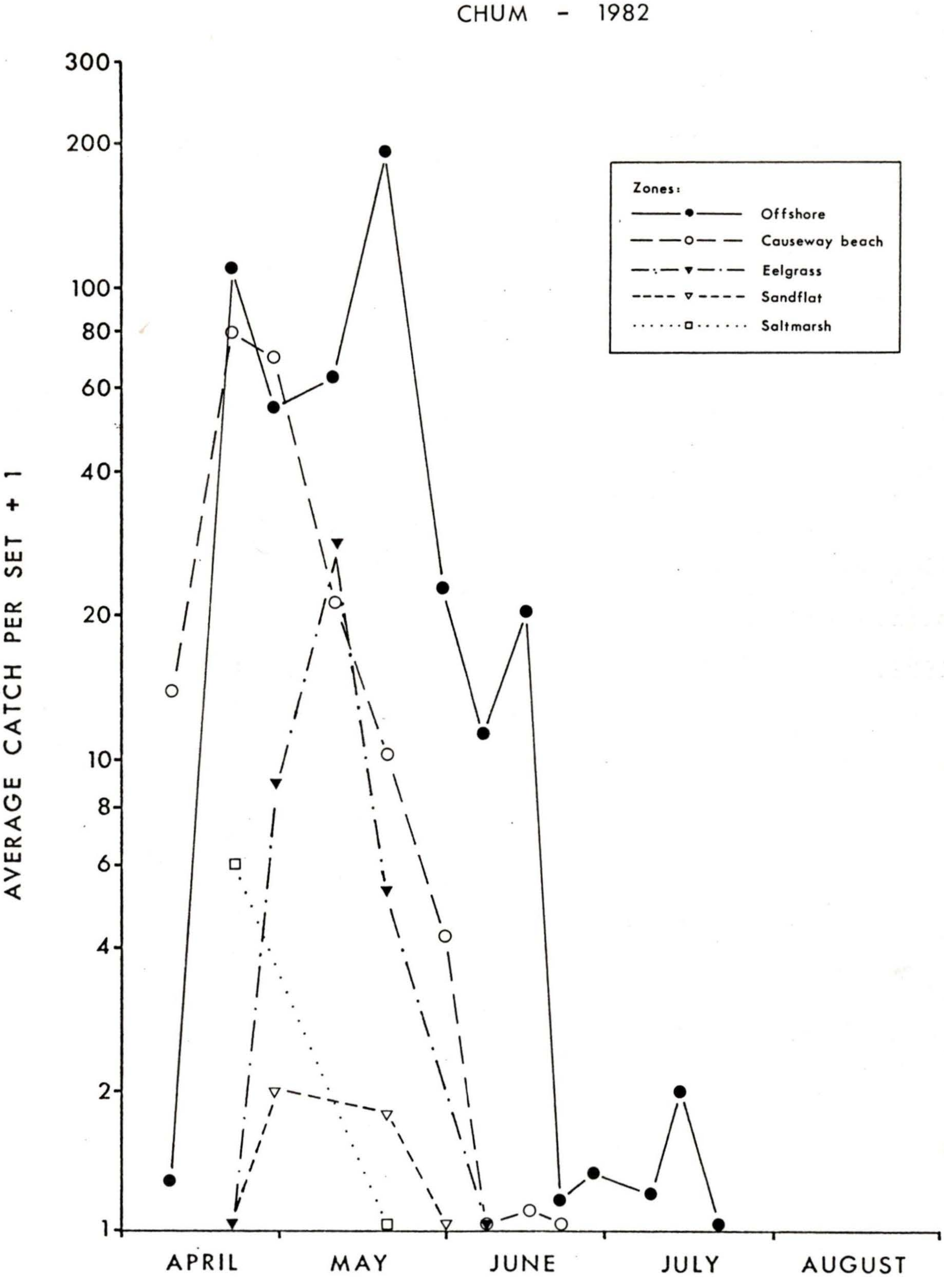

PINK - 1982
AVERAGE CATCH PER SET + 1
300
200
100
80
60
40
20
10
8
6
4
2
1
APRIL
MAY
JUNE
JULY
AUGUST
Zones:
Offshore
Causeway beach
Eelgrass
Sandflat
Saltmarsh

Table 1. Catch per set and mean fork lengths for chum, coho, and sockeye juveniles obtained on southern Roberts Bank in 1981 and 1982.

	Sample date			No. of	Catch			Fork length
Species	Year	Day	Zone	sets	Mean	Range	Total	Mean(mm+SD)
Chum	1981	June 16	Sandflat	1	1.0		1	40.0
		30	Offshore	2	5.5	0-11	11	67.9 + 14.7
		July 7	Offshore	1	1.0		1	83.0
		14	Offshore	4	0.3	0-1	1	67.0
Coho	1981	July 8	Causeway beach	5	0.2		1	161.0
	1982	June 1	Offshore	4	0.3	0-1	1	117.0
		8	Offshore	4	0.5	0-2	2	100.5
Sockeye	1981	June 29	Eelgrass	3	0.3	0-1	1	50.0
		30	Offshore	2	6.0	0-12	12	53.5 + 6.0
		July 28	Offshore	4	2.0	0-5	8	62.5 + 8.9
	1982	May 10	Offshore	3	0.3	0-1	1	69.0
		20	Offshore	3	0.3	0-1	1	71.0
		June 22	Offshore	5	0.4	0-1	2	43.5
		29	Offshore	4	0.3	0-1	1	52.0
		July 15	Offshore	4	0.5	0-2	2	59.0
		22	Offshore	7	2.4	0-17	17	59.0 + 4.0
		29	Offshore	7	0.4	0-1	3	64.0 + 3.6
		Aug. 4	Offshore	7	0.3	0-2	2	60.5

Fig. 6. Average catch of chum salmon juveniles per beach seine set in five zones on southern Roberts Bank during 1982.


CHUM - 1982
AVERAGE CATCH PER SET + 1
300
200
100
80
60
40
20
10
8
6
4
2
1
APRIL
MAY
JUNE
JULY
AUGUST
Zones:
Offshore
Causeway beach
Eelgrass
Sandflat
Saltmarsh

Chinook juveniles were present throughout the 1981 sampling period from mid-June to late August (Fig. 7). Catches in the offshore zone declined from an initial high of 31.0 fish per set on 30 June to a catch of 1.5 individuals per set on 27 August. The catch pattern indicates that only the latter part of the 1981 chinook migration was observed. In 1982, chinook juveniles were most abundant in the offshore zone between 20 May and 16 June (Fig. 8). Up to May 10 sampling produced a few individuals. Catches in the offshore zone then rose rapidly to a peak of 153 individuals per set on 20 May and declined to 1.0 - 2.0 individuals per set by late July and early August. Catches of from one to four chinook per set were common throughout most of the study site from late April to late July. A comparison of the 1981 and 1982 catches shows the size and temporal changes of catch were generally similar during July and August.

The numbers of pink and chum in 1982, and chinook in both 1981 and 1982 displayed statistically significant temporal fluctuations ($p < 0.05$, two-way ANOVA's, Table C-1) on southern Roberts Bank while seaward migrations were in progress. Differences in patterns of timing and abundance between pink, chum, and chinook juveniles were apparent. Pink fry were absent in 1981 catches. In 1982 both pink and chum juveniles appeared earlier than chinook. Peak

Fig. 7. Average catch of chinook salmon juveniles per beach seine set in four zones on southern Roberts Bank during 1981.

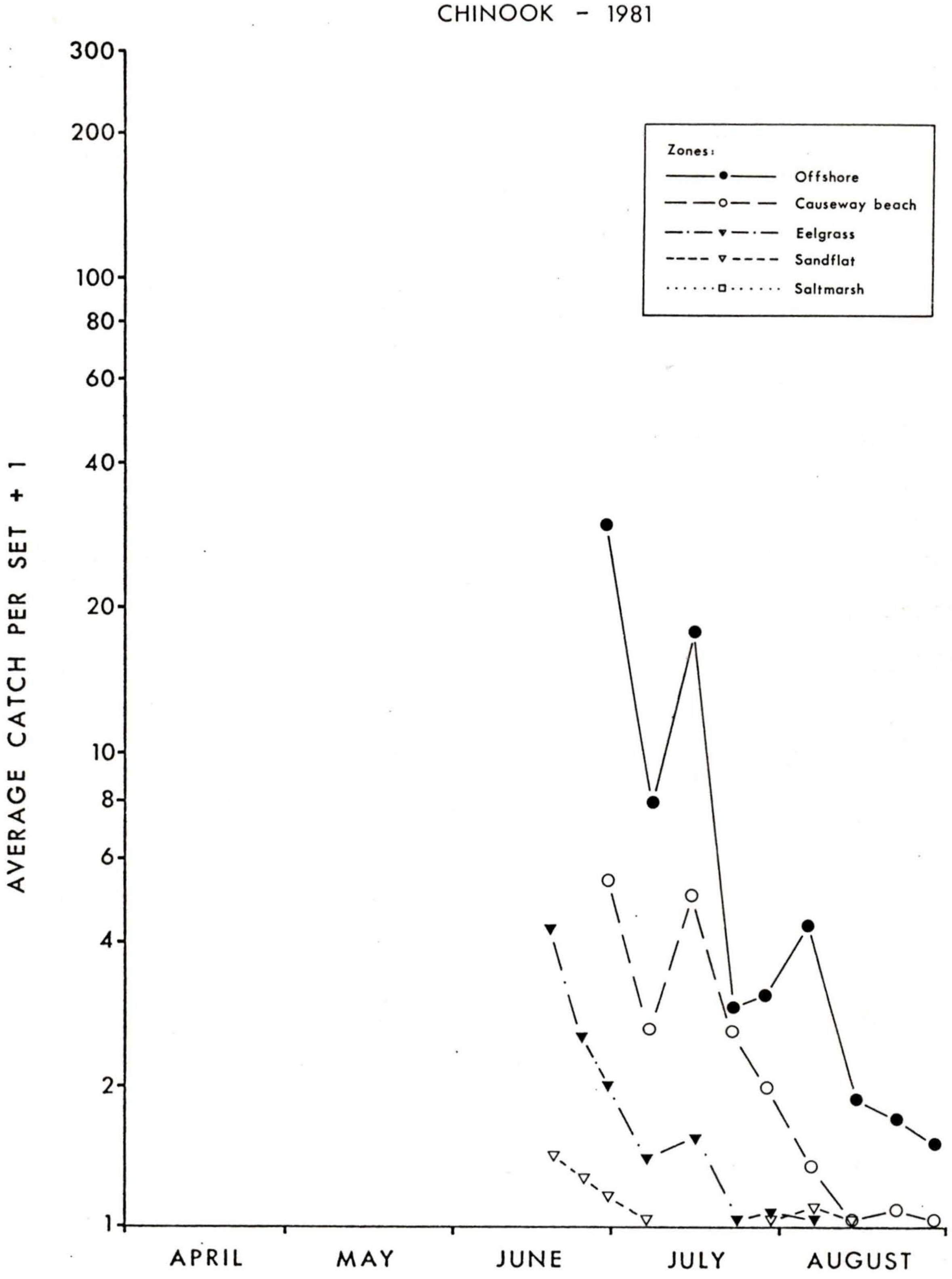
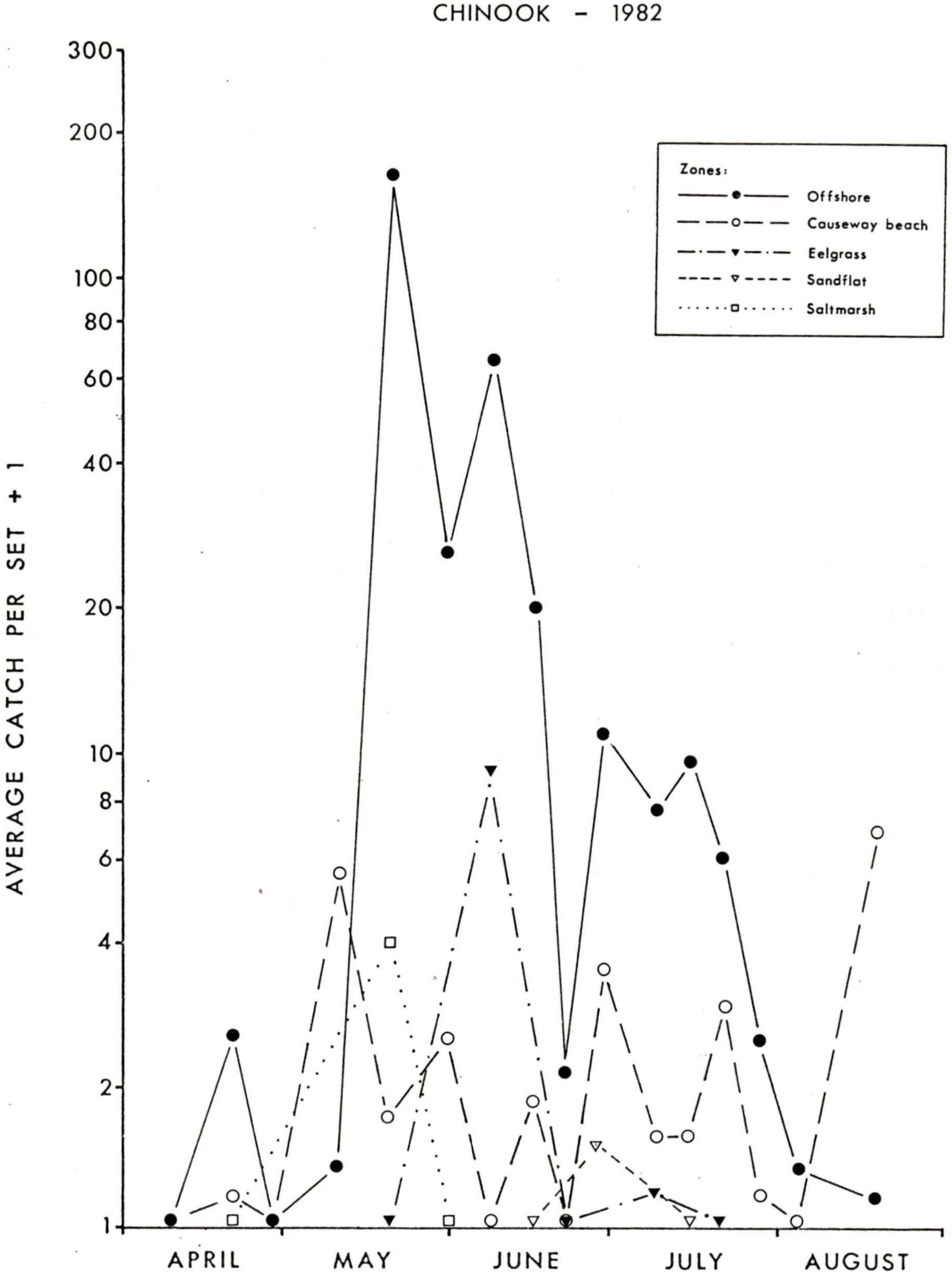

CHINOOK - 1981
AVERAGE CATCH PER SET + 1
300
200
100
80
60
40
20
10
8
6
4
2
1
APRIL
MAY
JUNE
JULY
AUGUST
Zones:
Offshore
Causeway beach
Eelgrass
Sandflat
Saltmarsh

Fig. 8. Average catch of chinook salmon juveniles per beach seine set in five zones on southern Roberts Bank during 1982.


CHINOOK - 1982
AVERAGE CATCH PER SET + 1
300
200
100
80
60
40
20
10
8
6
4
2
1
APRIL
MAY
JUNE
JULY
AUGUST
Zones:
Offshore
Causeway beach
Eelgrass
Sandflat
Saltmarsh

abundance and disappearance of pinks preceded those of chum by approximately 10 and 20 days respectively. Chum disappeared at least a month before chinook. Chinook were less abundant than both pink and chum but chinook catches did not decline as quickly after the period of peak abundance.

There were small and infrequent catches of both juvenile coho (yearling smolts) and young of the year sockeye (Table 1) at the study site. One coho was captured in 1981 and a total of three were caught in 1982. Sockeye juveniles were caught in June and July in 1981 and from May to August in 1982. The single largest catch of sockeye occurred on 22 July 1982 (17 individuals in one set).

Distribution and Relative Abundance of Juvenile Salmon Between Nearshore Zones

The abundance of pink and chum in 1982 and chinook in both 1981 and 1982 were significantly different between the zones of the study area ($p < 0.05$, two-way ANOVA's, Table C-1). The general temporal pattern of catch between zones for each of these species (Figs. 5-8) were similar. The largest catches were usually in the offshore zone at the terminus of each causeway and the edge of the borrow pit. Fewer salmon were caught in the other zones ($p<0.05$, Student Newman-Keuls multiple range test).

Catches of pink and chum along the causeway beaches generally exceeded those in eelgrass. Small numbers of pink and chum were caught on the sandflats when they were abundant in the other zones.

Although small, catches of chinook in the causeway beach zone in 1981 and 1982 were more consistent throughout the season than catches in either the eelgrass or sandflat zones. Catches of chinook on the sandflats totalled four and two individuals in 1981 and 1982 respectively. Although no salmon were found in the saltmarsh in 1981, five chum and three chinook were captured there in 1982.

Catches of chum (in 1981), coho, and sockeye juveniles (Table 1) were too small and infrequent to measure differences between zones. Except for one individual taken over the sandflats, all chum in 1981 were captured in the offshore zone. The one coho smolt caught in 1981 was obtained in the causeway beach zone. All three coho smolts caught in 1982 were obtained in the offshore zone. Juvenile sockeye were caught almost exclusively in the offshore zone in both 1981 and 1982.

Salinity and Temperature Conditions

Salinity at the study site varied considerably with the season and during short term periods. Mean salinities of surface waters between the causeways for 1982 ranged seasonally from 27‰ in early April, when Fraser River discharges were relatively low (Fig. B-1), to 14‰ in early July, when discharges were moderately high during the freshet period (Table 2). Surface salinities in the subtidal and intertidal zones were generally similar on most sampling days. Conditions on 29 June 1982 indicated that large fluctuations of salinity may occur in one day. On this date the intercauseway area received a pulse of Fraser River water on a flood tide. As a result salinities of surface waters in both intertidal and subtidal zones changed from 25.2‰ during low tide to 2.8‰ after the influx of water from the plume (Table 2). Inundations of fresh water like this are probably associated with discharge levels of the Fraser and tidal fluctuations. Surface salinities were measured on the north side of the coalport causeway during the tidal cycle on 20 May 1982 to determine what effect the coalport had on surface salinity regimes while salmon were abundant in the study area. At low tide mean salinities were 5-9‰ lower on the north side of the coalport than in the intercauseway region (see Table 2). However, at high tide salinities on both sides of the causeway were similar.

Table 2. Salinities and temperatures of surface waters on southern Roberts Bank during 1982.

Sample date	Salinity (‰)			Temperature (°C)		
	N	Mean	Range	N	Mean	Range
Apr. 9	5	27.1	26.5-27.3	15	10.7	8.0-14.0
21	6	26.7	26.0-27.1	11	12.4	10.0-16.0
29	4	22.5	21.9-22.7	10	10.9	10.0-12.0
May 10	5	20.4	19.1-22.8	10	14.9	12.0-16.5
20	5	23.8	20.4-24.2	13	15.5	13.5-20.0
June 1	4	21.2	20.6-21.8	14	15.3	13.0-18.0
8	3	18.0	16.7-21.4	11	17.0	15.0-18.5
16	5	19.8	15.8-25.7	13	19.3	17.5-21.0
22	6	23.5	22.1-24.0	11	20.1	19.0-22.0
29	6	19.6	2.8-25.2	14	18.7	15.0-20.5
July 9	5	14.0	12.1-17.0	12	18.4	16.5-20.0
15	4	16.5	15.3-18.9	14	16.0	15.5-17.0
22	8	23.8	23.1-24.1	10	17.8	15.0-21.0
29	4	16.7	13.6-18.0	16	19.3	18.0-21.0
Aug. 4	5	23.9	23.4-24.7	11	17.8	16.0-19.0
19	4	26.7	26.2-27.2	8	17.7	17.0-18.0

The flow of fresh water into the salt marsh from the drainage ditch and surface land runoff varied between sampling days but appeared to influence only salinities of waters within the marsh. When flows from the ditch were observed, salinities ranged from 15-19‰ in the upper reaches of the marsh to 20-26‰ at the mouth. When flows from the ditch were negligible and when there were no flows, salinities were unaltered and the same as those of intertidal waters which entered on flood tides.

Vertical salinity structures varied between the offshore and intertidal zones despite the similarity of surface salinities. At high tide, salinities at the 3.0m depth were usually 2-5‰ greater than at the surface in the offshore zone while at the same time, salinities of surface and subsurface waters over eelgrass and sandflats were similar at depths of 3.0m or less.

Juvenile chinook were captured when salinities ranged from 2.8 to 25.7‰. Chum and pink juveniles were captured in waters with a narrower range of salinities (15.8 - 25.7‰) but were also present during the effects of the Fraser freshet.

Seasonal changes and large local variations in temperature also occurred on Roberts Bank. In general, mean surface temperatures increased as the season progressed from

10-12^{o}C in April to 16-18^{o}C in July and August 1982 (Table 2). However, temperatures were influenced a great deal by variations in weather conditions, particularly in the intertidal zone. Temperatures were usually higher in the eelgrass and intertidal zones on warm sunny days than on cool overcast days. Changes of surface water temperatures in the offshore zone due to variable weather conditions were less apparent. To determine the effects of short term weather changes on local temperature regimes, temperatures were recorded over a 2 hour period at station X (Fig. A-1b) midpoint in the sandflat zone. These temperature measurements were conducted just prior to and during flood tides on two separate dates. The first day, 13 July 1981, was 16^{o}C (air temperature), overcast with light rain while the second day, 15 July 1981, was 22^{o}C (air temperature), clear and sunny. Surface water temperatures in the offshore zone on both these days remained unchanged at approximately 17^{o}C throughout the day. However, temperatures of intertidal waters on 15 July changed markedly (Table 3). Shallow water at the leading edge of the tidal front was 7^{o}C warmer than deeper water seaward of the front. Temperatures at these same locations on 13 July varied by only 1.2^{o}C. Water over the intertidal areas was generally warmer than in offshore areas on sunny days because temperatures over the eelgrass and sandflats on 15 July remained approximately 4^{o}C

Table 3. A comparison of surface water temperatures July 13 and 15, 1981, during a flood tide in the sandflat zone. Measurements, recorded at the same site, started just prior to the flood tide beginning at 1240 and 1425 PST respectively. Weather conditions were cool(16°C), overcast with light rain on 13 July, and warm(22° C), clear and sunny on 15 July.

Time after submersion of sandflat (min)	Water depth (cm)	Water temperature (°C)	
		13 July	15 July
0	1.0	18.4	28.6
5	9.0	17.6	27.7
10	30.5	17.5	23.7
15	38.0	17.5	23.6
20	40.0	17.5	23.7
120	125.0	17.2	21.3
240	180.0	17.4	21.3

higher even after they were flooded for 4 hours (Table 3). Temperatures of shallow (0-1.5 m) intertidal water were not observed to differ with depth during ebb and flood tides.

Pink and chum juveniles were captured in a temperature range of 8-21°C. Chinook juveniles were captured in a similar temperature range (10-22°C). Although the juveniles did not show specific temperature preferences on any one sampling day, catches of all species declined as seasonal temperatures increased. Salmon were not caught in shallow intertidal water (0.5 m or less) when temperatures exceeded 22°C.

Seasonal Size Changes of Juvenile Salmon

To describe seasonal size changes of juvenile salmon, linear regressions of fork length (mm) against time (days) were calculated by the method of least squares for all observations. Regressions were only computed for samples of fish collected on at least three separate dates from each of the different zones of the study area. To determine if the slopes (rate of length change in millimeters per day) of these regression lines were parallel, and to test for homogeneity of y-intercepts, an analysis of covariance (ANCOVA) was performed. The weight-length relationship for juvenile pinks, chum, and chinook are given in table D-1.

Pinks

The average lengths of pinks did not vary significantly between zones on most sample dates in 1982 (Fig. 9a). Average sizes, calculated from grouped lengths from all zones on each sample date, increased from 33 mm in early April to 44 mm in early to mid-June (Fig. 9b). The length frequency distributions of this grouped data are unimodal on all sample dates (Fig. 10). The presence of pinks in the 30-34 mm size classes from early April to early June indicates that recently emerged fry entered the outer Fraser estuary during a period of at least two months because this is the size (32-38 mm) at which pinks leave spawning areas (Pritchard 1944).

The rate of increase of pink lengths within the April-June period was significant in the offshore and causeway beach zones but not significant in the eelgrass zone (Table 4). The slope of the regression for the offshore zone was significantly greater than that of the causeway beach zone ($p<0.05$, ANCOVA) but the y-intercept of the former was significantly smaller than the latter ($p<0.05$, ANCOVA). Overall, these results indicate that fish size was independent of the zones sampled on Roberts Bank. The seasonal regression of pooled lengths showed a significant change ($p<0.001$) with a slope of 0.21 mm/day.

Fig. 9. Seasonal change in average fork lengths ±95% confidence limits of pink juveniles in 1982 for: (a) each of the zones on southern Roberts Bank, and (b) all zones combined. Points without confidence limits are composed of ≤2 measurements.

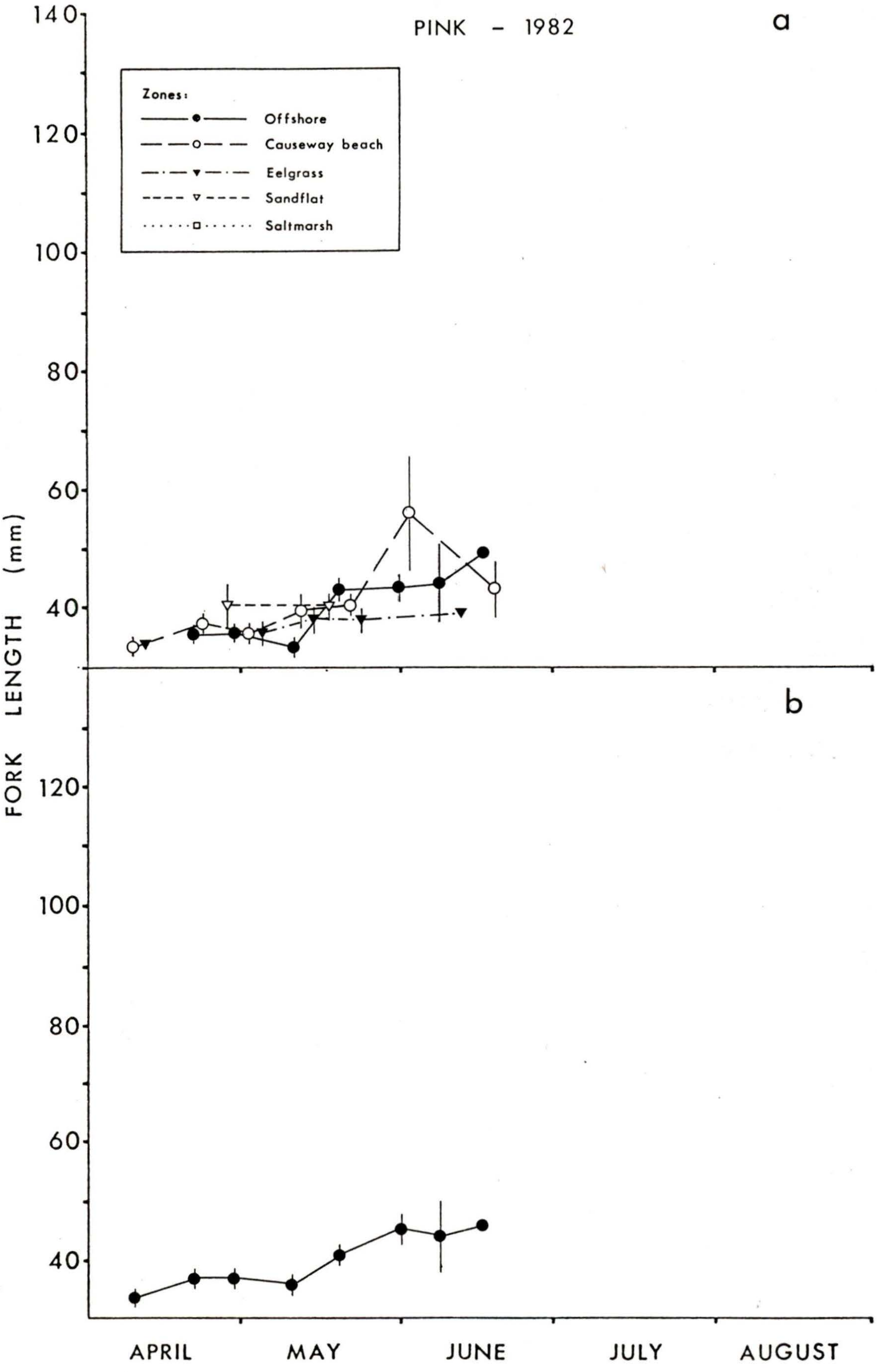
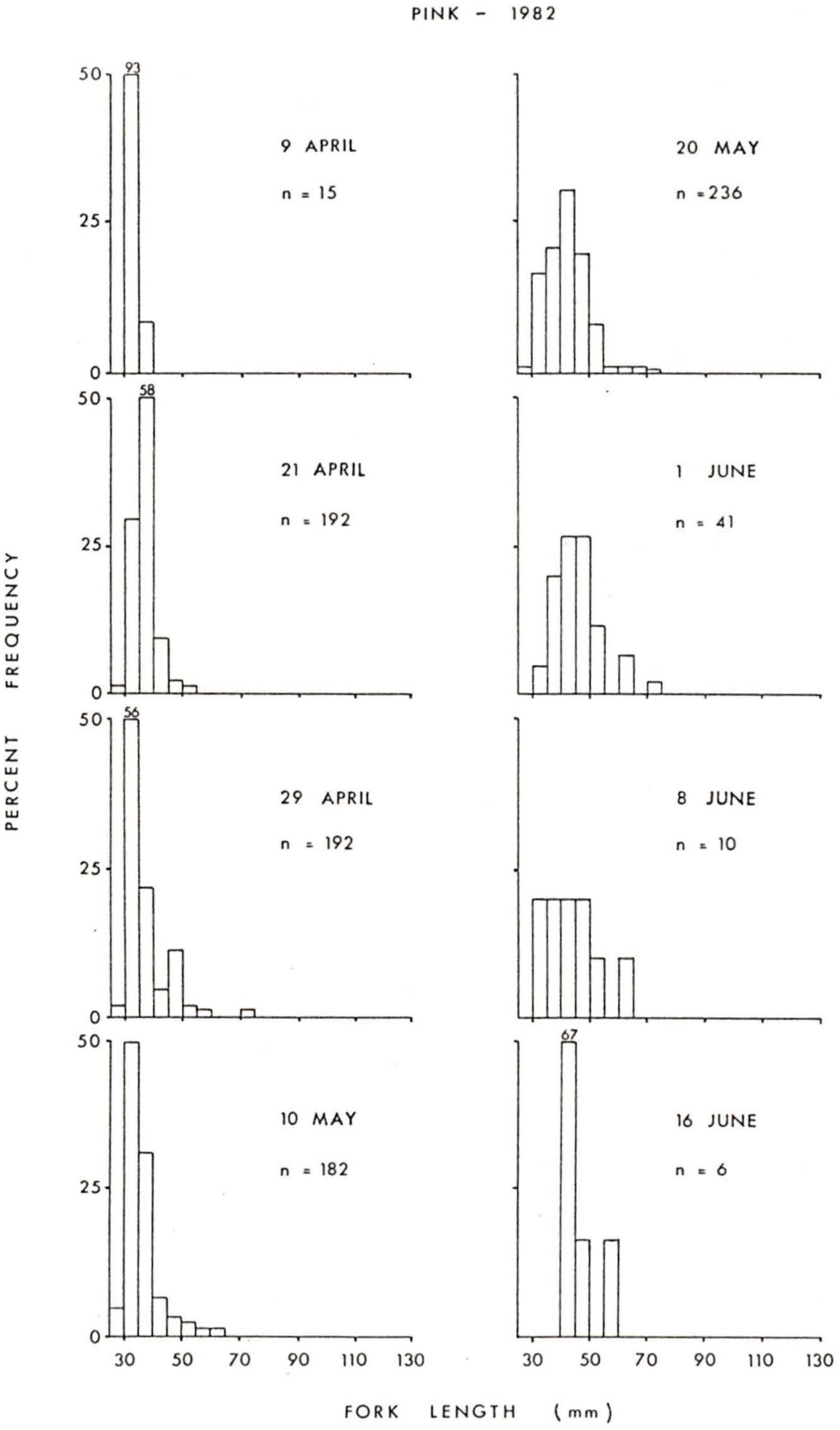

PINK - 1982
a
Zones:
Offshore
Causeway beach
Eelgrass
Sandflat
Saltmarsh
b
FORK LENGTH (mm)
140
120
100
80
60
40
120
100
80
60
40
APRIL
MAY
JUNE
JULY
AUGUST

Fig. 10. Length frequencies by size class for pink juveniles on southern Roberts Bank during 1982.



PINK - 1982

9 APRIL
n = 15
93
21 APRIL
n = 192
58
29 APRIL
n = 192
56
10 MAY
n = 182
20 MAY
n = 236
1 JUNE
n = 41
8 JUNE
n = 10
16 JUNE
n = 6
67
0
25
50
30
50
70
90
110
130
PERCENT FREQUENCY
FORK LENGTH (mm)

Table 4. Linear regression analysis of juvenile salmon fork lengths (mm), measured from samples collected on southern Roberts Bank, on time (days). P=probability.

Species	Year	Zone	n	Regression statistic Slope (mm/day)	Intercept (mm)	P of regression
Pink	1982	Offshore	407	0.26	29.7	<0.05
		Causeway beach	275	0.18	34.0	<0.05
		Eelgrass	169	0.11	34.6	>0.05
Chum	1982	Offshore	365	0.19	41.9	<0.05
		Causeway beach	190	0.14	41.2	<0.05
		Eelgrass	57	0.18	41.3	<0.05
Chinook	1981	Offshore	146	0.32	85.1	<0.05
		Causeway beach	39	0.53	70.8	<0.05
		Eelgrass	48	0.46	72.5	<0.05
Chinook	1982	Offshore	286	0.62	41.2	<0.05
		Causeway beach	63	0.63	38.2	<0.05

Chum

Seasonal changes in length for 1981 data were not analysed because of inadequate sample sizes (Table 1).

The average lengths of chum did not vary between zones on most sample dates in 1982 (Fig. 11a). Average lengths, calculated from grouped lengths from all zones on each sample date, increased from 42.0 mm in early April to 67.0 mm in mid-July (Fig. 11b). Length frequency distributions were unimodal for most sample dates (Fig. 12). The presence of chum in the size ranges of 35-39 mm and 40-44 mm from early April to mid-June indicates downriver migrant fry entered the outer Fraser estuary over a protracted period because this is the size at which chum leave spawning areas (Palmer 1972).

Chum captured in the offshore, causeway beach and eelgrass zones showed significant increases in length (Table 4). No differences in slopes and intercepts were found between sample sites ($p>0.05$, ANCOVA). The lengths of chum captured in the salt marsh on 21 April and on the sandflats on 29 April and 20 May were not different from those captured in the other zones on the same dates ($p>0.05$, t-tests). A seasonal regression of pooled lengths was significant ($p<0.001$) with a slope of 0.17 mm/day.

Fig. 11. Seasonal change in average fork lengths ±95% confidence limits of chum juveniles in 1982 for: (a) each of the zones on southern Roberts Bank, and (b) all zones combined. Points without confidence limits are composed of ≤2 measurements.

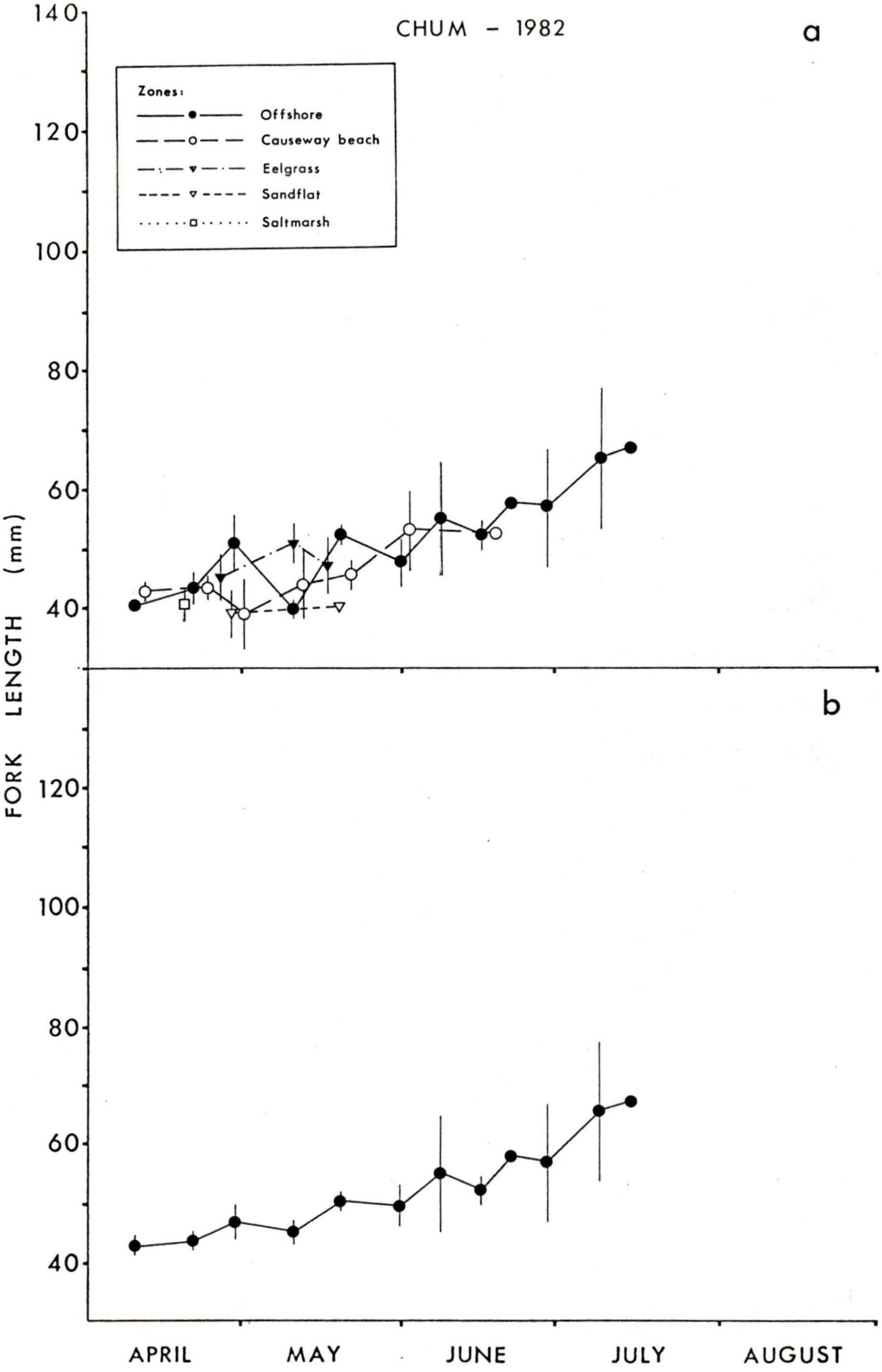
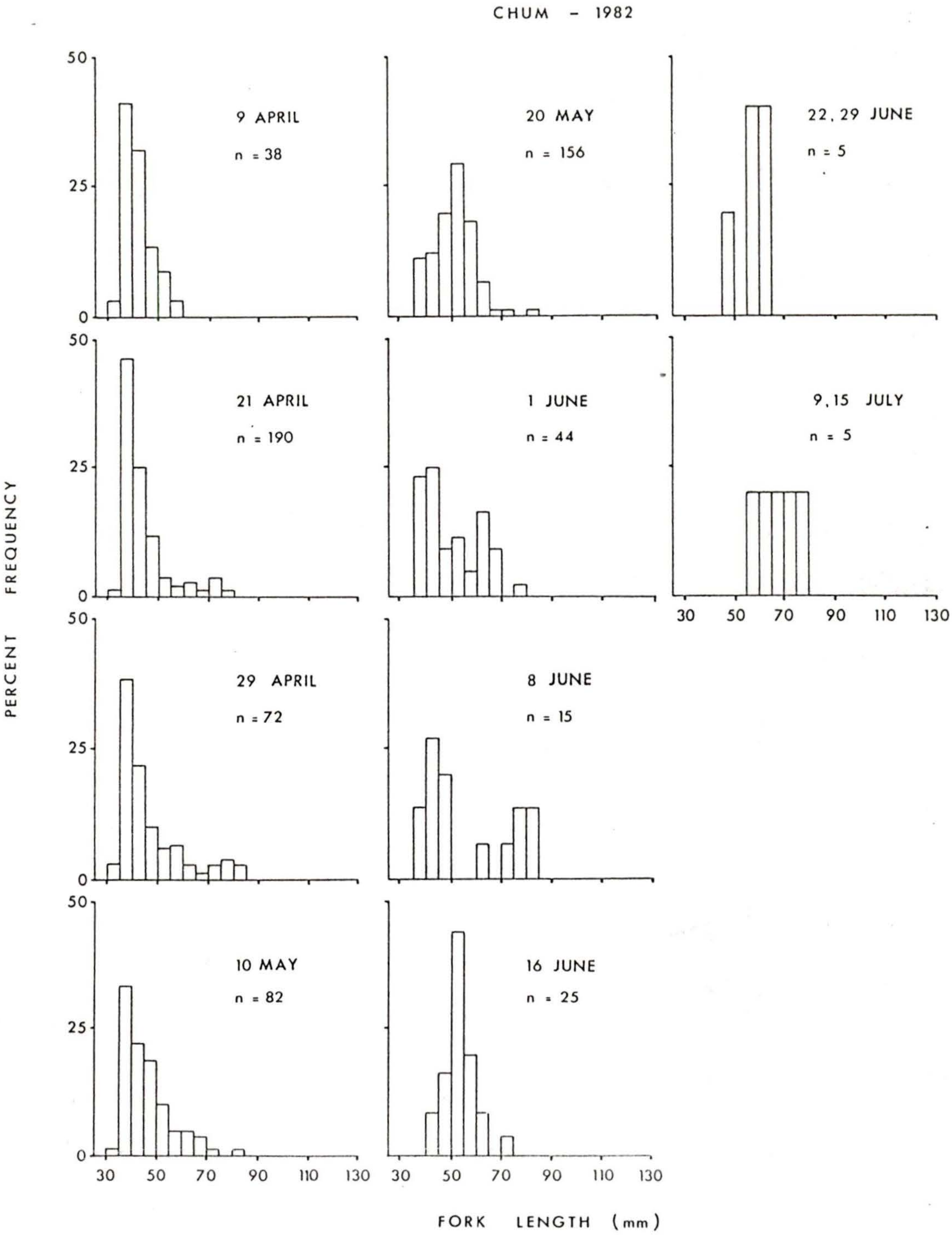

CHUM - 1982
a
b
Zones:
Offshore
Causeway beach
Eelgrass
Sandflat
Saltmarsh
FORK LENGTH (mm)
140
120
100
80
60
40
APRIL
MAY
JUNE
JULY
AUGUST

Fig. 12. Length frequencies by size class for chum juveniles on southern Roberts Bank during 1982.


CHUM - 1982
9 APRIL
n = 38
21 APRIL
n = 190
29 APRIL
n = 72
10 MAY
n = 82
20 MAY
n = 156
1 JUNE
n = 44
8 JUNE
n = 15
16 JUNE
n = 25
22, 29 JUNE
n = 5
9, 15 JULY
n = 5
PERCENT FREQUENCY
0
25
50
30
50
70
90
110
130
FORK LENGTH (mm)

Chinook

The average lengths of chinook varied between zones on some sample dates in 1981 (Fig. 13a) and increased (from pooled data) from 71.0 mm in mid-June to 115.0 mm in late August (Fig. 13b). Length frequencies (Fig. 14) were generally unimodal during June-late July. During August the frequency distribution did not have distinct modes and included a broad range of size classes.

In the June-August period of 1981, the rate of increase of chinook lengths was significant in the offshore, causeway beach, and eelgrass zones (Table 4). These regressions had similar slopes ($p>0.05$, ANCOVA) but different intercepts ($p<0.05$, ANCOVA). Chinook in each zone were thus different in average lengths on some sampling dates, but increased in length at the same rates. Although catches obtained in the sandflats were too small to compare quantitatively with other zones, lengths were similar (Fig. 13a). The seasonal regression of pooled lengths was significant ($p<0.001$) with a slope of 0.35 mm/day.

In 1982, chinook displayed the largest size change of all salmon species on Roberts Bank. Average lengths, which varied between zones on several sample dates (Fig. 15a), increased from 42.0 mm in mid-April to 115.0 mm in mid-August (Fig. 15b). Scale analysis indicated all individuals

Fig. 13. Seasonal change in average fork lengths ±95% confidence limits of chinook juveniles in 1981 for: (a) each of the zones on southern Roberts Bank, and (b) all zones combined. Points without confidence limits are composed of ≤2 measurements.

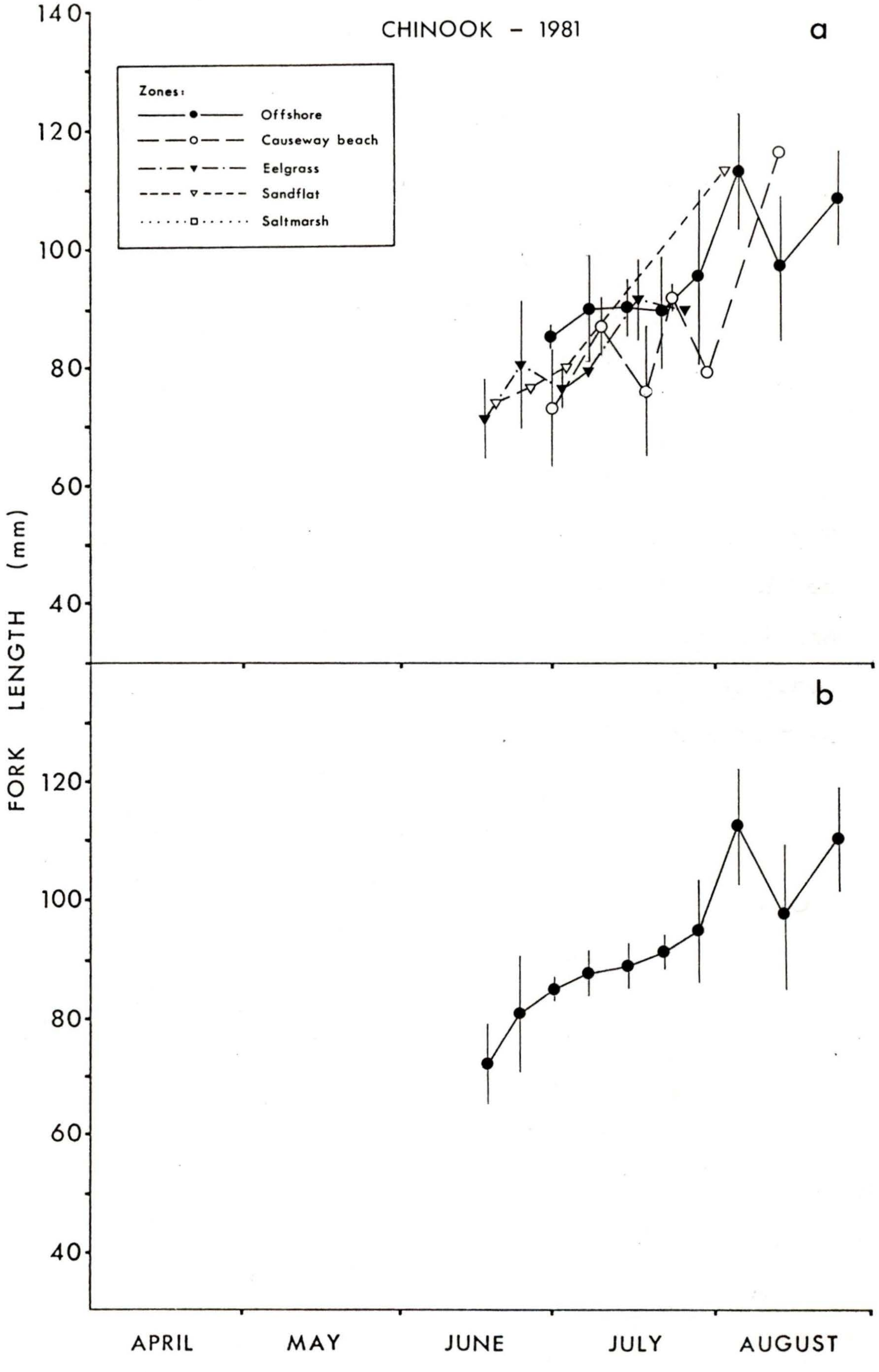

CHINOOK – 1981
a
Zones:
Offshore
Causeway beach
Eelgrass
Sandflat
Saltmarsh
b
FORK LENGTH (mm)
140
120
100
80
60
40
APRIL
MAY
JUNE
JULY
AUGUST

Fig. 14. Length frequencies by size class for chinook juveniles on southern Roberts Bank during 1981.

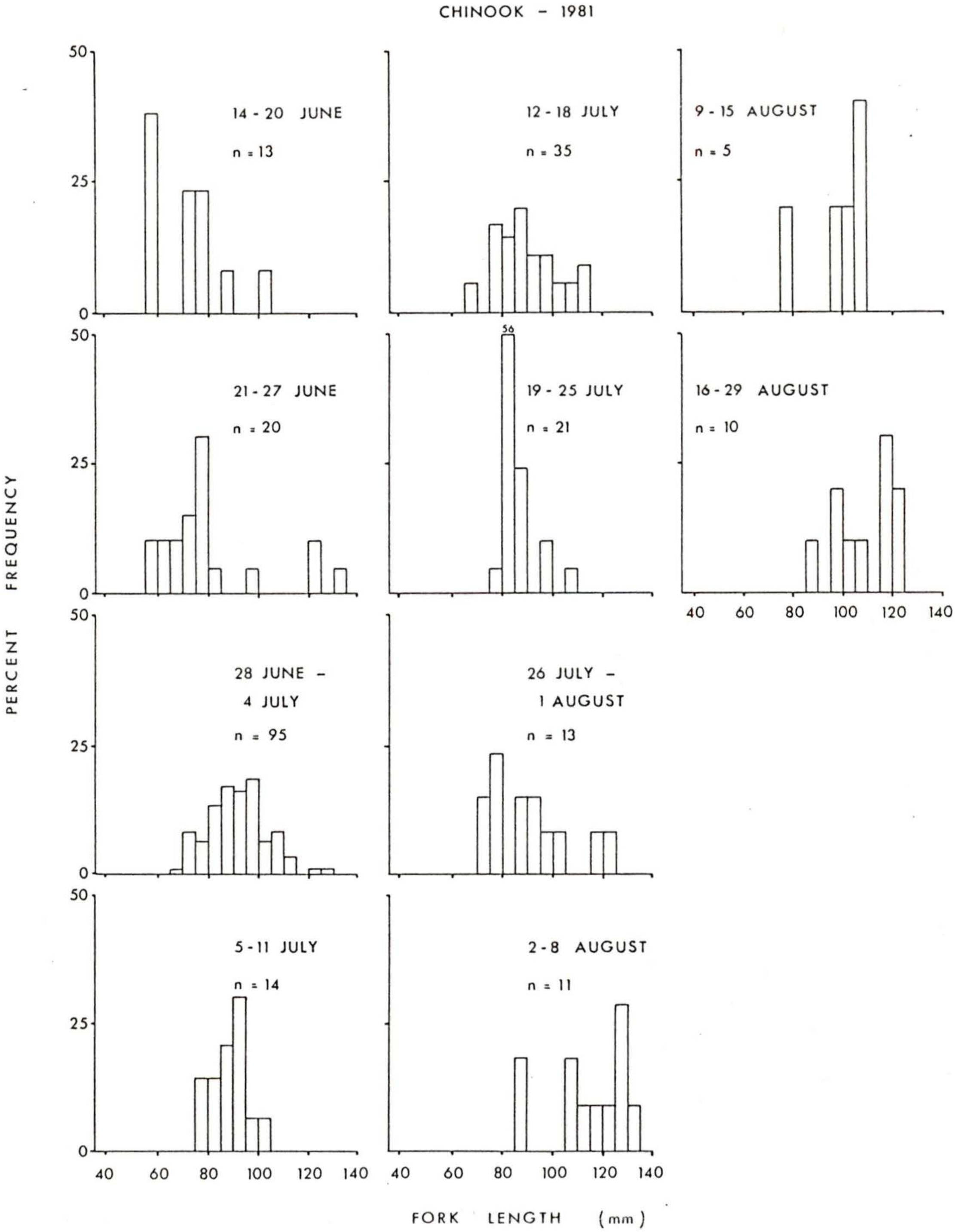
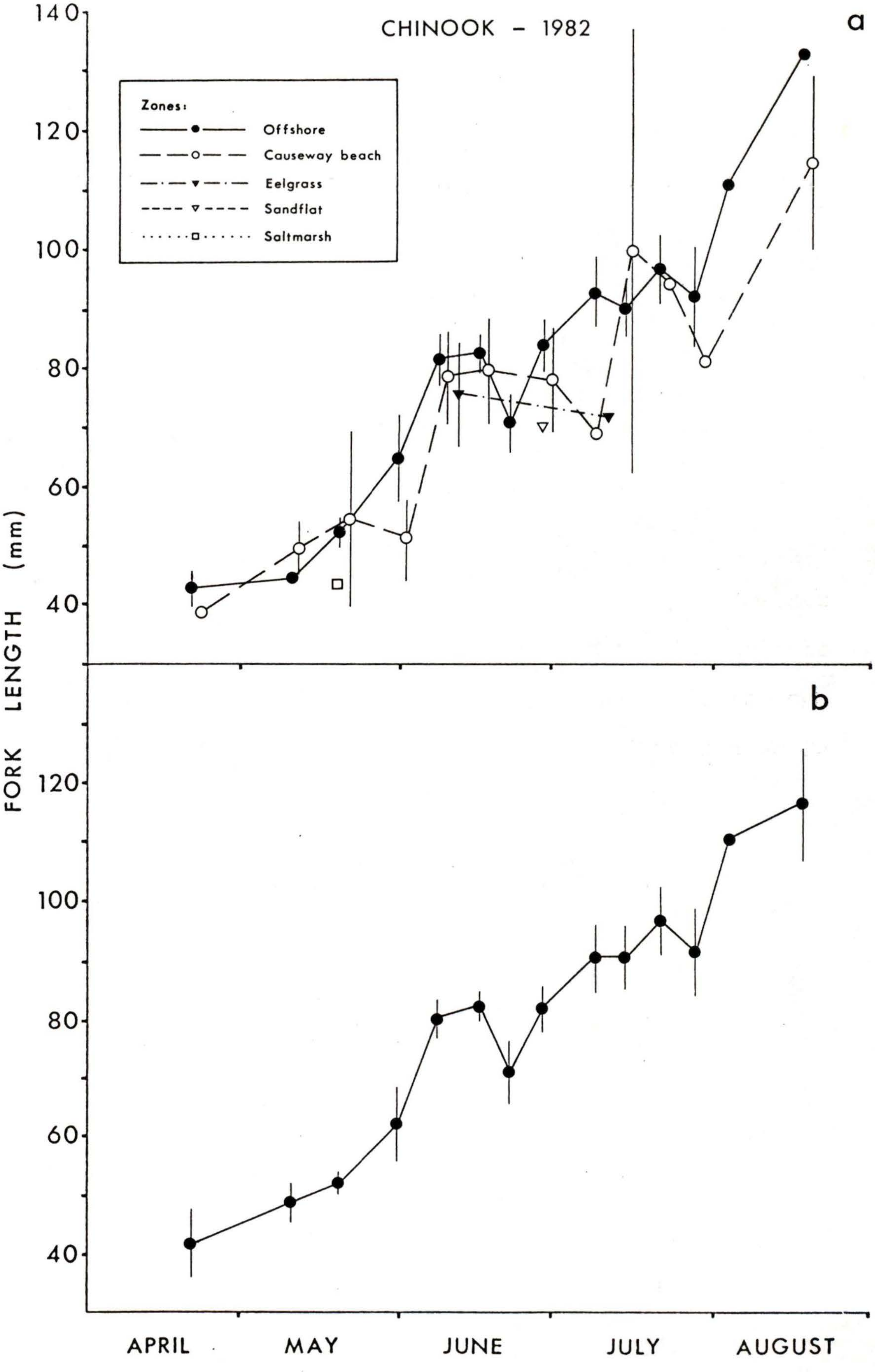

CHINOOK - 1981
14 - 20 JUNE
n = 13
12 - 18 JULY
n = 35
9 - 15 AUGUST
n = 5
21 - 27 JUNE
n = 20
56
19 - 25 JULY
n = 21
16 - 29 AUGUST
n = 10
28 JUNE -
4 JULY
n = 95
26 JULY -
1 AUGUST
n = 13
5 - 11 JULY
n = 14
2 - 8 AUGUST
n = 11
0
25
50
40
60
80
100
120
140
PERCENT FREQUENCY
FORK LENGTH (mm)

Fig. 15. Seasonal change in average fork lengths ±95% confidence limits of chinook juveniles in 1982 for: (a) each of the zones on southern Roberts Bank, and (b) all zones combined. Points without confidence limits are composed of ≤2 measurements.

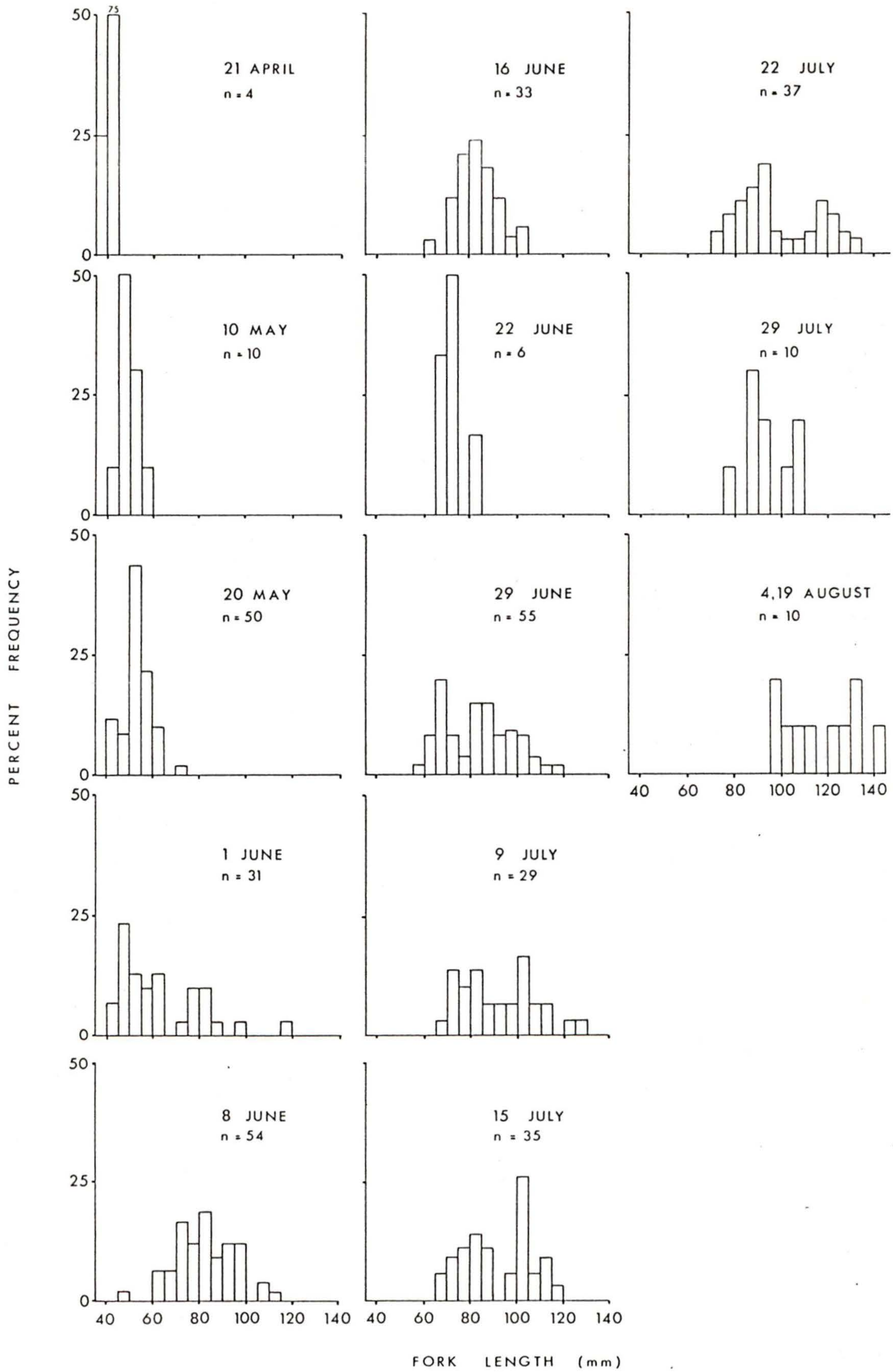

CHINOOK - 1982
a
b
Zones:
Offshore
Causeway beach
Eelgrass
Sandflat
Saltmarsh
FORK LENGTH (mm)
140
120
100
80
60
40
APRIL
MAY
JUNE
JULY
AUGUST

captured in 1982 were young of the year. Both size and pattern of size increase in 1981 and 1982 were similar for June, July, and August. Length frequencies of chinook in 1982 (Fig. 16) changed from unimodal distributions during April-mid-June to non-unimodal distributions during late June-August. The presence of chinook in the 40-44 mm size class from late April-early June indicates recently emerged fry entered the outer Fraser estuary over a period of about one month because this is the size (38-43 mm) at which some chinook leave spawning areas (Reimers 1973).

Chinook captured in the offshore and causeway beach zones increased significantly in average length during late April-August (Table 4). The slopes and intercepts of the regressions for the groups captured in these two zones were similar ($p>0.05$, ANCOVA). Chinook from these zones were often the same average lengths on each sampling date, and increased in length at similar rates. Lengths of chinook captured in the eelgrass, sandflats, and saltmarsh zones (Fig. 15a) were similar to the average lengths of juveniles in the other zones on the same sampling dates. The seasonal regression of pooled lengths was significant ($p<0.001$) with a slope of 0.65 mm/day.

Fig. 16. Length frequencies by size class for chinook juveniles on southern Roberts Bank during 1982.

CHINOOK - 1982



Abundance and Growth of Chinook Juveniles Released from Fraser River Hatcheries

Stocks of chinook juveniles released from hatcheries on the Fraser River in 1981 and 1982 included individuals that were both adipose fin-clipped and coded-wire tagged. Separate tag codes were used for each group of fish released. Origins of fish marked in this way could be identified from recaptures. Chinook with missing adipose fins captured on southern Roberts Bank were retained and analysed for the presence of coded-wire tags (CWT's). A total of 9 fin-clipped fish were captured and 8 of these had CWT's. Results of the CWT analysis (included in Table 5) showed the marked fish originated from the Chehalis and Chilliwack hatcheries on the lower Fraser River. Chinook released from hatcheries in the Fraser River system appeared on Roberts Bank in both 1981 and 1982. From data included in hatchery release reports (Tables E-1a, E-1b), the relative proportions of hatchery and wild chinook were estimated for each sample date that hatchery fish were captured. These estimates (Table 6) indicate a high proportion of chinook captured on Roberts Bank were from wild stocks (86-99% of total catch).

From the lengths of recaptured fish, estimates of average daily growth rates were calculated for the period

Table 5. Origin and size of coded-wire tagged chinook juveniles released from lower Fraser River hatcheries and recaptured on southern Roberts Bank.

Year	Capture date	Tag code	Hatchery	Size at capture Length (mm)	Weight (g)
1981	July 23	21-2-09	Chehalis	79.0	4.45
	July 31	21-2-09	Chehalis	85.0	6.02
	July 14	21-2-13	Chehalis	80.0	4.87
	Aug. 18	21-2-13	Chehalis	96.0	8.58
1982	June 16	21-2-63	Chilliwack	79.0	6.04
	June 29	21-2-63	Chilliwack	99.0	10.96
	June 16	22-2-05	Chehalis	84.0	6.32
	June 29	22-2-05	Chehalis	111.0	20.62

Table 6. Estimates of the ratio of wild vs. hatchery chinook in catches of juveniles on southern Roberts Bank.

Sample date		Total	Number of recaptured marks		Ratio of marked : unmarked in hatchery releases (%)		% of total catch	
Year	Day	catch	Chehalis	Chilliwack	Chehalis	Chilliwack	Hatchery	Wild
1981	July 14	88	1		100:0		1.1	98.9
	23	7	1		100:0		14.3	85.7
	31	12	1		100:0		8.3	91.7
	Aug. 18	7	1		100:0		14.3	85.7
1982	June 16	62	1	1	56:44	21:79	11.3	88.7
	29	55	1	1	56:44	21:79	12.7	87.3

from release at the hatchery to recapture at the study site on Roberts Bank. Estimates of growth rates are shown in Table 7. The average of these six estimates is 1.00 mm/day. Estimates were not calculated for the group tagged with the code 22-2-05 because the release date was not available.

Trophic Analysis of Chinook Juveniles

Spatial dietary differences in 1981

The composition of diets, for pooled samples between late June and late August 1981, revealed chinook fed upon juvenile fish and a variety of epibenthic, planktonic, and drift invertebrates on southern Roberts Bank (Table 8). In general, chinook from each of the zones fed on similar organisms but in different proportions. Three (amphipods, dipterans, and juvenile herring, *Clupea harengus*) of the 11 major prey groups present in Table 8 dominated chinook prey in all four zones. Amphipod prey consisted primarily of the gammarids, *Anisogammarus pugettensis* and *Eogammarus confervicolus*, and secondarily of *Corophium spinicorne* and *Caprella* spp. Fifteen families of flies comprised the dipteran prey taken by chinook but chironomids were the dominant items of this group. Juvenile *Aulorhynchus flavidus*, *Sebastes* spp., *Leptocottus armatus*, and *Platichthys stellatus* made up less than 5% of the fish consumed.

Table 7. Six estimates of growth rates of hatchery released juvenile chinook that were recaptured on southern Roberts Bank.

Year	Tag code	Estimated daily growth in fork length (mm/day)
1981	21-2-09	1.07
		0.98
	21-2-13	2.14
		0.83
1982	21-2-63	0.15
		0.82

Table 8. Diets of juvenile chinook salmon in four zones on southern Roberts Bank, 1981, expressed as percent frequency of occurrence (% F.O.) and percent numerical abundance (% N.A.). List of prey comprised numerically more than 95% of the organisms consumed. Values in brackets are ± standard deviations of % N.A.

	Offshore n=125		Causeway beach n=38		Eelgrass n=41		Sandflat n=5	
Prey taxon	%F.O.	%N.A.	%F.O.	%N.A.	%F.O.	%N.A.	%F.O.	%N.A.
Crustacea								
Mysidacea	2.7	1.3(0.1)						
Cumacea	6.2	12.0(0.9)	5.1	2.2(0.3)	11.1	2.3(0.2)	60.0	6.7(1.4)
Amphipoda	15.8	62.8(2.0)	41.0	9.1(0.5)	35.6	54.0(3.4)	40.0	5.0(1.5)
Decapoda, larvae[a]	7.5	2.8(0.1)			15.6	4.8(0.5)		
Total Crustacea	22.6	78.9(27.5)	43.6	11.3(0.6)	53.3	61.1(3.2)	80.0	11.7(1.5)
Insecta								
Psocoptera	4.1	2.1(0.1)	15.4	6.1(0.5)	15.6	3.0(0.2)		
Homoptera	13.7	3.2(0.1)	35.9	10.6(0.6)	26.7	5.2(0.3)	20.0	3.3(1.5)
Diptera	14.4	4.2(0.1)	63.2	61.1(3.6)	53.3	24.0(0.8)	40.0	76.7(23.0)
Hymenoptera			33.3	4.5(0.2)	11.1	1.8(0.2)		
Total Insecta[b]	18.5	9.5(3.4)	64.1	82.3(4.4)	55.6	34.0(1.0)	40.0	80.0(23.4)
Fish								
Clupea harengus	43.8	5.2(0.1)	20.5	1.0(0.1)	17.6	1.6(0.1)	20.0	5.0(2.2)
Ammodytes hexapterus	11.0	1.5(0)						
Unidentified	17.6	1.3(0)	15.4	0.6(0)	13.3	1.1(0.1)		
Total Fish	69.9	8.0(0.8)	41.0	1.6(0.1)	31.1	2.7(0.1)	20.0	5.0(2.2)

[a] Includes zoea and megalops

[b] Includes larvae, pupae and adults

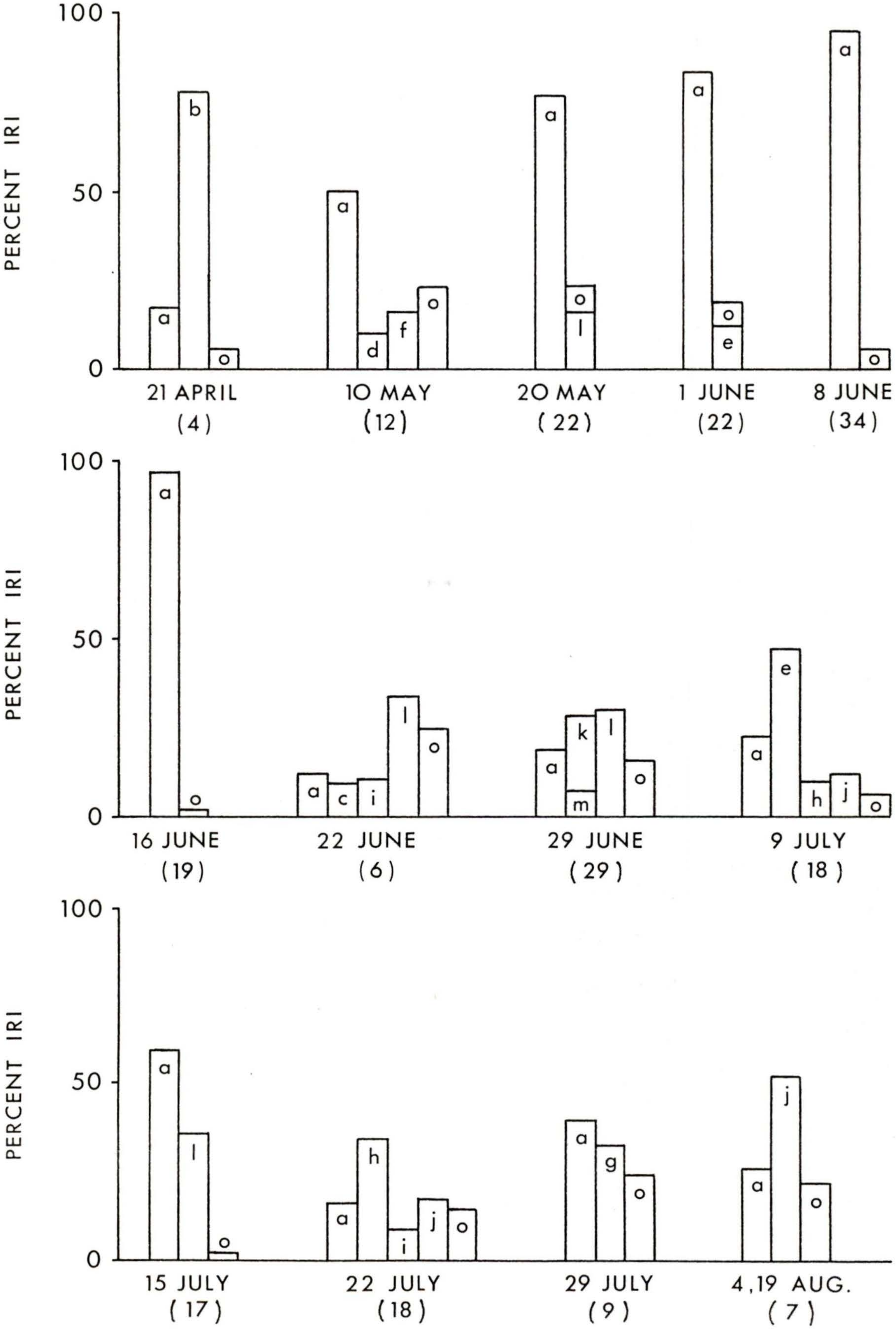
Chinook collected in the offshore zone fed primarily on herring and amphipods (Table 8). Herring, and fish as a group, were more frequently fed upon and numerically important in the offshore zone than in any of the other zones. Crustaceans, particularly amphipods and insects, were more frequently encountered in the diets of chinook captured in the causeway beach, eelgrass and sandflat zones than in the offshore zone. The relative composition of developmental stages within the insect group was not uniform in the various diets. Chinook consumed proportionally more dipteran larvae and pupae than adults in the causeway beach, eelgrass and sandflat zones whereas adult insects dominated the prey of chinook in the offshore zone.

Temporal dietary changes in 1982

The relative importance of the diet components of chinook captured in 1982 was assessed by use of the index of relative importance. The major prey items of chinook collected on each sample date are depicted in Fig. 17. Frequency of occurrence, numerical abundance, effective area and IRI values for all prey taxa are contained in table F-1. Gammarid amphipods (primarily *Anisogammarus pugettensis*), decapod larvae (Brachyuran megalops), and insects (adult dipterans) were major invertebrate prey. Larval and juvenile herring were the single most important prey items

Fig. 17. The relative importance (IRI) of the major prey items of chinook juveniles captured on southern Roberts Bank during 1982. Sample sizes are in brackets. IRI values for taxa within the 'other' category are contained in table F-1. Codes for the taxa are as follows:

a - *Clupea harengus*
b - *Calanus plumchrus*
c - *Calanus pacificus*
d - Harpacticoida
e - *Anisogammarus pugettensis*
f - *Hyale* sp.
g - Decapoda - juveniles
h - Decapoda - megalops
i - Aphidae
j - Brachycera - pupae
k - Tipulidae
l - Chironomidae
m - *Ammodytes hexapterus*
o - other


100
50
0
PERCENT IRI
a
b
o
a
d
f
o
a
o
l
a
o
e
a
o
21 APRIL
(4)
10 MAY
(12)
20 MAY
(22)
1 JUNE
(22)
8 JUNE
(34)
100
50
0
PERCENT IRI
a
o
a
c
i
l
o
a
k
m
l
o
a
e
h
j
o
16 JUNE
(19)
22 JUNE
(6)
29 JUNE
(29)
9 JULY
(18)
100
50
0
PERCENT IRI
a
l
o
a
h
i
j
o
a
g
o
a
j
o
15 JULY
(17)
22 JULY
(18)
29 JULY
(9)
4,19 AUG.
(7)

of chinook of most sizes. Fig. 18 shows three distinct temporal trends in the importance of two prey groups: 1. herring were the most important prey group between mid-May and mid-June (phase 2); and 2. invertebrates were important prey during the April-early May period and after mid-June (phases 1 and 3).

Chinook-herring relationship

(a) Occurrence, relative abundance , distribution, and size of juvenile herring

Seasonal catches of young herring on Roberts Bank during April-August 1982 (Fig. 19) showed this species co-occurred with juvenile chinook. Herring and chinook were often captured together. Herring catches decreased from peaks of greater than 100 fish per set in April and mid-May to less than 2 fish per set in mid-August. During the period of peak abundances in April and May larvae were so numerous in some sets (i.e thousands) that their numbers could not be accurately estimated while field sampling. In these circumstances a catch of 100 was recorded. Consequently the values of 100 for catches in April and May were underestimates of the actual herring abundance.

Average lengths of herring increased from 21.0 mm in April to over 65.0 mm in August (Fig. 20). A linear

Fig. 18. Temporal changes in the relative importance of herring and invertebrates as prey of chinook juveniles captured on southern Roberts Bank during 1982. A list of invertebrate prey taxa is contained in table F-1.

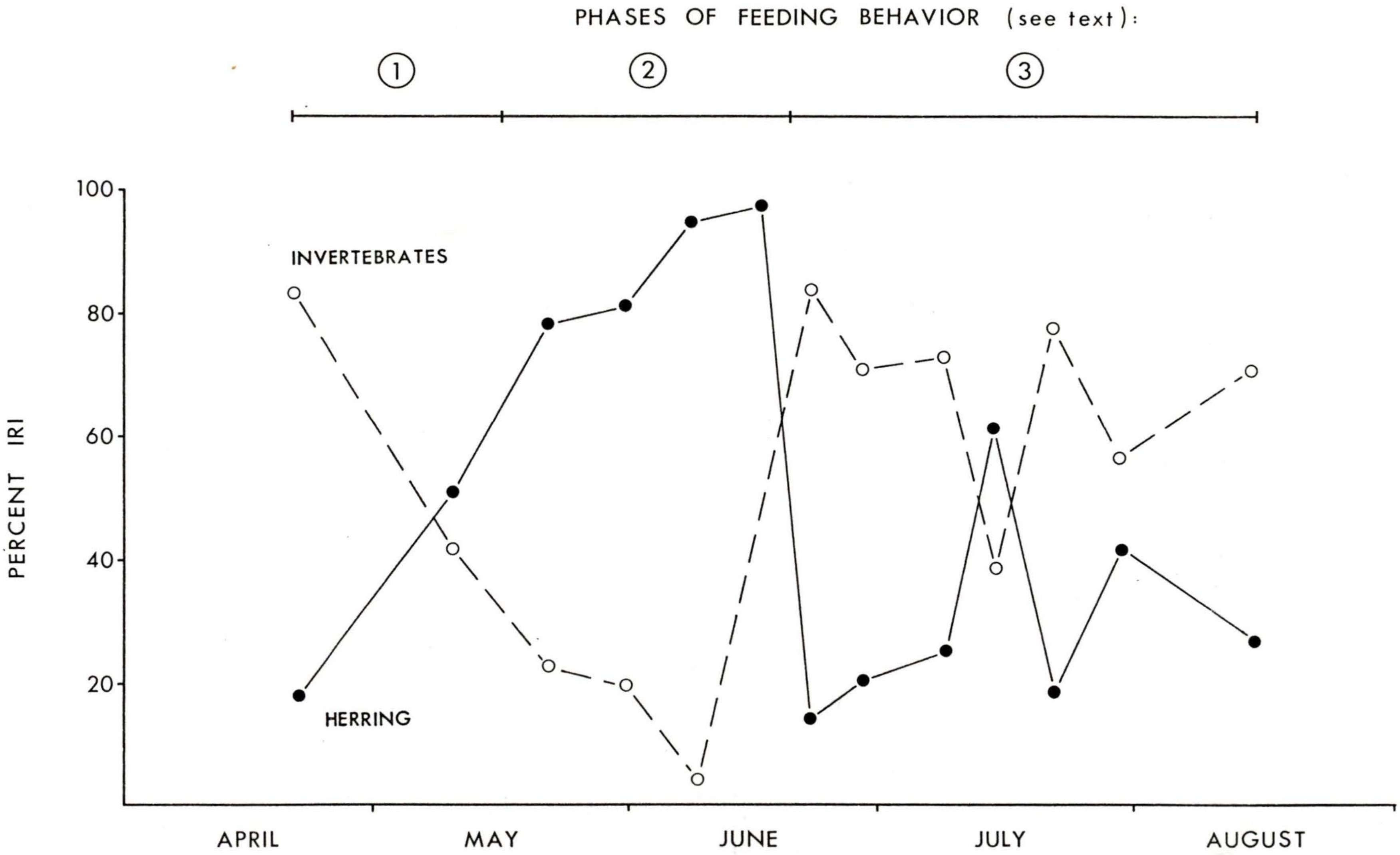

PHASES OF FEEDING BEHAVIOR (see text):
①
②
③
100
80
60
40
20
PERCENT IRI
INVERTEBRATES
HERRING
APRIL
MAY
JUNE
JULY
AUGUST

Fig. 19. Average catch of Pacific herring juveniles per beach seine set on southern Roberts Bank during 1982.

HERRING - 1982

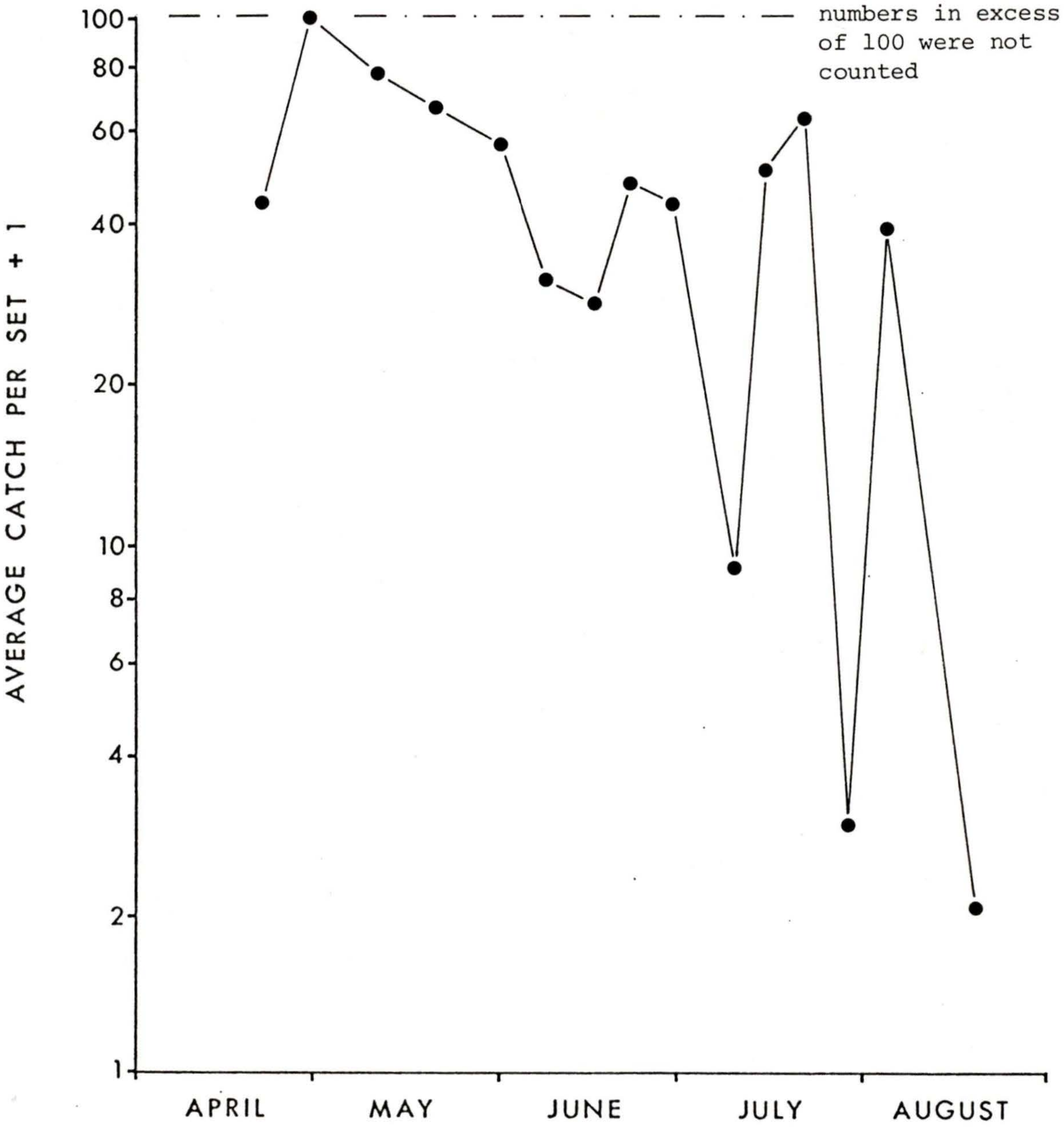
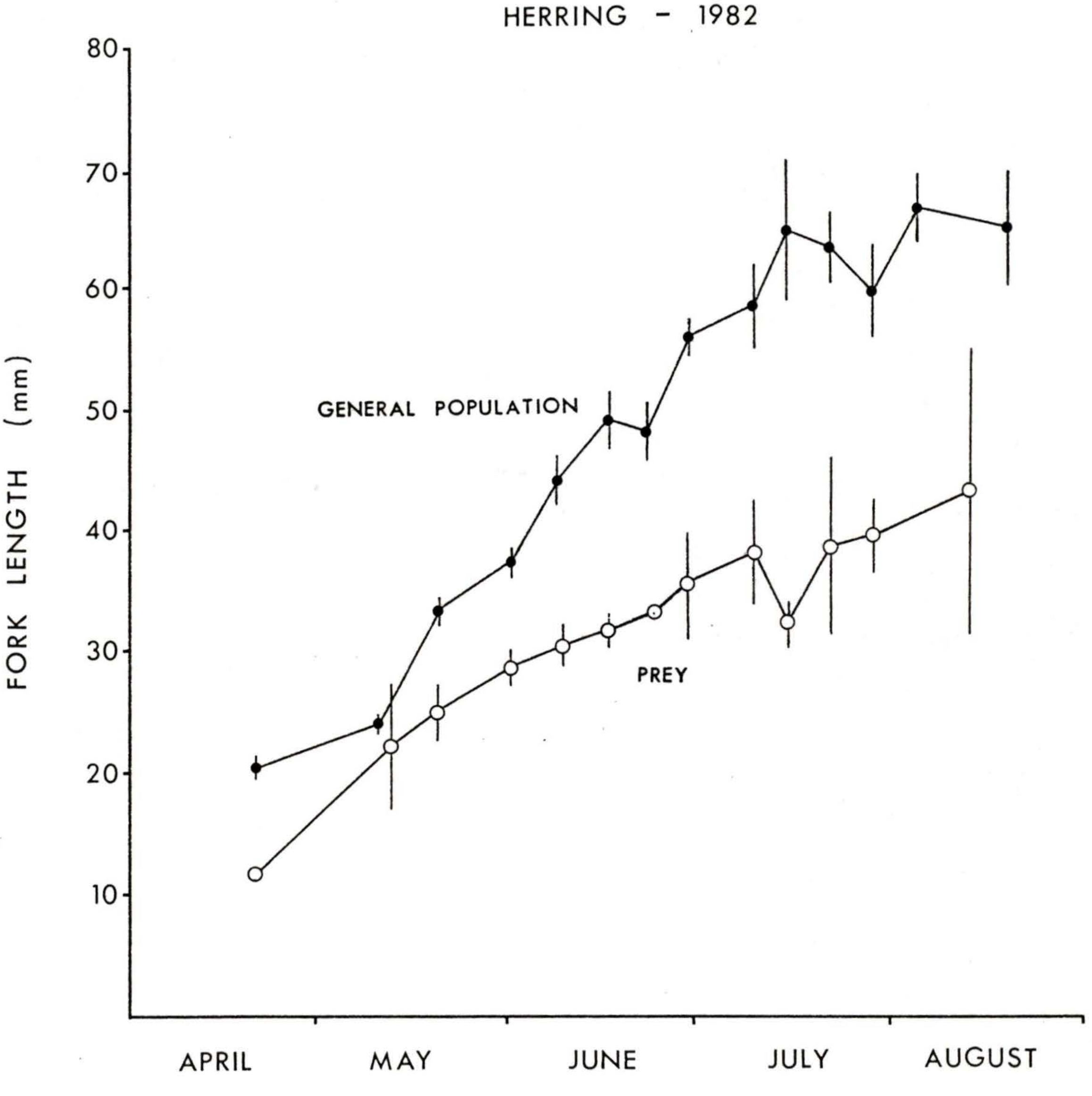


Fig. 20. Seasonal change in average fork lengths ±95% confidence limits of herring captured in beach seine sets on southern Roberts Bank (general population) and recovered from juvenile chinook stomachs (prey) during 1982. Points without confidence limits are composed of ≤2 measurements.


HERRING - 1982
80
70
60
50
40
30
20
10
FORK LENGTH (mm)
GENERAL POPULATION
PREY
APRIL
MAY
JUNE
JULY
AUGUST

regression of fork length (mm) on time (days) was significant ($p<0.001$) and showed average sizes of herring increased by 0.47 mm/day.

(b) Prey size

Herring found in the stomach contents of chinook were usually whole and relatively undigested. Fork lengths of 132 herring recovered from 108 chinook stomachs were accurately measured (±1.0 mm). Fig. 21 shows larger chinook consumed larger herring and the maximum length of herring eaten was approximately 48% of the predator size. A comparison of the size of herring prey to those captured in seines on Roberts Bank (Fig. 22) showed chinook exploited all size classes of herring during early May but consumed only individuals within the smaller size classes available during the late June-August period. Fig. 20 shows the difference in average lengths between the herring population and herring consumed by chinook consistently increased from early May to August. These differences were significant on all dates ($p<0.05$, paired t-tests) except for 10 May.

Fig. 21. The relationship between lengths of herring and chinook from which they were recovered. Numbers are replicate sample sizes.

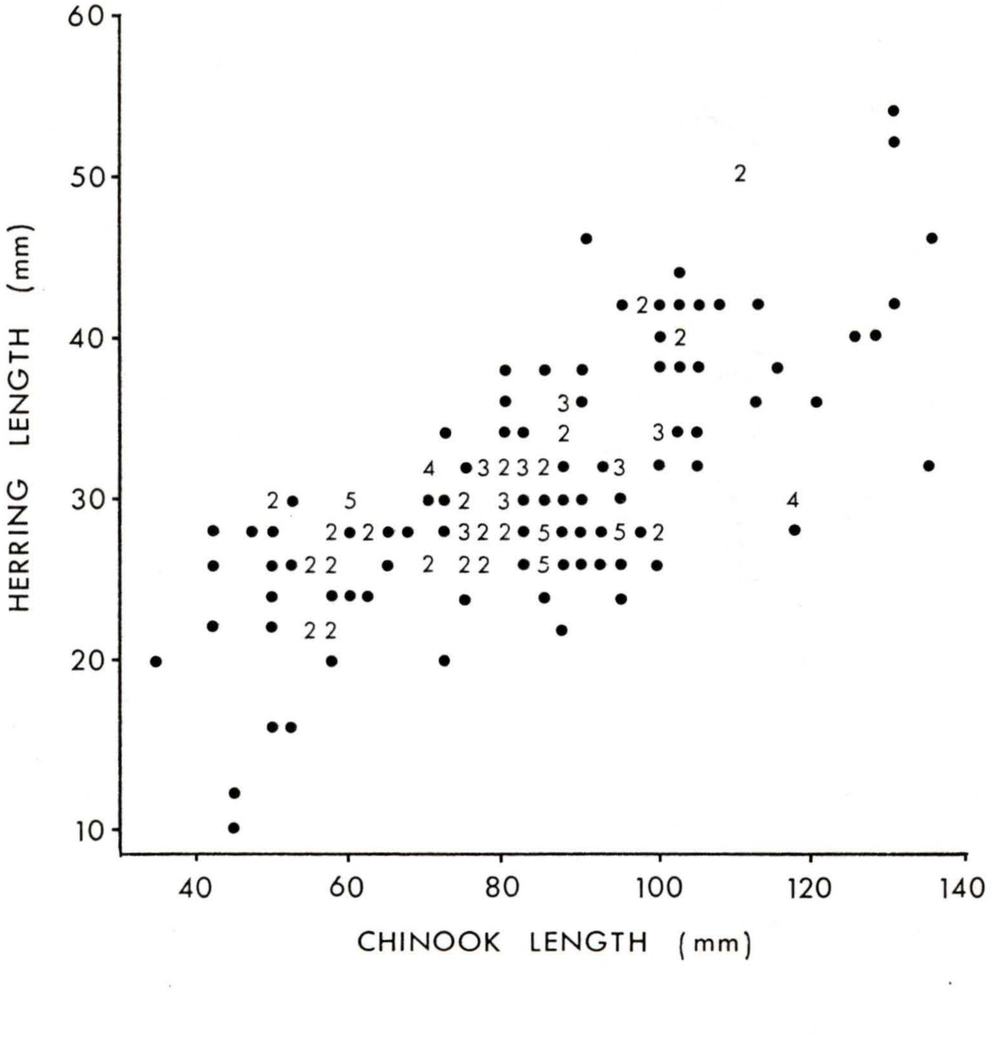
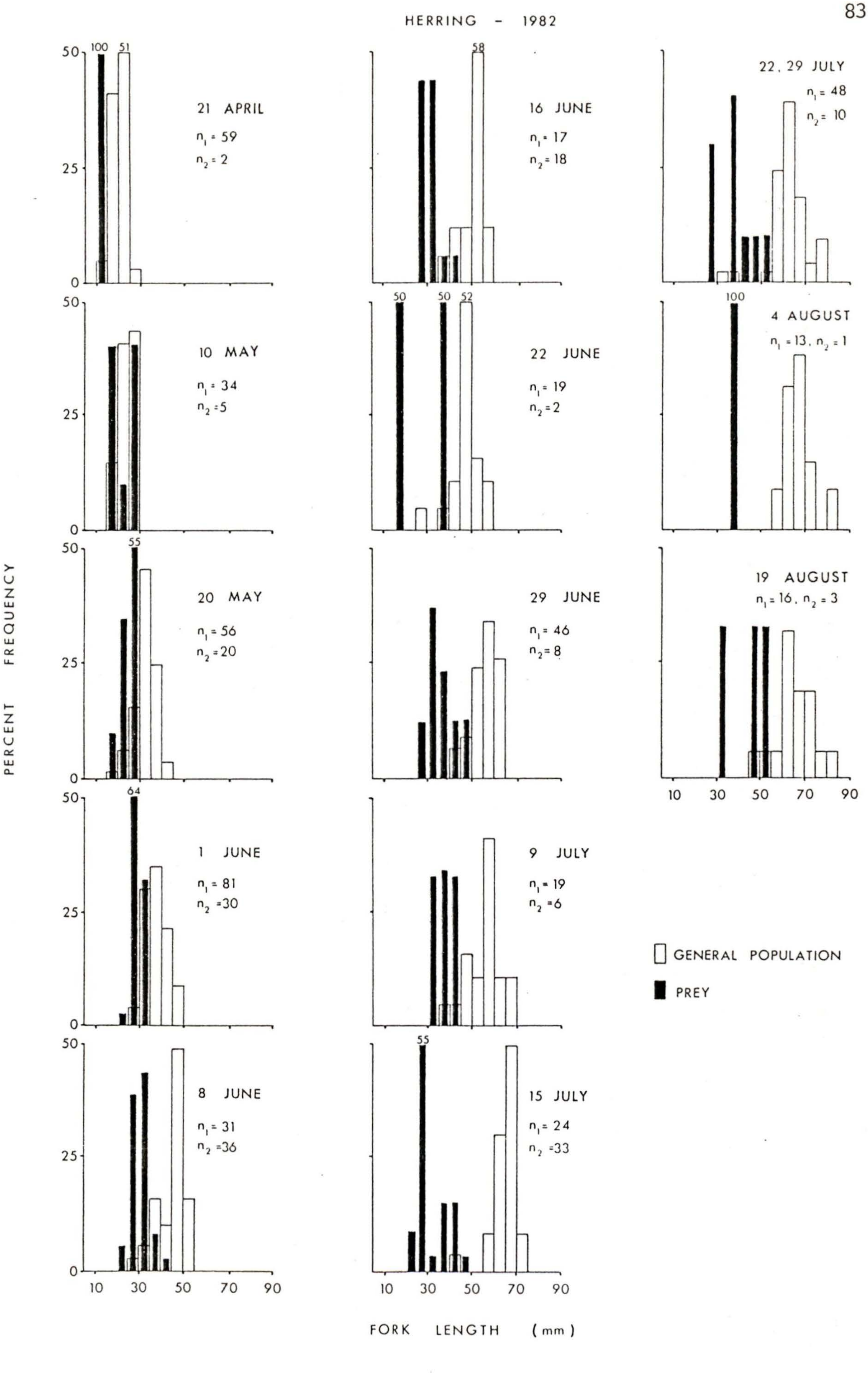

HERRING LENGTH (mm)
CHINOOK LENGTH (mm)
10
20
30
40
50
60
40
60
80
100
120
140

Fig. 22. Length frequencies by size class of herring captured on southern Roberts Bank (general population, n_1) and recovered from juvenile chinook stomachs (prey, n_2) during 1982.


HERRING - 1982
PERCENT FREQUENCY
FORK LENGTH (mm)
0
25
50
10
30
50
70
90
21 APRIL
n₁ = 59
n₂ = 2
100
51
10 MAY
n₁ = 34
n₂ = 5
20 MAY
n₁ = 56
n₂ = 20
55
1 JUNE
n₁ = 81
n₂ = 30
64
8 JUNE
n₁ = 31
n₂ = 36
16 JUNE
n₁ = 17
n₂ = 18
58
22 JUNE
n₁ = 19
n₂ = 2
50
50
52
29 JUNE
n₁ = 46
n₂ = 8
9 JULY
n₁ = 19
n₂ = 6
15 JULY
n₁ = 24
n₂ = 33
55
22, 29 JULY
n₁ = 48
n₂ = 10
4 AUGUST
n₁ = 13, n₂ = 1
100
19 AUGUST
n₁ = 16, n₂ = 3
GENERAL POPULATION
PREY

DISCUSSION

Seaward Migration Patterns of Fraser River Juvenile Salmon

An assessment of juvenile salmon migration patterns is required before consideration is given to findings of the present study. The timing of migrations, seaward migration routes and size distributions of salmon juveniles through the lower Fraser River and estuary and subsequently in the Strait of Georgia and Gulf Islands allow comparisons of the degree to which these areas are utilized as rearing habitats.

Most of the information in this section was obtained from studies conducted on the Fraser River at Mission (Vernon 1966, and unpublished data, Dept. of Fisheries and Oceans), in marsh habitats of the inner Fraser estuary (Anderson *et al.* 1981; Levy and Northcote 1981,1982; Levy *et al.* 1982) on the delta of the outer Fraser estuary (Goodman 1975; Greer *et al.* 1980; Conlin *et al.* 1982) and in the Strait of Georgia and Gulf Islands (Barraclough and Phillips 1978; Healey 1978;1980a).

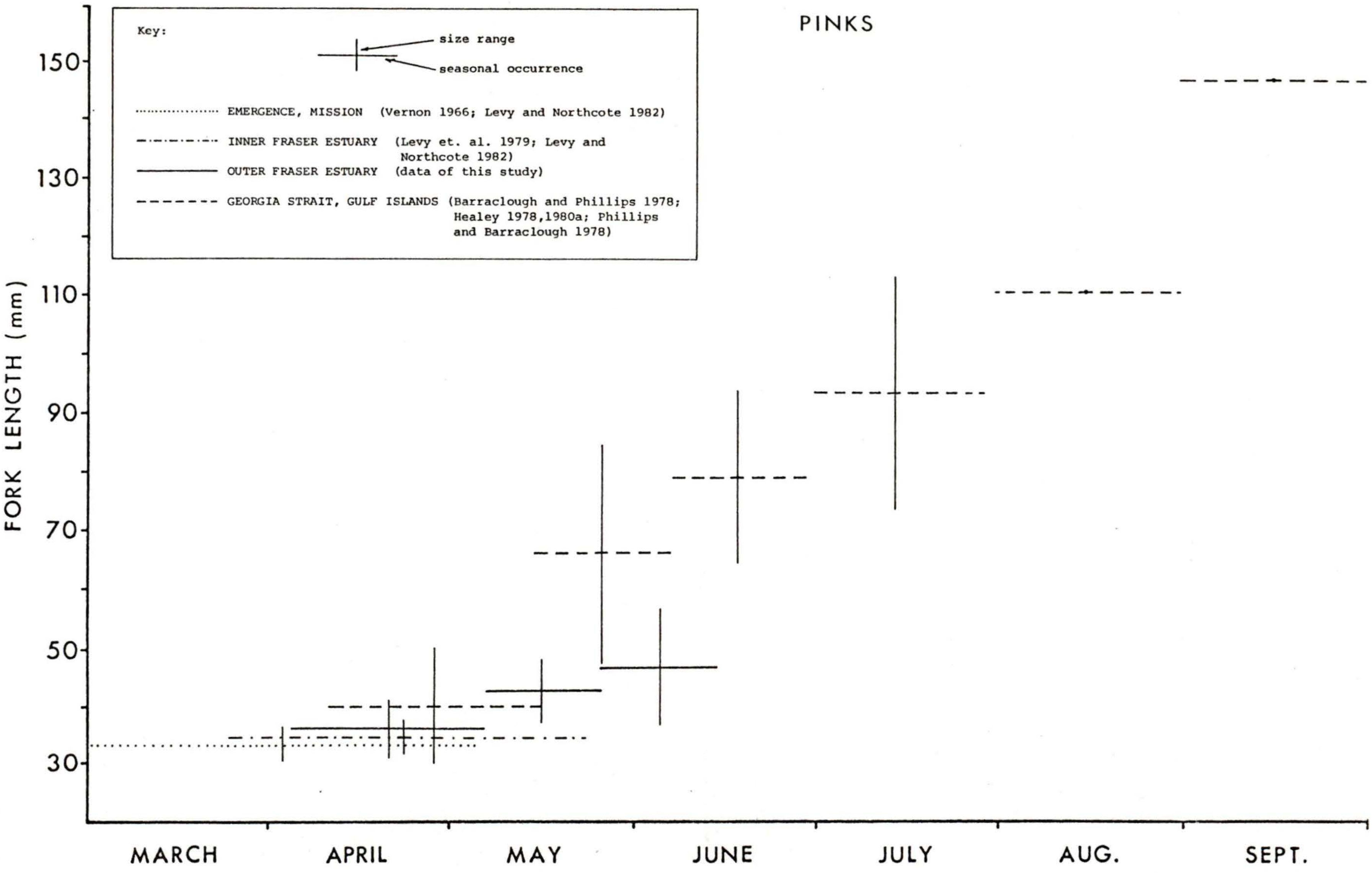
Pinks

Pinks migrate past Mission between early March and late May with peak abundances occurring during April or May, depending on yearly variations of emergence times.

Throughout their migration fork lengths ranged between 31.0 and 34.0 mm. An almost identical size range and timing was observed during migrations of pinks through the Fraser marshes of the inner estuary (Fig. 23). This pattern shows pinks migrate to the estuary with little or no growth or residency between these two locations on the Fraser River and conform to the general observations in other B.C. river systems of rapid downstream migration to estuaries after emergence from spawning gravels (Neave 1955; McDonald 1960; Parker and Vanstone 1966). A mark recapture study conducted in the marshes showed the longest recorded residence time for pinks was two days, indicating this species does not utilize the inner Fraser estuary as rearing habitat (Levy and Northcote 1982).

Pinks have also been captured on Sturgeon and Roberts Banks and in the Strait of Georgia from the Fraser plume to the shorelines of the Gulf Islands while downstream migrations of pinks in the Fraser were in progress (Fig. 23). The mean lengths of pinks occurring in the Gulf Islands in May was 36.0 mm. Godin (1979) believed the pinks he captured in Departure and Hammond Bays near Nanaimo, B.C., in May (mean fork lengths ranged between 42.1 and 44.0 mm) originated from the Fraser River. The combination of a rapid decline of catch in the Strait of Georgia and an increase in abundance in the Gulf Islands after the Fraser

Fig. 23. A summary of the early seaward migration of Fraser River pink juveniles. Data from the literature for August-October included mean size only.


PINKS
Key:
size range
seasonal occurrence
EMERGENCE, MISSION (Vernon 1966; Levy and Northcote 1982)
INNER FRASER ESTUARY (Levy et. al. 1979; Levy and Northcote 1982)
OUTER FRASER ESTUARY (data of this study)
GEORGIA STRAIT, GULF ISLANDS (Barraclough and Phillips 1978; Healey 1978,1980a; Phillips and Barraclough 1978)
FORK LENGTH (mm)
150
130
110
90
70
50
30
MARCH
APRIL
MAY
JUNE
JULY
AUG.
SEPT.

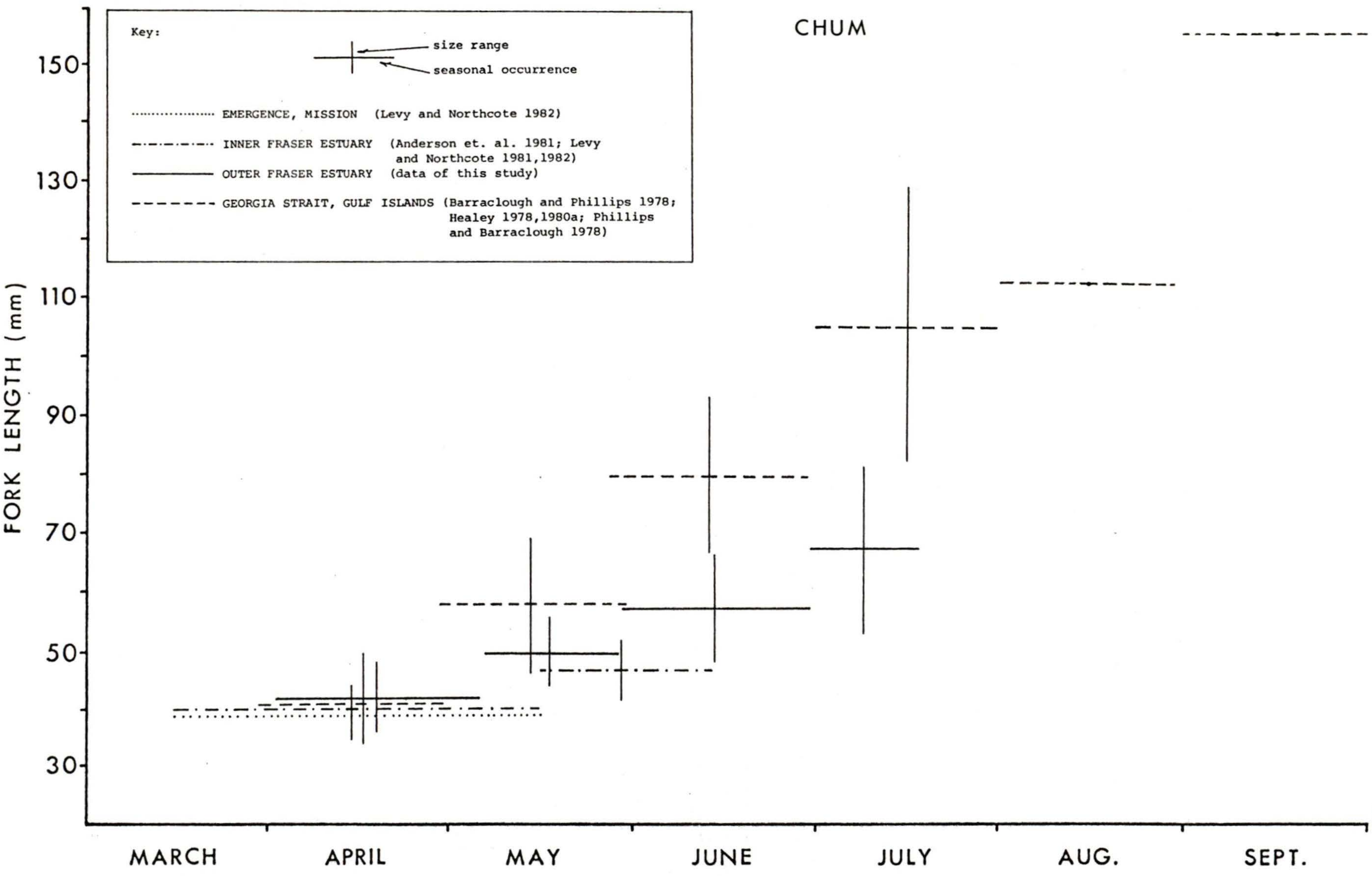
downstream migration had finished suggests pinks cross the strait to the Gulf Island region as small individuals. An incremental length increase from 36.0 mm in May to 193.0 mm in October was observed in the Gulf Islands (Fig. 23) and implies this area is used as a major rearing area for Fraser pinks.

The plume of brackish water resulting from the Fraser River discharge flows away from the mouth in a general direction towards the Gulf Islands (Waldichuck 1957). Pinks may be influenced initially by this flow and consequently are dispersed to nearshore areas across the Strait. Individuals captured along Sturgeon and Roberts Bank, and possibly not as influenced by the outward Fraser flow as those dispersed into the Strait may be maintaining an initial shoreline preference. These fish would display the same type of behavior as those pinks that disperse in a saltatory shoreline migration away from the mouth of the smaller Bella Coola River on the central B.C. coast (Healey 1967).

Chum

Chum show temporal migration patterns similar to pinks upriver from the Fraser marshes (Fig. 24). However, chum passing Mission were larger (range of 38.0-41.0 mm in fork length). Observations on their distribution and growth once

Fig. 24. A summary of the early seaward migration of the Fraser River chum juveniles. Data from the literature for August-October included mean size only.


CHUM
Key:
size range
seasonal occurrence
EMERGENCE, MISSION (Levy and Northcote 1982)
INNER FRASER ESTUARY (Anderson et. al. 1981; Levy and Northcote 1981,1982)
OUTER FRASER ESTUARY (data of this study)
GEORGIA STRAIT, GULF ISLANDS (Barraclough and Phillips 1978; Healey 1978,1980a; Phillips and Barraclough 1978)
FORK LENGTH (mm)
150
130
110
90
70
50
30
MARCH
APRIL
MAY
JUNE
JULY
AUG.
SEPT.

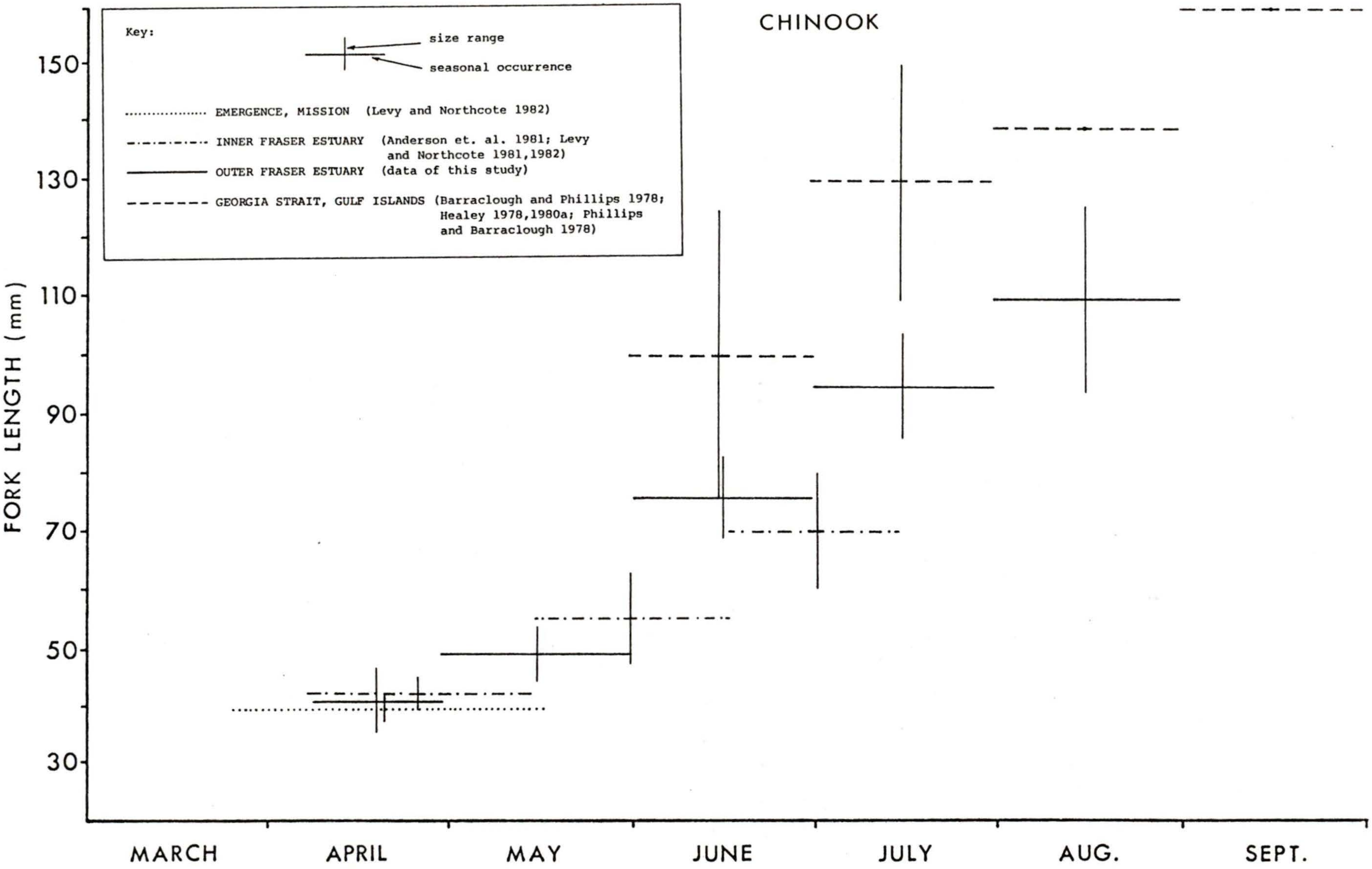
they have reached the Fraser estuary and seaward indicate this species may show some similarities to pinks. Recruitment of chum in the length range 38.0-41.0 mm to locations in the North, Middle and Main Arms of the Fraser River, in the marshes south of the Main Arm, on Sturgeon and Roberts Banks and seaward in the Fraser plume showed chum are initially dispersed, like pinks, throughout the entire Fraser estuary. Unlike pinks, part of the chum population paused in the marshes of the inner estuary for up to 11 days and grew to average lengths of 46.2 mm by early June (Levy and Northcote 1982). However, some of the chum captured in the marsh habitats of the estuary may also have been transients since a lack of incremental size increases was observed at several sites. Those chum distributed throughout the southern Strait of Georgia by late April - early May and in the Gulf Islands by mid-May, rear in higher salinity waters than the estuary, and often co-occur with pinks. In the Gulf Islands, average fork lengths of rearing chum increased from 72 mm in late May to 182 mm in October (Fig. 24).

Chinook

Chinook have a more complex migratory life history than either pink or chum and follow with three major patterns based upon the length of residence in freshwater. These patterns, all observed within the Fraser River, are: (1) fry that migrate to the estuary immediately after emerging in the spring; (2) fry that, before migrating seaward as smolts, rear in freshwater for 60 to 90 days ('90-day smolts'), and (3) juveniles that reside in rivers for one year (yearlings) or longer and migrate in the spring as smolts. Of these three types, the first two predominate in the Fraser River as indicated by scale analysis of returning adults (Fraser *et al.* 1982). These two types also predominate in most other B.C. river systems (Healey 1980a; 1983).

Fry migrating immediately seaward ranged between 38.2 and 39.4 mm in average fork length as they passed Mission during March - mid-May (Fig. 25). Fry of this size are initially distributed both in marshes of the inner and nearshore waters of the outer sections of the estuary, but unlike pinks and chum, remain in the immediate vicinity of the estuary and do not move into the Strait of Georgia or across to shoreline habitats in the Gulf Islands. Recaptures of marked chinook fry released in the marshes of the inner estuary showed some fry reside there for up to 30 days (Levy and Northcote 1982). The maximum average length attained by chinook was 70.5 mm in early July during the marsh residency period (Fig. 25). Juvenile chinook captured in the Strait of Georgia during July - September ranged

Fig. 25. A summary of the early seaward migration of the Fraser River chinook underyearlings. Data from the literature for August-October included mean size only.


CHINOOK
Key:
size range
seasonal occurrence
EMERGENCE, MISSION (Levy and Northcote 1982)
INNER FRASER ESTUARY (Anderson et. al. 1981; Levy and Northcote 1981,1982)
OUTER FRASER ESTUARY (data of this study)
GEORGIA STRAIT, GULF ISLANDS (Barraclough and Phillips 1978; Healey 1978,1980a; Phillips and Barraclough 1978)
FORK LENGTH (mm)
150
130
110
90
70
50
30
MARCH
APRIL
MAY
JUNE
JULY
AUG.
SEPT.

between 75.0 - 215.0 mm in length with the most abundant size around 100.0 mm (Fig. 25). The pattern of seasonal catch and size distributions both in the estuary and seaward in the strait indicate that the majority of the chinook juveniles that migrate to the estuary as fry rear in estuarine habitats prior to movement to more saline environments in the Strait and Gulf Islands.

Evidence of fry that rear in freshwater for 60-90 day periods before migration seaward was obtained from the South Thompson River system in the upper Fraser watershed (Fraser *et al.* 1982). These juveniles are thought to migrate from June to September. Although Fraser *et al.* (1982) did not report the size of these fish during downriver migrations, chinook following the same life history pattern entered estuaries of the Cowichan River (Argue *et al.* 1979) and Big Qualicum River (Lister and Genoe 1970) at lengths between 70.0 and 80.0 mm. Catches of young of the year chinook in the inner Fraser estuary in June and thereafter are generally very small, and those in the 70.0 - 80.0 mm size range are scarce during June and July and not present in August or September (Levy and Northcote 1982). This probably indicates that '90-day' smolts do not pause in the inner estuary, but may reside in the outer Fraser delta or move directly into the Strait of Georgia.

Overwintering chinook juveniles (82-102 mm) sampled in the upper Fraser River system (Chatwin *et al.* 1963; Tutty and Yole 1978) migrate through the inner Fraser estuary between April and July without exhibiting residency behaviour. Yearling or older smolts are generally captured offshore from Sturgeon and Roberts Banks and do not frequent nearshore intertidal waters along the Fraser delta.

Sockeye and Coho

In the Fraser system most sockeye juveniles rear to the smolt stage in lakes for at least one year (Foerster 1968). Migrant smolts pass through the inner estuary in April and May without a residency period and disperse rapidly into the Strait of Georgia. Some sockeye, apparently originating from the Harrison River stock (Foerster 1968), migrate seaward as fry. Small numbers of these (ranging between 31.0 and 33.0 mm in length) are present in marsh habitats of the inner Fraser estuary and offshore plume waters during the spring and summer. Lengths of sockeye fry captured in the Strait of Georgia in July and August ranged between 60.0 and 70.0 mm.

Coho juveniles in the Fraser system migrate seaward as yearling or older smolts and infrequent catches in the inner and outer sections of the estuary indicate these fish use the estuary for only migratory passage.

Occurrence, Relative Abundance, and Distribution of Juvenile Salmon on Southern Roberts Bank

The seasonal occurrence and abundance of pink, chum and chinook juveniles at the study site correspond with those exhibited by juveniles of these species during seaward migrations from the Fraser River. In 1981 pinks were absent from the intercauseway area in months prior to July (Conlin *et al.* 1982) and in July and August. However, in 1982 pinks were abundant at the study site during April and May. This pattern is due to a combination of a rigid two-year cycle and the dominance of even numbered year classes in the Fraser River (Vernon 1966). Between mid-April and late May in 1982 average catches of pinks exceeded 20 individuals per set in several zones at the study site. Such prolonged periods of abundance combined with little growth presumably results from many fry migrating daily out of the Fraser over an interval of several months. The seasonal timing of peaks in abundance and disappearance on southern Roberts Bank in 1980 (Conlin *et al.* 1982) and 1982, and in the marshes in 1978 (Levy and Northcote 1982) and 1980 (Levy *et al.* 1982) are similar between both sites and years (Fig. 23). These similarities indicate juvenile pinks occurring in shoreline habitats along the outer Fraser delta are either transients or residents for only short periods.

Catches of chum in June and July 1981 represented the last of the migrants just prior to their disappearance from the study area. Chum juveniles in previous years also disappeared by July after sharply declining in abundance in earlier months both in the Fraser marshes (Levy and Northcote 1981; Levy *et al.* 1982) and at Steveston (Anderson *et al.* 1981).

Chum were frequently captured in the same sets as pinks at the study site in 1982 and the general pattern of chum abundance is similar to that of pinks. These two species often travel in company in rivers during seaward migrations (Neave 1966b) and their co-occurrence in 1982 at the study site suggests similar migratory behaviors exist during their first presence in the Fraser estuary. The large numbers of chum juveniles which migrate from the Fraser River generally between early March and early June each year (Palmer 1972) may account for the sustained abundance of chum at the study site between late April and late May 1982. Catch patterns during this period were similar to those observed in the Fraser estuary in the marshes (Levy *et al.* 1982) and at Steveston (Anderson *et al.* 1981) (Fig. 24). However, chum at my study site on Roberts Bank disappeared a month after pinks and remained generally two to four weeks longer than in the marshes (yearly variations taken into account). The decline of chum catch between late May and mid-July suggests that individuals were continually leaving the outer estuary.

The consistent catches of chum in the Strait of Georgia offshore from the delta throughout this period (Barraclough and Phillips 1978) (Fig. 24) further suggests that fish were moving from shoreline habitats along the banks to open waters.

In 1982, chinook appeared at the study site in April, were abundant from mid-May to late July and disappeared by late August. The similarity of chinook catches from mid-June to late August in both 1981 and 1982 suggests seasonal occurrence and abundance on Roberts Bank is consistent from year to year. Migration timing and abundance of chinook fry in the Fraser marshes (Levy and Northcote 1981; Levy *et al.* 1982) did not vary significantly either in three years of sampling (1978-1980 inclusive). Chinook captured at the study site in 1982 first appeared and peaked in abundance at approximately the same time as in the marshes in previous years. However, unlike the sharp decline of chinook abundance in May - early June and their subsequent disappearance some time before early July in the Fraser marshes (Levy and Northcote 1981;1982), chinook were relatively abundant at the study site until mid-late July and disappeared by the end of August (Fig. 25). This observation indicates chinook occur for a longer period on the banks of the outer estuary than in the marshes of the inner estuary. During June and July, the presence of juvenile chinook in the Strait of Georgia just offshore from the Fraser delta and occasionally across to the Gulf Islands (Barraclough and Phillips 1978) indicates chinook were moving from shoreline habitats of the estuary during and after June to offshore waters and nearshore areas across the strait (Fig. 25).

The peak catch sizes of juvenile pink, chum, and chinook at the study site were related to the size of the escapement of the parent year to the Fraser River. In April and May 1982, catches of 100 individuals per set in the offshore zone of the study site were exceeded by pinks on three successive dates, by chum on two dates and by chinook only once. 1981 estimated adult escapements were 1,585,113 pinks, 435,316 chum and 58,387 chinook (unpublished data, Dept. of Fisheries and Oceans). Over the last 20 years, pink fry production in the Fraser River has ranged from a low of 143 million in 1961 to a high of 473 million in 1977 (I.P.S.F.C. 1982). The annual production of chum and chinook juveniles is substantially less than pinks. Chum average 80 million per year (unpublished data, Dept. of Fisheries and Oceans - in Levy and Northcote (1981)). The estimated number of juvenile chinook migrants averages 40 million per year (Fraser *et al.* 1982). A direct correlation between escapement and juvenile catch was not observed in the Fraser marshes or in the Strait of Georgia. Although large numbers of pinks, chum, and chinook juveniles were captured in intertidal tide channels within the marshes, pinks were the least abundant of these species (Levy and Northcote 1982). The lack of a correlation (for all salmonid juvenile species) in the Strait may be caused by very mobile fish occupying a large region (Healey 1978). Sampling at the study site in less restricted subtidal as well as intertidal sites, but in relatively close proximity to the Fraser River, may account for the differences in catch pattern between Roberts Bank and the other sites. Despite the millions of sockeye and thousands of coho which spawn in the Fraser River system (Aro and Shepard 1967), only a few sockeye fry and coho yearlings were captured at the study site. Similar discrepancies were observed for sockeye and coho juveniles in the inner Fraser estuary (Anderson *et al*. 1981; Levy and Northcote 1982).

Catches of salmon juveniles at the study site were generally larger in the offshore and causeway beach zones than in the intertidal eelgrass and sandflat zones. These differences in catch sizes may have been related to the volumes of water sampled by beach seining and seining with the ramp assembly. In the eelgrass and sandflat zones the depths of water during sampling were limited to a range between 1.2 and 1.5 m because the net was deployed by hand. In the offshore and causeway beach zones, since the net was deployed off the beach by boat into water deep enough for the entire depth of the net (3.0 m) to be extended, the water volumes sampled were at least twice those sampled with the ramp assembly in the intertidal zones. Therefore larger catches of salmon occurred when greater volumes of water were sampled. Alternatively, these differences in catch size between zones may be caused by habitat selection. Most members of the juvenile population may remain in locations over or adjacent to deep water (ie. >5 m) and catches in the eelgrass and sandflats are of a few fish that have strayed into these zones. However, pinks (Godin 1979), chum (Mason 1974; Healey 1979), and chinook (Healey 1980b) fry have been captured in only a few centimeters of water. This indicates fry do not avoid shallow areas altogether.

The behaviour and distribution of pink, chum, and chinook juveniles were influenced by tidal movements of water over the flats. Catches of salmon in the eelgrass zone were generally larger than in the sandflat zone because sampling in eelgrass was performed while the sandflat was mostly unflooded. After the tide had risen sufficiently to permit sampling in the sandflat zone an increased amount of potential habitat had become available. Tide related dispersal of the fish into these larger areas may have caused the smaller catches in the sandflat zone by decreasing the number of fish per unit area.

At the study site juvenile salmon are confined to the offshore zone and tide channels or beyond at low tide because the intertidal flats and salt marsh drain completely during most tide cycles. Although sampling sites in the offshore zone were limited to the causeway terminals and at low tide to the borrow pit, juveniles were distributed all across the delta front at low tide. This distribution was verified by catches of salmon in seines with the ramp assembly in this study and by Greer *et al*. (1980) in the subtidal section of the eelgrass bed along the delta front. Chinook also remained in a pit on the sandflats of Sturgeon Bank in the Fraser estuary (Levings 1982). Catches at the study site in the shallow water over the eelgrass and sandflat zones during and after a flood tide showed the salmon advance from the offshore zone into the intertidal zones and probably represent only the first entrants to these areas. Many more juveniles may proceed shoreward as the water becomes deeper and the habitat subsequently expands during flood tides. Catches in the salt marsh channel, though small, suggested a movement of juveniles of from one to four km occurred during one tidal cycle. These are the distances over which chum (1 km) and chinook (4 km) must have moved to reach the salt marsh because the tidal flats between the low tide mark and the marsh were dewatered on the ebb prior to their catch.

Salmon were captured in the offshore zone at high as well as low tides. The shoreline preference of pinks during migrations away from the natal rivermouths (LeBrasseur and Parker 1964; Healey 1967), and chum (Healey 1979) and chinook (Healey 1980b) during estuarine residence could be maintained in the offshore zone of the study site without moving shoreward with a flood tide because the coalport and ferry terminal causeways provided a permanent shoreline margin (at sites 1 and 2 in Fig. 2) at all tide levels.

Redistributions of chum and chinook juveniles on each tidal cycle have also been observed in other delta estuaries in B.C. In the estuaries of Lymn Creek (Mason 1974) and Nanaimo River (Healey 1979) chum were found at high tide across the landward margins of the intertidal zone and at low tide in creek or river channels, some with freshwater outflows, that ran through the delta at low tide. Unlike chum in these systems at low tide, those on Roberts Bank were not confined to channels but instead retreated to areas along or seaward of the delta front. From beach seine catches, Healey (1980b) observed chinook in the Nanaimo estuary at low tide retreated to river channels and the delta front, with a flood tide moved to the landward margin of the mudflat, and at high tide were scattered all across the shoreline of the intertidal area. Sets with a 90 x 7 m hand-hauled purse seine did not produce chum (Healey 1979) or chinook (Healey 1980b) in the open waters over the intertidal sandflats of the Nanaimo estuary at high tide. Healey (1980b) suggested that these observations implied chinook actively selected specific nearshore habitats throughout the tidal cycle. In the period between low and high tides at the study site, pink, chum, and chinook were distributed in several different nearshore habitats that included sand and cobble beaches adjacent to shallow and deep water. As well, juveniles were captured in shallow open waters over tidal flats with and without eelgrass. Therefore active habitat selection like that observed in the Nanaimo estuary was not apparent. These different conclusions may be due to the absence of a direct freshwater source entering southern Roberts Bank (between the causeways), the success of the ramp assembly in catching salmon over the flooded intertidal zone, and the presence of causeways which facilitated sampling during all stages of the tide. Additionally, Levings (1982) has caught chinook with a purse seine in open water on Sturgeon Bank.

Juvenile salmon tolerated a wide range of salinities (2.8-25.7‰) and temperatures (8-22^{o}C) during their period of occurrence on southern Roberts Bank. These ranges at the study site were very similar to those observed in the Nanaimo estuary (Healey 1980b) but different from those in the Fraser River marshes. Levy and Northcote (1982) reported salinities in the marshes ranged between 3‰ in March and 0‰ during the period April to July. Surface temperatures in the Main Arm of the Fraser ranged from 3-6°C in March to 13-19°C in July (Benedict *et al.* 1973) and presumably reflect temperatures in the marshes during the same period. At other locations in the outer Fraser estuary chinook and chum were captured in water of 10-20°C and 5-15 ‰ on Sturgeon Banks (Gordon and Levings 1984).

Seasonal changes of salmon abundance during late April - mid-June at the study site did not appear related to seasonal salinity patterns because salinities were similar throughout this period. Salinity distributions within the intercauseway region did not appear to be a factor affecting salmon catch because salinities were generally similar in all zones on each sampling day. Although salinities were uniform with depth in shallow waters of the intertidal zone, juveniles may have distributed themselves according to vertical salinity differences in the offshore zone. However, the differences measured between surface and 3m depths in the offshore zone were usually encompassed by the ranges of surface salinities in all the zones where the salmon were caught. Healey (1980b) observed a seaward movement of the center of the chinook population in a creek and river channel of the Nanaimo estuary as the season progressed. He did not attribute this movement (changes in habitat selection) to increasing adaptations to salinity because seaward salinities were often the same or slightly lower.

Sharp declines of pink and chum catches on 1 June 1982 followed peak or near peak catches 10 days earlier. This rapid change occurred while mean temperatures decreased or remained the same. Therefore seasonal declines of abundance were probably not caused by general seasonal temperature increases. However, distributions of fish within the intercauseway region may have been affected by local temperature fluctuations, particularly in the intertidal zone. Absence of salmon in very shallow water along the front of an incoming tide on sunny days may have been the result of a response to avoid relatively high temperatures (greater than 22°C). Although depths below 0.5 m were not rigorously sampled throughout the period of study, avoidance of very shallow water regardless of temperature seems unlikely because pinks, chum, and chinook have been either captured or observed on intertidal sandflats in only a few centimeters of water (Mason 1974; Godin 1979; Healey 1979; Healey 1980b). During sunny, warm days when temperatures in the intertidal zone remained high during intermediate or high tides, the juveniles may remain in the offshore areas or beyond where temperatures were generally cooler and more stable.

Variable physical conditions at the study site provided juvenile salmon with opportunities to select specific ranges of salinity (and possibly temperature) which were not available in the Fraser marshes. However, it would have been difficult for the fish to remain consistently within a specific range because of changing conditions within one day, from day to day, and throughout the season.

Residency in the Outer Fraser Estuary

The relative lengths of residency of salmon juveniles on southern Roberts Bank were evaluated from observations of seasonal occurrence, abundance, and growth. Growth rates were deduced from seasonal changes of average length, an approach that presents some practical and theoretical difficulties (LeBrasseur and Parker 1964) as follows:

1. Rates based on seasonal average size changes will underestimate the actual average growth rates when fry enter the sampling area at a uniform size over a protracted period and larger individuals emigrate prior to the general population movement.
2. Interpretation of growth depends on the assumption that a single stock has been sampled under a standard set of conditions.
3. Fish catches are subject to sampling errors, particlarly selectivity of gear used and non-random distributions of fish sizes in the areas sampled.

4. Since the growth rate of the apparent population rather than the surviving individuals is described, natural mortality may act differentially against the survival of slower growing individuals of the population.

These and other difficulties will be addressed where appropriate in the following sections of the discussion.

Pinks

The rate of average length increase for pinks at the study site (0.21 mm/day) is substantially less than rates also estimated from average size changes for pinks in the Strait of Georgia and Gulf Islands (Healey 1980a) and on the central B.C. coast (LeBrasseur and Parker 1964). Pinks grow rapidly in nearshore areas of estuaries and coastal waters (Healey 1980a) and those ranging 35-50 mm in length in the strait and central B.C. grew approximately 1.0 mm/day. In contrast, pinks collected at the study site were taken only a short distance from the natal river mouth. Consequently, actual growth rates of individuals were probably underestimated due to the prolonged entry of large numbers of small fish to, and the emigration of large individuals from the sample site. The cumulative increase of fish in size classes larger than those entering the outer estuary from the river indicates part of the Fraser pink population probably resided in nearshore subtidal and intertidal waters along the banks of the delta. Alternatively, if this observed growth occurred while pinks resided in the strait rather than nearshore waters then these fish, to return to Roberts Bank, would have had to reverse their general seaward migratory movement away from the estuary. No such reversed movement has been observed elsewhere along the B.C. coast.

The average lengths of pinks during late May-early June indicated this species was leaving the study site as they grew to 42.0-46.0 mm (Fig. 23). Pinks in the Gulf Islands (Healey 1980a) and on the central B.C. coast (LeBrasseur and Parker 1964) also moved away from shoreline habitats at similar sizes. If the growth rate of pinks at the study site was similar to those in the Gulf Islands and central B.C., then individuals that entered and left the outer Fraser estuary in the length ranges of 31-34 mm and 42- 46 mm respectively were residents for approximately 8 to 15 days.

As pinks grow to 45-55 mm, they move further away from the shoreline which leads to non-random size distributions (LeBrasseur and Parker 1964). At the study site, the larger rate of pink size increase observed in the offshore zone than in the causeway beach zone may be the result of this behavior. Larger individuals were possibly selecting deeper, subtidal habitats in the offshore zone and smaller fish were more frequent in intertidal waters. However, the apparent size-dependent distributions may also have been the result of sampling error. Juvenile pinks form schools in nearshore areas of estuaries and adjacent coastal waters (LeBrasseur and Parker 1964; Neave 1966a). Since pinks of similar sizes enter the Fraser estuary over a protracted period, growth of these fish would produce schools containing different proportions in each size class. If representative samples were not obtained from all schools, size-dependent distributions between zones at the study site may be indicated on any one sampling date. For example, the average size of pinks in the offshore zone was the smallest of all zones on 10 May 1982. But on the next sampling day of 20 May, pink lengths were largest in the offshore zone (Fig. 9a). This indicates that although schools of pinks may be size-dependent, the schools are not distributed within the intertidal zones according to the average lengths of fish within them.

Chum

Chum from the study site grew at a calculated rate of (0.17 mm/day), slower than those caught in the Strait of Georgia (Phillips and Barraclough 1978), Gulf Islands (Healey 1980a), and the Nanaimo River estuary (Healey 1979).

Rates of growth in the strait and Gulf Islands, estimated from changes of average length, were 0.80 and 0.72 mm/day respectively. In the Nanaimo estuary, recaptures of marked individuals showed chum grew approximatelyl.0 mm/day (Healey 1979). The actual growth rate of chum on the banks of the outer Fraser estuary was probably underestimated because of the entry of large numbers of 38-41 mm sized fish over a period of three months, emigration of larger individuals prior to the offshore movement of the general population, and relatively short or no residency periods for some individuals. The growth rate may have also been affected by growth of part of the chum population in marsh habitats of the inner estuary. Chum with variable residency periods in the marshes would enter the outer estuary in the length range 38-46 mm. This may have increased the rate of seasonal length changes by reducing the number of smaller sized entrants to Roberts Bank. Additionally, mortality of chum during the initial phase of saltwater entry is high (Bax 1983) and was shown by Healey (1982) to be size-selective over the range of 45-55 mm. Size-selective mortality may have influenced the rate of size change on Roberts Bank by reducing the number of individuals in the smaller size classes.

Although size increases in the range 35-46 mm at the study site may possibly reflect only a seasonal change in the size of recruits emigrating from the marshes rather than growth in the outer estuary, several observations strongly suggest residence of chum occurred in the outer estuary. First, chum appeared in nearshore waters at the study site in a size range (35-40 mm) similar to those migrating downstream in the Fraser River as recently emerged fry (Fig. 24). Residency times of chum that migrated to intertidal sandflats in the Nanaimo estuary in this size range varied between 0 and 18 days (Healey 1979). Second, chum at the study site achieved larger sizes before disappearing than those in the Fraser marshes. There was a cumulative increase of chum in size classes larger than maximum average lengths of chum leaving the marshes. Third, chum occurred for at least two to four weeks longer at the study site than in the marshes (Fig. 24). During this time, the numbers of new recruits ranging 35-40 mm in length decreased, and the number of individuals in larger size classes increased.

If the growth rates of chum are approximately 1.0 mm/day, then individuals that entered the outer estuary from the Fraser River in the size range 35-40 mm and left in the range of 54.5-60 mm resided for approximately 15-25 days. Chum emigrating from the marshes as 46 mm sized individuals may rear for an additional period in the outer estuary. Levings *et al.* (1983) also obtained evidence of chum residency in nearshore waters of the outer Fraser estuary.

During mark-recapture studies conducted in the intercauseway area on southern Roberts Bank, 10 of 515 marked chum juveniles were recovered 24 hours after their release. These results confirm the existence of short-term residency of at least part of the population. These results also suggest longer periods of residency are probable since the number of marked fish was relatively small compared to the numbers migrating from the Fraser, and the fish were released in an area subject to considerable immigration/emigration.

Differences in the size distributions of chum, like those of pinks, were apparent between zones on Roberts Bank on successive sampling dates in 1982 (Fig. 11a). As well, Levings *et al.* (1983) found these differences in size occurred within the offshore zone between the borrow pit and cobble beaches of the coal port causeway terminal. Schools are formed by this species in nearshore waters (Neave 1966b). Fish entering the outer estuary over a protracted period may form schools composed of different size classes. A similar mechanism may have caused the observed size differences between sampling locations at the study site. However, the similarity between the slopes and intercepts of the regressions of average lengths over the period of occurrence in the offshore, causeway beach, and eelgrass zones showed chum were exhibiting size-independent distributions (no specific habitat preferences according to fish size) between zones.

Chinook

Average lengths of chinook at the study site increased at rates of 0.35 and 0.63 mm/day in 1981 and 1982 respectively. The latter value was similar to the rate of average size change of chinook (0.75-0.85 mm/day) captured in the Gulf Islands (Healey 1980a), but less than the growth rate of 1.32 mm/day of chinook in the Nanaimo estuary (Healey 1980b). The difference in rates of average size change between years at the study site may have been the result of a difference in the lengths of the sampling periods. Sampling covered only the latter stages of the 1981 migration but encompassed the entire 1982 migration. The rates of average size change were not representative of true growth rates because of the entry of small fry to the outer estuary from the Fraser River over a prolonged period and the probable emigration of larger individuals.

Juvenile chinook did not become abundant in Georgia Strait until they reached lengths of approximately 100 mm or greater (Barraclough and Phillips 1978; Phillips and Barraclough 1978; Healey 1980a) (Fig. 25). Since fry were found to enter the study site at 40 mm in length, the seasonal size increase from 40 to approximately 100 mm appears to represent growth of fish residing in nearshore habitats of the outer estuary. Short term residence of 48 hours on Roberts Bank was shown in a mark-recapture study conducted by Levings *et al.* (1983).

The capture of two chinook from each of four hatchery broods on separate dates may indicate longer periods of estuarine residence. The time separating the capture of the first and second individuals from each brood, which varied between 7 and 35 days (Table 5), suggests this residence may extend for prolonged periods. However, these periods could also indicate river residence of individuals taking different times to migrate downriver from release sites.

The capture of hatchery released chinook provided a means of estimating growth rates. The six estimates of growth rates varied between 0.15 and 2.14 mm/day in length and averaged 1.00 mm/day. The sizes reached by chinook at the study site, and at which they appeared offshore in the Strait of Georgia suggest juveniles emigrate from nearshore habitats of the outer estuary in the length range 100-115 mm. If the growth rate of wild chinook is assumed to be 1.00 mm/day, then individuals that immigrated to Roberts Bank at lengths of 40 mm and subsequently grew to 100-115 in length resided in the outer estuary for approximately 60-75 days.

These estimates of growth and residence periods are similar to the results obtained by Healey (1980b) from the recapture of marked chinook juveniles in the Nanaimo estuary. Healey's results show growth rates in length, for individuals over the range 44-115 mm, varied between 0.40 and 1.50 mm/day. Five of the recaptured individuals resided for 47 and 57 days after marking, attained average lengths of more than 100 mm, and grew at rates of 1.25 mm/day.

The estimates for growth and residency of chinook at the study site are based on the assumption that a single stock of recently emerged fry, which migrated directly to the outer estuary, had been sampled. The size at time data, however, may have been potentially influenced by immigration to the outer estuary of: (1) hatchery produced fish; (2) 90-day smolts, and (3) fry that had grown in the inner Fraser estuary.

Hatchery fish were estimated to constitute less than 15% of the chinook population at the study site. These estimates were consistent with the fact that the numbers of hatchery produced juveniles (a total of 253,754 in 1981 and 1,043,625 in 1982) were relatively small compared to the size of the wild population (estimated to be approximately 40 million). At the time of capture the lengths of hatchery chinook were within the range of size classes of the other juveniles. These observations indicate the seasonal increase in average size was primarily the result of growth by wild chinook.

Healey (1980b) observed that chinook left the Nanaimo estuary and dispersed into the marine environment when they reached 70 mm in length. These chinook entered the estuary from the Nanaimo River as recently emerged fry. In the Cowichan River, B.C., 90-day smolts were estimated to constitute up to 50% of the total chinook juvenile population in certain years and increased from 90 to 170 mm while residing in the Cowichan estuary (Argue *et al.* 1979). Therefore, in the outer Fraser estuary recently emerged fry may have grown to only 70 mm before emigration, and 90-day smolts may have constituted the size change from 70-115 mm. Fraser *et al.* (1982) and Levy and Northcote (1981) have suggested recently emerged fry appearing in the Fraser estuary originate from Harrison River stocks whereas juveniles from stocks spawning in the upper Fraser (i.e. above Hope) migrate seaward as 90-day smolts or yearlings. Of the 5-year (1976-1980) mean total adult escapement to the Fraser River system, 23.6% return to the Harrison River system and 75.1% return to the upper Fraser (Fraser *et al.* 1982). Consequently, a substantial number of 90-day smolts (70-80 mm) and yearlings (82-102 mm) may be expected to appear in the estuary. During June-August 1982, there was no large increase in abundance of 70-80 mm juveniles or yearlings at the study site to signify such an immigration. Furthermore, 90-day smolts were not captured by Levy and Northcote (1981) in marshes of the inner estuary or by Anderson *et al.* (1981) at Steveston, even though yearlings were captured occasionally in both of these areas. The observed change in length of juveniles from 70 to 115 mm on Roberts Bank, therefore, was probably due to the growth of 40 mm sized entrants to the estuary, and not from that of 90-day smolts. The yearlings and 90-day smolts probably migrate in deeper water in the river channel and disperse into the Strait of Georgia without occurring in shallow intertidal areas. Johnsen and Sims (1973) found yearling chinook in the Columbia River travelled in deep main channel routes whereas young of the year fish were found near beaches.

Individuals that resided in the inner Fraser marshes prior to emigration to the outer estuary may have increased the number of chinook in size classes between 40 and 70 mm at the study site. Growth rates of the fish residing in the outer and inner sections of the estuary were probably not significantly different because the rate of average seasonal size changes between 40-70 mm in both areas appears similar. As a result, the rate of seasonal size changes of chinook at the study site would not be influenced a great deal by the entry of fry that had previously resided in the inner estuary. Chinook also occurred for at least six to eight weeks longer on Roberts Bank than in the marshes (Fig. 25). This additional period of growth allowed the fish to attain much larger sizes than the maximum lengths observed in the marshes.

Occasionally differences in size frequency distributions of chinook existed between some of the zones on Roberts Bank. Two observations from the data collected in 1982 suggest that these differences were not related to preferences by a size-specific group for one zone over another. First, differences of mean size between zones were not always apparent, and when differences did exist, the larger or smaller sized fish were found in any one of the zones at one time (Figs. 13a, 15a). Second, the similarity between slopes and intercepts for the regressions of seasonal size changes for the offshore and causeway beach zones showed chinook were exhibiting size-independent distributions. Samples taken from schools of fish with different size-frequency distributions may account for differences of mean size between zones on some sample dates. The movement shown by chinook in travelling up to several kilometers on one tidal cycle further suggests this species does not establish size-dependent distributions between nearshore subtidal and intertidal zones. On Sturgeon Bank of the outer Fraser estuary, Levings (1982) reported chinook juveniles in a pit were larger at the center than along the edges. This observation suggests that in confined nearshore estuarine areas chinook possibly segregate themselves according to size and/or habitat preference. In larger, less restricted areas such as those at the study site, size-dependent distributions (within the size range of captured chinook) probably do not exist.

Patterns of Food Exploitation by Chinook Juveniles

General patterns

Juvenile chinook at the study site displayed a marked flexibility in foraging behavior. Individuals of all size classes (40.0-115.0 mm fork length) consumed a wide range of epibenthic, pelagic, and surface drift invertebrates and larval and juvenile herring. These prey, although variable with respect to taxa, size, and position in the water column, have one characteristic in common. They are primarily associated with shallow subtidal and intertidal waters. The diet analysis has shown certain groups of nearshore invertebrates and sub-adult herring populations on the banks of the Fraser delta constitute important food resources for chinook rearing in the outer estuary.

Gammarid amphipods, chiefly juveniles and adults of *Anisogammarus pugettensis*, were the most important components of the epibenthic prey. In an analysis of cover types for amphipods, Pomeroy and Levings (1980) reported an association between *Zostera* and *A. pugettensis* on Roberts Bank. I found *A. pugettensis* in floating mats of *Ulva* in the sandflat zone, on *Enteromorpha* on sandflats and causeway beaches in the mid and upper intertidal, and in the beach seine net after hauls in eelgrass. Consequently, chinook may feed upon *A. pugettensis* in a number of different locations within the study site. This amphipod species is found throughout the year at Crescent Beach, Strait of Georgia (Chang and Parsons 1975) and therefore is presumably available during the April-August periods at the study site. *Corophium* spp., a gammarid of secondary importance in chinook diets, was also observed in benthic quadrat samples on Roberts Bank in the sandflat and eelgrass zones (Levings and Coustalin 1975)and benthic grabs in the offshore zone (Beak-Hinton 1977) of the study site.

Pelagic invertebrates were occasionally important prey items. Calanoid copepods were only prevalent in the diets of chinook less than 45.0 mm. The common calanoid prey of chinook, *Calanus* spp., is common in the Strait of Georgia (Parsons *et al.* 1979; 1980) and may be carried by currents into intertidal waters. Calanoids have been collected in plankton hauls over flooded intertidal flats in the Fraser (Levings and Coustalin 1975) and Squamish (Levings 1973) estuaries. These observations indicate that calanoids are available to chinook in both intertidal and subtidal areas. Larvae of Brachyuran decapods (principally the megalopa stage) dominated pelagic prey. Megalops may also be taken by chinook from the benthos because this is a transitional stage of the crab during which the organism both swims and settles on the bottom (Garth and Abbott 1980). On the Fraser delta, Brachyuran larvae were collected in plankton hauls over intertidal flats on Sturgeon Banks (Levings and Coustalin 1975) and in ponar grabs (benthos) in shallow subtidal waters on southern Roberts Bank (Beak-Hinton 1977). These observations indicate nearshore regions of the outer Fraser estuary are probably the sources of megalops prey for the chinook juveniles. Although temporal fluctuations of decapod larvae abundance in the Fraser estuary are unknown, megalops occur and are available to chinook in all months of the April-August period as indicated by their presence in chinook stomachs.

Surface drift prey were diverse taxonomically and consisted principally of adult insects in families with both aquatic and terrestrial immature forms. Dipterans were the most important group of insect prey. Of the nineteen dipteran families identified from chinook stomach contents, eleven are aquatic and contain species typically associated with saltmarshes, the intertidal zone and other seashore habitats (Borror *et al.* 1976; Byers 1979; Coffman 1979; Cole 1969; McAlpine *et al.* 1981; Merritt and Schlinger 1979; Teskey 1979) such as those found at the study site. Foreshore saltmarshes are generally characterized by large populations of both aquatic and terrestrial dipteran insects (Davis and Gray 1966) and those at the study site are probably a significant source of chinook prey. I observed large numbers of adult dipterans on vegetation and algal mats along the shoreline of the salt marsh. In nearshore waters of the outer Fraser estuary insects would be available to chinook because adult flies of most aquatic families spend most of their lives on or skimming over the water surface (Merritt and Cummins 1979).

Larval and juvenile herring were the single most important prey for chinook juveniles of most size classes. Previous diet studies by Goodman (1975) and Sibert and Kask (1978) also showed that chinook on Roberts Bank fed mainly on juvenile herring. Young herring rear in nearshore waters during the first summer of life (Stevenson 1962; Taylor 1964) and were present in all zones at the study site throughout the period of chinook occurrence. Catches of herring on Sturgeon and Roberts Banks by Goodman (1975), Greer *et al.* (1980) and Conlin *et al.* (1982) indicated juveniles are present each year throughout the outer estuary. Larval herring have also been caught in the Strait of Georgia (Barraclough 1967). The larvae captured by Barraclough (14.0-33.0 mm in length), were however, considerably smaller than the 55.0-60.0 mm long juveniles caught in this study during the same month and may represent a different stock. Growth rates of herring juveniles range between 0.3 and 0.8 mm/day (Stevenson 1962). Herring captured at the study site in 1982 increased an average of 0.47 mm/day. This average size increase appears to be indicative of a growth rate because it is within the range found by Stevenson. Therefore, the herring population preyed upon by chinook was probably resident on the outer Fraser estuary during the April-August period.

There are differences in young of the year chinook diets within the Fraser estuary and also between nearshore (Roberts Bank) and offshore (Georgia Strait) waters. In the marshes of the inner Fraser estuary and at Steveston, insect larvae, pupae, and adults (primarily chironomids) were the most important prey items, with the gammarids *Corophium spinicorne*, *Eogammarus confervicolus* and the mysid *Neomysis mercedis* of secondary importance (Levy *et al.* 1979 Anderson *et al.* 1981, Levy and Northcote 1982). In these studies, fish of Osmeridae and Salmonidae were only insignificant components of chinook diets. In contrast, chinook of the same sizes in the outer estuary were primarily piscivorous. These dietary differences within the Fraser estuary are probably a result of differences in the composition of prey populations. Herring, which were abundant in the outer estuary, occurred infrequently and only in smaller numbers in the inner estuary during the April-August period (Northcote *et al.* 1978, Anderson *et al.* 1981).

Various species of fish are the dominant prey items of chinook juveniles (Godfrey 1968; Beamish *et al.* 1976; Healey 1978) and young adults (Prakash 1962) in offshore waters. Although diets of chinook in the outer Fraser estuary are similar to these with respect to fish, they are somewhat different with respect to invertebrates. Invertebrate prey in offshore waters included hyperid amphipods (*Hyperia*, *Hyperoche*, *Parathemisto*, *Primno*), euphausids (*Euphasisia*, *Thysanoessa*), chaetognaths (*Sagitta*), and larvaceans (*Oikopleura*). These pelagic organisms are usually found in offshore marine waters (Bieri 1959; Brinton 1962; Kozloff 1974; Smith and Carlton 1980) and were either unimportant prey items or not present in the diets of chinook at my study site. The dietary differences between nearshore and offshore regions indicate chinook were feeding on prey resources directly related to nearshore subtidal and intertidal habitats, even though chinook were not physically restricted to nearshore areas in the outer estuary.

Temporal variations

Three relatively distinct phases of chinook feeding behaviour were apparent from the 1982 data if prey were divided into two major groups. The groups are composed of: (1) fish (principally herring) and (2) all other prey (invertebrates). The phases were defined by temporal changes in the relative importance of these two prey groups.

The first phase depicts a transitional period during which prey shifts from primarily invertebrates in mid-April (80% of IRI) to predominately herring by mid-May (76% of IRI). A similar diet shift of chinook juveniles took place in the Nanaimo River estuary except the transition to fish occurred off the intertidal area of the estuary (Healey 1980b). The existence of a dietary shift while chinook were within the intertidal area at the study site was probably due to the availability of herring. Healey (1980b) did not report whether potential fish prey occurred in the intertidal area of the Nanaimo estuary. Feeding trends in mid-April at the study site appeared unrelated to the availability of fish since herring larvae co-occurred with chinook and were abundant at this time. The importance of invertebrate prey in April may have reflected the initial behavior of feeding on invertebrates by chinook fry during their freshwater and early estuarine life as well as a selection for smaller organisms. Once the period of estuarine residence lengthened, chinook began to acquire the piscivorous habits of juveniles and adults in marine environments.

The second phase of feeding covers the period from mid-May to mid-June. Throughout this time juvenile herring dominated chinook diets (76-99% of IRI). Since invertebrates were important prey both before mid-May and after mid-June, they were probably equally available to chinook during the second phase. The shift to fish appeared to be independent of the relative abundance of herring since, from May to mid-June, the importance of herring in chinook diets increased while the catch of herring dropped. Therefore chinook appeared to selectively prey on herring rather than invertebrate food resources. In general, chinook juveniles occurring throughout Georgia Strait also prefer fish and herring in particular (Healey 1980b).

The third phase is another, but less defined, transitional period covering late June, July, and August. In this phase, a shift from an almost exclusive diet of herring to diets in which invertebrates were again important prey items was observed. Because herring were apparently a preferred food source, a decline in the availability of this prey species may have dictated a rise in the importance of alternative prey items. Among fishes, the relationship between the size of both prey and predators and prey abundance are two of several important factors that determine prey availability (Ivlev 1961; Popova 1967; Hyatt 1979). The influences that these two factors may have on chinook feeding behavior are considered in the following section.

Size-selective predation and prey abundance

Chinook juveniles exploited all size classes of herring during the initial period of extensive fish predation in early May. By late June and throughout July and August however, only individuals within the smaller size classes of the herring population were selected. Lacking herring, and being opportunistic feeders (Healey 1978; 1980a), chinook shifted to alternative prey sources. Two principal factors appear to explain the shift.

First, individual herring apparently outgrew their vulnerability to chinook predation despite the simultaneous growth of chinook. This would create an effective "turn off" mechanism (Parker 1971). Observations from two studies of predator-prey relationships provide support for this mechanism. In cases of yearling coho predation on pink fry (Parker 1971) and adult walleye (*Stizostedion vitreum*) predation on juvenile yellow perch (*Perca* *flavescens*)(Nielson 1980), selection for smaller individuals occurred when the majority of size frequencies of prey extended beyond the size of possible ingestion. In both of these cases the prey eventually outgrew their vulnerability to predation. Second, since the herring population decreased from May to August, a decline in abundance in the smaller size classes probably limited availability.

Although prey size and abundance appear to be obvious factors affecting availability, the relationship between chinook and herring likely involves many other integrated aspects of predator-prey interactions such as avoidance behaviors of herring and search and pursuit behavior of chinook.

Importance of Nearshore Zones on Roberts Bank

The relative importance of each of the zones at the study site (offshore, causeway beach, eelgrass, sandflats, saltmarsh) to chinook could not be assessed from a diet analysis of juveniles. The prey resources utilized for substantial periods by chinook occur in many different microhabitats within all the zones and no one zone appears singularly important in terms of prey production. There are a number of reasons which make an evaluation of the relative importance of nearshore zones, by an examination of diets, difficult. First, chinook showed they are capable of travelling up to four km on one tidal cycle. Consequently they may move through and feed in one or more zones in a relatively short time. As well, the time required for gastric evacuation of stomach contents may exceed the period of feeding in one zone. For example, Levings (1982) found adult insects in the diets of chinook in a pit on Sturgeon Bank even though at the time of chinook capture, adult insects were not present in samples of potential prey organisms. Levings speculated the insects were taken by chinook in the high intertidal zone 2-3 km away. Second, organisms fed upon by chinook in one zone may have originated from another. Examples of this include epibenthic invertebrates that may be carried by tide currents (Levings 1982) or insects from terrestrial sources that appear as surface drift prey. Third, there is a paucity of data on the distribution and abundance of potential prey species within each zone with which to compare to prey taken.

Seasonal occurrence, distribution and relative abundance of pink, chum, and chinook juveniles indicates these species occur, independent of size, throughout nearshore subtidal and intertidal areas and do not select specific zones within these areas. However, the zones at the study site are components of the nearshore region that in combination with other such areas in the outer Fraser estuary comprise an important transitional rearing habitat for juvenile salmonids. Growth during residency was shown for pink, chum, and chinook. Chinook growth resulted at least in part from the direct exploitation of food resources from nearshore habitats on Roberts Bank.

A direct link was obtained between chinook and the terrestrial and aquatic insect habitats (including the salt marsh zone). Since the other prey items besides insects may not have habitat affinities to any one zone, links between chinook and the offshore, causeway beach, eelgrass, and sandflat zones must be shown through a food chain hierarchy. For example, juvenile herring (a dominant prey item) feed on epibenthic zooplankton (Simenstad *et al.* 1979) which are abundant in eelgrass habitats (Simenstad *et al.* 1980). Further information about abundance and distribution of salmon prey communities is required before relative importances of each zone in the intertidal areas can be assessed.

SUMMARY and CONCLUSIONS

The principle findings of this study are as follows:

1. Juvenile pink, chum, and chinook salmon were abundant on southern Roberts Bank between April and August 1982, and differences in peak catch sizes between species in 1982 were positively correlated with the difference in size of the adult escapements of the 1981 parent year to the Fraser River.
2. The absence of the juvenile coho and sockeye populations (except for incidental catches), despite large adult escapements to the Fraser River, indicates that the nearshore region of the outer estuary was not utilized as nursery habitats by these species.
3. Pink, chum and chinook juveniles were distributed between the subtidal and intertidal zones independent of fish size, and seasonal salinity and temperature patterns. Juveniles were not captured in shallow waters where temperatures exceeded 22^{o}C.
4. The largest catches of pink, chum, and chinook were usually in the offshore zone at the terminus of each causeway and at the edge of the borrow pit. Catches of pink and chum along the causeway beaches generally exceeded those in the eelgrass and sandflats. Differences in catch size may have been related to the volumes of water sampled by beach seines in the offshore

and causeway beach zones and seining with the ramp assembly in the eelgrass and sandflat zones.

5. Chinook juveniles released from two Fraser River hatcheries were captured on Roberts Bank. From unpublished data included in hatchery release reports, and catch data of chinook on Roberts Bank, the relative proportions of hatchery and wild chinook were estimated. These estimates indicated most chinook captured on Roberts Bank were from wild stocks.
6. Statistically significant seasonal increases of average length occurred for pink, chum, and chinook juveniles. Chinook displayed the largest change in size. Rates of seasonal average size change probably underestimated actual growth rates because of the prolonged immigration of small fish to the outer Fraser estuary and the probable emigration of larger individuals.
7. From an examination of available information on life history patterns, migration timing, seaward migration routes, and size distributions of juveniles in the lower Fraser River and estuary and in the Strait of Georgia and Gulf Islands, the size increases observed on Roberts Bank were concluded to be the result of varying residency periods on the delta-front of the Fraser estuary.

8. Based upon growth rates of pink and chum juveniles estimated from previous studies conducted elsewhere in B.C. and the average lengths of fish at the beginning and end of their seasonal occurrence on Roberts Bank, residency periods for at least a part of the juvenile population in the outer Fraser estuary were estimated to range 8 to 15 days for pinks, and 15-25 days for chum.
9. A growth rate for chinook was estimated from captures of individuals released from three hatcheries on the lower Fraser River. From this estimate, and the average length of chinook at the beginning and end of their seasonal occurrence on Roberts Bank, the residency period for at least part of the juvenile population in the outer Fraser estuary was estimated at 60 to 75 days.
10. Chinook consumed a wide range of epibenthic, pelagic, and surface drift invertebrates and larval and juvenile herring. Herring were the single most important prey items as indicated by the index of relative importance which incorporates frequency of occurrence, numerical abundance, and volume of organisms in the stomach.
11. Most prey are associated with intertidal waters and constituted important food resources for chinook rearing in the outer Fraser estuary.
12. An analysis of chinook temporal feeding patterns suggested herring were preferred prey. The chinook-

herring relationship may have been influenced by size-selective predation of chinook and the abundance of herring. Most members of the herring population appeared to outgrow their vulnerability to chinook predation as the season progressed.

13. The nearshore subtidal and intertidal zones of the outer Fraser estuary were concluded to comprise an important transitional rearing habitat for juvenile salmonids.

The contribution of the Fraser estuary to rearing juvenile salmon had previously been evaluated from analysis of growth and residency in the inner marshes. However, the habitat characteristics of the delta encompassed by the estuary are considerably different along the delta-front (Sturgeon and Roberts Banks). As a result, salmon production for the entire Fraser estuary can not be adequately assessed without studies in the outer region of the estuary. This study has identified that intertidal habitats on Roberts Bank are utilized by pink, chum, and chinook juveniles prior to offshore migrations. Additionally, new observations on estuarine tidal flats of habitat selection by juveniles, and the feeding ecology of chinook have been reported. These results may enable researchers to evaluate more precisely potential salmonid nursery habitats on tidal flat areas of both the Fraser and other estuaries along the Pacific coast.

Growth and residency periods for juveniles at the study site on Roberts Bank are estimates based on observations of seasonal occurrence, relative abundance, and seasonal size changes. Esimates of greater accuracy might be obtained with comprehensive mark-recapture studies in the outer estuary. Additionally, if the numbers of marked releases from hatcheries were increased substantially, then sampling in the estuary to obtain a greater number of recaptures than were caught in this study may also provide more accurate growth estimates.

The dietary differences between nearshore (study site) and offshore regions indicate chinook were feeding on prey resources directly related to nearshore intertidal habitats. However, further studies are required to identify chinook prey habitats and productivity within the nearshore areas of the estuary. I have provided a comprehensive data base of chinook prey that may be used for future analysis of such prey habitats as eelgrass beds, sandflats, and salt marshes. Without these kinds of studies, salmonid nursery areas in the outer Fraser estuary that may require restoration or may become subject to negative impacts from human activities can not be effectively managed.

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Table A-1. List of fish species captured in each of the zones on southern Roberts Bank in 1981 and 1982. The offshore, causeway beach, and salt marsh zones were sampled with beach seines. The eelgrass and sandflat zones were sampled with seines using the portable ramp assembly. Numbers represent the following zones: (1) offshore; (2) causeway beach; (3) eelgrass; (4) sandflat; and (5) salt marsh. X denotes the presence of species. Unsampled zones within a month are indicated by U.

Species	1981															1982																								
	June					July					Aug.					April					May					June					July					Aug.				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
					U																																		U	U
Squalus acanthias											X																													
Clupea harengus	X		X	X		X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X		X	X	X	X	X	X		X	X	X	X		X	X	X		
Engraulis mordax			X			X	X	X																																
Oncorhynchus gorbuscha																X	X	X	X		X	X	X	X		X	X	X												
O. keta	X			X		X										X	X	X	X	X	X	X	X	X	X	X	X				X									
O. kisutch							X																			X														
O. nerka	X		X			X																				X					X					X				
O. tshawytscha	X	X	X	X		X	X	X	X		X	X				X	X				X	X			X	X	X	X	X		X	X	X			X	X			
Hypomesus pretiosus	X	X	X	X		X	X	X	X		X	X				X	X	X		X	X	X	X	X		X	X	X	X		X	X				X	X			
Porichthys notatus			X			X		X																									X							
Gobiesox maeandricus											X															X														
Microgadus proximus			X			X		X			X		X													X		X					X							
Aulorhynchus flavidus	X		X	X		X	X	X	X		X		X			X		X									X	X			X	X	X			X	X	X		
Gasterosteus aculeatus	X		X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			X	X	X	X	X	X	X	X	X	X	X		X		
Syngnathus griseolineatus	X		X	X		X	X	X	X		X	X	X	X	X		X	X	X			X	X		X	X	X	X	X		X		X	X		X		X		
Cymatogaster aggregata	X		X	X		X	X	X	X		X	X	X		X							X	X		X	X	X	X	X		X	X	X	X	X	X	X	X		
Rhacochilus vacca			X			X		X			X	X	X									X				X		X				X	X			X				
Lumpenus sagitta			X			X		X					X										X			X	X	X	X		X		X			X				
Apodichthys flavidus	X		X			X	X	X			X	X	X					X				X	X			X	X	X			X	X	X			X		X		
Pholis laeta	X		X			X	X	X			X	X	X					X			X	X	X			X	X	X			X	X	X					X		
P. ornata						X		X			X	X	X									X					X	X					X					X		
Ammodytes hexapterus	X	X	X			X	X	X			X	X		X		X	X	X	X	X	X	X	X			X	X		X		X	X	X	X		X				
Clevelandia ios	X	X	X	X			X	X	X			X		X			X		X					X					X					X						
Sebastes sp.						X					X		X			X																								
Hexagrammos decagrammus						X																				X					X									
H. stelleri			X			X		X					X			X	X	X				X	X			X		X					X							
Artedius fenestralis	X		X			X	X	X	X		X		X																			X								
Blepsias cirrhosus								X																									X							
Clinocottus acuticeps			X								X		X				X						X			X	X	X					X							
Enophrys bison	X		X			X	X	X			X					X										X					X	X								

Table A-1. con't.

	1981															1982																								
	June					July					Aug.					April					May					June					July					Aug.				
Species	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
					U																																		U	U
Leptocottus armatus	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		
Myoxocephalus polyacanthocephalus						X	X	X			X		X		X											X		X												
Oligocottus maculosus						X	X	X			X	X	X			X	X				X	X				X	X	X			X	X				X	X			
Psychrolutes paradoxus			X													X												X					X							
Citharichthys sordidus			X					X																																
C. stigmaeus								X					X			X										X		X			X		X							
Lepidopsetta bilineata																															X									
Parophrys vetulus	X	X	X	X		X	X	X	X		X	X	X			X	X	X				X	X			X	X	X			X	X	X			X	X	X		
Platichthys stellatus	X	X	X	X		X	X	X	X		X	X	X			X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X		
Pleuronichthys coenosus								X																																

Table B-1. Chinook catch data in 1981. Location of sample sites (one set per site) are shown in Fig. A-1. The offshore, causeway beach, and salt marsh zones were sampled with beach seines. The eelgrass and sandflat zones were sampled with seines using the portable ramp assembly. Letters of sample sites represent sets in the following zones: (O) offshore; (C) causeway beach; (E) eelgrass; (S) sandflat; and (M) salt marsh.

Sample date	Sample site	Catch
June 14-20	E- 1	5
	2	8
	3	
	4	
	S- 1	1
	2	
21-27	C- 1	
	4	2
	E- 5	
	6	1
	7	
	8	2
	9	
	10	
	11	
	12	1
	13	
	S- 4	
	5	2
	6	
	7	
	8	
	9	
	10	
	11	
June 28- July 4	O- 2	
	3	73
	5	16
	C- 4	2
	6	2
	7	10
	E- 14	
	15	2
	16	

Table B-1. con't.

Sample date	Sample site	Catch
	17	1
	18	1
	19	
	20	
	21	1
	22	
	23	
	24a	4
	24b	7
	24c	7
	S- 12	
	13	
	14	
	15	
	16	
	17	1
July 5-11	O- 14	7
	C- 8	9
	9	2
	10	
	11	1
	12	2
	13	
	14	
	15	
	16	
	E- 25	
	26	
	27	1
	S- 18	
	19	
	20	
	21	
	22	
	23	
	24	
	25	
July 12-18	O- 17	72
	18	
	19	
	20	
	21	11

Table B-1. con't.

Sample date	Sample site	Catch
	C- 22	4
	E- 28	
	29	
	30	
	31	
	33	
	34	
	35	
	36	
	37	
	38	
	39	
	40	
	41	
	42	
	43	
	44	
	45	
	46	1
	47	1
	S- 26	
	27	
19-25	O- 28	1
	29	1
	30	5
	C- 23	
	24	2
	25	6
	26	
	27	
	31	3
	32	3
	33	
	E- 48	
	49	
	50	
	51	
	52	
	S- 28	
	29	
	30	
	31	
	32	

Table B-1. con't.

Sample date	Sample site	Catch
	33	
	34	
	35	
	36	
	37	
	38	
	39	
	40	
	41	
July 26- Aug. 1	O- 35	4
	36	
	37	7
	38	1
	42	
	C- 43	1
	E- 54	1
	55	
	56	
	57	
	58	
	59	
	60	
	61	
	62	
	63	
	64	
	65	
	66	
	67	
	S- 42	
	43	
	M- 1	
	2	
	3	
	4	
Aug. 2-8	O- 46	
	47	7
	48	3
	C- 44	
	45	
	50	
	51	2
	53	

Table B-1. con't.

Sample date	Sample site	Catch
	54	
	E- 68	
	S- 44	
	45	
	46	
	47	
	48	
	49	
	50	1
	51	
	54	
	M- 5	
	6	
9-15	O- 55	
	58	1
	59	1
	60	
	61	1
	63	2
	C- 56	
	57	
	62	
	64	
	65	
	66	
	E- 69	
	70	
	71	
	72	
	73	
	74	
	75	
	76	
	S- 55	
	56	
16-22	O- 68	
	69	1
	70	
	71	1
	72	1
	81	
	83	3

Table B-1. con't.

Sample date	Sample site	Catch
	84	1
	85	
	C- 67	
	73	
	74	
	75	
	76	
	77	
	78	
	79	
	80	
	82	
	86	
	87	
	88	
	89	
	90	
	91	
	92	
	93	
	94	1
	E- 77	
	78	
	79	
	80	
	81	
	82	
	S- 57	
	58	
	59	
	60	
	61	
23-29	O- 98	
	99	1
	101	
	102	
	103	2
	104	
	C- 95	
	96	
	97	
	100	
	E- 83	

Table B-1. con't.

Sample date	Sample site	Catch
	84	
	S- 62	
	63	

Table B-2. Salmon catch data in 1982. Location of sample sites (one set per site) are shown in Fig. A-2. The offshore, causeway beach, and salt marsh zones were sampled with beach seines. The eelgrass and sandflat zones were sampled with seines using the portable ramp assembly. Letters of sample sites represent sets in the following zones: (O) offshore; (C) causeway beach; (E) eelgrass; (S) sandflat; and (M) salt marsh.

Sample date	Sample site	Catch		
		Pink	Chum	Chinook
April 9	O- 2			
	5			
	6			
	7		1	
	8		1	
	C- 1	3	10	
	3	7	6	
	4	4	20	
	E- 1			
	2			
	3			
	4			
	5			
	6	1		
	S- 1			
21	O- 9	1	1	
	10	58	205	3
	C- 11	7	3	1
	12			
	13	270	352	
	14	52	46	
	15	5	4	
	E- 7			
	8			
	S- 2			
	M- 1			5
29	O- 17	79	4	
	18			
	20	423	28	
	21			
	22	258	248	
	C- 19	303	72	
	E- 9			
	10		1	

Table B-2. con't.

Sample date	Sample site	Catch		
		Pink	Chum	Chinook
	11	79	22	
	S- 3	10	4	
May 10	O- 23	624	175	
	24			
	25	3	10	1
	C- 26			2
	27	76	44	7
	E- 12	1		
	13	1		
	14	59	96	
	15	30	26	
	16	30	14	
20	O- 28	304	286	9
	29	84	181	433
	30	161	111	17
	C- 31	24	31	2
	32	5	2	1
	34			
	35	42	4	
	E- 17	30	8	
	18	1		
	S- 7	2		
	8	5		
	9	7	2	
	M- 2			3
June 1	O- 36	50	10	19
	37	11	11	5
	38	29	50	65
	45	4	22	11
	C- 39	2	6	1
	40	3	4	1
	41			
	44		3	4
	S- 10			
	11			
	12			
	13			
	M- 3			
	4			
8	O- 46	15	31	17

Table B-2. con't.

Sample date	Sample site	Catch		
		Pink	Chum	Chinook
	47	8	8	46
	49	8		190
	50	1	3	14
	C- 48			
	51			
	E- 19			
	20	1		
	21			
	21			
	22			39
	23			
16	O- 52	3	49	6
	53	1	8	50
	55		2	1
	C- 54	1	1	
	56			1
	57	3		1
	58			3
	59			
	61			
	S- 14			
	15			
	16			
	M- 5			
22	O- 62			1
	64			3
	65			
	66		1	2
	68			
	C- 63			
	67			
	E- 24			
	25			
	26			
	27			
29	O- 69		1	1
	70		3	29
	71			10
	78			
	C- 72			5
	73			3
	74			4

Table B-2. con't.

Sample date	Sample site	Catch Pink	 Chum	 Chinook
	75			
	77	1		
	S- 17			
	18			
	19			2
	20			
	M- 6			
July 9	O- 79			8
	80			11
	81			8
	84		1	
	C- 82			1
	83			
	E- 28			1
	29			
	30			
	31			
	32			
	33			
15	O- 85			2
	86		3	29
	87			
	95		1	4
	C- 88			2
	89			
	90			
	91			1
	93			
	94			
	S- 21			
	22			
	23			
	M- 7			
22	O- 96		1	13
	97			
	98			6
	99			3
	100			
	101			1
	102			12
	C- 103			2
	E- 34			

Table B-2. con't.

Sample date	Sample site	Catch Pink	Chum	Chinook
	35			
29	O- 104			
	105			
	106			
	107			2
	108			
	114			1
	115			6
	C- 109			
	110			1
	111			
	112			
	113			
	E- 36			
	37			
	S- 24			
	25			
Aug. 4	O- 116			
	117			
	119			2
	120			
	121			
	122			
	123			
	C- 118			
	E- 38			
	39			
	40			
19	O- 124			
	125			
	126			
	127			1
	128			
	129			
	130			
	131			
	C- 129			7

Table C-1. Two- way ANOVA of juvenile salmon catch with time in intertidal zones.

Source of variation	Degrees of freedom	Sum of squares	Mean square	F
CHUM (1982):				
Zones	3	2.76	.92	2.87*
Time	12	17.61	1.47	4.57**
Zones x Time	14	11.86	.85	2.64*
Error	77	24.73	.32	
PINK (1982):				
Zones	3	4.47	1.49	3.07*
Time	8	18.53	2.32	4.77**
Zones x Time	15	6.91	.46	.95 ns
Error	68	32.99	.49	
CHINOOK (1982):				
Zones	1	3.32	3.32	25.51**
Time	15	11.22	.75	5.75**
Zones x Time	15	8.46	.56	4.33**
Error	93	12.10	.13	
CHINOOK (1981):				
Zones	3	1.44	.48	5.37*
Time	10	3.93	.39	4.40**
Zones x Time	13	1.68	.13	1.45 ns
Error	119	10.61	.09	

*p<.05
**p<.001
ns - not significant

Table D-1. Weight-length relationships for juvenile salmon captured on southern Roberts Bank.

Species	Year	n	Length range (mm)	Weight range (gm)	Weight(W)-Length(L) relationship
Pink	1982	851	26.0 - 73.5	0.10 - 4.11	$\log W = -6.18 + 3.65(\log L)$
Chum	1982	620	31.0 - 84.0	0.21 - 5.87	$\log W = -5.76 + 3.42(\log L)$
Chinook	1981	233	57.0 - 133.0	1.93 - 30.15	$\log W = -5.31 + 3.17(\log L)$
Chinook	1982	349	35.5 - 142.0	0.41 - 30.33	$\log W = -5.25 + 3.17(\log L)$

Table E-1a. Coded-wire tag and related data of chinook juveniles released from hatcheries in the Fraser River system in 1981.[a]

Hatchery site	Tag code	Release date	Number of individuals released				Size at release	
			Tagged with CWT'S	Tagged with adipose fin-clip only	Un-marked	Total released	Weight (gm)	Length[b] (mm)
Chehalis River	21-2-09	July 4	18,876	0	0	18,876	1.97	58.6
	21-2-13	July 4	18,876	0	0	18,876	1.97	58.6
Birkenhead River	18-2-35	Apr. 28	68,289	2,732	4,124	75,145	3.13	67.8
Bonaparte River	19-2-06	May	18,413	600	3,000	22,013	2.62	64.1
	19-2-07	May	19,200	600	12,600	32,400	2.26	61.2
Bowron River	21-2-45	Aug. 18-22	24,432	2,148	2,386	28,966	1.62- 1.78	55.1- 56.8
Slim Creek	19-2-52	July 11-18	44,053	1,185	12,240	57,478	2.21	60.8

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[a] Unpublished data, Dept. of Fisheries and Oceans, Vancouver, B.C.
[b] Lengths derived from weight-length relationship of chinook captured on Roberts Bank in 1981.

Table E-1b. Coded-wire tag and related data of chinook juveniles released from hatcheries in the Fraser River system in 1982.[a]

			Number of individuals released				Size at release	
Hatchery site	Tag code	Release date	Tagged with CWT'S	Tagged with adipose fin-clip only	Un-marked	Total released	Weight (gm)	Length[b] (mm)
Chilliwack River	21-2-57	Apr. 8	48,299	1,001	0	49,300	3.00	64.1
	21-2-59	May 10	48,188	3,156	0	51,344	8.72	89.7
	21-2-28	31	4,638	28	0	4,666	3.19	65.3
	21-2-63	June 2	74,018	1,280	281,090	356,388	5.34	76.9
Chehalis River	22-2-05	May	43,501	797	35,252	79,550	2.27	58.7
Birkenhead River	23-2-40	Apr. 30	26,045	483	0	26,528	3.22	65.5
	19-2-15	30	8,291	1,463	0	9,754	44.51	150.0
Bonaparte River	24-2-17	Apr. 26-30	29,100	900	0	30,000	2.70	62.0
	24-2-18	26-30	15,360	640	0	16,000	2.70	62.0
	unmarked	26-30	0	0	6,500	6,500	1.00	45.3
Nicola River	24-2-15	Apr. 26-30	23,280	720	0	24,000	3.30	66.0
	24-2-16	26-30	7,050	450	0	7,500	1.25	48.6
Bowron River	23-2-19	July 23	34,017	1,234	5,302	40,553	1.23	48.4
	23-2-20	23	31,851	485	11,546	43,882	1.42	50.6
Slim Creek	23-2-18	July 29	26,533	680	8,504	35,717	1.57	52.2
	23-2-17	29	26,287	1,530	3,524	31,341	1.74	54.0
Quesnel River	22-2-47	May 3	24,456	929	0	25,385	4.98	75.2
	22-2-48	3	25,529	894	0	26,423	4.32	71.9
	19-2-03	3	5,592	212	5000	10,804	2.20	58.1
Tenderfoot River	19-2-46	Apr. 27-29	0	0	167,990	167,990	5.47	77.4

[a] Unpublished data, Dept. of Fisheries and Oceans, Vancouver, B.C.

[b] Lengths derived from weight-length relationships of chinook captured on Roberts Bank in 1982.

Table F-1. List of importance of prey items for juvenile chinook captured on southern Roberts Bank on each sample date in 1982.

Sample date	Prey taxon[a]	% Frequency of occurrence	% Numerical abundance	% Volume	% IRI
April 21	O.Calanoida; *Calanus plumchrus*	50.00	76.92	68.11	76.59
N=4	*C. pacificus*	25.00	10.26	3.04	3.51
	O.Amphipoda	25.00	2.56	2.46	1.32
	O.Diptera; F.Chironomidae	25.00	2.56	0.38	0.78
	F.Clupeidae; *Clupea harengus*	50.00	7.69	26.01	17.80
May 10	O.Calanoida; *Acartia* sp.	8.33	0.57	0.12	0.11
N=12	O.Harpacticoida	25.00	21.59	1.67	10.73
	O.Mysidacea; *Neomysis mercedis*	16.66	1.14	13.72	4.57
	O.Cumacea; *Hemilamprops* sp.	8.33	3.98	2.79	1.04
	Lamprops sp.	8.33	0.57	0.71	0.20
	O.Amphipoda; *Anisogammarus pugettensis*	25.00	3.98	1.67	2.60
	Corophium spinicorne	8.33	0.57	0.21	0.12
	Eogammarus sp.	8.33	0.57	0.09	0.10
	Hyale sp.	16.66	38.64	15.02	16.49
	Pontogeneia sp.	8.33	0.57	1.76	0.36
	O.Decapoda; megalopa	25.00	7.39	2.85	4.72
	O.Diptera; F.Chironomidae[b]	16.66	1.14	0.05	0.36
	Sphaeroceridae	8.33	0.57	0.18	0.12
	Tethinidae	8.33	0.57	0.66	0.19
	F.Clupeidae; *Clupea harengus*	58.33	3.41	43.30	50.25
	F.Cottidae	8.33	0.57	7.03	1.17
	Unidentified fish	16.66	14.20	8.17	6.87
May 20	O.Calanoida; *Calanus plumchrus*	4.55	0.66	0.20	0.04
N=22	*C. pacificus*	13.64	15.23	4.30	2.72
	O.Mysidacea; *Neomysis mercedis*	4.55	0.66	0.83	0.07
	O.Cumacea; *Cumella vulgaris*	4.55	0.66	0.04	0.03
	O.Amphipoda; *Anisogammarus pugettensis*	4.55	1.32	0.16	0.07
	Corophium spinicorne	4.55	0.66	0.31	0.05
	Eogammarus sp.	4.55	0.66	0.09	0.04
	E. confervicolus	4.55	0.66	0.39	0.05
	F. Ischyroceridae	4.55	0.66	0.25	0.04
	O.Homoptera; F.Aphidae	9.10	2.65	0.40	0.28
	O.Diptera; F.Chironomidae	9.10	6.62	0.36	0.65
	Chironomidae[b]	4.55	1.99	0.21	0.10

Table F-1. con't.

Sample date	Prey taxon	% Frequency of occurrence	% Numerical abundance	% Volume	% IRI
	Chironomidae[c]	31.82	49.01	4.50	17.38
	Sphaeroceridae	4.55	0.66	0.07	0.03
	O.Hymenoptera	4.55	0.66	0.04	0.03
	F.Clupeidae; *Clupea harengus*	77.27	15.23	83.44	77.83
	Unidentified fish	9.10	1.99	4.40	0.59
June 1 N=22	O.Thoracica[d]	13.64	24.05	2.76	4.07
	O.Mysidacea; *Neomysis mercedis*	4.55	0.63	0.51	0.06
	O.Amphipoda; *Anisogammarus pugettensis*	9.10	2.53	0.76	0.34
	Corophium spinicorne	4.55	0.63	0.04	0.30
	Parapleustes sp.	4.55	1.27	0.34	0.08
	Caprella sp.	4.55	0.63	0.19	0.04
	O.Decapoda; megalopa	22.73	44.94	8.82	13.68
	C.Arachnida	4.55	0.63	0.04	0.03
	O.Homoptera; F.Cicadellidae	4.55	0.63	0.06	0.04
	F.Aphidae	4.55	0.63	0.05	0.04
	O.Diptera; F.Chironomidae[b]	9.10	1.90	0.17	0.21
	Sciaridae	4.55	1.27	0.07	0.07
	Phoridae	4.55	0.63	0.02	0.03
	F.Clupeidae; *Clupea harengus*	68.18	19.62	86.16	81.01
June 8 N=34	O.Mysidacea; *Neomysis* sp.	2.94	2.54	1.59	0.13
	O.Amphipoda	2.94	5.93	0.23	0.20
	Anisogammarus pugettensis	2.94	0.85	0.09	0.03
	Calliopius sp.	5.88	36.44	1.34	2.42
	O.Diptera; F.Chironomidae	5.88	14.41	0.44	0.95
	Chironomidae[b]	2.94	9.32	0.46	0.31
	Chironomidae[c]	5.88	7.63	0.19	0.50
	F.Clupeidae; *Clupea harengus*	76.47	18.64	94.94	94.51
	Unidentified fish	17.65	4.24	0.72	0.95
June 16 N=19	O.Diptera; S.O.Brachycera[c]	10.53	6.38	0.80	0.58
	F.Chironomidae	5.26	19.15	0.54	0.80
	Sciaridae	5.26	2.13	0.04	0.09
	Empididae	5.26	4.26	0.22	0.18
	Phoridae	5.26	2.13	0.05	0.09
	Chloropidae	10.53	4.26	0.34	0.37

Table F-1. con't.

Sample date	Prey taxon	% Frequency of occurrence	% Numerical abundance	% Volume	% IRI
	O.Hymenoptera	5.26	6.38	0.16	0.26
	F.Clupeidae; *Clupea harengus*	84.21	53.19	97.41	97.53
	Unidentified fish	5.26	2.13	0.44	0.10
June 22 N=6	O.Calanoida; *Calanus pacificus*	16.70	29.66	15.44	11.21
	O.Thoracica	16.70	0.69	1.44	0.53
	O.Mysidacea; *Neomysis* sp.	16.70	1.38	3.34	1.17
	O.Amphipoda	16.70	6.21	15.97	5.51
	Anisogammarus pugettensis	16.70	0.69	1.10	0.45
	Eogammarus confervicolus	16.70	5.52	3.20	2.17
	O.Decapoda; megalopa	33.30	7.59	6.71	7.08
	C.Arachnida	16.70	0.69	0.13	0.20
	O.Psocoptera; F.Pseudocaeciliidae	33.30	3.45	1.34	2.37
	O.Homoptera; F.Aphidae	66.70	7.59	4.77	12.27
	O.Diptera; F.Chironomidae	66.70	26.90	9.30	35.93
	Sciaridae	16.70	0.69	0.20	0.22
	Tethinidae	16.70	0.69	0.42	0.27
	Chloropidae	33.30	3.45	1.12	2.26
	O.Hymenoptera	50.00	2.07	0.34	1.79
	F.Clupeidae; *Clupea harengus*	33.30	2.07	26.85	14.33
	Unidentified fish	16.70	0.69	8.33	2.24
June 29 N=29	O.Thoracica[d]	6.90	5.90	4.69	1.69
	O.Isopoda; *Synidotea nodulosa*	10.34	2.95	0.83	0.90
	O.Mysidacea; *Neomysis mercedis*	6.90	0.49	0.84	0.21
	O.Amphipoda	6.90	0.98	0.48	0.23
	Ampithoe sp.	3.45	0.49	0.52	0.08
	Anisogammarus pugettensis	10.34	1.23	1.39	0.63
	Corophium brevis	6.90	0.98	0.33	0.21
	C. spinicorne	3.45	0.25	0.17	0.03
	Caprella sp.	10.34	1.97	0.74	0.65
	O.Decapoda; megalopa	20.69	2.70	2.01	2.25
	C.Arachnida	3.45	0.25	0.03	0.02
	O.Psocoptera; F.Psocidae	3.45	0.25	0.07	0.03
	Pseudocaeciliidae	24.14	4.42	1.18	3.12
	O.Homoptera; F.Cicadellidae	6.90	0.49	0.50	0.16
	Aphidae	3.45	1.23	0.47	0.13

Table F-1. con't.

Sample date	Prey taxon	% Frequency of occurrence	% Numerical abundance	% Volume	% IRI
	Delphacidae	6.90	0.49	0.29	0.12
	O.Neuroptera; F.Hemerobiidae	3.45	0.25	0.43	0.05
	Chrysopidae	3.45	0.25	0.26	0.04
	O.Diptera; S.O.Brachycera[c]	27.58	21.87	9.28	19.81
	F.Tipulidae	6.90	0.49	0.47	0.15
	Chironomidae	3.45	0.25	0.01	0.02
	Chironomidae[b]	3.45	0.25	0.06	0.02
	Chironomidae[c]	34.48	33.42	6.19	31.50
	Cecidomyiidae	6.90	0.98	0.22	0.19
	Empididae	3.45	0.25	0.09	0.03
	Dolichopodidae	3.45	0.74	0.52	0.10
	Coelopidae	3.45	0.25	0.07	0.02
	Lauxaniidae	10.34	0.74	0.48	0.29
	Tethinidae	31.03	5.16	2.19	5.61
	Ephydridae	3.45	0.74	0.13	0.07
	Diastatidae	3.45	0.25	0.09	0.03
	Chloropidae	3.45	0.25	0.04	0.02
	O.Hymenoptera	17.24	5.19	1.83	1.89
	F.Clupeidae; *Clupea harengus*	24.14	1.97	34.05	20.05
	F.Ammodytidae; *Ammodytes hexapterus*	13.79	1.23	29.08	9.64
July 9	O.Thoracica[d]	5.56	0.66	0.00	0.08
N=18	O.Isopoda; *Synidotea nodulosa*	5.56	1.97	0.90	0.34
	O.Cumacea; *Lamprops* sp.	5.56	0.33	0.07	0.05
	Lamprops quadriplicata	5.56	0.33	0.04	0.04
	Cumella vulgaris	5.56	0.98	0.07	0.12
	O.Amphipoda	11.12	0.66	0.20	0.20
	Anisogammarus pugettensis	33.33	39.34	25.80	46.26
	Atylus sp.	5.56	0.33	0.39	0.09
	Corophium spinicorne	5.56	10.16	5.24	1.82
	Eogammarus sp.	5.56	0.33	0.23	0.07
	Caprella sp.	5.56	0.33	0.04	0.04
	O.Decapoda; megalopa	33.33	9.18	5.27	10.26
	C.Arachnida	5.56	0.33	0.03	0.04
	O.Psocoptera; F.Pseudocaeciliidae	11.12	3.61	0.88	1.06
	O.Homoptera; F.Cicadellidae	5.56	0.33	0.44	0.09
	Aphidae	11.12	0.66	0.27	0.22

Table F-1. con't.

Sample date	Prey taxon	% Frequency of occurrence	% Numerical abundance	% Volume	% IRI
	O.Diptera; S.O.Brachycera[c]	16.67	24.59	11.10	12.69
	F.Chironomidae	5.56	0.33	0.04	0.04
	Chironomidae[b]	5.56	0.33	0.10	0.05
	Sciaridae	5.56	0.98	0.20	0.14
	Tethinidae	5.56	0.33	0.08	0.05
	O.Hymenoptera; F.Braconidae	5.56	0.33	0.04	0.04
	F.Clupeidae; *Clupea harengus*	27.78	2.62	39.14	24.72
	F.Ammodytidae; *Ammodytes hexapterus*	5.56	0.33	7.88	0.97
	Unidentified fish	11.12	0.66	1.55	0.52
July 15 N=17	O.Thoracica[d]	17.65	0.85	1.01	0.37
	O.Isopoda; *Synidotea nodulosa*	5.88	0.11	0.05	0.01
	O.Amphipoda	5.88	0.11	0.03	0.01
	Anisogammarus pugettensis	5.88	0.43	0.98	0.09
	Corophium spinicorne	5.88	0.11	0.03	0.01
	Eogammarus sp.	5.88	0.11	0.02	0.01
	Ischyrocerus sp.	5.88	0.43	0.55	0.06
	S.O.Caprellidea	5.88	0.11	0.07	0.01
	O.Decapoda; juveniles	5.88	0.11	0.04	0.01
	o.Diptera; F.Chironomidae	29.41	93.94	21.99	37.98
	F.Clupeidae; *Clupea harengus*	76.47	3.62	67.95	60.96
	F.Ammodytidae; *Ammodytes hexapterus*	5.88	0.11	7.26	0.48
Aug. 4 N=2	O.Diptera; S.O.Brachycera[c]	50.00	50.00	10.96	30.48
	F.Clupeidae; *Clupea harengus*	50.00	50.00	89.04	69.52
Aug. 19 N=5	O.Amphipoda	40.00	5.26	2.98	4.47
	Anisogammarus pugettensis	40.00	3.29	4.81	4.39
	O.Decapoda	20.00	0.66	0.88	0.42
	O.Hemiptera; F.Lygaeidae	40.00	1.97	2.02	2.17
	O.Homoptera; F.Aphidae	20.00	1.32	0.12	0.39
	O.Trichoptera; F.Hydroptilidae	20.00	0.66	0.39	0.28
	O.Diptera; S.O.Brachycera[c]	40.00	61.84	25.14	47.17
	F.Tephritidae	20.00	0.66	0.68	0.36
	Sphaeroceridae	20.00	0.66	0.35	0.27
	Tethinidae	40.00	10.53	2.93	7.30
	Ephydridae	40.00	4.61	4.27	4.82

Table F-1. con't.

Sample date	Prey taxon	% Frequency of occurrence	% Numerical abundance	% Volume	% IRI
	Agromyzidae	20.00	4.61	2.17	1.84
	O.Hymenoptera	20.00	1.32	0.18	0.41
	F.Clupeidae; *Clupea harengus*	40.00	1.97	37.18	21.23
	F.Aulorhynchidae; *Aulorhynchus flavidus*	20.00	0.66	15.90	4.48

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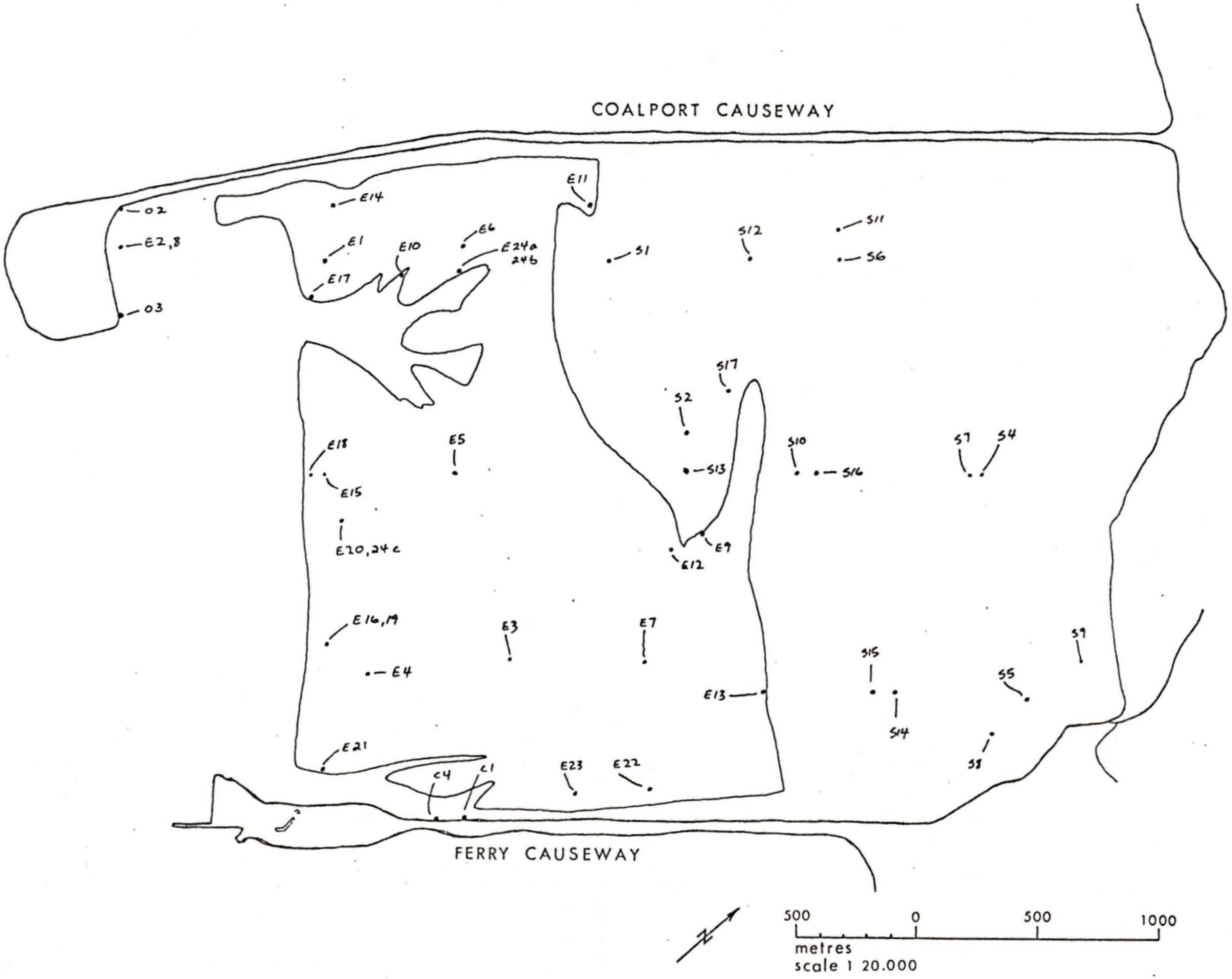
[a] Insects are adults unless otherwise noted
[b] Larvae
[c] Pupae
[d] Cirri of adult barnacles

Fig. A-1a. Locations of sample sites (1 set per site) during 14 June - 4 July, 1981.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FERRY CAUSEWAY
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E2,8
O3
E14
E1
E17
E10
E6
E24a
24b
E11
S1
S12
S11
S6
S17
S2
S13
S10
S16
S7
S4
E18
E15
E5
E20,24c
E9
E12
E16,19
E4
E3
E7
E13
S15
S14
S9
S5
S8
E21
C4
C1
E23
E22
500
0
500
1000
metres
scale 1 20.000

Fig. A-1b. Locations of sample sites (1 set per set) during 5 July - 1 Aug., 1981.

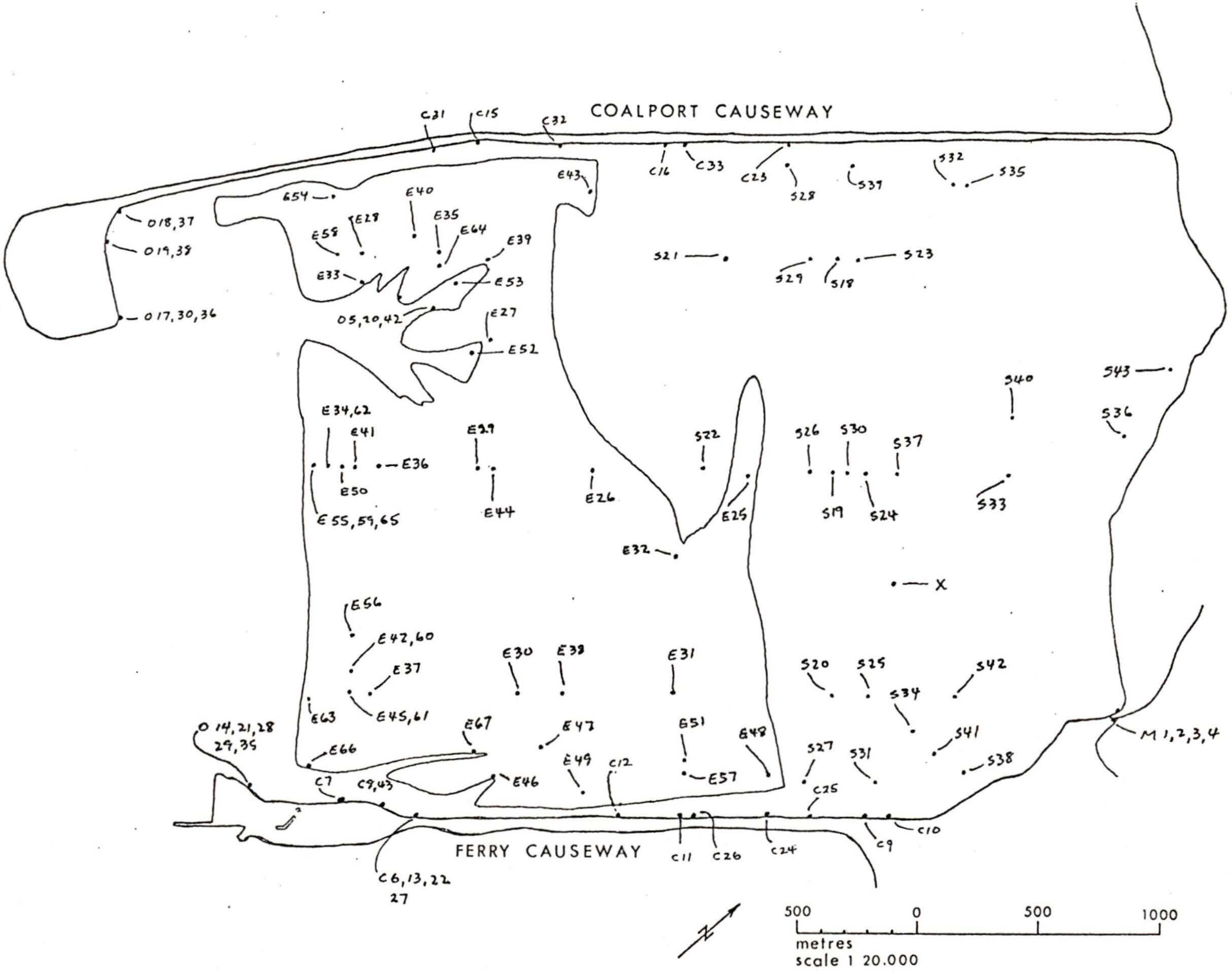
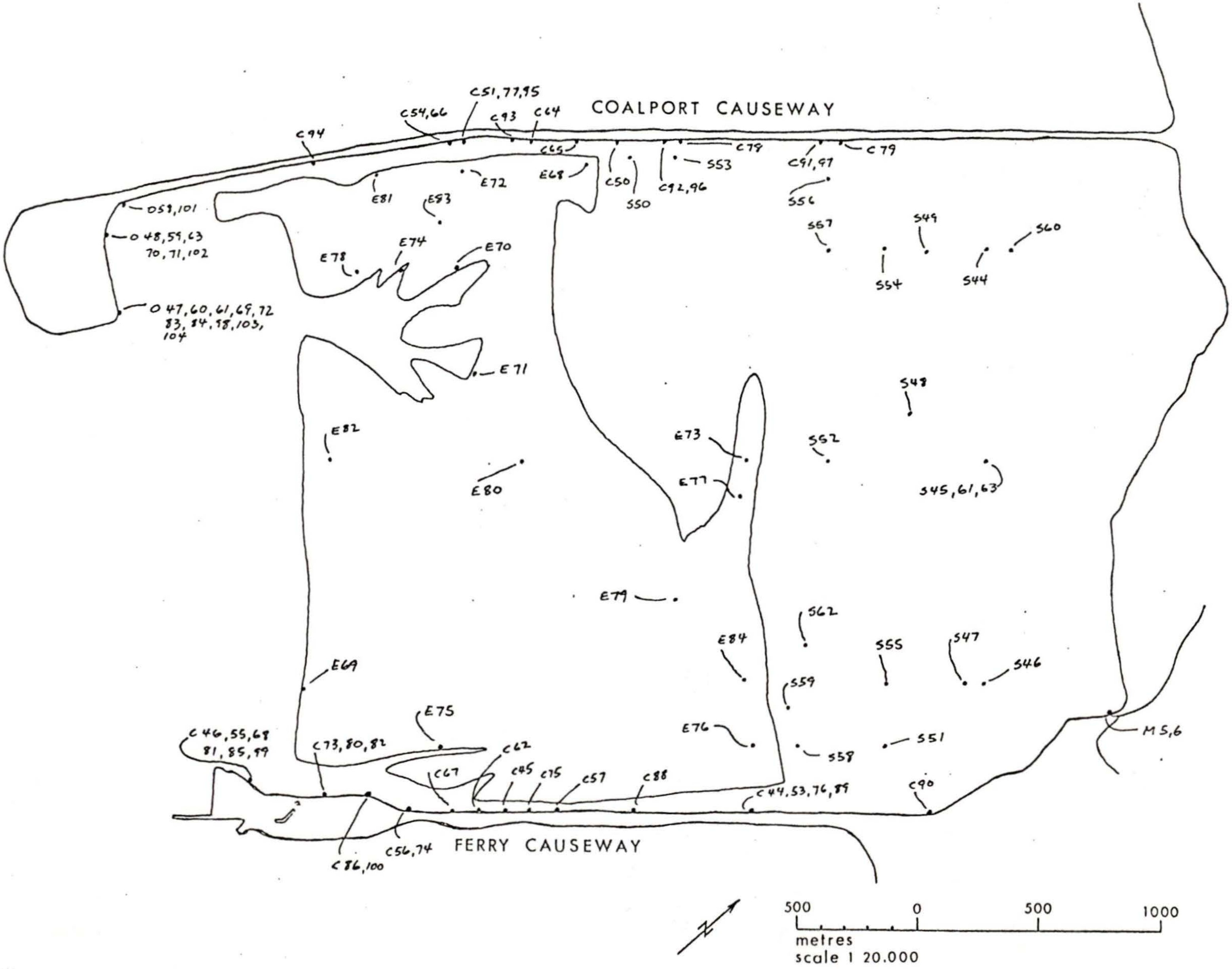

COALPORT CAUSEWAY
FERRY CAUSEWAY
C31
C15
C32
C16
C33
C23
S28
S39
S32
S35
E43
E54
E40
E58
E28
E35
E64
E39
E33
E53
O5,20,42
E27
E52
O18,37
O19,38
O17,30,36
S21
S29
S18
S23
S43
S40
S36
E34,62
E41
E36
E50
E55,59,65
E29
E44
E26
S22
E25
E32
S26
S30
S37
S19
S24
S33
X
E56
E42,60
E37
E63
E45,61
E30
E38
E31
S20
S25
S34
S42
S41
S38
M1,2,3,4
O14,21,28
29,35
E66
E67
E47
E49
E46
E51
E57
E48
S27
S31
C25
C7
C9,43
C12
C6,13,22
27
C11
C26
C24
C9
C10
N
500
0
500
1000
metres
scale 1 20.000

Fig. A-1c. Locations of sample sites (1 set per site) during 2-27 Aug., 1981.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C93
C64
C94
C65
C78
C79
C91,97
S53
C50
C92,96
S50
E68
E72
E81
E83
O59,101
O48,59,63
70,71,102
O47,60,61,69,72
83,84,98,103,
104
E78
E74
E70
E71
S56
S57
S49
S60
S54
S44
S48
E82
E80
E73
E77
S52
S45,61,63
E79
S62
E84
S55
S47
S46
E69
S59
E75
E76
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S51
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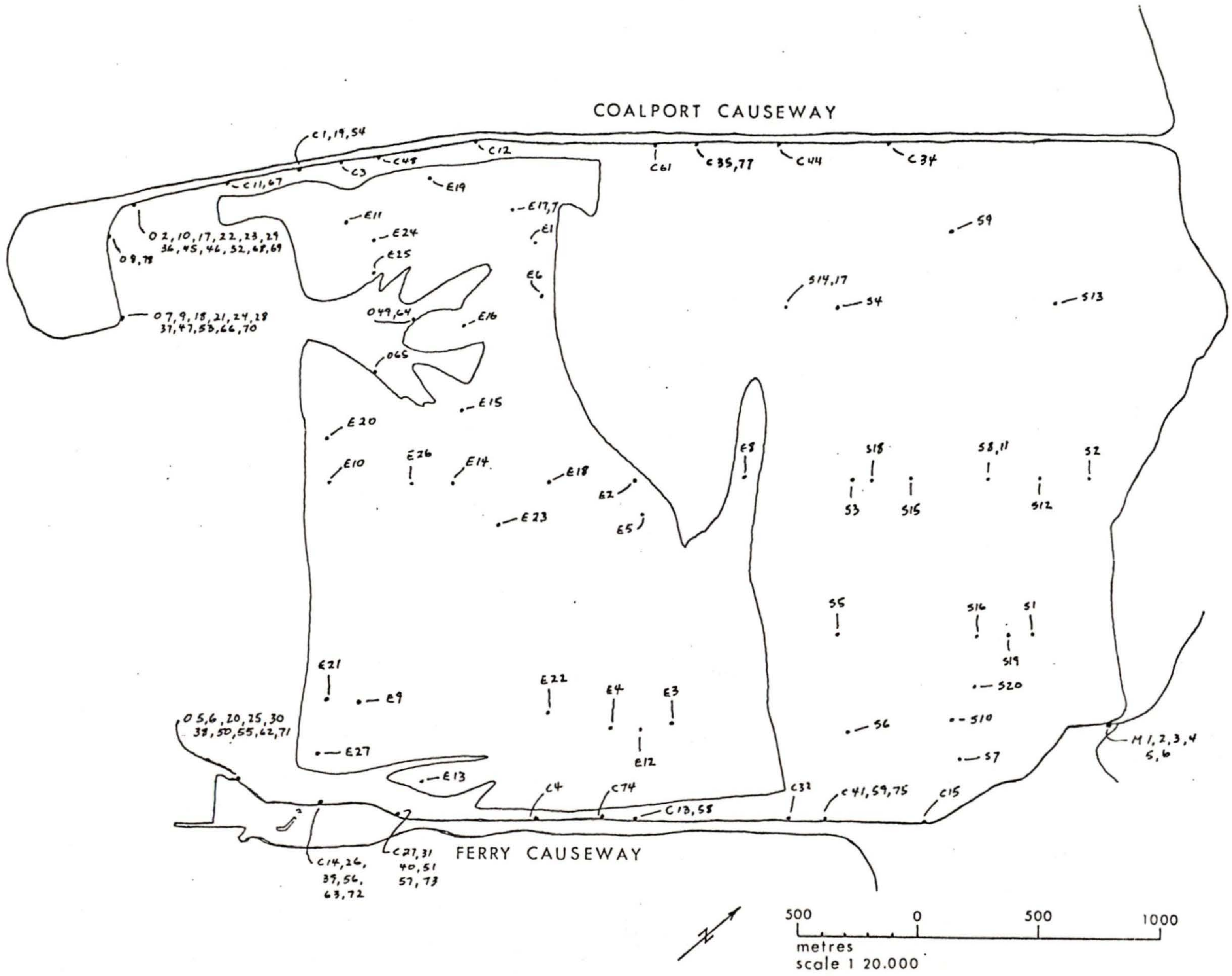
C67
C45
C75
C57
C88
C44,53,76,89
C90
C56,74
C86,100
FERRY CAUSEWAY
N
500
0
500
1000
metres
scale 1 20.000

Fig. A-2a. Locations of sample sites (1 set per site) during 9 April - 29 June, 1982.



COALPORT CAUSEWAY
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C48
C3
C11,67
C61
C35,77
C44
C34
E19
E17,7
E11
E24
E1
E25
E6
O2,10,17,22,23,29
36,45,46,52,68,69
O8,78
O7,9,18,21,24,28
37,47,53,66,70
O49,64
E16
O65
E15
E20
E10
E26
E14
E18
E2
E23
E5
E8
S9
S14,17
S4
S13
S18
S8,11
S2
S3
S15
S12
S5
S16
S1
S19
S20
S10
S6
S7
E21
E9
E22
E4
E3
E12
E27
E13
O5,6,20,25,30
38,50,55,62,71
M1,2,3,4
5,6
C4
C74
C13,58
C32
C41,59,75
C15
C14,26,
39,56,
63,72
C27,31
40,51
57,73
FERRY CAUSEWAY
N
500
0
500
1000
metres
scale 1 20.000

Fig. A-2b. Locations of sample sites (1 set per site) during 9 July - 19 Aug., 1982.

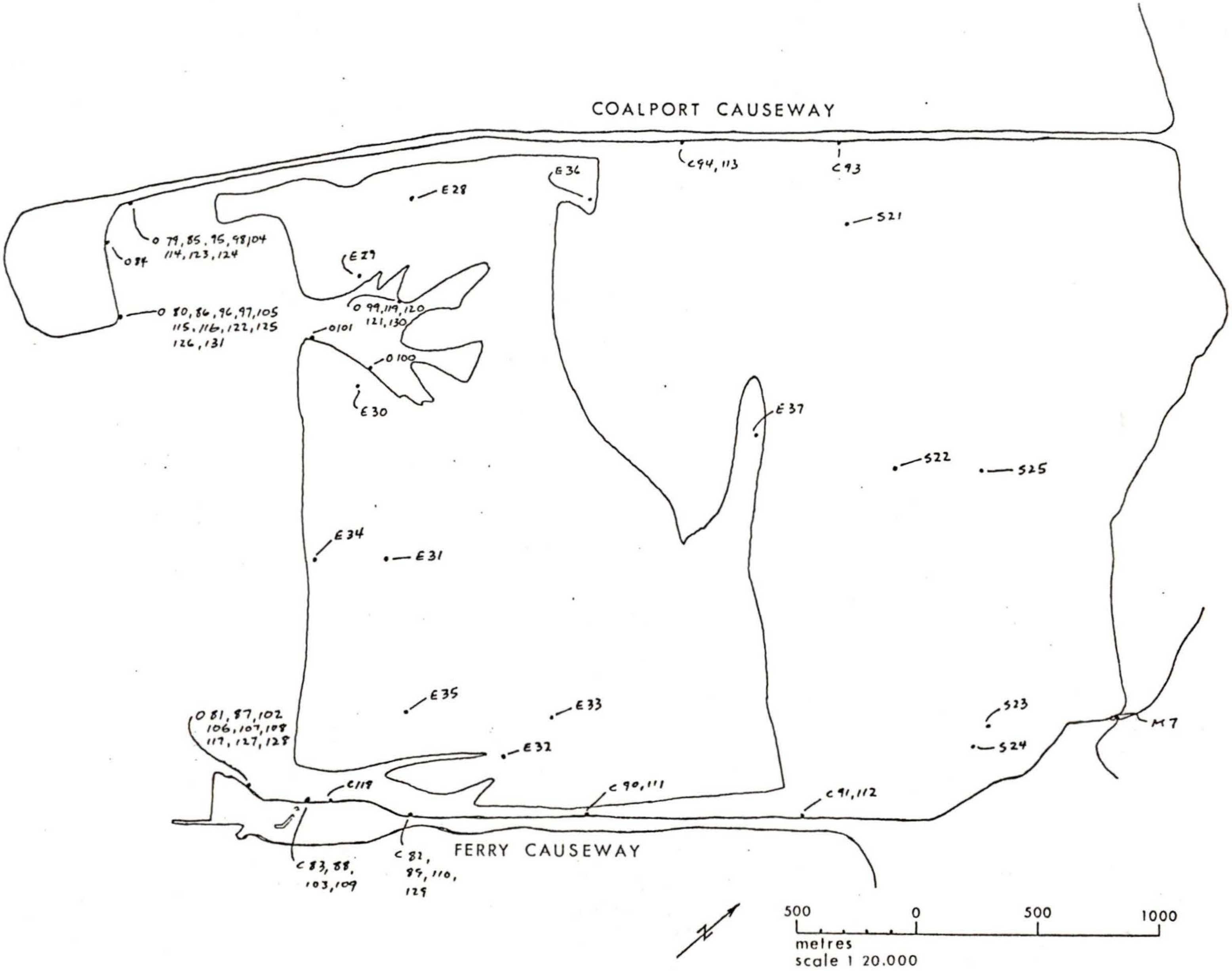
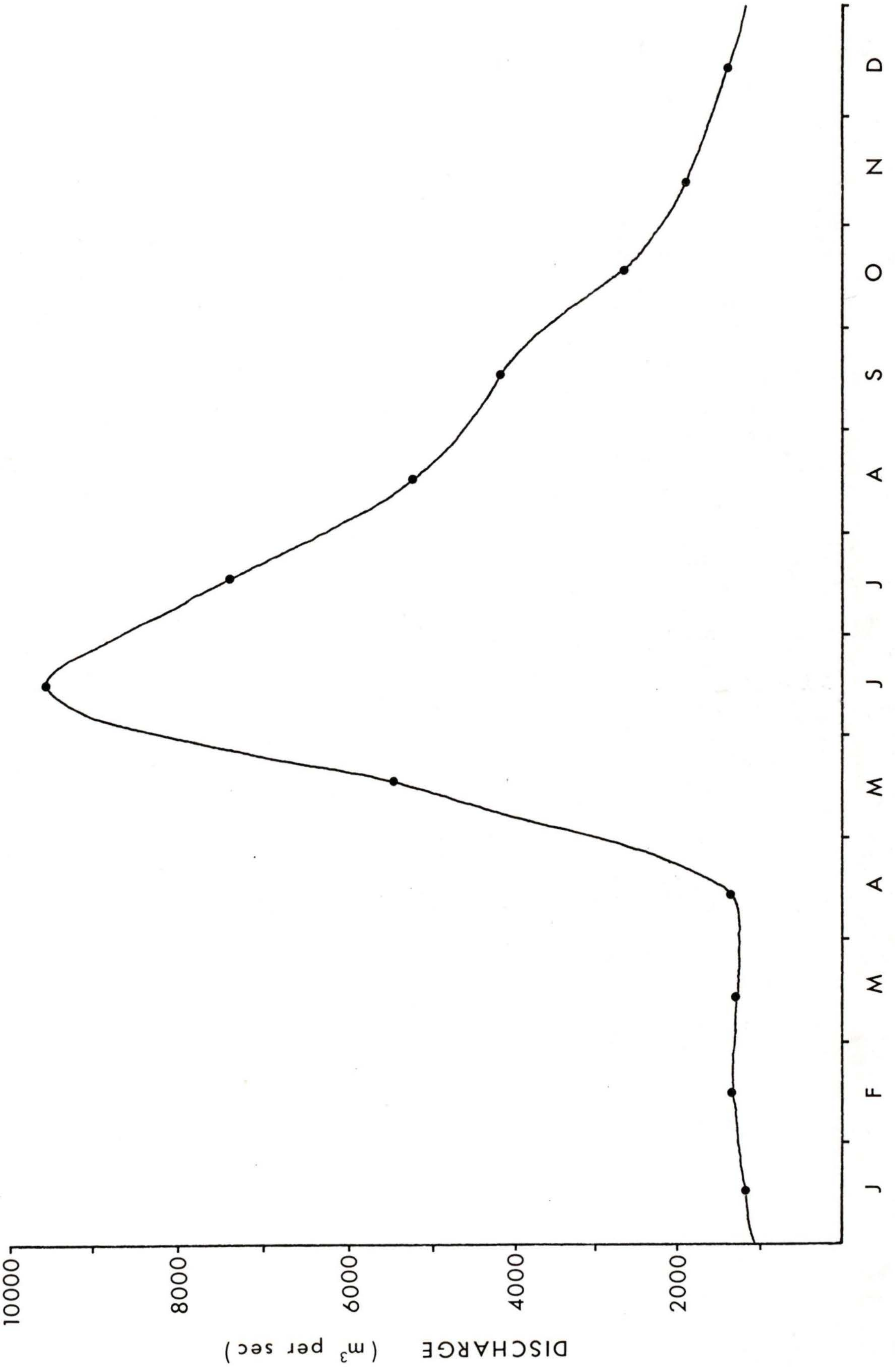

COALPORT CAUSEWAY
C94, 113
C93
E36
E28
S21
O 79, 85, 95, 98, 104, 114, 123, 124
O84
E29
O 99, 119, 120, 121, 130
O 80, 86, 96, 97, 105, 115, 116, 122, 125, 126, 131
O101
O100
E30
E37
S22
S25
E34
E31
E35
E33
S23
S24
M7
O 81, 87, 102, 106, 107, 108, 117, 127, 128
E32
C118
C90, 111
C91, 112
C83, 88, 103, 109
C82, 89, 110, 129
FERRY CAUSEWAY
N
500
0
500
1000
metres
scale 1 20.000

Fig. B-1. Mean daily discharge per month of the Fraser River at Mission for 1982 (Environment Canada 1983).


DISCHARGE (m³ per sec)
10000
8000
6000
4000
2000
J
F
M
A
M
J
J
A
S
O
N
D

VITA

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BY JUVENILE PACIFIC SALMON ON THE DELTA-FRONT
OF THE FRASER RIVER ESTUARY, BRITISH COLUMBIA

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2 October 1984
Date