SIZE AND DIET OF JUVENILE PACIFIC SALMON DURING SEAWARD MIGRATION THROUGH A SMALL ESTUARY IN SOUTHEASTERN ALASKA

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ABSTRACT

To assess competition and predation among juvenile Pacific salmon (*Oncorhynchus* spp.) migrating through the estuary of Porcupine Creek, a small stream in southeastern Alaska, their size and diet were determined in 1979 and 1981. Mean fork length (FL) during May and June increased from 32 to 73 mm (1.5 mm/day) for pink salmon, *O. gorbuscha*; from 39 to 51 mm (0.4 mm/day) for chum salmon, *O. keta*; and during June and July, from 99 to 165 mm (1.6 mm/day) for coho salmon, *O. kisutch*. Prey, in order of importance, included larval fish (mostly Gadidae), larval molluscs (Mesogastropoda), and calanoid copepods for pink salmon; larval molluscs, larvaceans, and hyperiid amphipods for chum salmon; and fish (*Clupea harengus pallasi*, *Ammodytes hexapterus*, and Gadidae), insects, and larval decapods (Brachyrhyncha) for coho salmon. No pink or chum salmon were found in the coho salmon stomachs. Prey size for pink and chum salmon was similar (median, 0.4 mm long for both species), and much smaller than that of coho salmon (median, 2.3 mm). Diet overlap was greater between pink and chum salmon than between either species and coho salmon. Pink salmon, however, ate almost exclusively (95%) pelagic prey, whereas chum salmon ate both pelagic (74%) and epibenthic (26%) prey. Rapid early growth and differences in diet probably help minimize predation and competition among salmon during seaward migration.

The early marine life stage of juvenile Pacific salmon (*Oncorhynchus* spp.), during transition from freshwater to seawater, is important in determining brood-year survival and subsequent adult returns (Manzer and Shepard 1962; Parker 1968); their survival rate is lowest during this time (Parker 1968; Bax 1983). Salmon often school in large concentrations in estuaries as they migrate seaward, and are more likely to deplete food supplies and compete for food than after they disperse to the sea (Bailey et al. 1975; Feller and Kaczynski 1975). Survival depends on size (Parker 1971; Healey 1982), and competition for food can depress early growth (Peterman 1984) and prolong vulnerability to predators (Taylor 1977; Walters et al. 1978). Size and diet of juvenile salmon in an estuary, therefore, determine the potential for predation and competition and can greatly affect survival.

As salmon aquaculture expands and more juvenile salmon are released into estuaries, competition and predation among salmon may increase (Johnson 1974). To optimize hatchery production and avoid adversely affecting wild stocks, an understanding is needed of how different stocks of salmon interact in estuaries. This paper compares size and diet of juvenile pink, *O. gorbuscha*; chum, *O. keta*; and coho, *O. kisutch*, salmon to assess potential predation and competition between the species during their seaward migration through the estuary of a small, pristine stream.

STUDY AREA

This study was conducted in the estuary of Porcupine Creek, the only salmon stream flowing into Steamer Bay in southeastern Alaska (Fig. 1). The estuary (about 5.5 km long) consists of a 1.5 km stream reach that is periodically inundated by tides, and a 4 km series of three estuarine basins. At low tide, the inner and middle basins are small (2 and 7 ha, respectively) and shallow (14 and 16 m, respectively) compared with the outer basin (120 ha and 42 m deep). The littoral zone ranges from low-gradient mudflats to steep cobble. Bottoms of the basins are level and composed of shell, gravel, and mud.

During low tide, the inner and middle basins are partially isolated from the outer basin and the main part of Steamer Bay by tidal rapids 1–3 m deep. Salinity is lower in the inner and middle

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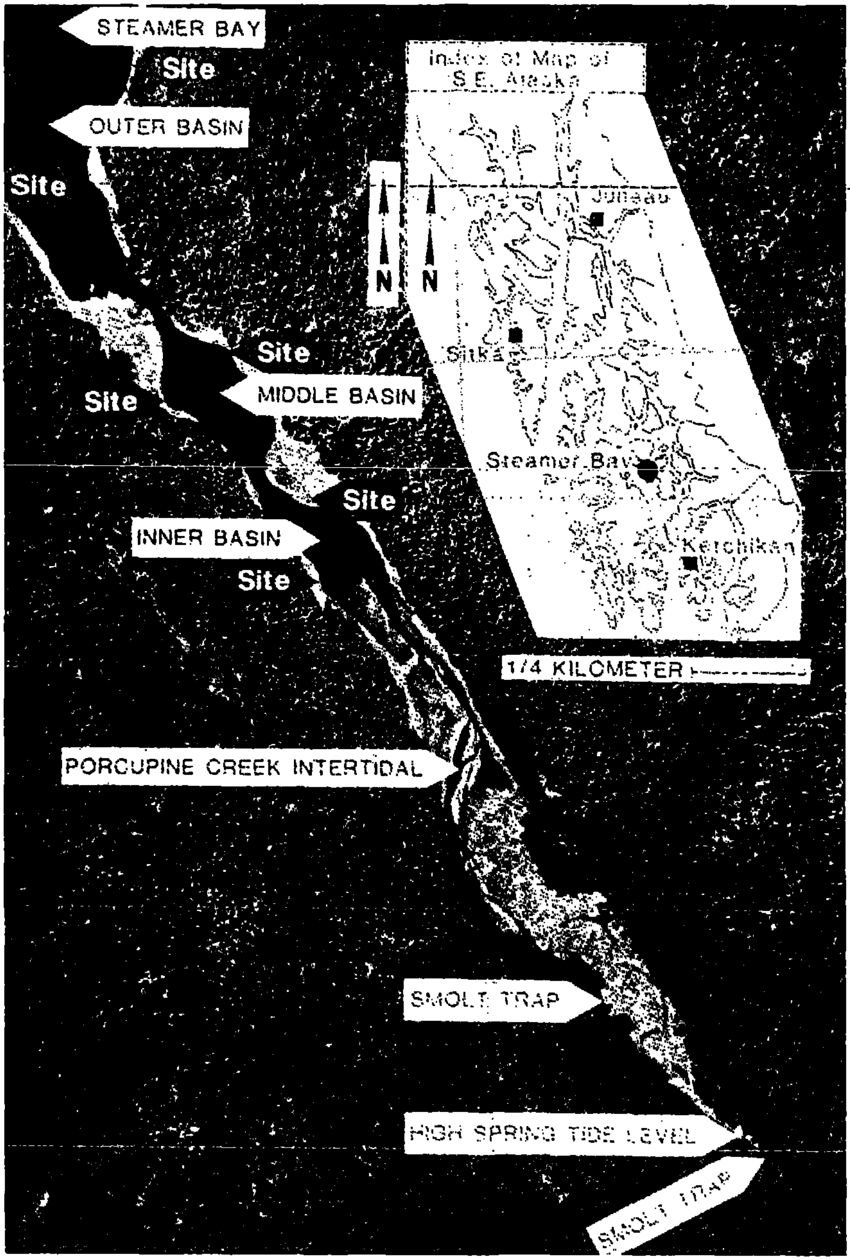

FIGURE 1.—Aerial photo of study site in the inner part of Steamer Bay, southeastern Alaska, showing the Porcupine Creek estuary at low tide and location of smolt traps used by Thedinga (1985).

basins (24–29‰) than in the outer basin (28–30‰), but temperature does not differ between basins in spring and summer (11°–13°C from May to September 1981). Heavy tidal flushing, particularly during spring tides, results in a diverse community within the estuary; e.g., eel grass, *Zostera*; Dungeness crabs, *Cancer magister*; bull kelp, *Nereocystis*; and rock scallop, *Hinnetes*. A detailed description of the study area is in Merrell and Koski (1978) and Koski (1984).

Porcupine Creek, upstream of tidal influence, is 4.5 km long and has an average discharge of about 0.5 m^3/second. Its watershed is forested by mature western hemlock, *Tsuga heterophylla*, and Sitka spruce, *Picea sitchensis*. Annually, 5,000–75,000 adult pink salmon and 200–4,000 chum salmon spawn in the creek from late July to October, and 250–600 adult coho salmon spawn from late September to November (Koski 1984). Pink and chum salmon fry typically migrate from Porcupine Creek from late March to mid-May (Koski[2]). Coho salmon smolts migrate from late April to early June, but over 90% usually migrate in late May (Thedinga 1985).

METHODS

Six stations, one each on the east and west sides of the three basins (Fig. 1) were sampled by a beach seine 37 m long, with 1.6 cm stretch mesh on the wings, and a central bag of 6 mm stretch mesh. The seine tapered from 2 m deep at the central bag to 1 m deep at each end. In 1979, only one station in each basin was seined about every 4 days from 16 May to 12 June. In 1981, all six stations were seined biweekly from 26 May to 7 July and monthly thereafter through 11 November. Seines were set parallel to and about 40 m from shore by a skiff, and retrieved from shore. Setting and retrieval were accomplished within 10 minutes.

All fish caught were identified and counted. Fork lengths (FL) were measured to the nearest millimeter from a random sample of ≤25 salmon per species, station, and sampling period. Stomach contents were collected only in 1981 from ≤10 salmon per species and station in May, June, and July. Contents were collected from anesthetized fish by flushing the stomach with water from a syringe (Meehan and Miller 1978; Koski and Kirchhofer 1984) and preserved in 5% formaldehyde. Prey were later identified, counted, measured, and weighed.

For diet analysis, the index of relative importance (IRI) was calculated, where

IRI = (% number + % weight) (% frequency of occurrence)

(Pinkas et al. 1971). Diet overlap between salmon species was calculated (McCabe et al. 1983):

$$C = \frac{2\sum_{i=1}^{s} X_i Y_i}{\left(\sum_{i=1}^{s} X_i^2 + \sum_{i=1}^{s} Y_i^2\right)}$$

where C = overlap coefficient and X_i and Y_i are proportions of the total diet of salmon species X and Y, respectively, contributed by prey taxon i of s prey taxa. Diet overlap was calculated separately for proportions based on prey number and weight. Prey were also classified as epibenthic or pelagic to assess overlap in foraging mode (Feller and Kaczynski 1975). Epibenthic prey were polychaetes, gammarid amphipods, harpacticoid copepods, barnacle cyprids, and cumaceans. Pelagic prey were calanoid copepods, euphausiids, barnacle nauplii, cladocerans, larvaceans, larval decapods (Brachyrhyncha), hyperiid amphipods, and fish (eggs, larvae, and juveniles).

RESULTS

Size

In May 1979, pink salmon were the size of newly emergent fry, about 32 mm FL (Fig. 2). Average length increased 1.5 mm/day, to 73 mm on 12 June 1979. In 1981, pink salmon averaged 73 mm FL in late May and early June. Changes in average FL in 1981 could not be calculated because most migration occurred before sampling began.

Average FL of chum salmon increased slower than that of pink salmon. Mean FL of chum salmon increased 0.4 mm/day in both years, from 39 mm to 51 mm in 1979, and from 60 mm to 78 mm in 1981 (Fig. 2). Chum salmon averaged about 10 mm FL longer in 1981 than in the same period in 1979. Chum salmon were not found in the estuary after early July, except for two fry caught in the outer basin in November.

Average FL of coho salmon was nearly constant, between 85 and 110 mm, throughout May and early June in both 1979 and 1981 (Fig. 2). Average FL of coho salmon in the estuary during this period was influenced by an influx of Porcupine Creek migrants, which averaged between 75 and 96 mm FL (Thedinga 1985). After the migration from Porcupine Creek in 1981 (≈9 June), average FL increased 1.6 mm/day to 165 mm by 20 July. Average FL then decreased to 85 mm in

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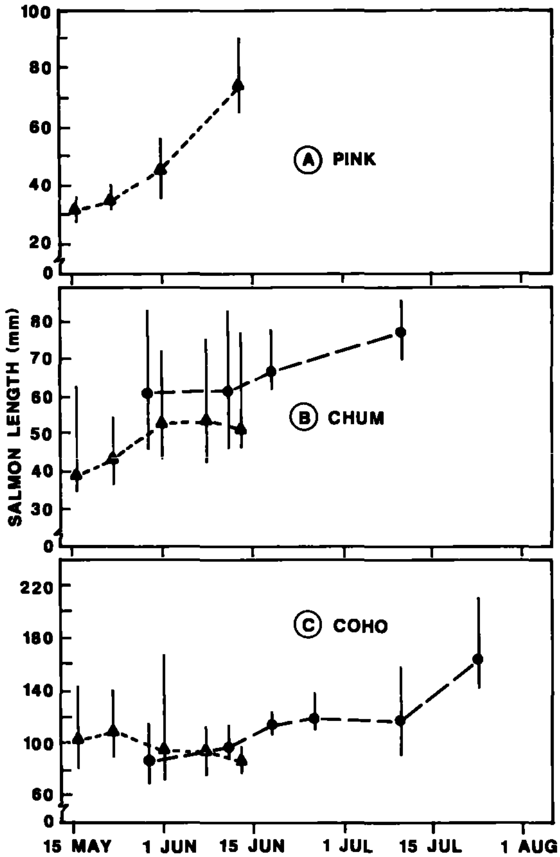

FIGURE 2.—Length of salmon in 1979 and 1981. Data shown are means and ranges for pooled samples from all stations on each sampling date. Data for pink salmon in 1981 are omitted because of small sample sizes. (▲ = 1979, ● = 1981.)

August and 106 mm in September, after most smolts had left and a few new smolts entered the estuary.

Diet

A wide variety of prey was eaten by the three salmon species, but usually only one or two prey taxa dominated the diet (Table 1). Pink salmon ate mostly larval molluscs (Mesogastropoda) and larval fish (mostly Gadidae) in May, and calanoid copepods in June. Chum salmon ate mostly larval molluscs in May; larval molluscs, larvaceans, and cladocerans in June; and hyperiid amphipods and larval decapods in July. Coho salmon ate mostly fish and insects in May and June, and fish and larval decapods in July. The identifiable fish prey of coho salmon consisted of 53% Pacific herring, *Clupea harengus pallasi*; 45% cod (Gadidae); and 2% Pacific sand lance, *Ammodytes hexapterus*. No identifiable pink or chum salmon were in the coho stomachs. Catch of coho, but not that of the other salmon, was significantly correlated ($r = 0.46$, $P < 0.001$) with aggregate catch of herring, sand lance, and cod, indicating that coho salmon congregated near prey schools.

Diet overlap was higher between pink and chum salmon than between either species and coho salmon (Table 2). Diet overlap between pink and chum salmon was especially high in May when both species ate large numbers of larval molluscs. If based on prey weight, diet overlap between pink and coho salmon was negligible. If based on prey number, however, overlap was >50% in June when both pink and coho salmon ate large numbers of calanoid copepods. Diet overlap between chum and coho salmon was consistently low, especially when based on prey weight.

Of the 12 most important prey taxa in May and June, when all 3 salmon species were present in the estuary, only 4 differed significantly ($P < 0.05$) in mean number per stomach between pink and chum salmon, whereas 9–10 differed significantly between the two species and coho salmon (Table 3). Compared with pink salmon, chum salmon ate more harpacticoid copepods, cladocerans, and insects. Coho salmon ate fewer small plankton and more fish than did the other salmon species. Coho salmon averaged fewer than 20 total prey items, compared to more than 100 in pink salmon and 200 in chum salmon.

Coho salmon ate larger prey than did the other salmon (Fig. 3). Median prey length for coho salmon was 2.3 mm, compared with 0.4 mm for pink and chum salmon. Coho salmon generally selected larger individuals of each prey taxon—particularly larger calanoid copepods, gammarid amphipods, euphausiids, and larval decapods—than did pink and chum salmon (Table 4). Of fish prey, coho salmon ate mostly juveniles, whereas pink and chum salmon ate mostly eggs and larvae.

As they grew larger, all three salmon species selected larger prey. Numbers of hyperiid amphipods, euphausiids, and fish larvae—all relatively large prey—were positively correlated with FL of pink or chum salmon, whereas numbers of cladocerans and larvaceans—both relatively small prey—were negatively correlated with chum salmon FL (Table 5). Numbers of calanoid copepods and fish were positively correlated with coho salmon FL, whereas the number

TABLE 1.—Stomach contents of juvenile salmon in Porcupine Creek estuary, 26 May–7 July 1981. %*N* is percent by number, %W is percent by wet weight, %FO is percent frequency of occurrence of fish with prey item *i*, and %IRI is percent of total sum of IRI for all prey taxa. IRI = (%*N* + %*W*)%FO. Taxa are omitted if %IRI is ≤3 for all salmon species.

Prey taxon	Pink salmon				Chum salmon				Coho salmon			
	%*N*	%*W*	%FO	%IRI	%*N*	%*W*	%FO	%IRI	%*N*	%*W*	%FO	%IRI
26–29 May 1981												
Mollusc larvae	47	2	71	28	59	36	100	60	2	0	4	0
Calanoida	12	2	57	7	5	4	71	5	0	0	4	0
Harpacticoida	1	0	29	0	11	9	90	12	17	1	18	3
Cladocera	1	0	43	1	14	5	77	10	0	0	4	0
Cumacea	0	0	0	0	2	9	32	3	16	1	41	6
Euphausiacea	11	2	71	8	0	2	42	1	0	0	0	0
Decapod larvae												
Shrimp	9	5	71	8	0	1	13	0	0	0	0	0
Crabs	8	2	60	4	3	3	60	2	2	0	12	0
Fish eggs and larvae	8	86	57	44	0	21	13	2	1	6	4	0
Fish	0	0	0	0	0	0	0	0	22	62	48	38
Insects[1]	1	0	29	0	1	5	52	2	29	23	100	47
Total	98	99		100	95	95		97	89	93		94
(Number of stomachs)			(7)				(31)				(27)	
9–10 June 1981												
Mollusc larvae	9	5	100	8	24	16	73	23	0	0	7	0
Calanoida	47	52	100	58	5	5	65	5	22	0	43	9
Harpacticoida	3	5	25	1	4	4	65	4	0	0	7	0
Cladocera	13	7	75	9	19	8	81	17	1	0	23	0
Decapod larvae												
Shrimp	1	1	75	1	0	1	20	0	0	0	0	0
Crabs	4	11	100	5	7	12	100	8	19	0	21	4
Larvacea, Oikopleura	9	5	100	8	20	13	85	23	7	0	14	1
Fish eggs and larvae	6	5	100	6	11	12	35	6	0	0	0	0
Fish juveniles	0	0	0	0	0	0	0	0	10	94	71	70
Insects[1]	0	1	50	0	3	10	75	8	28	2	50	14
Total	92	92		96	93	91		94	87	96		98
(Number of stomachs)			(4)				(26)				(14)	
7 July 1981												
Calanoida	—	—	—	—	4	1	43	3	16	0	24	5
Hyperiidea	—	—	—	—	12	30	88	45	4	0	29	2
Decapod larvae												
Shrimp	—	—	—	—	61	40	14	18	1	0	6	0
Crabs	—	—	—	—	3	10	86	9	55	5	53	25
Fish eggs and larvae	—	—	—	—	0	3	57	2	0	0	0	0
Fish juveniles	—	—	—	—	0	0	0	0	9	94	50	65
Insects[1]	—	—	—	—	6	4	100	14	5	0	24	2
Total	—	—	—	—	86	88		91	90	99		99
(Number of stomachs)			(0)				(7)				(17)	

[1]Mostly adult Diptera.

of insects was negatively correlated. As a consequence of the selection of larger prey as the salmon grew, total prey weight increased with salmon FL, whereas total prey number did not (Table 5). Although pink and chum salmon ate prey of similar size, they foraged differently (Fig. 4). Pink salmon consumed about 95% pelagic prey; chum salmon, only 74%. Individual taxa changed, but the importance of pelagic prey did not change significantly between sampling periods, estuary basins, or salmon FL classes.

Diet of coho salmon, on the other hand, varied widely depending on salmon FL, date, and location (Fig. 4). Pelagic prey increased from 1% of total prey for coho salmon <80 mm FL to 80% for those >100 mm FL. Coho salmon ate fewer pelagic prey in May, when most coho were in the inner basin and feeding mainly on insects, than in July when most were in the outer basin and feeding mainly on fish (Table 1). Analysis of variance, however, showed that differences between basins and sampling periods were not significant

TABLE 2.—Diet overlap (McCabe et al. 1983) based on number (n) and weight (W) of prey by sampling period for juvenile salmon in Porcupine Creek estuary, 26 May–7 July 1981. The number of stomach samples is in Table 1.

Sampling period	Pink vs. chum		Pink vs. coho		Chum vs. coho	
	n	W	n	W	n	W
26–29 May	0.87	0.40	0.07	0.09	0.13	0.08
9–10 June	0.47	0.38	0.54	0.00	0.29	0.00
7 July	—	—	—	—	0.10	0.01

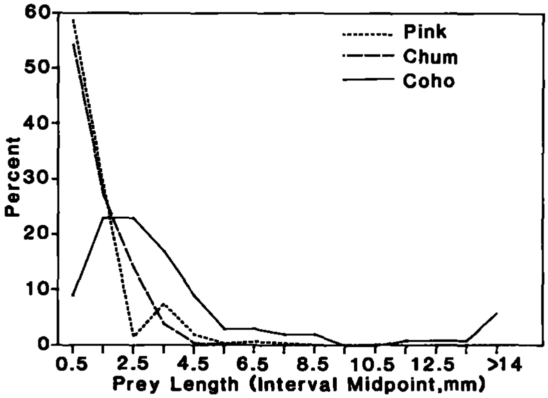

FIGURE 3.—Relative frequencies of length of prey eaten by pink, chum, and coho salmon in the Porcupine Creek estuary in 1981. Total prey measured were 687 in 11 pink, 5,634 in 63 chum, and 1,179 in 53 coho salmon.

TABLE 3.—Comparison of mean number of the 12 most important prey and total of all prey per salmon stomach from Porcupine Creek estuary, 26 May–10 June 1981. Means followed by the same letter are not significantly different (Kruskal-Wallis analysis of variance, $P>0.05$) compared within a row and across columns. The number of stomach samples is in Table 1.

Prey item	Pink salmon	Chum salmon	Coho salmon
Mollusc larvae	28 a	86 a	0 b
Barnacle larvae	4 a	5 a	0 b
Calanoida	40 a	12 b	0 b
Harpacticoida	2 a	19 b	3 a
Cladocera	10 a	37 b	0 c
Cumacea	0 a	5 a	2 a
Euphausiacea	5 a	1 a	0 b
Decapod larvae	11 a	12 a	0 b
Larvacea	6 a	20 a	0 b
Fish eggs and larvae	3 a	11 a	0 b
Fish	0 a	0 a	4 b
Insects	0 a	4 b	6 b
Total	115 a	216 a	19 b

TABLE 4.—Mean length (mm) of prey items in salmon stomachs from Porcupine Creek estuary, 26 May–7 July 1981. Mean prey length within prey taxa was significantly greater for coho salmon than for pink or chum salmon (sign test, $n=12$ means, $P=0.03$ and $P=0.003$, for coho salmon vs. pink and chum salmon, respectively). The number of stomach samples is in Table 1.

Prey item	Pink salmon	Chum salmon	Coho salmon
Mollusc larvae	0.5	0.5	0.4
Barnacle larvae	0.4	0.7	0.4
Calanoida	1.2	1.2	4.8
Harpacticoida	1.3	1.1	1.3
Cladocera	0.6	0.6	0.7
Cumacea	2.4	2.5	2.8
Hyperiidea	3.3	2.4	3.0
Gammaridea	1.5	1.8	5.2
Euphausiacea	3.5	3.0	18.0
Decapod larvae	2.8	2.0	3.5
Larvacea	0.8	0.9	—[1]
Fish, all life stages	2.0	1.2	23.9
Insects	2.8	2.2	3.5

[1]None present.

TABLE 5.—Spearman rank correlations between number of prey items and fork length of juvenile salmon. Because of the large number of correlations tested, significance levels were adjusted by multiplying the probability P by the number of tests for each salmon species. The number of stomach samples is in Table 1.

Prey item	Pink salmon	Chum salmon	Coho salmon
Mollusc larvae	−0.32	0.05	−0.18
Barnacle larvae	−0.36	−0.02	0.22
Calanoida	−0.51	0.10	0.33*
Harpacticoida	−0.30	−0.03	−0.19
Cladocera	−0.06	−0.34*	−0.04
Cumacea	−0.20	0.04	−0.28
Hyperiidea	−0.35	−0.37*	0.19
Euphausiacea	0.84*	0.36*	0.15
Decapod larvae	0.43	−0.19	0.25
Larvacea	−0.36	−0.50*	—[1]
Fish eggs	−0.33	−0.18	—[1]
Fish larvae and juveniles	0.86*	−0.04	0.36*
Insects	0.61	−0.11	−0.71**
Total prey number	−0.40	−0.04	−0.09
Total prey weight	0.85*	0.35*	0.66**

[1]None present in any stomachs.
*Adjusted probability $P < 0.05$.
**Adjusted probability $P < 0.01$.

after adjusting for differences in coho salmon FL (Table 6). Thus, changes in diet were mainly related to increasing size of coho salmon as they migrated through the estuary.

DISCUSSION

Both size and diet can affect predation and competition among juvenile salmon in an estuary. A

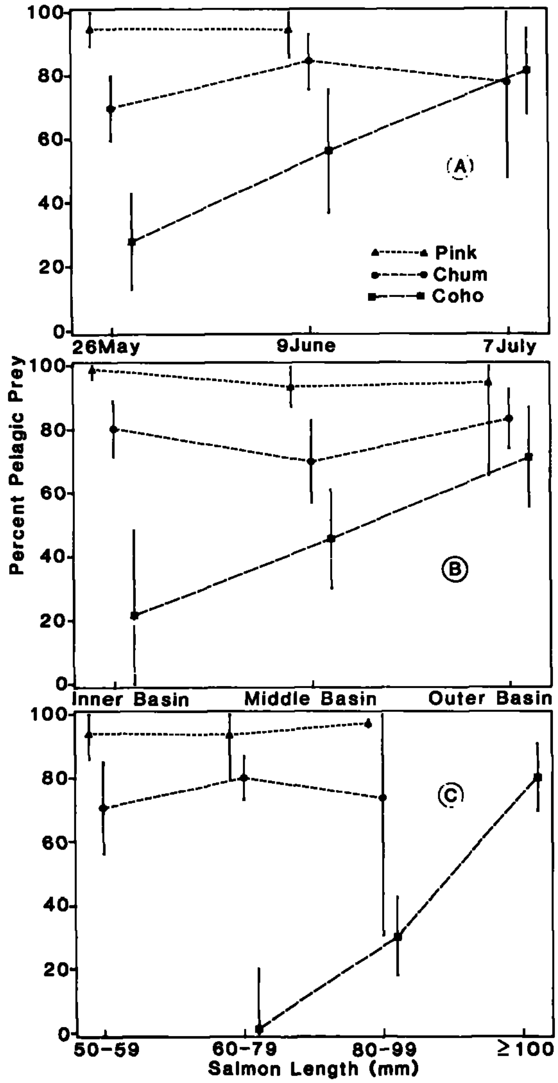

FIGURE 4.—Number of pelagic prey as percent of total prey eaten by individual salmon compared between sampling periods (A), estuary basins (B), and salmon fork length classes (C) in the Porcupine Creek estuary in 1981. Symbols are means; bars are ±2 SE of the means. Symbols in *B* and *C* are the same as in *A*. Pelagic prey are defined in the text.

salmon's size mainly influences its vulnerability to predators, whereas its diet determines potential competition for food. Size and diet, however, are not independent. Salmon change their diet as they grow, which helps relieve competition between salmon of different size, and a poor diet slows their growth, which prolongs vulnerability to predation.

TABLE 6.—Analysis of variance of percentage pelagic prey of coho salmon, with sampling period and estuary basin as factors and salmon fork length as covariate. Factors, covariate, and interactions were adjusted simultaneously before assessing significant (Kim and Kohout 1975).

Source of variation	df	Mean square	F	P
Length	1	8,458	9.4	0.004
Sampling period	2	1,580	1.8	0.184
Basin	2	654	0.7	0.489
Residual	47	900	—	—
Total	52	1,519	—	—

Because of similar diets, pink and chum salmon are potential competitors. Although diets of pink and chum salmon in the Porcupine Creek estuary were similar in prey size and some prey taxa, however, pink salmon fed almost solely on pelagic prey , whereas chum salmon foraged both pelagically and epibenthically; such differences may help reduce competition. Competition probably also was reduced because, as the salmon grew larger, they switched to larger prey. Coho salmon probably did not compete for food with the other two species because the coho fed on larger, different prey.

Rapid early growth of salmon is important in reducing vulnerability to predators (Parker 1971; Taylor 1977). For example, hatchery pink salmon fry raised for 60 days (to 40 mm FL) before release into an estuary in southeastern Alaska survived 68% better at sea than did fry released immediately after emergence (Martin et al. 1981). Marine survival also is higher for year classes of larger (9–11 cm FL) than for smaller (6–8 cm FL) sockeye salmon, *O. nerka*, smolts (Foerster 1954). Coho salmon smolts from Porcupine Creek in 1978 averaged 99 mm FL and their survival was twice that of the 1979 smolts, which averaged only 91 mm FL (Thedinga 1985). Smolt size and migration timing, however, interact complexly to influence marine survival of coho salmon (Bilton 1978).

Growth of juvenile salmon in estuaries usually is inferred from changes in mean size (LeBrasseur and Parker 1964; Healey 1978), but these estimates are subject to bias. In this study, changes in mean size of fish in the catches on successive dates could underestimate real growth for two reasons: 1) small individuals may have migrated continuously into the estuary from freshwater and 2) larger individuals may have migrated continuously from the estuary to the sea. Conversely, growth could be overestimated if predators of salmon selected small individuals (Parker 1971). In addition, although the inner and middle basins are semiisolated from adjacent marine waters during low tide, juvenile salmon from adjacent waters could easily enter the estuary, especially the outer basin, during flood tide and mix with salmon from Porcupine Creek.

Estimates of salmon growth in estuaries and nearshore marine waters are variable, but generally range between 1 and 2 mm/day. LeBrasseur and Parker (1964) estimated pink salmon growth to be 0.9 mm/day during the first 30 days at sea, and Healey (1978) estimated pink salmon growth during summer to be 1.0 mm/day; our estimate was 1.5 mm/day. Our estimate for chum salmon at 0.4 mm/day was considerably less than that of Healey (1978) at 1.5 mm/day, also based on change in mean length; however, our estimate for coho salmon of 1.6 mm/day was similar to that of Healey (1978) at 1.2 mm/day. Summer growth back-calculated from scales of salmon from the Sea of Okhotsk was about 1.6 mm/day for pink and chum salmon (Birman 1969).

Because of their initial small size, pink and chum salmon particularly are vulnerable to predators including juvenile coho salmon (Parker 1971). Several authors have suggested that a major share of pink salmon mortality in the first weeks at sea results from juvenile coho salmon predation (Parker 1971; Kaczynski et al. 1973; Hargreaves and LeBrasseur 1985), but such predation has not been found in field collections. Parker (1971) demonstrated predation by juvenile coho salmon on pink salmon fry in the laboratory, and juvenile coho salmon are known predators of salmon fry in freshwater (Hunter 1959; Koski and Kirchhofer 1984). However, we have not found any published data that show predation by juvenile coho salmon on other salmon in estuaries or marine waters. Predation by juvenile coho salmon on pink salmon fry migrating from freshwater does occur in the tidal-influenced reach of Porcupine Creek (Koski and Kirchhofer 1984), but such predation apparently does not extend into the estuarine basins. Many fishes have been identified as predators of pink and chum salmon in estuaries, including Pacific herring (Thorsteinson 1960), sea-run cutthroat trout, *Salmo clarki*; cod, *Gadus macrocephalus*; and sculpin, *Leptocottus armatus*, (Bax et al. 1977). We speculate that predation by coho salmon on salmon fry may occur only under circumstances in which the coho salmon are combined with small fry as they migrate from freshwater.

The period of vulnerability of pink and chum salmon fry to predation by juvenile coho salmon is probably relatively short. Within the first 3 weeks after entering the estuary, pink salmon fry can grow larger than the prey fish of juvenile coho salmon. In the laboratory, juvenile coho salmon ate the smallest pink salmon available and did not eat any larger than about 50 mm FL (Parker 1971), which coincides with the largest fish eaten by coho salmon in our study. At a growth of 1 mm/day, pink salmon entering the estuary at 32 mm FL will outgrow predation by coho salmon smolts in 18 days. In Porcupine Creek, most pink and chum salmon migrated from the stream several weeks before coho salmon, which enables them to grow large enough to avoid predation by coho salmon in the estuary. Thus, early migration and rapid growth of pink and chum salmon fry probably are important in reducing predation by coho salmon.

In the Porcupine Creek estuary, competition and predation probably were slight. Competition for food was minimal, as evidenced by the rapid salmon growth, because of differences in prey and foraging mode and because regular tidal flushing probably replenished food supplies, as in Traitors Cove, AK (Bailey et al. 1975). Natural stocking levels in the estuary also probably were below thresholds where competition for food would depress survival. Predation by coho salmon on pink and chum salmon was avoided because the pink and chum salmon migrated earlier than coho salmon and rapidly grew too large for the coho to handle. Thus, in this natural system, competition and predation probably were unimportant because of moderate stocking levels, rapid growth, and differences in diet and timing of migrations. In systems with hatchery inputs, however, stocking levels would probably be higher and salmon size and timing of migrations different than in natural systems, which could increase competition and predation.

Stocking levels and timing of hatchery releases of juvenile salmon in estuaries are important in minimizing competition and predation (Myers 1980). Hatchery releases should avoid combining large concentrations of pink and chum salmon fry so as not to deplete food supplies. Conversely, releases during low predator abundance and good growing conditions—high food availability and warm temperature—could increase growth and survival. Early releases of coho salmon could increase predation on pink and chum fry (Johnson 1974), especially fry <50 mm FL, if the releases coincide with fry migrations through the estuary.

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