Early Marine Residence, Growth, and Feeding by Juvenile Salmon in Northern Cook Inlet, Alaska

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ABSTRACT: Juvenile salmon were captured in June and July 1993 with a surface townet in the northern portion of Cook Inlet, a glacially turbid estuary. Hydroacoustic sampling indicated that most fish targets were in the top 2 m of the water column. Many salmon juveniles, particularly chinook *Oncorhynchus tshawytscha*, sockeye *O. nerka*, and coho *O. kisutch*, moved rapidly out of the sampling area, although residence in northern Cook Inlet extended into mid July. Chum salmon *O. keta* were more abundant than any other salmon species in northern Cook Inlet, and by July were widely distributed throughout the study area. Diets of juvenile salmon in June were similar to those reported in other studies, calanoid copepods, fish larvae, and other zooplankton being abundant in stomachs. Chum salmon, followed by pink salmon *O. gorbuscha*, fed most intensively. Drift insects were an important part of chum salmon diets in June and predominated the diet of all species in July. Heavy feeding on drift insects demonstrated by all juvenile salmon was probably a response to high turbidities reducing feeding efficiency and effecting a near-surface orientation. Apparent growth in chum salmon juveniles was within the reported range for other regions. During July, both chum and pink salmon juveniles rearing in northern Cook Inlet achieved growth rates and conditions comparable to those of nearby Prince William Sound, which is not glacially occluded.

INTRODUCTION

Pacific salmon juveniles feed and grow rapidly as they move through coastal estuaries toward the Pacific Ocean. In Prince William Sound, Alaska, for example, pink *Oncorhynchus gorbuscha* and chum *O. keta* salmon fry emigrate from freshwater streams to the nearshore region in April and May; they rear in the sound through early summer, leaving for open ocean by mid August after substantial growth (Wertheimer and Celewycz 1996). This early marine residence is a critical period in marine life history because most mortality suffered in the marine environment occurs during the first few months (Heard 1991; Salo 1991). Extremely rapid growth during this period reduces vulnerability to predation during the later period of residence in the open ocean.

Although patterns of habitat use by juvenile Pacific salmon have been documented in many estuaries throughout the North Pacific, studies of such habitat use within Cook Inlet are rare (Blackburn 1977). We found no such studies in northern Cook Inlet, which supports numerous stocks of salmon, including major runs in the Susitna and Chakachatna River systems and smaller runs in other drainages, including the Beluga and Little Susitna Rivers (Barrett et al. 1984, 1985; Thompson et al. 1986; Bartlett 1992). There is ample documentation of emigration from and immigration to northern Cook Inlet river systems (Roth and Stratton 1985; Roth et al. 1986), but the period immediately following entry into marine waters has not been studied. Although juveniles of all 5 eastern Pacific salmon species move through the inlet during their seaward migration, a combination of ex

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Author: LAWRENCE MOULTON is a fisheries biologist with MJM Research, 5460 NE Tolo Road, Bainbridge Island, WA 98110.

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Table 1. Number of surface trawl tows taken during sampling in northern Cook Inlet in 1993, by region and time interval.

	Period 1				Period 2		Period 3	Region
Region	Jun 3–7	Jun 8–12	Jun 13–17	Jun 18–20	Jul 8–12	Jul 13–15	Sep 8–10	Total
Susitna Delta	6	4	6	6	11	0	5	38
East Midchannel	3	5	4	2	4	3	3	24
Moose Point	2	2	2	0	3	0	2	11
Tyonek	3	3	3	4	2	1	2	18
Central Midchannel	0	6	6	4	6	4	1	27
Otter Creek	1	1	0	1	1	0	2	6
Trading Bay	0	5	11	0	8	6	7	37
West Midchannel	0	4	4	4	4	5	1	22
Boulder Point	0	1	1	1	1	1	1	6
Time Interval Total:	15	31	37	22	40	20	24	189

treme tides and high turbidity make this area unsuitable for substantial rearing opportunities. The high turbidity of northern Cook Inlet marine waters limits light penetration and retards marine productivity; Larrance et al. (1977) found that lower Cook Inlet marine productivity decreased in a northerly direction. At a station immediately south of the Forelands, the euphotic zone was extremely shallow, ranging from 1 to 3 m (Larrance et al. 1977; Atlas et al. 1983).

This study was designed to evaluate whether northern Cook Inlet marine waters serve as an important rearing environment for juvenile salmon and whether there is differential use by any particular species. Specific objectives were to examine: (1) entry timing into northern Cook Inlet waters, (2) duration of residence within estuarine habitats, (3) size and growth of juvenile salmon during early marine residence, (4) distribution and feeding intensity of juvenile salmon in inlet waters, and (5) availability of prey for juvenile salmon.

METHODS

We investigated distribution and abundance of juvenile salmon in northern Cook Inlet using trawl and hydroacoustic surveys. Samples of juvenile salmon were retained for biological analysis, including weight-length relationships. Age composition and growth characteristics were determined from length frequencies and scales. Stomach contents were analyzed to determine feeding ecology. Prey availability was examined by sampling the zooplankton community in northern Cook Inlet waters.

Field Sampling

Sampling of juvenile salmon began in the vicinity of the Susitna River and proceeded southwest to the Forelands. Sampling was conducted in both nearshore and mid-inlet waters, emphasizing the central and northwest inlet (Table 1). The surface trawl used for sampling was 6.1 m wide, 3.1 m deep, and 15 m long; stretched mesh at the mouth was 76 mm tapering to 3 mm at the cod end. The trawl was fished between 2 boats to minimize surface disturbance. Tows, 10 min in duration, followed the direction of the surface current and were supported by hydroacoustic monitoring. All tows were made during daylight hours. We used a flow meter to measure the distance covered by each tow. Sampling was conducted within 3 periods: June 3– 20, July 7–15, and September 8–10, 1993.

At the end of each tow, a profile of temperature and salinity within the top 10 m of the water column was made with a YSI Model 33[1] temperature/ salinity meter, and water clarity was measured by Secchi disk. Invertebrates caught during townet sampling were measured volumetrically and released. All salmon captured were identified to species and measured for fork length to the nearest millimeter. Up to 20 fish per tow, selected without known bias, were preserved in 10% formalin to evaluate condition and feeding. Scales were collected from all chinook *O. tshawytscha*, sockeye *O. nerka*, and coho *O. kisutch* salmon.

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[1] Mention of trade names is included for scientific completeness and does not imply endorsement.

Zooplankton were sampled with a 0.5-m-diameter plankton net constructed of 250-µm mesh. The net was lowered by hand to a depth of 20 m, or to the bottom if <20 m deep, and retrieved upwards, thus integrating the plankton density over the top 20 m of the water column. Samples were preserved in 10% formalin at the time of collection. One such zooplankton sample was taken for every townet sample conducted (Table 1).

We conducted hydroacoustic sampling in conjunction with the townet sampling during June and July. Side-looking and down-looking transducers were mounted on the same side of the boat as the townet so that all sampling was done within the same portion of the water column. The side-looking transducer was mounted on a pole and set 2 m below the water surface. The transducer was oriented to sample perpendicular to the direction of travel and angled 5^o upwards to sweep the area in front of the net. The down-looking transducer was mounted directly below the side-looking transducer. The hydroacoustic system used included a BioSonics Model ES-2000 420-kHz Dual-Beam Scientific Echosounder with two 6/15-degree circular dual-beam transducers. Data were collected using the BioSonics Model 281 Echo Signal Processor (ESP) and stored on a personal computer.

Laboratory Procedures

The fork length of each preserved salmon was remeasured in the lab to the nearest millimeter. Each fish was then weighed to the nearest 0.01 g. Scales were read under a dissecting microscope at 60x magnification. Salmon ages were determined according to the number of annuli on their scales; fish lengths were secondarily used to assist in some decisions. A salmon having a scale with 5 or fewer widely spaced circuli was classified as age 0. A salmon having a scale with 6 or more circuli before the first annulus, or circuli that were closely spaced, was classified as age 1. Plus growth on sockeye and chinook scales was rare.

A total of 426 salmon stomachs comprising 53 chinook, 120 sockeye, 40 coho, 103 pink, and 110 chum salmon were analyzed. Salmon stomachs processed were selected from trawled samples that at least contained either 4 salmon species or 2 or more sockeye salmon. All sockeye stomachs and up to 5 stomachs from each of the other salmon species were processed from each selected sample. When more than 5 of a nonsockeye species were encountered in the selected sample, the 5 to be processed were chosen randomly. The wet weight of the stomach contents was obtained prior to sorting and identification.

We processed 79 zooplankton samples by pouring each sample through a 150-µm mesh and sorting the items retained under a dissecting microscope at 10–40x magnification. All zooplankters were separated from detrital material and subsequently identified by major taxonomic group. Copepods were identified as calanoid, harpacticoid (cyclopoids were not found), or "other." Fish larvae appeared to be mostly osmerids (smelt) or Pacific herring *Clupea harengus*.

Approximately 40% of the zooplankton samples were split because of large amounts of detritus or animals. Those samples with detritus were first quick-sorted without magnification to pick out readily visible larger organisms (i.e., fish larvae, chaetognaths, insects, large amphipods). These samples were then split with either a wheel-type plankton splitter or a Hansen-Stempel pipette. Zooplankters were then sorted from each split and counted; the final numbers of animals were adjusted by the appropriate multiplier.

Analytical Techniques

The study area was stratified into 9 regions to identify areas of greatest use by migrating or rearing salmon (Figure 1). Regions along the northwest shoreline encompass the nearshore area and delta fronts of main river systems in northern Cook Inlet; most depths were between 10 and 30 m. Most of the early emigration is along this shoreline. Regions along the southeastern shoreline encompass a broad shoal area that extends from Moose Point to Boulder Point; most tows were made at depths of 15–30 m. Few salmon-producing rivers enter along the southeastern shoreline. Regions in the center inlet enabled examination of movements in offshore areas, primarily over deep water (20–50 m). To examine changes through time, data were stratified into 5-d intervals beginning June 3 and running consecutively through July 15.

A tidal-exchange index was calculated by scaling the maximum daily difference between high and low tides to the maximum annual difference. Resulting indices ranged from 0.0 on September 10, when the exchange was 6.0 m, to 1.0 on October 16, when the exchange was 11.9 m. An additional important habitat feature for juvenile salmon was the rip line between water masses. A formal classification of rips was not developed; rips were identified as being either present or absent.

Catch data were converted to catch per unit effort (CPUE) in fish per 1,000 m^2 of surface area traversed by the trawl. Because fish were oriented near the sur-

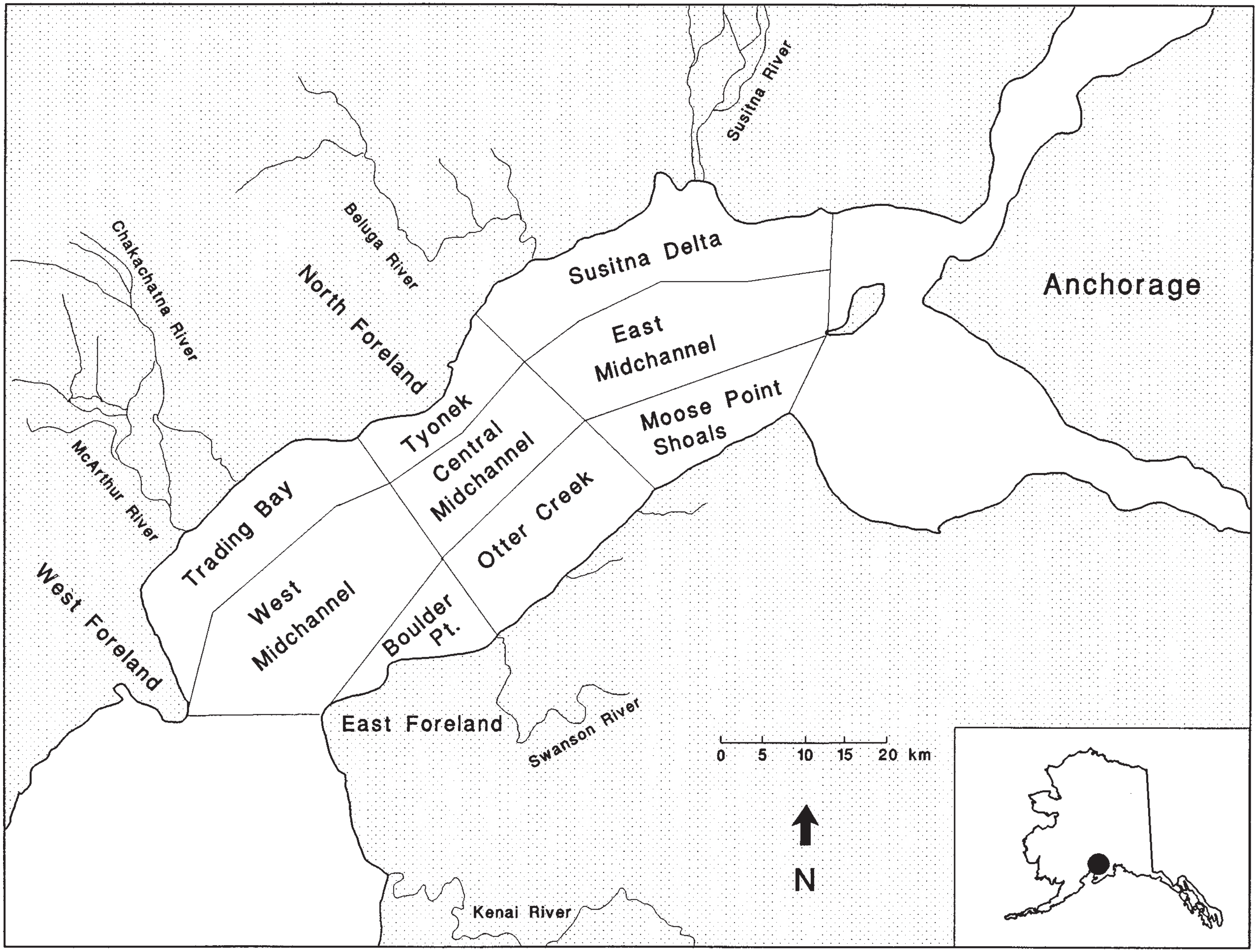

Figure 1. Northern Cook Inlet 1993 sampling area, showing regions used for analysis.

face, a volumetric correction was not used. The net was assumed to fish an effective width of 4.6 m or 75% of the net opening. The effective width was then multiplied by the individual distance, measured by flow meter, to estimate the area swept by each tow.

Primary hydroacoustic analysis consisted of selecting fish from the electronic echograms using a software program that extracts pertinent information from each fish; i.e., entrance to and exit from the beam, number of echoes, and target strength. Electronic echograms were compared to paper echograms collected during sampling to check for accuracy. Threshold levels of 0.12 volts (-60 dB) were used for the side-looking transducer and 1.5 volts (-64.5 dB) for the down-looking transducer.

Length and weight data were used to evaluate change in fish condition during the study. Regressions were calculated using log-transformed length and weight data and were compared using analysis of covariance to detect differences in slope or elevation. To facilitate interpretation of regressions, a comparison length was assigned to each group of lines being compared, and the weight associated with the comparison length was calculated for each regression. A comparison length was the rounded mean of the mean lengths for the samples used to generate the regressions. When slopes were significantly different, the length at which the 2 lines intersected was calculated to compare calculated weights.

I used correlation analysis to examine statistical relationships between CPUE and physical variables. To test for differences in length-weight relations, analysis of covariance was performed using methods described in Snedecor and Cochran (1967).

RESULTS

Physical Factors

Tidal range within Cook Inlet is among the greatest in the world. In 1993 maximum exchange (the difference between daily high and low tides) was nearly 12 m, and during the 1993 sampling, daily ranges were between 6.0 and 10.5 m. Tows had to be made with the current, and samples were arranged and conducted to avoid running upcurrent to reach sampling stations.

Water clarity, as measured by Secchi disk, was inversely correlated to tidal exchange ($r = -0.368$, 126 df, $P < 0.001$), presumably because suspended sediments increased as differentials between high and low tides increased. Turbidity was high throughout the study period; few Secchi disk readings exceeded 1 m. Water clarity increased with increasing temperature ($r = 0.432$, 123 df, $P < 0.001$) but did not show a significant relation to surface salinity ($r = 0.059$, 123 df, $P = 0.513$). This relation may reflect the low tidal exchange in July, which may have effected a reduced mixing rate of surface waters and increased deposition of suspended sediments.

Surface temperatures of 8–12°C in early June increased to 14–16°C in mid July. During June and July, surface temperature tended to be lowest in the western portion of the study area and highest near the Susitna Delta. By September, surface water temperature had decreased to 11–13°C. Surface salinity varied widely during the study. In June it was lowest, 6–13 parts per thousand (ppt) near the Susitna Delta and highest, 20–22 ppt, in the Western Midchannel region. Surface salinity was inversely correlated to surface temperature during June ($r = -0.712$, 97 df, $P < 0.001$) and July ($r = -0.705$, 59 df, $P < 0.001$). These relations reflect the discharge of fresh, relatively warm water from rivers in northern Cook Inlet, the Susitna River exerting the greatest influence.

The volume of crustaceans caught in each tow showed a significant direct correlation with the tidal-exchange index ($r = 0.398$, 64 df, $P = 0.001$) and an inverse correlation with Secchi depth ($r = -.0502$, 126 df, $P < 0.001$). The volume of crustaceans (principally crangonid shrimps, mysids, and amphipods) caught was highest in very turbid water and decreased rapidly as water clarity increased. Few crustaceans were caught when Secchi disk readings exceeded 1.0 m. The relationship between the volume of crustaceans and tidal index probably was due to increasing turbidity as the tidal index increased.

Areal and Depth Distribution of Fish in Northern Cook Inlet

Hydroacoustic sampling provided information on both areal and depth distribution of fish in the study area. Estimated fish densities were greater in June than in July, the greatest mean densities occurring along the northwest shoreline and eastern regions (Susitna Delta, Tyonek, East and Central Midchannel; Figure 1). Lowest densities were along the southeastern shoreline (Moose Point, Otter Creek, and Boulder Point).

The distribution of fish targets within the beam indicated that fish were surface-oriented. Fish densities were lowest from near the side-looking transducer out to 10 m, the deepest area sampled by the transducer. Densities increased in the 10–25-m range, where the upper edge of the beam approached the surface. In

Table 2. Catch by species and frequency of species occurrence in 190 townet samples taken in northern Cook Inlet in June, July, and September 1993.

Species		Number of Fish Caught	Percent of Total Catch	Frequency of Occurence In Nr of Tows	Frequency of Occurence In Percent
Threespine stickleback	*Gasterosteus aculeatus*	4,172	25.0	58	30.5
Pacific herring	*Clupea pallasi*	4,019	24.1	148	77.9
Pink salmon	*Oncorhynchus gorbuscha*	2,752	16.5	140	73.7
Eulachon	*Thaleichthys pacificus*	2,388	14.3	100	52.6
Chum salmon	*O. keta*	1,701	10.2	130	68.4
Walleye pollock	*Theragra chalcogramma*	447	2.7	43	22.6
Longfin smelt	*Spirinchus thaleichthys*	300	1.8	63	33.2
Saffron cod	*Eleginus gracilis*	236	1.4	29	15.3
Chinook salmon	*O. tshawytscha*	206	1.2	57	30.0
Sockeye salmon	*O. nerka*	163	1.0	74	38.9
Coho salmon	*O. kisutch*	123	0.7	46	24.2
Arctic lamprey	*Lampetra japonica*	103	0.6	53	27.9
Pacific sandfish	*Trichodon trichodon*	21	0.1	15	7.9
Pacific sandlance	*Ammodytes hexapterus*	9	0.1	9	4.7
Snake prickleback	*Lumpenus sagitta*	8	0.0	5	2.6
Capelin	*Mallotus villosus*	4	0.0	4	2.1
Starry flounder	*Platichthys stellatus*	1	0.0	1	0.5
Ninespine stickleback	*Pungitius pungitius*	1	0.0	1	0.5
Total:		16,654			

all but 2 sampling regions, fish densities increased in the 10–15-m range, peaked in the 15–20-m range, and then decreased in the 20–25-m and 25–30-m ranges, indicating that few additional fish were counted as the beam spread beyond 20 m. In the Susitna Delta region, the densities peaked at 10-15 m, whereas in the Central Midchannel, densities peaked at 20–25 m. If significant numbers of fish had been deeper in the water column, the densities would have remained high or continued to increase.

Although fish were primarily surface-oriented, there were exceptions. The most notable exceptions were during June 13–17 in the Tyonek and West Midchannel regions, when fish densities at depths of 10–20 m (1.22 and 2.14 fish per 1,000 m^3) exceeded those recorded at 0–2 m (0.65 and 2.08 fish per 1,000 m^3). The species composition of deeper targets is not known because they exceeded the depth sampled with the townet (3 m).

Catch Composition

We caught 18 fish species during the sampling program (Table 2). Threespine stickleback *Gasterosteus aculeatus* were the most abundant but were only caught in large numbers during July. Pacific herring were second in abundance, occurring in 78% of the 190 townet samples, and were present throughout the study. Eulachon *Thaleichthys pacificus* were fourth in overall abundance, but were present only for a brief time early in June.

Pink and chum salmon predominated the catch of salmonids, and the 3 species that rear in fresh water, chinook, sockeye and coho salmon, were approximately an order of magnitude less abundant (Table 2). Pink salmon were most numerous in the June 3–20 samples, occurring in over 92% of the samples and composing almost 25% of the catch. Pink salmon numbers decreased in the July 7–15 samples, whereas chum salmon numbers increased. Chum salmon were present in 82% of the July samples and 76% of the June samples.

Abundance and Distribution of Pacific Salmon

Chinook salmon juveniles were the third most abundant salmon species, 206 captured during the June and July sampling (Table 2). Mean catch rate peaked

Table 3. Mean catch rate, in fish per 1,000 m^2, and standard deviation (SD) of juvenile salmon caught during townet sampling in northern Cook Inlet, 1993.

Salmon Species		Time Interval						
		Jun 3–7	Jun 8–12	Jun 13–17	Jun 18–20	Jul 8–12	Jul 13–15	Sep 8–10
Chinook	Mean	0.23	0.17	0.40	0.25	0.38	0.79	0.00
	SD	0.32	0.44	0.94	0.41	1.37	1.81	0.00
Sockeye	Mean	0.29	0.41	0.41	0.21	0.25	0.23	0.00
	SD	0.58	0.71	0.62	0.36	0.38	0.43	0.00
Coho	Mean	0.15	0.20	0.39	0.17	0.06	0.36	0.01
	SD	0.23	0.39	0.78	0.40	0.20	0.87	0.06
Pink	Mean	5.13	6.57	8.67	2.70	1.74	5.67	0.00
	SD	5.58	7.81	15.61	2.87	2.79	7.25	0.00
Chum	Mean	0.81	2.07	2.12	2.19	1.56	9.62	0.00
	SD	1.30	3.46	5.13	2.73	1.55	21.76	0.00
Number of Tows:		15	31	37	22	41	20	24

in both mid June and mid July (Table 3). None were caught in September. Chinook salmon were primarily caught along the northwest shore and consistently in the Susitna, Tyonek, and Trading Bay regions. Offshore catches of chinook salmon were usually made along rip lines.

Chinook salmon catch rates had a significant inverse correlation with salinity (r = -0.224, 158 df, P = 0.04), and all other correlations with physical variables were not significant. The one significant correlation appears to be spurious, caused by 2 high catch rates at lower salinities and many zero values in the mid to upper salinity range.

Sockeye salmon juveniles were fourth in abundance among the 5 species of Pacific salmon (Table 2). Sockeye were caught in 44% of the samples during both June and July sampling but were not caught during September. Mean catch rates were highest from June 8 to 17, although there was not great variation among sampling intervals (Table 3).

During June, sockeye salmon were caught throughout the study area, and in July they were encountered mostly in the eastern and middle inlet. Sockeye catch rates were not correlated to any measured physical variable.

Coho salmon were the least abundant salmon species in the samples (Table 2) and the only salmon species caught in September. Mean catch rates were highest in mid June (June 13–17) and in mid July (Table 3). Coho salmon catches were scattered throughout the study area, the highest catches recorded near the Susitna Delta (Susitna Delta, East Channel, and Tyonek regions).

Pink salmon were the most abundant salmon species, particularly during June, when 75% of the pink salmon catch was obtained (Table 2). Pink salmon abundance decreased by July, when they were present in 70% of the tows, compared to 92% in the previous period. Mean catch rates peaked in mid June (Table 3).

Pink salmon were most abundant during mid June near the Susitna river mouth, although they were abundant throughout the study area. A large catch in a single tow in the Eastern Midchannel region accounted for the high catch observed in mid July. Pink salmon showed a significant inverse correlation with time (r= -0.243, 164 df, P=0.002), indicating a general decrease in abundance throughout the sampling period. Correlations with physical variables were not significant.

Chum salmon were the second most abundant salmon species and were the predominant salmon species in July samples (Table 2). Mean catch rates were low at the start of the survey, rose to a constant level through June and early July, and then increased in mid July (Table 3). During June, chum salmon were clustered near the Susitna Delta, whereas in July they were widespread and found in all regions. As with pink salmon, a large catch in a single tow in the Eastern Midchannel region accounted for the high mid-July catch in that region.

Chum salmon catch rates were significantly correlated with all measured physical variables. Chum catch rates were directly correlated with time (r = 0.209, 164 df, P=0.007) and surface temperature (r= 0.327, 158 df, P<0.001) and inversely correlated with surface salinity (r=-0.272, 158 df, P<0.001) and tidal

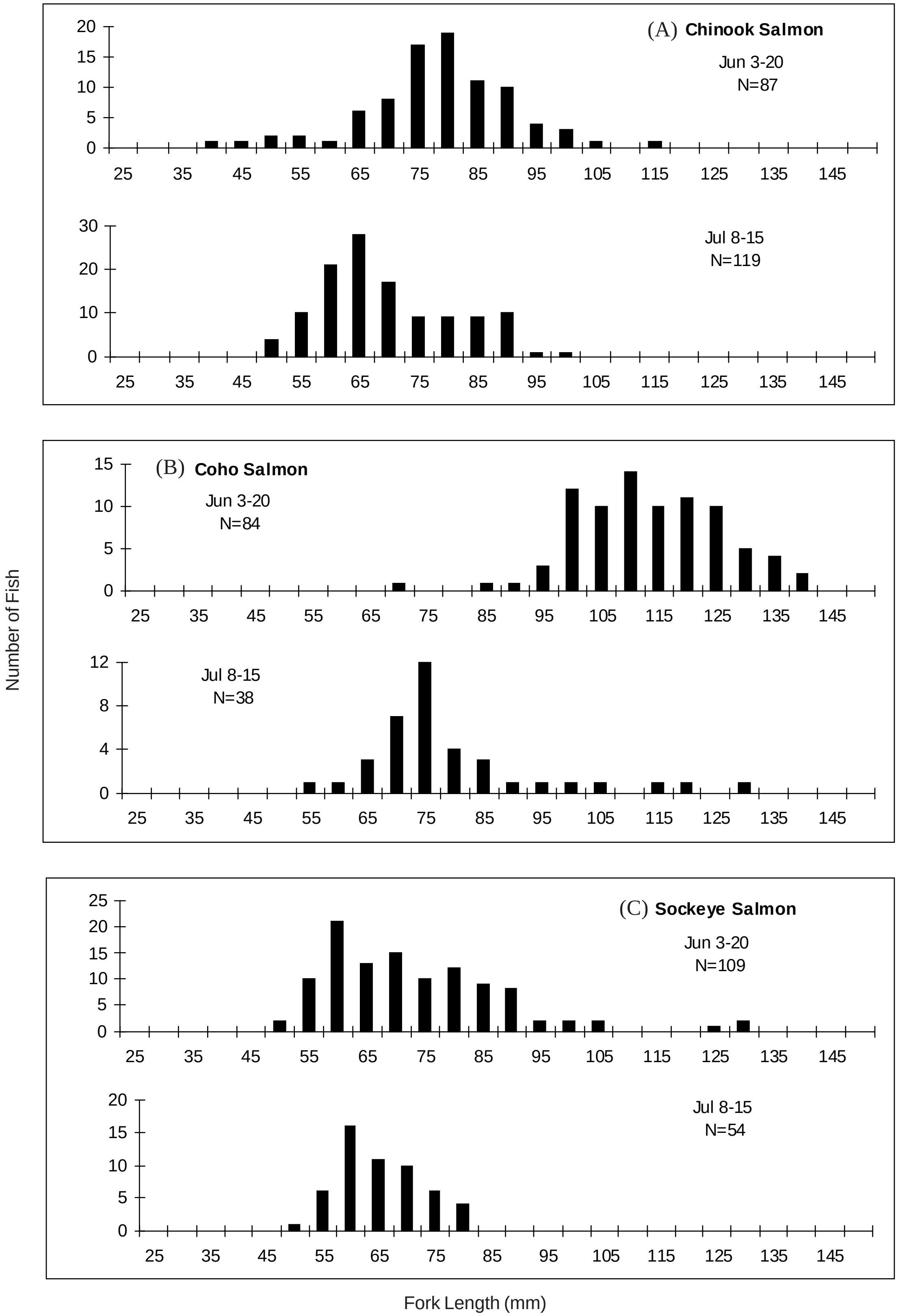

Figure 2. Length frequencies of (A) chinook, (B) coho and (C) sockeye salmon by sample period, northern Cook Inlet, 1993.

Table 4. Age-length summary by time interval for juvenile chinook, sockeye, and coho salmon captured in northern Cook Inlet, June 3–July 15, 1993.

Species	Time Interval	Age	Number of Fish	Mean Length (mm)	Standard Deviation	Minimum (mm)	Maximum (mm)
Chinook	Jun 3–20	0.0	1	69.0	—	69	69
		0.1	73	81.4	9.5	56	115
		0.2	7	93.3	9.1	80	109
	Jul 7–15	0.0	43	61.7	4.7	50	69
		0.1	74	76.0	9.5	57	100
		0.2	7	87.1	3.0	83	90
Sockeye	Jun 3–20	0.0	1	61.0	—	61	61
		0.1	101	74.5	14.9	53	131
		0.2	5	92.8	20.9	74	128
	Jul 7–15	0.0	28	64.5	5.2	53	76
		0.1	23	70.3	7.9	57	84
		0.2	3	78.3	5.5	73	84
Coho	Jun 3–20	0.0	0	—	—		
		0.1	58	112.5	13.4	71	144
		0.2	26	121.1	10.3	100	141
	Jul 7–15	0.0	4	70.3	10.8	55	78
		0.1	23	80.4	10.8	65	115
		0.2	5	109.4	18.0	85	130

index ($r = -0.204$, 164 df, $P = 0.008$). Although some correlations appear to be driven by 1 or 2 high values, they reflect increasing abundance of chum salmon during the July sampling.

Size and Age Structure

During June, chinook salmon were primarily 70–90 mm long, and few individuals were outside that range (Figure 2). In July, 2 size modes were apparent, one at 50–70 mm and a second at 75–90 mm. Examination of scales indicated that chinook salmon captured in June were primarily age 1, and those captured in July comprised ages 0 and 1 (Table 4). In both cases, age-2 chinook salmon were present in low numbers. For all 3 age groups, mean size at age decreased between the June and July sampling periods. Mean lengths were greatest in the Susitna, Tyonek, and Central Midchannel regions. The smallest chinook salmon were in the Trading Bay and West Midchannel regions.

Juvenile sockeye salmon covered a broad range of sizes with no dominant modes. Age 1 predominated in June, ages 0 and 1 being caught in similar numbers in July (Table 4). As with chinook salmon, mean size at age decreased from June to July, although there was considerable overlap as indicated by standard deviations. There was no consistent trend in size among various regions.

The change in size structure between sampling periods was more dramatic for coho salmon than for other species. Coho salmon were primarily >95 mm in June but between 65 and 85 mm in July. The June samples were ages 1 and 2, whereas most July samples were age 1 (Table 4). Mean size of each age group again decreased with time. There was no consistent trend in size among various regions.

Size of pink salmon juveniles was stable during June, virtually all fish being <40 mm (Figure 3). Mean length in all 4 time intervals during June ranged from 35.9 to 36.3 mm (Table 5). In July, however, larger individuals were present, and by the last interval in mid July, fish >40 mm outnumbered those <40 mm. Mean length by the end of July was 41.5 mm. Mean lengths were similar in all regions in June; however, in July mean lengths were greater in the western regions (Central Midchannel, Otter Creek, Trading Bay, and West Midchannel) than in the eastern regions.

Examination of daily mean lengths revealed no apparent growth during June 8–20, as opposed to an apparent growth of 0.55 mm·d^{1} in July (Figure 4). The lack of apparent growth in June was probably due to a continuous inflow of small emigrat-

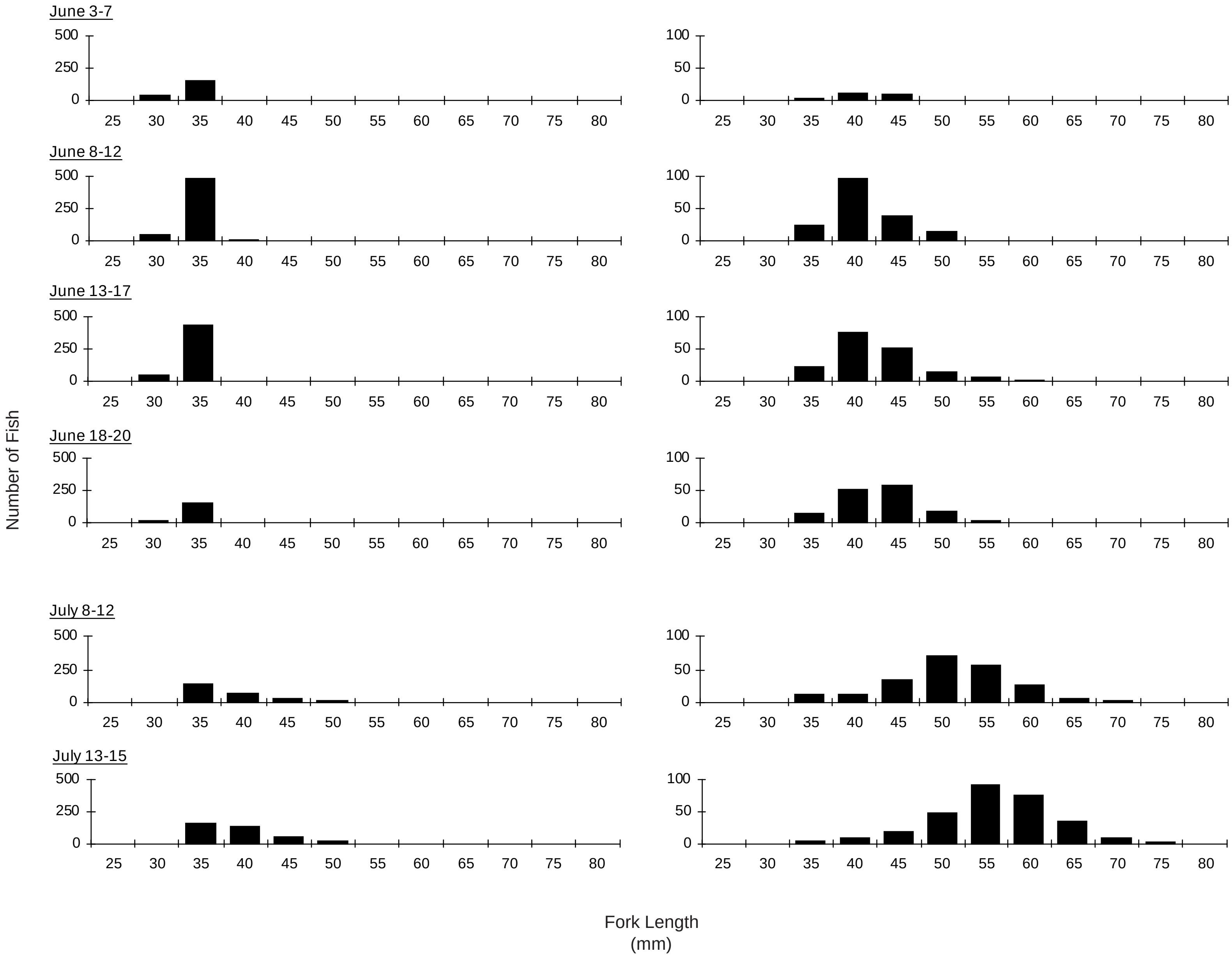

Figure 3. Length frequencies of pink and chum salmon by time interval, northern Cook Inlet, 1993.

Table 5. Mean length of pink and chum salmon by time interval from townet sampling in northern Cook Inlet, 1993.

	Pink Salmon			Chum Salmon		
Time Interval	Number of Fish	Mean Length (mm)	Standard Deviation	Number of Fish	Mean Length (mm)	Standard Deviation
Jun 3–7	197	35.9	1.7	30	43.6	4.2
Jun 8–12	552	36.3	1.4	178	43.1	4.0
Jun 13–17	490	36.1	1.4	177	44.5	4.9
Jun 18–22	191	36.0	1.7	147	45.1	4.5
Jun 23–Jul 7			No Sampling			
Jul 8–12	255	39.8	4.2	226	52.7	6.9
Jul 13–17	383	41.5	4.9	289	57.7	7.1

ing pink salmon during June, thus masking any growth that may have occurred.

Chum salmon showed a different pattern than other salmon species, with steady increases in size during the study (Figure 3; Table 5). After the second 5-d interval, when mean length was 43.1 mm, there was a progression to larger sizes in each succeeding interval through the end of the July sampling, when mean length had increased to 57.7 mm. As with pink salmon, mean lengths were similar in all regions in June but in July were greater in the western regions (Trading Bay and West Midchannel) than in the eastern regions.

Examination of daily mean lengths revealed an apparent growth rate of 0.23 mm·d^{-1} during the June 8–20 period, as opposed to an apparent growth of 1.15 mm·d^{-1} in July (Figure 4). The increase in apparent growth in July was probably induced largely by cessation of freshwater emigration, which would reduce the numbers of small fish entering the sampled population. Growth rates may also have increased because of warmer water temperatures.

Food Availability and Feeding Habits

Plankton samples were predominated by calanoid copepods, fish larvae, spionid worms, and mysids (Table 6). Several types of invertebrate eggs were also abundant. Mean density of calanoid copepods increased 4-fold from June to July, although much of this apparent increase was from one high-density sample encountered in the East Channel region during July. Other regions, such as Tyonek and Trading Bay, did not show a similar response. Density of adult dipterans and homopterans on the inlet surface increased over 10-fold from the June to July samples, East Channel and Trading Bay regions showing the greatest increase. Other adult drift insects increased 6-fold. Density of surface insects is described as number per unit area because they were essentially surface drift.

Mean density of calanoid copepods increased steadily through the summer. Densities of fish larvae, principally herring and eulachon, and surface insects increased through June; fish larvae decreased in July, whereas insects peaked in early July and then decreased.

Considerable interspecific variability in diets was noted, as well as intraspecific variations among periods. Diets tended to be diverse in June, with many taxonomic groups present. Major groups in June were dipterans, homopterans, and other assorted insects; calanoid copepods; fish larvae; and barnacle cyprids. Insects were present in just over 52% of the chum salmon stomachs examined from June. June samples of coho salmon had a high frequency of fish, probably pink and chum salmon fry, although most specimens were too well digested to conclusively identify. July samples showed greater contrast, with dipterans/homopterans predominating stomach contents of all salmon species except pink salmon (Table 7). Even though calanoid copepods predominated numerically in pink salmon stomachs, dipterans/homopterans occurred in 64% of the stomachs from July and probably contributed greater biomass because of the variation in size of individual organisms.

A detailed examination of insect taxa revealed that homopteran aphids predominated stomach contents in all 5 salmon species; numerically, >50% of all insects consumed were adult aphids, except in coho salmon (49%). Adult dipterans were second in abundance; all other taxa were present in much lower numbers.

In general, the weight of stomach contents expressed as a percent of body weight (an index of stomach fullness) increased through June, reached a peak in early July, then decreased in mid July for all species but coho salmon (Figure 5).

The fullness index in chinook juveniles was significantly correlated to the densities of 3 prey categories in numbers per 100 m^3: dipterans and homopterans ($P = 0.019$), other insects ($P = 0.01$) and all insects ($P = 0.002$; $r = 0.517$, 0.562 and 0.646, respectively, 18 df). Insects were major contributors to the July diet of chinook salmon. Fullness index in pink salmon was significantly correlated to the densities of 4 prey categories: calanoid copepods ($P = 0.033$), fish larvae ($P = 0.028$), other insects (= 0.007), and all insects ($P = 0.004$; $r = 0.504$, 0.518, 0.611, and 0.649, respectively, 16 df). Calanoid copepods and fish larvae were major components of the pink salmon diet in June, and insects increased in July. The fullness index for chum salmon was significantly correlated to densities of 3 prey categories: fish larvae ($P = 0.002$), other insects ($P = 0.022$), and all insects ($P = 0.041$; $r = 0.604$, 0.477, 0.417, respectively, 21 df). Fish larvae were major components of chum salmon diets in June and July; insects increased in July. Stomach fullness indi-

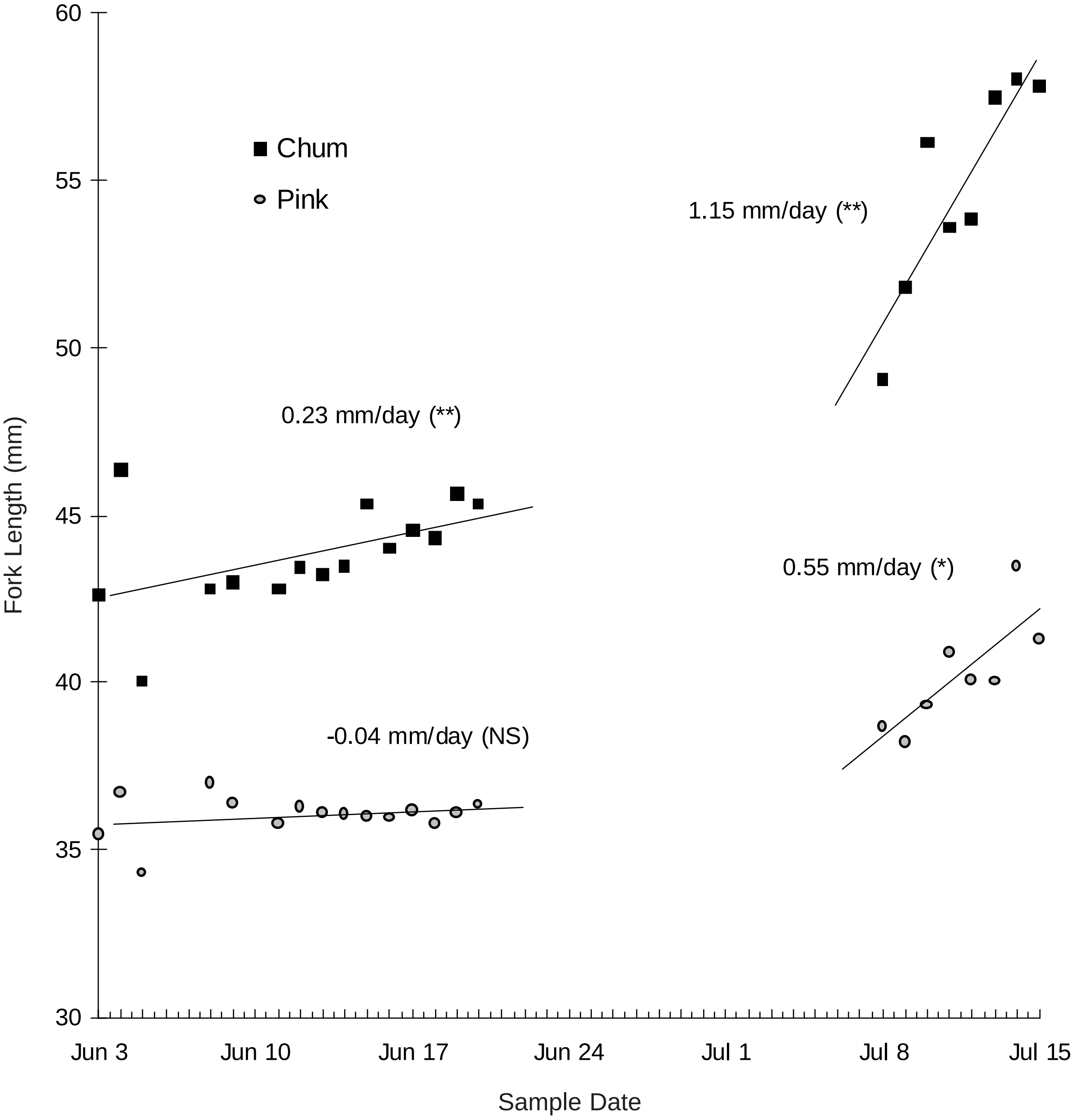

Figure 4. Mean fork lengths by sample day and associated growth-per-day estimates for pink and chum salmon juveniles, northern Cook Inlet, 1993 (NS = correlation not significant, * = significant at $P < 0.05$, * = significant at $P < 0.01$).

Table 6. Mean density of planktonic organisms by sampled period in northern Cook Inlet, June 3 – July 15, 1993.

	June 3-20 (mean of 48 samples)			July 7-15 (mean of 30 samples)		
Taxon	Nr per 100 m^3	Nr·m^{-2}	Percent Frequency	Nr per 100 m^3	Nr·m^{-2}	Percent Frequency
Calanoids	12,800.8		95.8	52,264.0		100.0
Fish Larvae	2,004.9		77.1	413.3		83.3
Spionid Larvae	362.5		79.2	314.2		83.3
Invert. Egg 1	323.7		72.9	13.8		33.3
Harpacticoids	173.0		52.1	20.8		23.3
Mysids	99.5		83.3	65.9		76.7
Barnacle Cyprids	92.6		45.8	15.6		33.3
Amphipods	27.6		47.9	49.6		43.3
Polychaete Larvae	26.5		54.2	5.9		30.0
Shrimp	17.8		31.3	1.6		10.0
Invert. Egg 2	15.1		39.6	4.3		10.0
Invert. Egg 3	14.5		27.1	30.0		6.7
Barnacle Nauplii	14.0		25.0	120.2		50.0
Euphausids	7.9		8.3	0.6		3.3
Other Insects[a]	6.5	1.6	18.8	30.9	10.0	40.0
Cumaceans	5.2		14.6	0.5		3.3
Isopods	3.4		18.8	8.7		26.7
Chaetognath	2.2		10.4	67.0		53.3
Other Copepods	2.2		6.3	7.6		10.0
Dipterans + Homopterans[a]	2.1	0.6	4.2	31.5	8.3	23.3
Pycnogonids	1.7		8.3	4.1		13.3
Nematodes	1.4		2.1	1.0		6.7
Ostracods	0.0		0.0	0.5		3.3
Crab Larvae	0.0		0.0	2.6		13.3

[a] All insects were drifting on the surface, so the nr·m^{-3} is somewhat misleading; as such insects were also reported in nr·m^{-2}. "Other insects" included the following: coleopterans, hemipterans, lepidopterans, neuropterans, plecopterans, psocopterans, thysanopterans, trichopterans.

ces of sockeye and coho salmon did not show any significant correlation with prey density.

Mean stomach fullness index was greatest in the Tyonek region for chinook and sockeye salmon, in the Trading Bay region for pink salmon, and in the Central Midchannel region for coho salmon (Table 8). Chum salmon fullness indices were equally high in Tyonek and Trading Bay and were the highest observed in any species. Coho salmon had the lowest mean values, followed by sockeye salmon. In all species the stomach fullness index increased from June to July (Table 9).

Analysis of Condition

We compared weight-length regressions for each species to evaluate changes in condition through the study period (Table 10). For chinook salmon, condition was similar across all intervals, although some significant differences were detected (Table 11). The primary differences were between Interval 2 and Intervals 4, 8, and 9. Examination of sample mean lengths and calculated weights indicate that chinook salmon in Interval 2 were composed of relatively small fish of low weight, possibly the result of a recent emigration.

Sockeye salmon showed significant differences in condition between June (Intervals 1-4) and July (Intervals 8 and 9), but mean lengths decreased between the 2 periods (Table 11). There were also significant differences between Interval 4 and Intervals 2 and 3; Interval 4 sockeye salmon were heavier at the comparison length, which may reflect the greater feeding intensity observed in Interval 4.

Condition in coho salmon from July samples tended to be different from June samples. Coho salmon caught in July were substantially smaller and younger than those caught in June, as reflected in the mean length (Table 10). Coho salmon from Interval 9 were noticeably lighter at the comparison length than those from earlier intervals, whereas those from Interval 3 had the lowest condition among the coho groups analyzed.

The condition of pink salmon among the first 3 intervals was statistically similar, after which all in-

Table 7. Composition of stomach contents for juvenile salmon caught in northern Cook Inlet, by sample period, June 3 – July 15, 1993.

Sample Period:	June 3–20				July 7–15			
Food Item	Number	Percent by Nr	Occurrences	Frequency of Occur. (%)	Number	Percent by Nr	Occurences	Frequency of Occur. (%)
Chinook Salmon Stomachs:	(33 examined, 6 empty)				(20 examined, 0 empty)			
Dipterans + Hemipterans	19	10.4	5	15.2	471	93.8	17	85.0
Other Insects	13	7.1	5	15.2	22	4.4	4	20.0
Calanoids	1	0.5	1	3.0	0	0.0	0	0.0
Fish	1	0.5	1	3.0	0	0.0	0	0.0
Fish Larvae	144	78.7	4	12.1	0	0.0	0	0.0
Mysids	3	1.6	3	9.1	1	0.2	1	5.0
Amphipods	2	1.1	1	3.0	6	1.2	4	20.0
Nematodes	0	0.0	0	0.0	2	0.4	2	10.0
Total Nr	183		33		502		20	
Sockeye Salmon Stomachs:	(84 examined, 9 empty)				(36 examined, 0 empty)			
Dipterans + Hemipterans	117	10.1	17	20.2	471	67.6	21	58.3
Other Insects	172	14.8	22	26.2	167	24.0	13	36.1
Calanoids	254	21.9	10	11.9	38	5.5	5	13.9
Harpacticoids	304	26.2	3	3.6	0	0.0	0	0.0
Other Copepods	22	1.9	2	2.4	2	0.3	1	2.8
Fish	5	0.4	4	4.8	0	0.0	0	0.0
Fish Larvae	236	20.3	3	3.6	3	0.4	1	2.8
Mysids	6	0.5	4	4.8	0	0.0	0	0.0
Amphipods	14	1.2	5	6.0	7	1.0	5	13.9
Barnacle Nauplii	1	0.1	1	1.2	0	0.0	0	0.0
Barnacle Cyprids	8	0.7	4	4.8	0	0.0	0	0.0
Crab Larvae	0	0.0	0	0.0	5	0.7	1	2.8
Chaetognath	1	0.1	1	1.2	0	0.0	0	0.0
Invertebrate Eggs	21	1.8	2	2.4	1	0.1	1	2.8
Nematodes	1	0.1	1	1.2	3	0.4	3	8.3
Total Nr	1162		84		697		36	
Coho Salmon Stomachs:	(35 examined, 4 empty)				(5 examined, 0 empty)			
Dipterans + Hemipterans	5	7.4	5	14.3	63	96.9	5	100.0
Other Insects	10	14.7	8	22.9	0	0.0	0	0.0
Calanoids	32	47.1	2	5.7	0	0.0	0	0.0
Fish	16	23.5	12	34.3	0	0.0	0	0.0
Mysids	1	1.5	1	2.9	1	1.5	1	20.0
Shrimp	1	1.5	1	2.9	0	0.0	0	0.0
Invertebrate Eggs	0	0.0	0	0.0	1	1.5	1	20.0
Nematodes	3	4.4	1	2.9	0	0.0	0	0.0
Total Nr	68		35		65		5	

— continued —

Table 7 (continued).

Sample Period:	June 3–20				July 7–15			
Food Item	Number	Percent by Nr	Occur- rences	Frequency of Occur. (%)	Number	Percent by Nr	Occur- ences	Frequency of Occur. (%)
Pink Salmon Stomachs:	(64 examined, 1 empty)				(39 examined, 3 empty)			
Dipterans + Hemipterans	31	1.7	11	17.2	322	13.1	25	64.1
Other Insects	25	1.4	9	14.1	45	1.8	4	10.3
Calanoids	1385	76.0	16	25.0	2064	83.9	25	64.1
Harpacticoids	32	1.8	8	12.5	4	0.2	3	7.7
Other Copepods	58	3.2	3	4.7	1	0.0	1	2.6
Fish Larvae	253	13.9	5	7.8	9	0.4	5	12.8
Mysids	0	0.0	0	0.0	1	0.0	1	2.6
Amphipods	0	0.0	0	0.0	3	0.1	3	7.7
Barnacle Cyprids	36	2.0	11	17.2	0	0.0	0	0.0
Crab Larvae	0	0.0	0	0.0	2	0.1	2	5.1
Cumaceans	1	0.1	1	1.6	1	0.0	1	2.6
Spionid Larvae	0	0.0	0	0.0	1	0.0	1	2.6
Invertebrate Eggs	1	0.1	1	1.6	6	0.2	1	2.6
Nematodes	0	0.0	0	0.0	1	0.0	1	2.6
Total Nr	1822		64		2460		39	
Chum Salmon Stomachs:	(61 examined, 1 empty)				(49 examined, 1 empty)			
Dipterans + Hemipterans	120	12.9	23	37.7	1163	76.6	39	79.6
Other Insects	54	5.8	20	32.8	227	15.0	9	18.4
Calanoids	511	54.8	12	19.7	66	4.3	16	32.7
Harpacticoids	12	1.3	5	8.2	0	0.0	0	0.0
Other Copepods	1	0.1	1	1.6	1	0.1	1	2.0
Fish Larvae	178	19.1	8	13.1	41	2.7	15	30.6
Mysids	1	0.1	1	1.6	1	0.1	1	2.0
Amphipods	0	0.0	0	0.0	11	0.7	9	18.4
Barnacle Cyprids	54	5.8	10	16.4	0	0.0	0	0.0
Ostracods	0	0.0	0	0.0	2	0.1	2	4.1
Crab Larvae	1	0.1	1	1.6	2	0.1	1	2.0
Cumaceans	1	0.1	1	1.6	1	0.1	1	2.0
Nematodes	0	0.0	0	0.0	3	0.2	3	6.1
Total Nr	933		61		1518		49	

terval comparisons were significantly different. Condition early in the study reflects emigrating fry, evidenced by the small mean length and low slope values. The later values (Interval 4 in late June and Intervals 8 and 9 in July) reflect increasing condition as the fry began to feed and convert to a marine condition.

The condition of chum salmon followed a pattern similar to that of pink salmon, i.e., condition early in the study reflected emigrating fry, and later values (Interval 4 in late June and Intervals 8 and 9 in July) reflected increasing condition as the fry began to feed and convert to marine condition.

Pink and chum salmon were present in sufficient numbers to evaluate differences in condition across the study area within intervals. For pink salmon, fish in the eastern portion of the study area (Susitna Delta, East Midchannel, and Moose Point regions) were significantly different from fish in the central and western portions (Table 12). In 4 cases (Intervals 2, 3, 8, and 9), pink salmon from the Eastern region were lighter than the other regions at the comparison length, but in Interval 4 they were heavier. This general pattern is consistent with fish entering from the Susitna and other northern Cook Inlet rivers and rearing as they move south and west. The Interval 4 results may reflect a period when emigration rates were low and primarily rearing fish were captured.

Chum salmon did not show significant differences in condition among regions during Intervals 2 and 3, but differences were significant during Intervals 4, 8,

Table 8. Mean stomach fullness (MSF; weight of stomach contents as percent of body weight) and standard deviation (SD) by region for juvenile salmon captured in northern Cook Inlet, 1993.

		Region									
Salmon Species		Susitna Delta	East Midchannel	Moose Point	Tyonek	Central Midchannel	Otter Creek	Trading Bay	West Midchannel	Boulder Point	Overall:
Chinook	*n*	9	8	0	10	4	0	21	1	0	53
	MSF	0.69	1.45	—	2.05	1.89	—	0.86	1.75	—	1.45
	SD	0.61	1.70	—	1.32	1.39	—	1.22		—	0.56
Sockeye	*n*	20	22	2	16	27	0	24	9	0	120
	MSF	1.38	1.01	1.70	1.75	1.20	—	1.22	1.57	—	1.40
	SD	1.51	1.01	2.09	1.67	2.04	—	1.54	2.41	—	0.28
Coho	*n*	7	10	0	7	4	0	11	1	0	40
	MSF	0.98	0.50	—	0.65	1.88	—	0.98	0.20	—	0.87
	SD	0.83	0.69	—	0.87	1.28	—	1.01		—	0.58
Pink	*n*	15	22	0	20	10	0	20	16	0	103
	MSF	0.70	1.93	—	2.90	1.37	—	3.43	1.40	—	1.95
	SD	0.34	2.20	—	1.86	1.07	—	2.44	0.94	—	1.03
Chum	*n*	22	17	0	19	18	0	19	15	0	110
	MSF	2.33	2.01	—	3.98	2.33	—	3.97	1.79	—	2.74
	SD	2.49	1.73	—	3.50	2.55	—	2.50	1.38	—	0.98

and 9 (Table 12). The pattern was not as consistent as that for pink salmon. During July (Intervals 8 and 9), the heaviest fish at the comparison length were in the western area.

DISCUSSION

Effectiveness of Gear Types

The townet proved to be an efficient sampling tool in northern Cook Inlet because of the surface orientation of the fish. The results from the hydroacoustic sampling indicated that most fish were in the top 2 m of the water column, and the townet readily fished the top 3 m. High turbidities probably effected surface orientation of the fish and reduced net avoidance.

Hydroacoustic sampling was not particularly effective for studying juvenile salmon in northern Cook Inlet because of small target sizes, near-surface orientation, lack of large and well-defined schools, and the noisy environment. Pink and chum salmon were at the lower end of the detectable range for much of the study, and their surface orientation made them difficult to separate from surface noise. When winds exceeded 5.0 $\mathrm{m \cdot sec^{-1}}$, the side-looking transducer was ineffective. Rip noise and woody debris also rendered the side-looking transducer ineffective, and fish were often concentrated in such areas.

Emigration Timing and Period of Residence

The appearance of juvenile salmon in northern Cook Inlet was generally consistent with timing reported for smolts emigrating from the Susitna River, where emigration from streams begins in late May and peaks in June (Roth and Stratton 1985; Roth et al. 1986). I initiated sampling to immediately follow expected onset of emigration from the streams; thus, the initial appearance of smolts into the estuarine environment was not established. The initial catches of juvenile salmon were consistent and often highest in the Susitna Delta and East Midchannel regions, indicating proximity to the source river.

The emigration of pink and chum salmon from northern Cook Inlet streams occurs substantially later than in Prince William Sound. Pink salmon in Prince William Sound enter the marine environment from mid April to late May (Sharp et al. 1993); chum salmon probably enter at a similar time because they are caught with pink salmon in the marine environment during late April and May (Sturdevant et al. 1996).

The 3 rearing species, i.e., chinook, sockeye and coho salmon, apparently moved through northern Cook Inlet quickly, based on their catch pattern, age composition, and size changes. Catches of these species were low throughout the area, although consistent catches of chinook and sockeye salmon were made along the northwest shore. Sockeye salmon also taken in the offshore regions. Older fish appeared first in the catches,

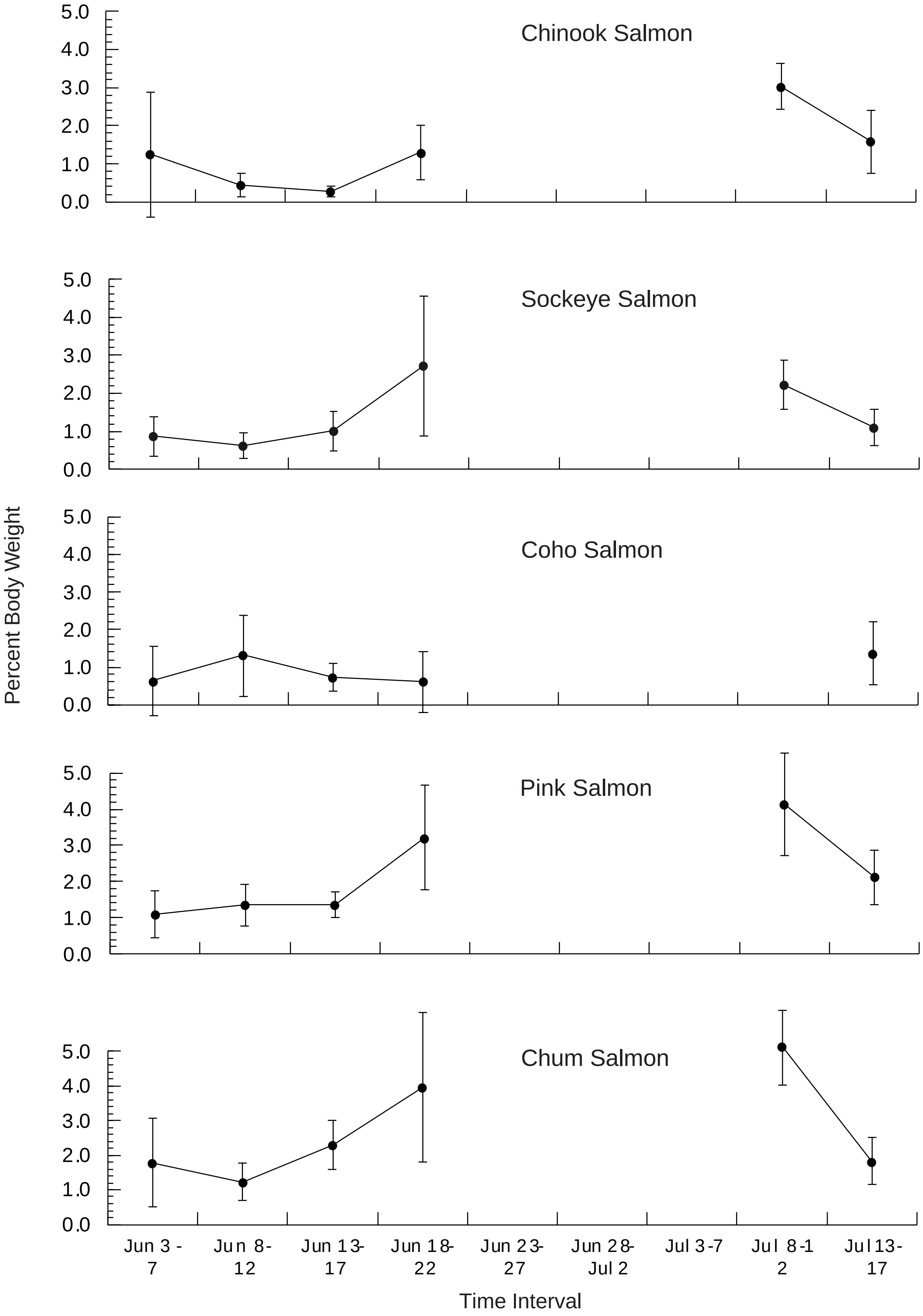

Figure 5. Seasonal change in stomach contents as percent of body weight in juvenile salmon during June and July, 1993.

Table 9. Mean stomach fullness (expressed as percent of body weight represented by stomach contents) by time interval for juvenile salmon captured in northern Cook Inlet, 1993.

Species	Time Interval	Mean Sample Size	Stomach Fullness	Standard Deviation
Chinook	Jun 3-20	33	0.55	0.68
	Jul 7-15	20	2.38	1.31
Sockeye	Jun 3-20	84	1.10	1.72
	Jul 7-15	36	1.79	1.40
Coho	Jun 3-20	35	0.80	0.93
	Jul 7-15	5	1.36	0.93
Pink	Jun 3-20	64	1.60	1.47
	Jul 7-15	39	2.90	2.41
Chum	Jun 3-20	61	2.19	2.31
	Jul 7-15	49	3.50	2.78

followed by younger fish, which is consistent with emigration patterns previously described (Roth and Stratton 1985; Roth et al. 1986). There was little evidence of apparent growth in these species. Mean sizes reflected change in age structure in that fish caught later in the study period were smaller than fish caught earlier. Had there been any significant residence time, mean size should have increased, which it did not, except for a minor increase in the size of age-0 chinook salmon during July.

Pink salmon also moved rapidly out of the sampling area, particularly in June when almost all were <40 mm and mean size remained 36 mm throughout the period. In July, however, the pink salmon juveniles grew to a mean of 40–41 mm. Condition indicated that pink salmon during the first 3 intervals (June 3–17) had not fed sufficiently to increase body mass, but condition noticeably increased by the June 18–20 interval. Distribution of sizes in the study area indicated that larger pink salmon in July were in the western portion of the study area (West Midchannel and Boulder Point), reaching eastward to Tyonek and Central Midchannel. These fish also had significantly higher condition than fish in the eastern portion of the study area. It is possible some of these fish were redistributing back into the northern inlet after some rearing south of the Forelands. The period of residence in northern Cook Inlet thus extended into mid July and probably continued into late July.

Chum salmon used the northern Cook Inlet region more than any other species of salmon. Growth was detected by mid June and was obvious in July. Chum were also widely distributed throughout the study area by July and were feeding heavily. Intensity of feeding was higher in chum salmon than for any other salmon species in all regions and periods. As with pink salmon, the largest chum salmon captured during July tended to be in the western portion of the study area, which may reflect fish moving back into the northern inlet after rearing south of the Forelands. Condition of chum salmon increased significantly by mid July, and there was no indication that their numbers were declining.

Distribution of Juvenile Salmonids

Salmon juveniles were widespread and abundant throughout the sampling region, as reflected by the catch of juvenile salmon in 161 of the 166 townet samples taken in June and July. The juveniles were not evenly distributed, as discussed above, but it was clear that all portions of the sampling area were used to some extent. The lack of extremely large catches indicates that juvenile salmon were not forming large schools, as supported by visual observations. Juvenile pink and chum salmon were observed near the surface as small aggregations, often in groups of 10–50 fish.

Hydroacoustic data suggested that most juvenile salmon were oriented near the surface. The diet of the juvenile salmon also reflected a surface orientation because of the preponderance of drift (i.e., surface) insects in stomach contents. Turbulent mixing could move some drift insects to deeper water, but their abundance should be greatest near the surface.

Juvenile pink and chum salmon were observed in association with rip lines or remnants of rips and around floating debris. When startled, they would move to deeper water, apparently using turbidity as cover. Kittiwakes and phalaropes were frequently observed feeding along rip lines, thus the behavior of diving to deeper and more turbid water was appropriate behavior to escape these surface predators.

The greatest and most diverse catches were made in association with rip lines. Tidal rips often contained floating debris, which offered cover. Birds were most frequently seen diving into or drifting with rip lines. Tows made directly in rip lines produced the largest catches and often contained 4 or 5 salmon species. It is not clear if smaller salmon species, such as pink and chum salmon, sought out rip lines or were entrained by the moving water mass and carried along. Larger species, such as coho and possibly chinook and larger sockeye salmon, presumably had greater ability to avoid rips if desired. The rips, however, concentrated prey items as well and provided greater feeding opportunities for fish in the vicinity.

Table 10. Length-weight regressions of juvenile salmon by species for each time interval, northern Cook Inlet 1993, based on log-transformed lengths and weights and calculated weights at comparison lengths.

Salmon Species	Time Interval	Slope	Intercept	*r*	df	Sample Mean Length (mm)	Calculated Wt (g) at Comparison Length[a]
Chinook	Jun 3–7	3.013	-4.957	0.973	6	83.0	4.72
	Jun 8–12	3.150	-5.222	0.992	12	73.8	4.64
	Jun 13–17	3.123	-5.166	0.989	45	79.2	4.69
	Jun 18–20	3.190	-5.279	0.997	15	70.4	4.84
	Jul 8–12	3.109	-5.124	0.992	52	67.7	4.87
	Jul 13–15	3.016	-4.957	0.991	63	69.7	4.80
Sockeye	Jun 3–7	3.074	-5.143	0.978	8	74.9	3.38
	Jun 8–12	3.075	-5.150	0.979	33	71.8	3.34
	Jun 13–17	3.079	-5.147	0.995	47	71.5	3.42
	Jun 18–20	2.786	-4.590	0.995	13	70.1	3.56
	Jul 8–12	3.128	-5.187	0.963	34	64.9	3.83
	Jul 13–15	3.237	-5.395	0.986	16	64.0	3.78
Coho	Jun 3–7	2.695	-4.283	0.998	4	116.8	12.80
	Jun 8–12	3.028	-4.981	0.985	15	108.5	11.87
	Jun 13–17	2.761	-4.440	0.982	47	112.1	12.08
	Jun 18–20	3.110	-5.139	0.993	10	103.6	12.07
	Jul 8–12	3.131	-5.172	0.997	6	76.3	12.28
	Jul 13–15	2.902	-4.754	0.993	28	78.3	11.25
Pink	Jun 3–7	2.101	–3.746	0.791	144	35.9	0.35
	Jun 8–12	2.335	-4.102	0.805	287	36.3	0.36
	Jun 13–17	2.183	-3.871	0.702	263	36.1	0.36
	Jun 18–20	2.687	-4.602	0.811	125	36.0	0.41
	Jul 8–12	3.092	-5.206	0.946	244	39.8	0.44
	Jul 13–15	3.356	-5.650	0.968	230	41.5	0.41
Chum	Jun 3–7	2.906	-4.891	0.949	28	43.6	0.99
	Jun 8–12	3.433	-5.754	0.971	145	43.1	1.04
	Jun 13–17	3.310	-5.560	0.971	117	44.5	1.01
	Jun 18–20	3.127	-5.207	0.958	145	45.1	1.12
	Jul 8–12	3.301	-5.486	0.983	224	52.7	1.16
	Jul 13–15	3.185	-5.310	0.975	189	57.7	1.11

[a] Comparison mean lengths were 74 mm for chinook, 70 mm for sockeye, 100 mm for coho, 37 mm for pink, and 48 mm for chum salmon.

Prey Composition and Availability

The diet composition of juvenile salmon captured in June was similar to that reported from other studies: calanoid copepods, fish larvae, and other zooplankton being important components of the diet in sockeye, pink, and chum salmon; fish larvae and drift insects in chinook salmon; and fish and drift insects in coho salmon. However, occurrence of drift insects in the June diets appeared high compared to other studies (Burgner 1991; Heard 1991; Salo 1991; Healey 1991; Sandercock 1991). The extreme predominance of drift insects in July samples for all salmon species was even more unusual. For example, in a review of 20 studies of juvenile pink salmon diets, only 3 showed significant occurrence of insects (Heard 1991), but many reported heavy feeding on calanoid copepods and other zooplankton (Cooney et al. 1981; Heard 1991; Sturdevant et al. 1996).

Dipterans were the predominant prey in chum salmon juveniles in Kotzebue Sound, however, and were also common, but not predominant, in chum salmon diets from Prince William Sound and the Fraser River estuary (Cooney et al. 1981; Salo 1991; Sturdevant et al. 1996). A more typical diet for chum salmon includes harpacticoid copepods, calanoid cope-

Table 11. Summary of length-weight comparisons between time intervals for salmon juveniles collected in northern Cook Inlet, 1993.

Species	Comparison[a,b]	Interval 1[b]	Interval 2	Interval 3	Interval 4	Interval 8
Chinook						
	Interval 2	ns				
	Interval 3	ns	ns			
	Interval 4	ns	*	ns		
	Interval 8	ns	*	*	ns	
	Interval 9	ns	*	ns	* s / 70.3	ns
Sockeye						
	Interval 2	ns				
	Interval 3	ns	ns			
	Interval 4	ns	*	** s	80.0	
	Interval 8	**	**	**	* s / 56.3	
	Interval 9	*	**	**	** s / 61.3	ns
Coho						
	Interval 2	ns				
	Interval 3	ns	ns			
	Interval 4	ns	ns	* s / 100.7		
	Interval 8	* s / 109.9	ns	* s / 95.7	ns	
	Interval 9	**	*	**	*	ns

[a] Interval 1 = June 3-7
Interval 2 = June 8-12
Interval 3 = June 13-17
Interval 4 = June 18-20
Interval 8 = July 8-12
Interval 9 = July 13-15

[b] *=significant at 0.05; **= significant at 0.01; s = significant difference in slopes / numeric value = length intersect for comparisons with significant slope differences.

pods, and other pelagic and epibenthic zooplankton in addition to drift insects. Similarly, insects were an important component of the diet in sockeye juveniles from the Strait of Georgia (Burgner 1991) but did not predominate to the extent observed in the northern Cook Inlet.

Predominance of insects in the diet is more commonly reported in early marine residence of chinook salmon than in the other species (Healey 1991). Coho salmon typically feed more on marine invertebrates, switching, as they grow, to small fish, particularly chum and pink salmon fry (Sandercock 1991).

Heavy feeding on drift insects is probably a result of high turbidities, hence reduced light penetration, in northern Cook Inlet. The mean Secchi disk reading was 0.38 m in June and 0.68 m in July. In June 5% of the Secchi disk readings exceeded 1.0 m, whereas in July almost 30% equaled or exceeded 1.0 m. These high turbidities and the resulting low light penetration retard marine productivity (Larrance et al. 1977) and restrict prey options. The result is a near-surface orientation, suggesting reliance on or preference for food sources found near or at the surface. A similar pattern of near-surface distribution in a highly turbid rearing environment has been described for sockeye juveniles in Tustumena Lake (Kyle 1992).

Growth of Pink and Chum Salmon

The apparent growth in pink salmon for July, 0.55 $\text{mm}\cdot\text{d}^{-1}$, is below that reported for other regions (Heard 1991) and may indicate continuing emigration from fresh water or emigration of larger fish from the study area. Continuing emigration from fresh water would inject small fish into the population, while emigration of large fish would leave small fish behind, thus obscuring real growth. In British Columbia, growth rates of 0.87 and 0.97 $\text{mm}\cdot\text{d}^{-1}$ have been reported (Heard 1991), and in Prince William Sound apparent growth for pink salmon juveniles caught by townets averaged 0.97 $\text{mm}\cdot\text{d}^{-1}$ (Brannon et al. 1995).

Condition of pink salmon caught in northern Cook Inlet during June reflected the low condition of fry emigrating from fresh water, but condition increased substantially by July (Figure 6). During July, when

Table 12. Length-weight relationships for chum and pink salmon juveniles caught in northern Cook Inlet, by time interval and region, 1993.

Interval	Zone[a]	Slope	Intercept	*r*	df	Sample Mean Length (mm)	Comparison Length (mm)	Calculated Wt (gm) at Comparison Length	Significant Differences in Regression[b]	Intersect[c] (mm)
Pink Salmon										
Jun 8-12	East	2.091	-3.736	0.781	124	34.2	34.0	0.29	**	
Jun 8-12	Mid	2.248	-3.964	0.746	88	34.3	34.0	0.30	**	
Jun 8-12	West	2.495	-4.340	0.863	71	35.0	34.0	0.30		
Jun 13-17	East	2.236	-3.966	0.696	104	34.3	34.0	0.29	*	
Jun 13-17	Mid	2.065	-3.687	0.831	29	34.1	34.0	0.30	**	
Jun 13-17	West	2.323	-4.076	0.741	125	34.2	34.0	0.30		
Jun 18-20	East	2.483	-4.279	0.781	33	34.3	34.0	0.33	*	34.0
Jun 18-20	Mid	3.378	-5.651	0.900	40	34.0	34.0	0.33	**s	
Jun 18-20	West	1.872	-3.369	0.741	48	34.0	34.0	0.31	**s	32.8
Jul 8-12	East	3.226	-5.435	0.909	81	36.8	38.0	0.46	**	
Jul 8-12	Mid	2.939	-4.946	0.970	53	39.1	38.0	0.50	**	
Jul 8-12	West	3.000	-5.056	0.948	106	37.8	38.0	0.48		
Jul 13-15	East	3.554	-5.986	0.967	101	39.0	41.0	0.56	**s	49.4, 49.0
Jul 13-15	Mid	3.119	-5.250	0.977	38	41.2	41.0	0.60	**s	
Jul 13-15	West	3.029	-5.099	0.975	87	42.6	41.0	0.61		
Chum Salmon										
Jun 8-12	East	3.455	-5.787	0.972	87	41.2	41.0	0.61		
Jun 8-12	Mid	3.380	-5.664	0.968	28	41.6	41.0	0.61		
Jun 8-12	West	3.366	-5.653	0.969	26	40.7	41.0	0.60		
Jun 13-17	East	3.266	-5.495	0.972	49	44.8	44.5	0.78		
Jun 13-17	Mid	3.013	-5.055	0.981	5	46.6	44.5	0.81		
Jun 13-17	West	3.436	-5.761	0.966	59	42.2	44.5	0.80		
Jun 18-20	East	3.181	-5.284	0.967	86	42.6	43.0	0.82		
Jun 18-20	Mid	2.934	-4.884	0.960	24	43.4	43.0	0.81	**	
Jun 18-20	West	3.108	-5.207	0.960	31	42.7	43.0	0.74	**	
Jul 8-12	East	3.322	-5.525	0.987	115	49.1	50.0	1.31		
Jul 8-12	Mid	3.370	-5.617	0.978	37	51.3	50.0	1.28	**	
Jul 8-12	West	3.210	-5.317	0.983	68	50.8	50.0	1.37	**	
Jul 13-15	East	3.299	-5.519	0.976	76	55.4	56.0	1.77	*	59.9
Jul 13-15	Mid	2.985	-4.961	0.982	35	56.1	56.0	1.81	**	
Jul 13-15	West	3.110	-5.167	0.977	74	56.8	56.0	1.86		

[a] Zones:
East = Susitna Delta, East Midchannel and Moose Point regions
Mid = Tyonek, Central Midchannel, and Otter Creek regions
West = Trading Bay, West Midchannel, and Boulder Point regions

[b] significant differences in slope indicated by "s"; all others are significant differences in intercept.
* = $p<0.05$; ** = $p<0.01$; brackets indicate line pairs that are significantly different.

[c] Intersect = length at which regression lines intersect when slopes are significantly different.

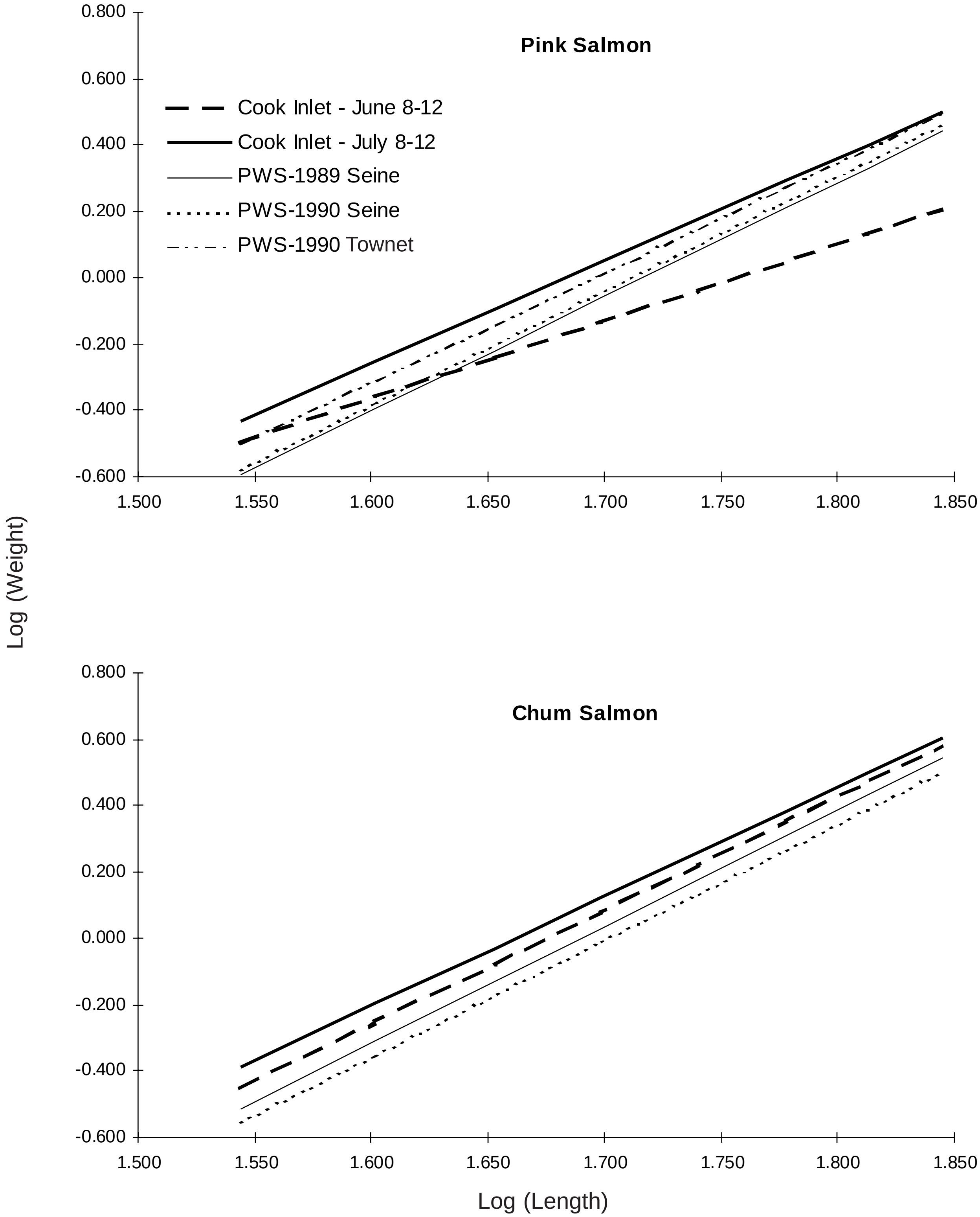

Figure 6. Comparison of length-weight relationships for pink and chum salmon juveniles, 35–70 mm fork length, from northern Cook Inlet and Prince William Sound (Wertheimer and Celewycz 1996).

many rearing juveniles (as opposed to emigrating fry) were present, the condition of the fish exceeded that of pink salmon juveniles from Prince William Sound. Some of the difference appeared to be related to gear differences; i.e., pink salmon from Prince William Sound caught by seines had lower weight-length relationships than fish caught by townets (Brannon et al. 1995; Wertheimer and Celewycz 1996).

Apparent growth in chum salmon juveniles, 1.15 $mm\cdot d^{-1}$ during July, is within the reported range. Daily length change is reported to average 1.0 $mm\cdot d^{-1}$, ranging from 0.75 to 1.7 $mm\cdot d^{-1}$ (Salo 1991). Condition of chum salmon in northern Cook Inlet was greater than the condition of those caught in Prince William Sound during 1989 and 1990 (Figure 6), but some of the difference may be related to the types of collection gear used. Pink salmon taken in seines in Prince William Sound had a lower condition than those taken in townets the same year. Part of the difference in chum salmon condition may result from such gear biases. It is clear, however, that rearing chum and pink salmon juveniles studied in northern Cook Inlet achieved growth and condition comparable to that of Prince William Sound.

Size differences are also caused by later emigration from fresh water in northern Cook Inlet. Pink salmon juveniles caught by townets in Prince William Sound averaged 70 mm by June 20 (Brannon et al. 1995), whereas those from northern Cook Inlet averaged 36 mm on the same date. Because growth rates during summer appear similar, juvenile chum and pink salmon from northern Cook Inlet may either migrate to the open ocean at a smaller size or at a later time than those that had an extra month or two of growth in Prince William Sound or lower portions of Cook Inlet.

LITERATURE CITED

Atlas, R. M., M. I. Venkatesan, I. R. Kaplan, R. A. Feely, R. P.Griffiths, and R. Y. Morita. 1983. Distribution of hydrocarbons and microbial populations related to sedimentation processes in lower Cook Inlet and Norton Sound, Alaska. Arctic 36:251–261.

Barrett, B. M., F. M. Thompson, and S. N. Wick. 1984. Adult anadromous fish investigations: May–October 1983. Alaska Department of Fish and Game, Susitna River Aquatic Studies Program, Report 1, Anchorage.

Barrett, B. M., F. M. Thompson, and S. N. Wick. 1985. Adult salmon investigations: May–October 1984. Alaska Department of Fish and Game, Susitna River Aquatic Studies Program, Report 6, Anchorage.

Bartlett, L. D. 1992. Creel, escapement, and stock statistics for coho salmon on the Little Susitna River, Alaska, during 1991. Alaska Department of Fish and Game, Division of Sport Fish, Fishery Data Series 92-24, Anchorage.

Blackburn, J. E. 1977. Pelagic and demersal fish assessment in the lower Cook Inlet estuary system. Pages 483–526 *in* Annual reports of principal investigators for the year ending March 1977, volume 10. Environmental assessment of the Alaskan continental shelf, outer continental shelf environmental assessment program, U.S. Department of Commerce and U.S. Department of Interior, Boulder, Colorado.

Brannon, E. J, L. L. Moulton, L. G. Gilbertson, A. W. Maki, and J. R. Skalski. 1995. An assessment of oil spill effects on pink salmon populations following the *Exxon Valdez* oil spill — Part I: early life history. Pages 548–584 *in* P. G. Wells, J. N. Butler, and J. S. Hughes, editors. *Exxon Valdez* oil spill: fate and effects in Alaskan waters. American Society for Testing and Materials, ASTM STP 1219, Philadelphia, Pennsylvania.

Burgner, R. L. 1991. Life history of sockeye (*Oncorhynchus nerka*). Pages 3–117 *in* C. Groot and L. Margolis, editors. Pacific salmon life histories. UBC Press, Vancouver, British Columbia.

Cooney, R., D. Urquhart, and D. Barnard. 1981. The behavior, feeding biology, and growth of hatchery released pink and chum salmon fry in Prince William Sound, Alaska. University of Alaska Fairbanks, Alaska Sea Grant College Program, Report 81-5, Fairbanks.

Healey, M. C. 1991. Life history of chinook salmon (*Oncorhynchus tshawytscha*). Pages 313–393 *in* C. Groot and L. Margolis, editors. Pacific salmon life histories. UBC Press, Vancouver, British Columbia.

Heard, W. R. 1991. Life history of pink salmon (*Oncorhynchus gorbuscha*). Pages 119–230 *in* C. Groot and L. Margolis, editors. Pacific salmon life histories. UBC Press, Vancouver, British Columbia.

Kyle, G. B. 1992. Summary of sockeye salmon (*Oncorhynchus nerka*) investigations in Tustumena Lake, 1981–1991. Alaska Department Fish and Game, FRED Division Report 122, Juneau.

Larrance, J. D., D. A. Tennant, A. J. Chester, and P. A. Ruffio. 1977. Phytoplankton and primary productivity in the northeast Gulf of Alaska and lower Cook Inlet. Pages 2–64 *in* Annual reports of principal investigators for the year ending March 1977, volume 10. Environmental assessment of the Alaskan continental shelf, outer continental shelf environmental assessment program, U.S. Department of Commerce and U.S. Department of Interior, Boulder, Colorado.

Roth, K. J., D. C. Gray, J. W. Anderson, A. C. Blaney, and J. P. McDonell. 1986. The migration and growth of juvenile salmon in the Susitna River, 1985. Alaska Department of Fish and Game, Susitna River Aquatic Studies Program, Report 14, Anchorage.

Roth, K. J., and M. E. Stratton. 1985. The migration and growth of juvenile salmon in the Susitna River. Resident and juvenile anadromous fish investigations (May–October 1984), part 1. Alaska Department of Fish and Game, Susitna River Aquatic Studies Program, Report No. 7, Anchorage.

Salo, E. O. 1991. Life history of chum salmon (*Oncorhynchus keta*). Pages 231–309 *in* C. Groot and L. Margolis, editors. Pacific salmon life histories. UBC Press, Vancouver, British Columbia.

Sandercock, F. K. 1991. Life history of coho salmon (*Oncorhynchus kisutch*). Pages 397–445 *in* C. Groot and L. Margolis, editors. Pacific salmon life histories. UBC Press, Vancouver, British Columbia.

Sharp, D., C. Peckham and J. Smith. 1993. Application of half length coded-wire tags to wild and hatchery pink salmon fry in Prince William Sound, 1989–1991. Pages 108–111 *in Exxon Valdez* oil spill symposium abstract book. Exxon Valdez Oil Spill Trustee Council, Anchorage, Alaska.

Snedecor, G. W., and W. G. Cochran. 1967. Statistical methods, 6th edition. Iowa State University Press, Ames.

Sturdevant, M. V., A. C. Wertheimer, and J. L. Lum. 1996. Diet of juvenile pink and chum salmon in oiled and non-oiled nearshore habitats in Prince William Sound, 1989 and 1990. Pages 578–592 *in* S. D. Rice, R. B. Spies, D. A. Wolfe, and B. A. Wright, editors. Proceedings of the *Exxon Valdez* oil spill symposium. American Fisheries Society Symposium 18, Bethesda, Maryland.

Thompson, F. M., S. N. Wick, and B. L. Stratton. 1986. Adult salmon investigations: May–October 1985. Alaska Department of Fish and Game, Division of Commercial Fisheries, Technical Data Report 13, Anchorage.

Wertheimer, A. C., and A. G. Celewycz. 1996. Abundance and growth of juvenile pink salmon in oiled and non-oiled locations of western Prince William Sound after the *Exxon Valdez* oil spill. Pages 518–532 *in* S. D. Rice, R. B. Spies, D. A. Wolfe, and B. A. Wright, editors. Proceedings of the *Exxon Valdez* oil spill symposium. American Fisheries Society Symposium 18, Bethesda, Maryland.