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Population Estimates of Juvenile Salmon Downstream Migrants in the Taku River, Alaska

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Abstract: To assess the magnitude of downstream migrations of juvenile Pacific salmon (Oncorhynchus spp.) in the Taku River, Alaska, a mark-recapture method was used to estimate migrant populations from April to September 1989. Sockeye (0. nerka), coho (O. kisutch), and chinook (0. tshawytscha) salmon were captured in fyke nets in the lower river, marked by fin clip, and released 5 km upriver. In spring, trap efficiency (percent fish recaptured) for coho, sockeye, and chinook smolts (age at least 1) was5, 1, and l%, respectively; in summer, trap efficiency for coho and sockeye fingerlings (age 0, mean fork length 54 mm) was 8 and 5%, respectively. Less than 1% of marked chinook fingerlings were recaptured in summer, indicating negligible summer migration. Estimated smolt populations were about one-third of expected numbers based on adult returns, whereas age-0 migrants were comparatively abundant, indicating that age-0 salmon that migrate to and rear in the lower river may account for a large part of the river's smolt production the following year.

POPULATION ESTIMATES OF JUVENILE SALMON DOWNSTREAM MIGRANTS IN THE TAKU RIVER, ALASKA

by

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ABSTRACT

To assess the magnitude of downstream migrations of juvenile Pacific salmon (Oncorhynchus spp.) in the Taku River, Alaska, We used mark-recapture methods to estimate migrant populations from April to September 1989. Sockeye (O. nerka), coho (O. kisutch), and chinook (O. tshawytscha) salmon were captured in fyke nets in the lower river, marked by fin clip, and released 5 km upriver. In spring, trap efficiency (percent fish recaptured) for coho, sockeye, and chinook smolts (age ≥ 1) was 5, 1, and 1%, respectively; in summer, trap efficiency-for coho and sockeye fingerlings (age 0, mean fork length 54 mm) was 8 and 5%, respectively. Less than 1% of marked chinook fingerlings were recaptured in summer, indicating negligible summer migration? Numerous small fry (<40 mm) also were captured in spring, but population estimates were unreliable. An estimated 340,000 sockeye, 277,000 chinook, and 165,000 coho smolts migrated to sea in spring, and 455,000 sockeye and 124,000 coho fingerlings migrated to the lower river in summer. Estimated smolt populations were about one-third of expected numbers based on adult returns, whereas age-0 migrants were comparatively abundant, indicating that age-0 salmon that migrate to and rear in the lower river may account for a large part of the river's smolt production the following year.

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INTRODUCTION

The Taku River, which flows. from British Columbia through Southeast Alaska (Fig. 1), is important habitat to both U.S. and Canadian stocks of Pacific salmon (Oncorhynchus spp.) l Annual harvests of Taku River stocks include about 70,000 sockeye (0. nerka), and large numbers of coho (0. kisutch), chinook (O. tshawytscha), chum (O. keta), and pink (O. gorbuscha) salmon (Transboundary Technical Committee 1988). Population dynamics of the stocks and carrying capacity of the river, however, are too poorly understood to manage for optimum production (Transboundary Technical Committee 1988).

The lower Taku River (downstream of Canyon Island; Fig. 1) provides rearing habitat for juvenile salmon spawned upriver (Murphy et al. 1989), and consequently, may be an important component in the stocks' population dynamics and the river's carrying capacity. Juvenile salmon migrate downstream in the Taku River from April to November (Meehan and Siniff 1962; Murphy et al. 1988), and many age-0 migrants remain and rear in the lower river and associated off-channel habitat. Because the numbers of migrants are unknown, the importance of the lower river is difficult to evaluate in the context of the river's total salmon production. To better evaluate the role of lower-river habitat, we used mark-recapture methods to estimate the number of smolts produced upstream of Canyon Island and the number of age-0 salmon that migrate downstream from Canyon Island, possibly to rear in the lower river.

STUDY AREA

The Taku River originates in British Columbia and empties into Taku Inlet near Juneau, Alaska (Fig. 1). The river's drainage area is 16,000 km^2, of which 95% is in Canada. The main-stem Taku River is about 5 m deep and 500 m wide and is extensively braided in most areas. Discharge is low (<100 m^3/s) in winter when the river freezes over. It increases rapidly in late April as ice breaks up, peaks (>1,000 m^3/s) in June during snowmelt, and declines through summer (Fig. 2). The lower river usually floods twice each summer when glacially formed lakes on the Tulsequah River (Fig. 1) suddenly drain. From April to November, the river is swift and turbid with glacial silt and often heavily laden with woody debris.

Five species of salmon occur in the drainage. Sockeye salmon is commercially the most important, with recent adult returns averaging 173,000 fish (Transboundary Technical Committee 1988). Coho salmonescapement to the upper river above Canyon Island has been conservatively estimated at

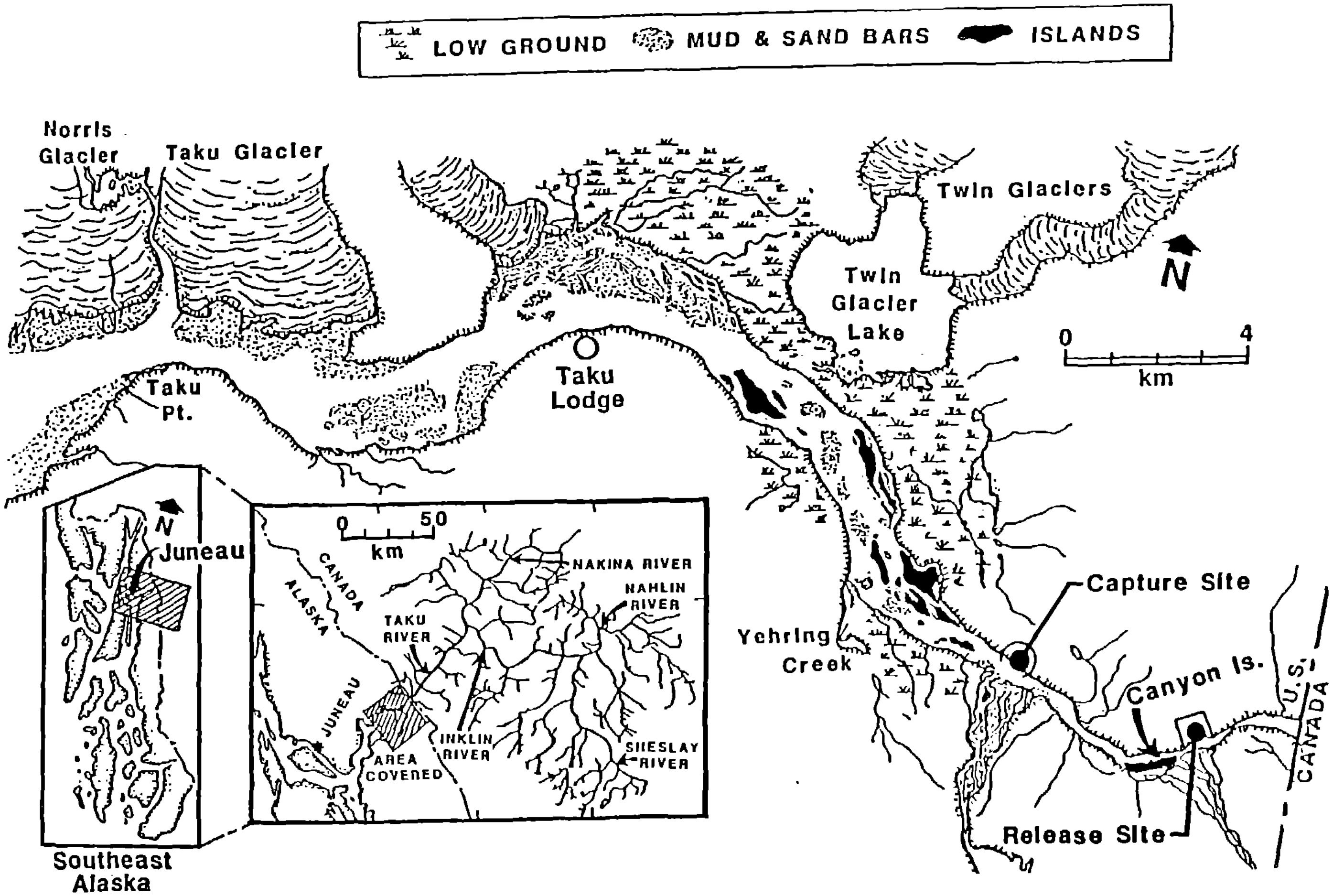

Figure 1.--Location of the fyke nets for catching downstream migrants in the Taku River, Alaska, and sites where marked fish were released.

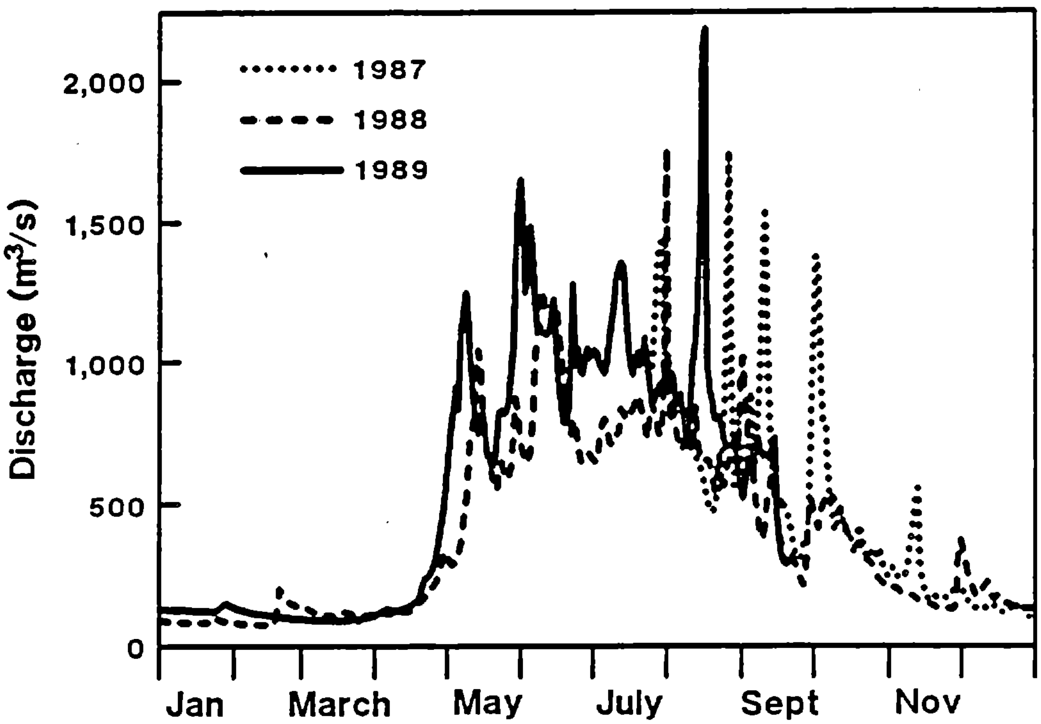

Figure 2. --Discharge of the Taku River, Alaska, July 1987 to September 1989. Data are from the U.S. Geological Survey.

37,000 fish. Chinook salmon returns recently (1985-89) averaged about 12,000 adults excluding jacks (≤2 years in ocean; Mecum 1990). Pink salmon returns vary widely and have reached 1 million in odd-numbered years (Clark et al. 1986). Information on returns of chum salmon is unavailable.

METHODS

To capture downstream migrants, three fyke nets were set along the east bank of a narrow (200 m wide) reach of the lower river, 6 km downstream from the U.S.-Canada border (Fig. 1). Two nets were 12 m long and had openings 3 m wide by 1.5 m deep; the third net was 8 m long and had an opening 2 m wide by 1.4 m deep. Each net was made of 13-mm square mesh and funnelled into a cod end of 6-mm mesh that led to a floating live box. The nets were set together, 1 to 8 m from shore perpendicular to river flow. Current speed at the nets' entrance averaged 75 cm/s in the outer net in the main river current, 45 cm/s in the middle net, and 32 cm/s in the net nearest shore. The nets were periodically removed from the river and cleaned to prevent clogging. Fish probably could not avoid the nets because of the turbid water and fast current, though small fish could pass through the 13-mm mesh. The nets were fished during four sampling periods: 29 April-26 June, 10-23 July, 5-14 August, and 22 August-13 September 1989. Sampling was continuous during each period, except for 4 days of the first sampling period (29 May-l June) when nets were removed because of flooding.

Each day, captured fish were removed from the live boxes, tranquilized with MS-222, and enumerated. up to 100 fish of each species were randomly selected to be weighed and measured for fork length (FL) each week. Condition factor was calculated by dividing weight in grams by the cube of FL in millimeters (Tesch 1968). Scale samples were taken from a size range of each species to determine age: age 0 were young-of-the-year; and age 1 and 2 had been in fresh water 1 and 2 winters, respectively.

Most fish caught each day were marked by clipping a tip from a fin (upper caudal, lower caudal, left pelvic, or right pelvic) and were released in quiet water 5-6 km upstream (Fig. 1). Coho salmon were also coded-wire tagged and adipose-fin clipped. Fish showing stress or descaling were not marked and were released downstream. To assess possible mortality from handling, twice each sampling period we marked 25 fish of each species and age group in the usual way and held them in aquaria for 24 hours; mortality was <1%. Each sampling period was divided into two or more marking periods when distinctively marked fish were released. Marking was stopped usually 1 week before the end of each sampling period to allow time to recover marked fish. The same mark was used on all fish for each marking period, and the mark was changed about every week so that a given mark was not repeated for 4 weeks. Each time the mark was changed, the release location was switched to the opposite side of the river to test the assumption of random mixing of marked and unmarked fish.

Numbers of migrants were estimated by dividing the number of fish caught by estimated trap efficiency:

$$\hat{N} = C/\hat{E}, \quad (1)$$

where N is the estimated number of fish migrating past the nets, C is the total number of unmarked fish in the catch, and E is estimated trap efficiency. Trap efficiency was calculated from the equation:

$$\hat{E} = R/M, \qquad (2)$$

where M is the number of marked fish released upstream, and R is the number of marked fish recaptured. For each sampling period, trap efficiency was tested to determine if it differed between marking periods. If significant ($P < 0.05$; Chi-square test), migrants were estimated separately for the different marking periods; if not significant, data were pooled. Confidence intervals for N were determined by the bootstrap method (Efron and Tibshirani 1986) by resampling R from the binomial distribution (M, E) and C from the binomial distribution (N, E). Confidence intervals for individual population estimates were obtained by the percentile method (Efron and Tibshirani 1986) based on 200 bootstrap replications. Variance of summed population estimates was calculated as the sum of the bootstrap variances of the individual estimates.

To account for migrants during unsampled periods, we extrapolated between marking periods by multiplying the mean daily population estimates for adjoining marking periods by the number of days not sampled:

$$\hat{N}_u = ((\hat{N}_1/d_1 + \hat{N}_2/d_2)/2)\ d_u, \qquad (3)$$

where N_u, is the estimated number of migrants during the unsampled period; N_1, N_2, d_1, and d_2 are the population estimates and number of days in the previous and following marking periods, respectively; and d_u is the number of days not sampled. We assumed all migration began on 15 April (i.e., N = 0 on 14 April), when river discharge first began to increase (Fig. 2), to calculate number of migrants before sampling began.

Coho salmon with missing adipose fins but with no other fin clips were also captured in the fyke nets. These fish had been coded-wire tagged previously in the Canadian part of the watershed by the Canadian Department of Fisheries and Oceans (CDFO). All such fish were checked for presence of coded-wire tags with a Northwest Marine Technology, Inc.[1] quality control device. One-third of the coho salmon with tags were frozen and later decoded in the laboratory.

RESULTS

Migration Characteristics

Numerous juvenile salmon migrated downstream throughout the spring and summer. Age-l and -2 sockeye, coho, and chinook smolts moved downstream from late April to late June, and numerous age-0 fry and fingerlings moved downstream from late April to mid-September (Fig. 3). Catch of coho and chinook smolts was high the first sampling day in late April but declined the first week of May; apparently, numerous coho and chinook smolts moved as river flow first began to increase (Fig. 2). The main migration of smolts of all three species, however, began in mid-May and lasted to mid-June.

Smolts of all three species were mostly age 1. In May and June, of the total number of sockeye smolts captured, 96% were age 1 and 4% were age 2; mean FL was 67 and 93 mm for age 1 and 2, respectively (Fig. 4). Coho smolts were predominantly (80%) age 1 with a lesser fraction (20%) age 2 (Fig. 5). Mean FL of age-l coho increased from 67 mm in May to 89 mm in June; mean FL of age-2 smolts was 100 mm. Chinook smolts were predominantly (97%) age 1 with a lesser fraction (3%) age 2, and most age-2 smolts migrated in May (Fig. 6). Mean FL of age-l chinook smolts increased from 72 mm in May to 84 mm in June; mean FL of age-2 chinook smolts was 101 mm.

Between 29 April and 17 June, 38 coho smolts that had been coded-wire tagged the previous year by the CDFO (missing adipose fins but not showing any other fin clips) were captured in the fyke nets in the lower river. These 38 coho smolts represented 0.6% (95% confidence interval, 0.4-0.8%) of the total catch of 6,208 coho smolts. Of the 38 coho smolts, 33 (87%) had retained tags, and 13 were decoded (Table 1): six (46%) had been tagged in the Taku River main stem, one (8%) in Flannigan Slough near the U.S.-Canada border, one (8%) in the Nahlin River (a major tributary of the Taku River) 150 km from the U.S.-Canada border, and five (38%) in Tatsamenie Lake 170 km upstream from the U.S.-Canada border. Timing of migration was similar for tagged coho smolts from all locations.

'Reference to trade name does not indicate endorsement by the National Marine Fisheries Service, NOAA.

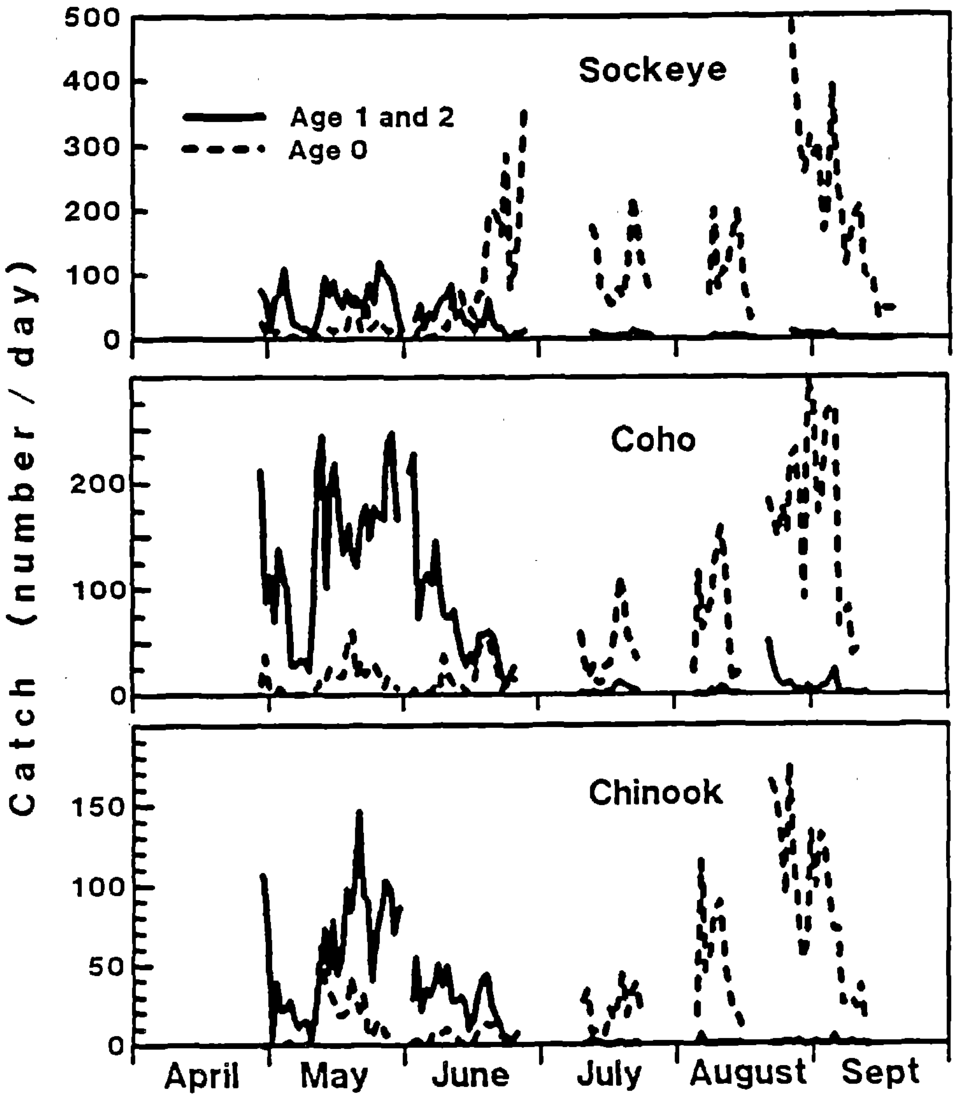

Figure 3. --Daily catch of juvenile salmon by age class from the Taku River, Alaska, April to September 1989.

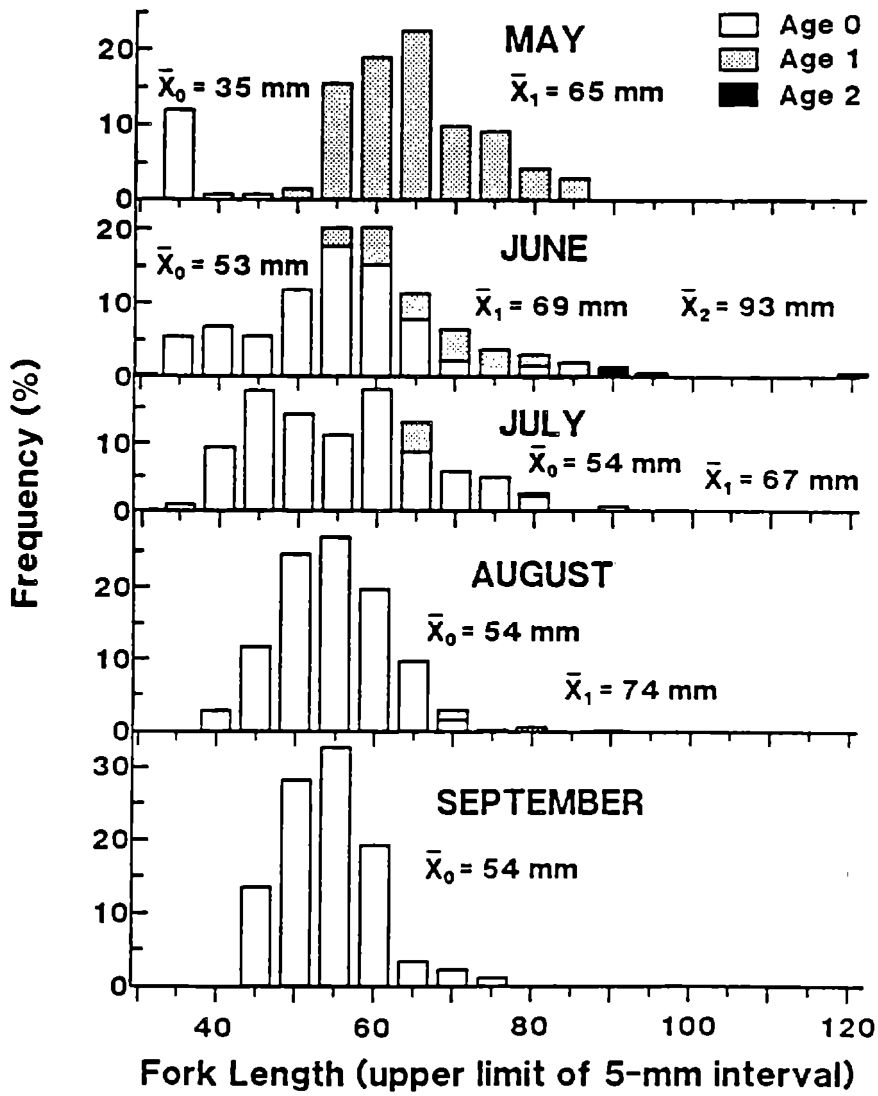

Figure 4.--Length frequencies of juvenile sockeye downstream migrants by age group in the Taku River, Alaska, May to September 1989. Means (X) are shown for each age group.

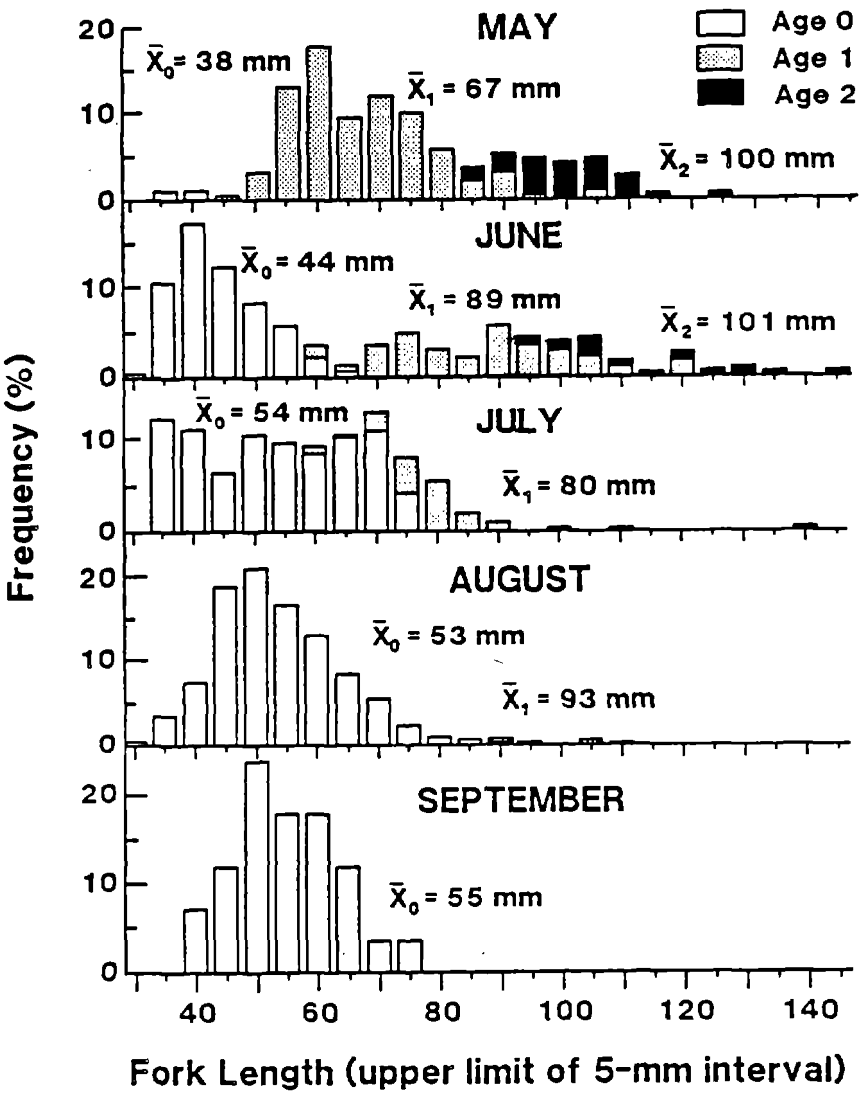

Figure 5. --Length frequencies of juvenile coho downstream migrants by age group in the Taku River, Alaska, May to September 1989. Means (X) are shown for each age group.

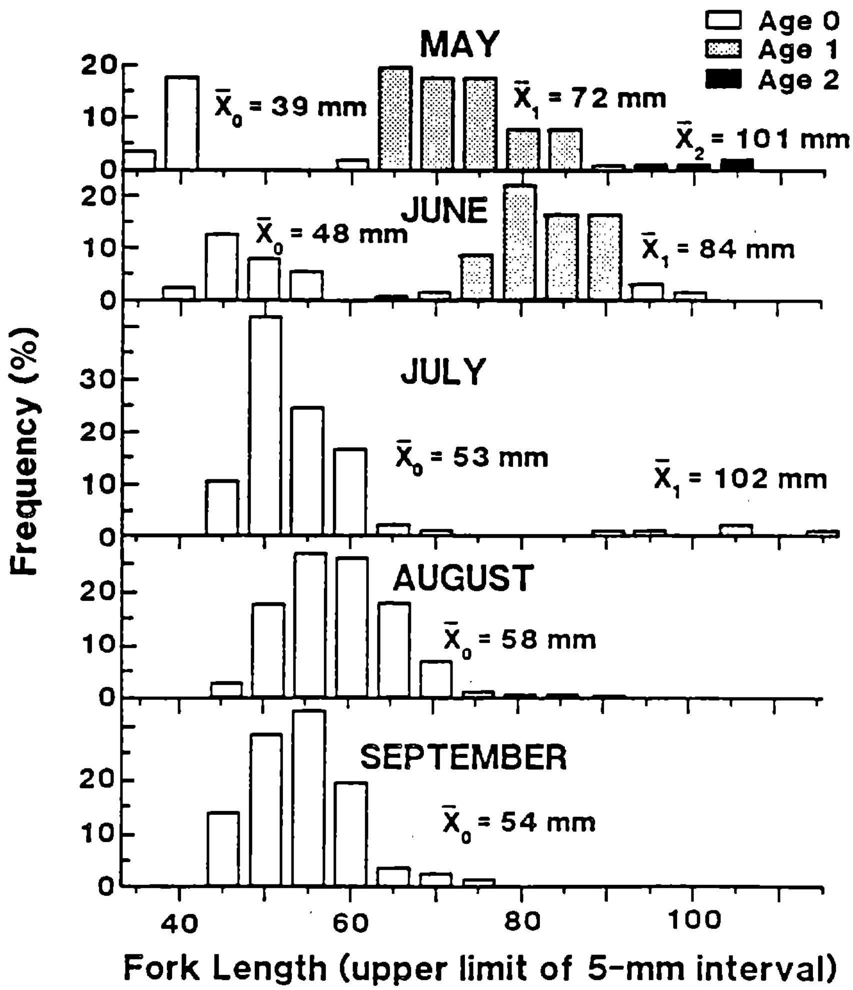

Figure 6.--Length frequencies of juvenile chinook downstream migrants by age group in the Taku River, Alaska, May to September 1989. Means (X) are shown for each age group.

Table 1.--Data for coho smolts that had been tagged in the Canadian part of the Taku River drainage and recovered in fyke nets in the lower Taku River in 1989.

Tagging site and date	Tag code	Recovery date	Fork length (mm)
Taku River	024843	11 May	103
main stem near	025625	6 June	82
U.S.-Canada	025627	2 June	76
border	025627	6 June	78
(Sept-Oct 1988)	025627	3 June	119
	025627	15 June	104
Flannigan Slough	025623	9 May	81
(Aug 1988)			
Nahlin River	042824	2 June	127
(Aug-Sept 1988)			
Tatsamenie Lake	042920	9 May	75
(July-Aug 1988)	042920	6 June	110
	042921	2 June	109
	042921	4 June	107
	042921	7 June	105

Age-O sockeye juveniles consisted of two size groups that moved downstream at different times: fry (mean FL of 35 mm) in May and fingerlings (mean FL of 54 mm) from mid-June to September (Figs. 3 and 4). Catch and mean FL increased suddenly in mid-June as distinctively different sockeye juveniles with small eyes and robust bodies began to migrate. Catch remained high throughout the summer and declined in early September. Mean FL of age-0 sockeye juveniles was constant (54 mm) throughout the summer after increasing sharply in mid-June.

Condition of age-0 sockeye fingerlings in June differed from age-l smolts of comparable size migrating at the same time. In June, length-weight regressions differed significantly ($P < 0.001$; F test) between age-0 fingerlings and age-l smolts (Fig. 7). The regression for age-0 sockeye fingerlings had a higher elevation than for age-l sockeye smolts. Differences were greatest for fish 55 to 70 mm FL, and regression lines converged for larger fish. For sockeye juveniles of comparable FL (55-70 mm) in June, mean condition of age-0 sockeye fingerlings was significantly ($P < 0.001$; t test) greater than that of age-l sockeye smolts ($9.25\ 10^{-6}$ compared with $8.17\ 10^{-6}$).

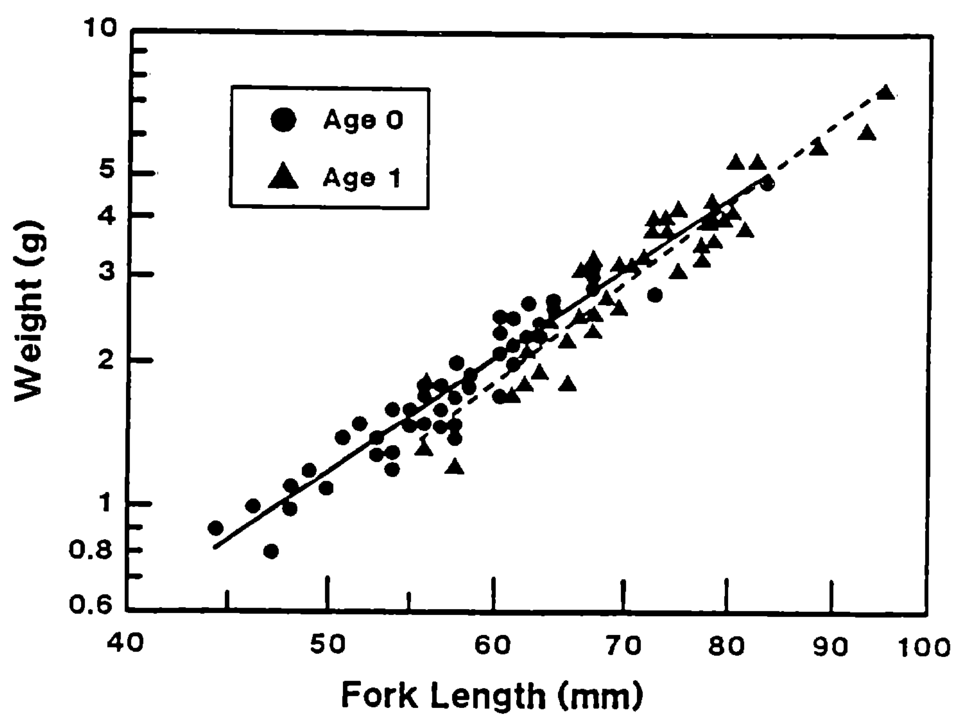

Figure 7.--Comparison of length-weight regressions of age-0 and age-1 sockeye migrants in the Taku River, Alaska, June 1989. Both axes are in logarithmic scale. For age-0 sockeye: Log_{10} weight = -4.82 + 2.88 $\log_{10}$ FL; $R^2 = 0.92$; N = 67. For age-1 sockeye: Log_{10} weight = -5.57 + 3.26 $\log_{10}$ FL; $R^2 = 0.93$; N = 45.

Numerous age-0 coho fry and fingerlings moved downstream, particularly from mid-July to mid-September (Fig. 3). Few age-0 coho fry were caught in May, probably because they were too small (mean FL, 38 mm) to be caught effectively by our nets. Mean FL increased from 38 mm in May to 55 mm in September (Fig. 5).

Age-O chinook fry and fingerlings moved downstream primarily in May and from mid-July to early September (Fig. 3). Many of the chinook fry in May still had yolksacs, and evidently had only recently emerged from redds. Mean FL of age-0 chinook juveniles increased steadily from 39 mm in May to 54 mm in September (Fig. 6).

Downstream movement of juvenile salmon was usually rapid, as indicated by recapture of marked fish, following their release in many cases by only 1 day (Fig. 8). Marked age-0 sockeye, coho, and chinook juveniles in September exhibited more delay than earlier recaptured juveniles, indicating a slowing of migration toward the-end of summer.

Trap efficiency differed widely between species, life stages, and sampling periods (Fig. 9). Efficiency was highest (7-11%) for coho and sockeye fingerlings in late August, intermediate (4-10%) for coho smolts in spring, and low (1-3%) for sockeye and chinook smolts in spring and for chinook fingerlings in summer. Trap efficiency was inversely related to river discharge (Figs. 2 and 9); efficiency was moderate in early May, dipped in June during high water, and then trended higher as water receded, except for the Tulsequah River flood in mid-August.

Trap efficiency was particularly low for age-0 chinook fingerlings in summer (Fig 9). Although 1,500 chinook fingerlings were marked and released upstream in summer, only 11 (0.7%) were subsequently recaptured. To determine possible reasons for the low recapture of age-0 chinook fingerlings, several groups of marked fish were released 200, 900, and 5,000 m upstream on the same side of the river as the nets. Significantly ($P < 0.05$; Chi-square test) more chinook fingerlings were recaptured from the two closest release sites than from the farthest release site (Table 2), indicating that age-0 chinook fingerlings moved less than 5 km downstream in a sampling period. In addition, baited minnow traps (Bloom 1976) set at the release sites caught several marked chinook fingerlings, indicating that many of the marked age-0 fish remained at the release sites.

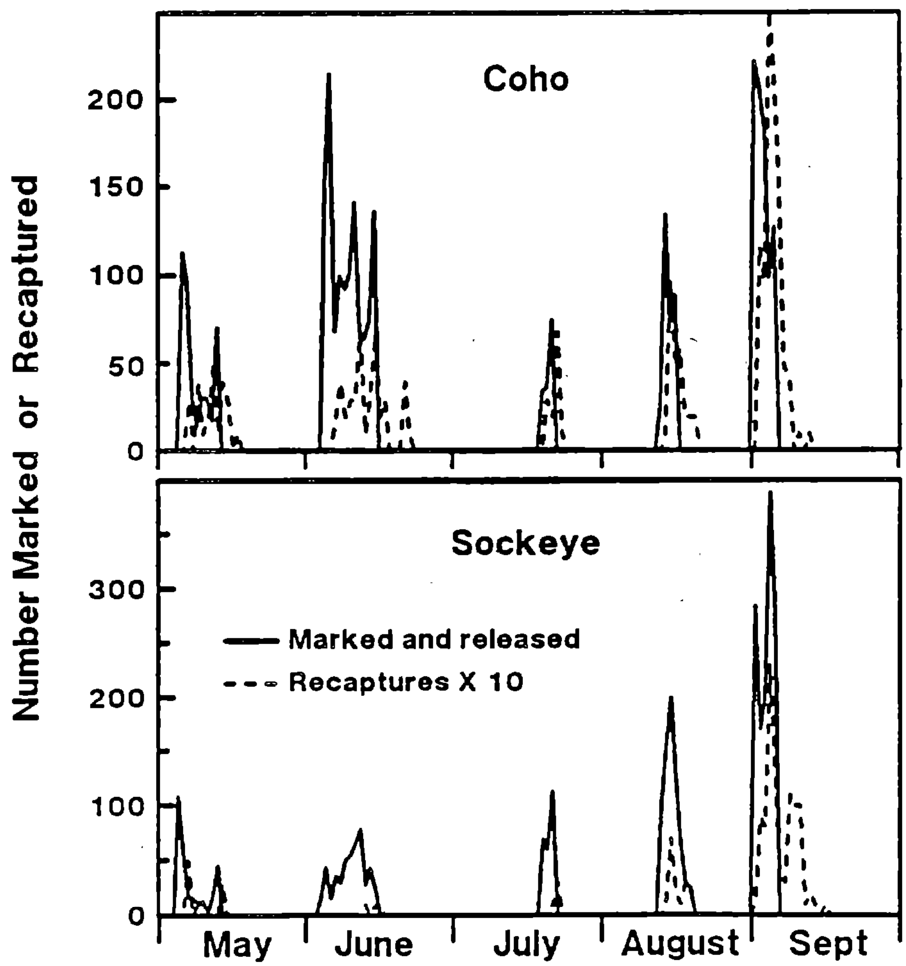

Figure 8. --Daily numbers of juvenile coho and sockeye salmon marked and released 5 km upriver of the capture site and numbers of subsequent recaptures for five marking periods, May to September 1989 in the Taku River, Alaska. Shown are numbers of fish for the first marking period of each sampling period. Numbers of recaptures are multiplied by 10.

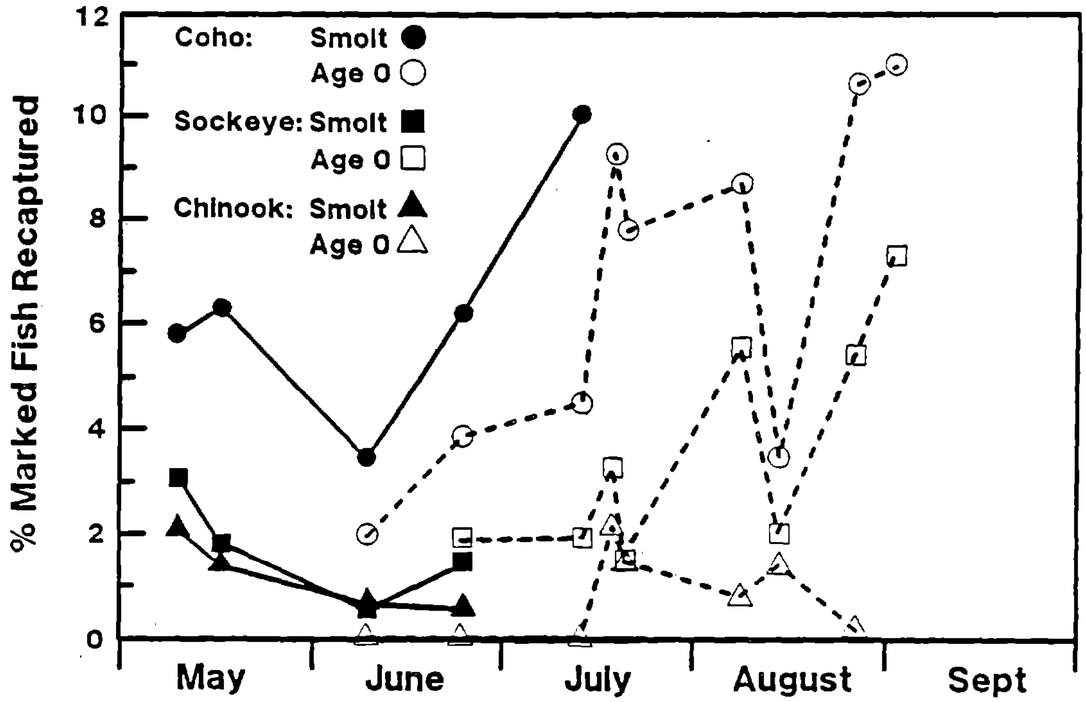

Figure 9.--Trap efficiency (percent of marked fish recaptured) for different species and age groups of juvenile salmon in the Taku River, Alaska, May to September 1989.

Table 2.--Comparison of recapture rate of marked age-0 chinook fingerlings released at different distances upstream from the capture site, 22 August-5 September 1989. Recapture rate differed significantly ($P < 0.05$; Chi-square test) between release sites.

Distance released upstream (m)	Number released	Number (%) recaptured
200	401	13 (3.2%)
900	389	6 (1.5%)
5,000	826	2 (0.2%)

Population Estimates

Sufficient numbers of fish were caught to estimate populations of age-l and -2 smolts of all species in spring and age-0 sockeye and coho fingerlings in summer. Fry populations in spring were not estimated because our nets were ineffective on small fry. Chinook fingerlings were not estimated in summer because marked fish apparently did not move back downstream.

Population estimates for sockeye, coho, and chinook smolts covered most of the smolt migration. Approximately 274,000 sockeye, 136,000 coho, and 214,000 chinook smolts were estimated to migrate downstream between 29 April and 26 June (Table 3; Fig. 10). Accuracy of total population estimates was greater for coho smolts than for sockeye or chinook smolts. The 95% confidence interval was ±14% of the estimate for coho smolts, whereas it was ±72% for sockeye smelts and ±56% for chinook smolts (Table 3). The most important missing data were for 14 days (15-28 April) at the start of the migration, and 4 days (29 May to 1 June) during the main migration when the nets were removed because of flooding. Population estimates extrapolated for these periods were 66,000 sockeye, 29,000 coho, and 63,000 chinook smolts; estimated total numbers for the entire migration period were 340,000 sockeye, 165,000 coho, and 277,000 chinook smolts (Table 4).

During the four sampling periods between 16 June and 13 September, age-0 migrants were estimated to total 266,000 sockeye and 76,000 coho fingerlings (Table 3; Fig. 10). Accuracy of the estimated totals was ±23% for age-0 sockeye fingerlings and ±14% for age-0 coho fingerlings. A total of 32 days were not sampled between 16 June and 13 September. Extrapolated populations for these periods with missing data were 189,000 sockeye and 48,000 coho fingerlings; estimated total populations were 455,000 sockeye and 124,000 coho fingerlings (Table 4). In addition, unknown numbers of fry of all species moved downstream in May and early June.

Comparison of the size of marked fish and recaptured fish (Fig. 11) showed that the population estimates generally were not biased by size selectivity of the fyke nets, except that the smallest marked age-0 coho fingerlings (<40 mm) were recaptured in low numbers ($P < 0.001$; Kolmogorov-Smirnov test). Length frequencies of marked and recaptured coho smolts and sockeye juveniles (all ages), however, were similar ($P > 0.10$). Because of ineffectiveness in catching fish less than 40 mm, spring fry populations were not estimated.

Table 3.--Number of juvenile salmon caught (C), marked (M), and recaptured (R) to estimate number (N) of downstream migrants in the Taku River by sampling period in 1989. Confidence Intervals (CI) are in parentheses.

Sampling Period	C	M	R	$\hat{N}$ (95% CI) (Thousands)	
Age-1 and -2 Sockeye Smolt					
29 April-19 May	1,095	774	18	47	(31-85)
19 May-26 June[a]	1,535	1,330	9	227	(132-506)
Total				274	(76-472)
Age-1 and -2 Coho Smolt					
29 April-28 May	4,301	3,169	154	89	(77-101)
2-15 June	1,474	1,206	42	42	(33-58)
16-26 June	433	326	26	5	(4-9)
Total				136	(117-155)
Age-1 and -2 Chinook Smolt					
29 April-26 June[a]	2,391	1,254	14	214	(141-379)
Age-0 Sockeye Fingerlings					
16-26 June	1,972	947	20	93	(66-161)
10-23 July	1,635	747	21	58	(40-101)
5-14 Aug	1,275	1,113	41	35	(27-45)
22 Aug-13 Sept	5,000	3,358	211	80	(70-91)
Total				266	(204-328)
Age-0 Coho Fingerlings					
16-26 June	327	212	10	7	(4-17)
10-23 July	744	521	38	10	(7-14)
5-14 Aug	1,066	943	49	21	(15-27)
22 Aug-13 Sept	4,204	1,743	193	38	(33-44)
Total				76	(65-87)

[a]Except for 4 days (29 May-l June) when sampling was ineffective because of flooding.

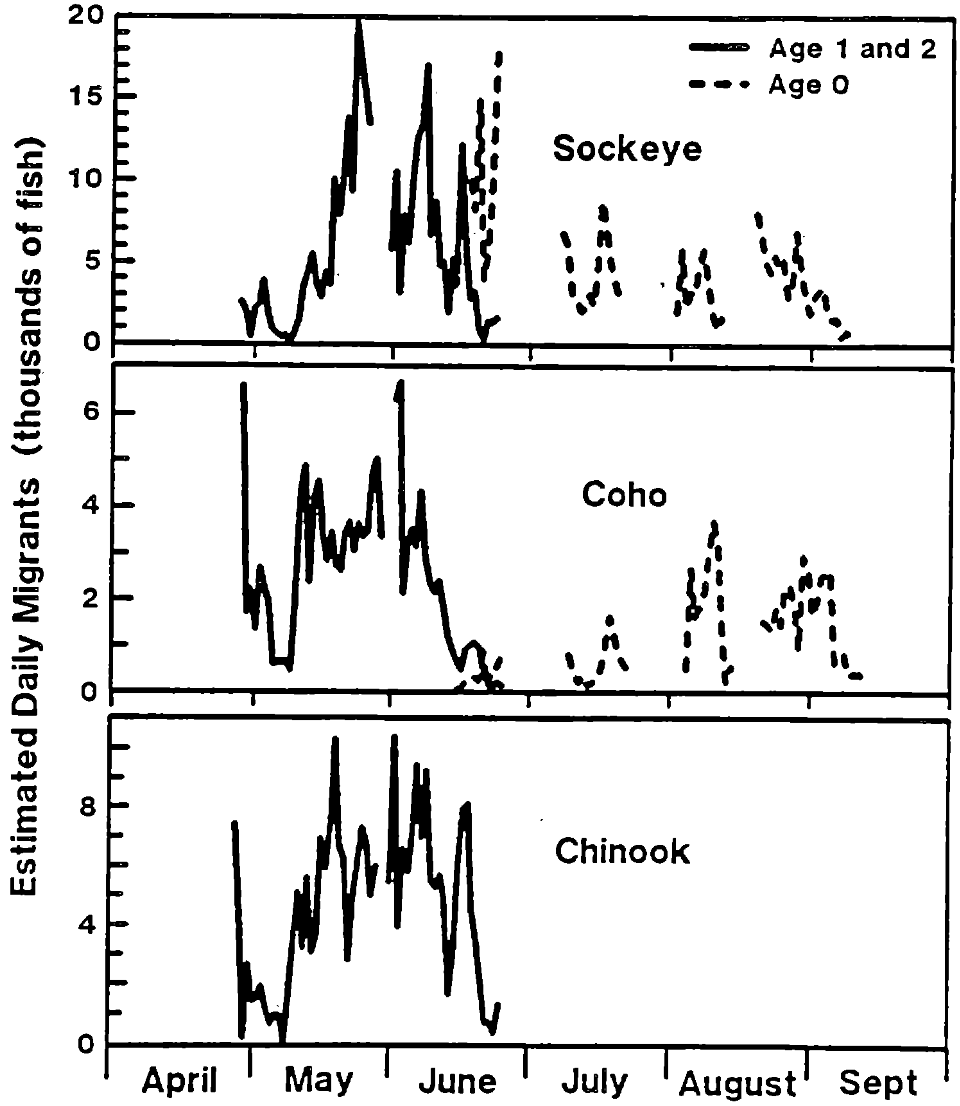

Figure 10.--Estimated number of juvenile sockeye, coho, and chinook salmon migrating downstream daily in the Taku River, Alaska, April to September 1989. Numbers of salmon fry in spring and chinook fingerlings in summer were not estimated.

Table 4.--Extrapolation of downstream migrant numbers during unsampled periods from the mean numbers in adjoining marking periods (as described in the Methods), sum of mark-recapture in Table 3, and estimated total populations of migrants for the study period.

Period	Number of days in period	Mean $\hat{N}/d$ in adjoining periods	Estimated migrants in period (thousands)
Age-1 and -2 Sockeye Smolts			
Unsampled periods:			
15-28 April	14	806	11
29 May-1 June	4	13,778	55
Mark-recapture estimates	55		274
Total (15 April-26 June)	73		340
Age-1 and -2 Coho Smolts			
Unsampled periods:			
15-28 April	14	964	14
29 May-1 June	4	3,663	15
Mark-recapture estimates	55		136
Total (15 April-26 June)	73		165
Age-1 and -2 Chinook Smolts			
Unsampled periods:			
15-28 April	14	864	12
29 May-1 June	4	12,721	51
Mark-recapture estimates	55		214
Total (15 April-26 June)	73		277
Age-0 Sockeye Fingerlings			
Unsampled periods:			
27 June-9 July	13	7,486	97
24 July-4 Aug	12	4,348	52
15-21 Aug	7	5,654	40
Mark-recapture estimates	58		266
Total (16 June-13 Sept)	90		455
Age-0 Coho Fingerlings			
Unsampled periods:			
27 June-9 July	13	1,122	15
24 July-4 Aug	12	1,064	13
15-21 Aug	7	2,865	20
Mark-recapture estimates	58		76
Total (16 June-13 Sept)	90		124

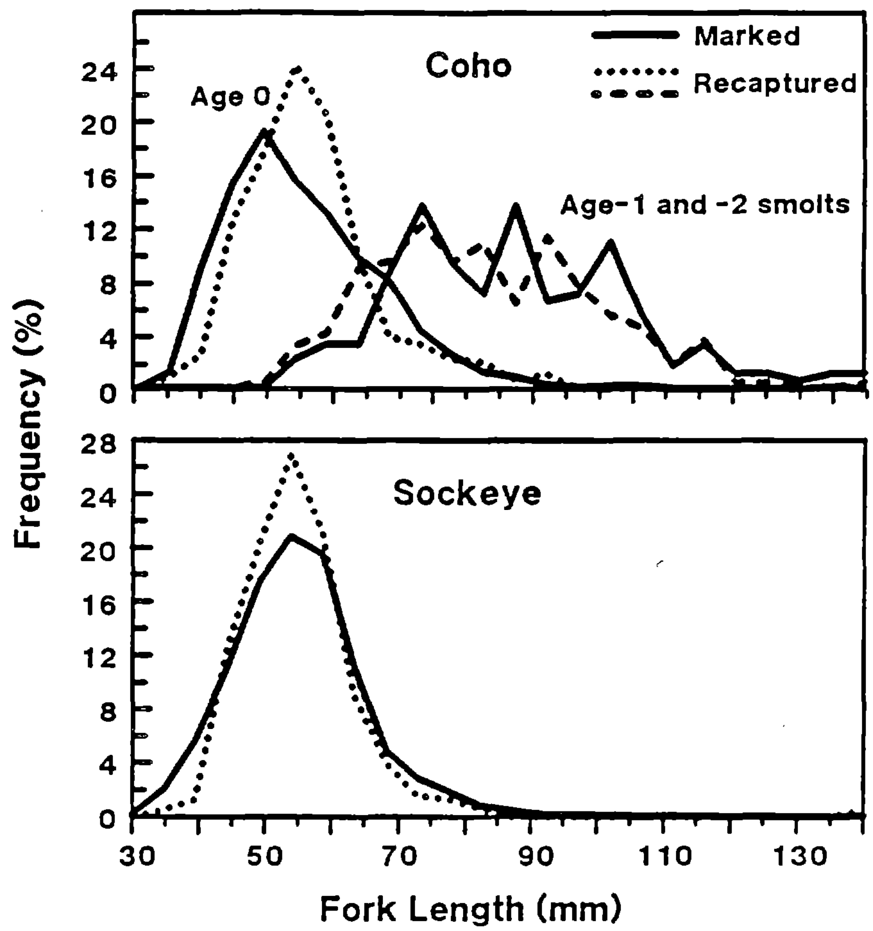

Figure 11.--Comparison of length frequencies of age-0 coho fingerlings, age-l and -2 coho smolts, and juvenile sockeye salmon (all ages) marked and released upstream (solid lines) with those subsequently recaptured (broken lines) in the Taku River, Alaska, May to September 1989.

The assumption of random mixing of marked and unmarked fish was verified. Comparison of trap efficiency for marked fish released on opposite sides of the river showed no significant (P > 0.50; Chi-square test) effect of release location for any fish group (Table 5). Complete mixing of marked and unmarked fish probably occurred as fish passed through the gorge at Canyon Island (Fig. 1).

Table 5.--Comparison of trap efficiency for groups of marked fish released on east and west sides of the Taku River 5-6 km upstream from the capture site. There was no significant (P > 0.05; Chi-square test) difference in recapture rate between release sites for any fish group.

	East side		West side	
	No. Marked	% Recap.	No. Marked	% Recap.
Coho smolt	3,002	5.4	1,545	5.0
Coho, age 0	1,912	8.4	1,597	8.0
Sockeye[a]	4,849	3.9	3,947	3.6
Chinook smolt	976	1.2	962	0.6
Chinook, age-0	1,154	0.5	352	1.4

[a]Ages 1 and 2 before mid-June and age 0 after mid-June.

DISCUSSION

This study provides the first quantitative estimates of salmon smolts and age-0 migrants in the Taku River. Although the estimates have wide confidence intervals and were partially extrapolated for unsampled periods, the results do provide approximate estimates of the yield of smolts from the upper river and number of age-0 salmon that migrate to the lower river in summer. The data provide a clearer picture of the magnitude of juvenile salmon migrations and the role of lower-river habitat in the Taku River's salmon production.

The estimated numbers of age-l and age-2 smolts were less than expected, given the estimated adult returns to the area above Canyon Island. For sockeye salmon, about 140,000 adults with at least one freshwater annulus on their scales return each year to the area above Canyon Island (Eiler et al. 1988; McPherson et al. 1988). If populations are roughly stable and marine survival is about 15% (an average for sockeye salmon from nearby Auke Lake, Alaska[2]), the 140,000 adults would have been derived from 933,000 smolts. Thus, our estimate of 340,000 sockeye smolts is only 36% of the expected number. For coho salmon, the estimated escapement

[2]S. Taylor. 1990. Auke Bay Laboratory, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA, 11305 Glacier Highway, Juneau, AK 99801. Unpubl. data.

of 37,000 adults to the area above Canyon Island (Transboundary Technical Committee 1988) suggests a total return to this area of 65,000 adults, based on 57% fisheries exploitation for wild coho salmon. stocks (Shaul et al. 1984; Elliott et al. 1989). If marine survival is 8% (Elliott et al. 1989), the expected number of coho smolts should be 812,000; our estimate of 165,000 is 20% of the expected number. For chinook salmon, the estimated total return of adults excluding jacks (≤ 2 years in ocean) has averaged about 12,000 fish between 1985 and 1989 (Mecum 1990). If jacks are 48% of the return (Kissner and Hubartt 1986), and marine survival is 3% (Kissner 1984), the expected number of chinook smolts should be about 833,000; our estimate of 277,000 smolts is 33% of the expected number.

Numbers of smolts could have been underestimated if more fish migrated during unsampled periods than indicated by the mean numbers in adjoining marking periods. In particular, more fish could have migrated during the 4-day flood between 29 May and 2 June. Because of the large size and multi-basin characteristics of the Taku River watershed, however, migrations are irregular and extended (Hartman et al. 1967); therefore, we were unlikely to have missed much of the migration in just 4 days.

To explain the lower than expected smolt yields from the upper river, we speculate that a large proportion of age-0 salmon that are spawned upriver migrate to the lower river and go to sea from there the following spring. Our estimates for age-0 salmon demonstrate a major summer migration to the lower river. An estimated 455,000 age-0 sockeye fingerlings and 124,000 age-0 coho fingerlings moved downstream in summer. If winter mortality is about 50% (Murphy et al. 1984), the summer migrants alone could yield 227,000 sockeye smolts and 62,000 coho smolts the following year. In addition, unknown numbers of age-0 sockeye, coho, and chinook fry and fingerlings moved downstream in spring, when they were too small to be caught effectively, and in fall after sampling ceased. Based on our low estimates of smolts from the upper river, the combined numbers of age-0 salmon migrating to the lower river in spring, summer, and fall might account for as much as two-thirds of the smolt yield from the river the following year.

Recent studies corroborate this possibility. Radio-tagging showed that nearly two-thirds of returning adult sockeye salmon spawn in the upper main-stem Taku River and other riverine areas not associated with lakes (Eiler et al. 1988). In summer, however, age-0 sockeye juveniles were virtually absent from the upper main stem[3], whereas up to 1.1 million age-0 sockeye juveniles were estimated to rear in the lower river and associated off-channel habitat (Murphy et al. 1989). Another contributing cause of the low sockeye, smolt yield in 1989 may have been the low 1987 escapement (2,794 compared with an average of 12,192 fish) to Tatsamenie Lake, one of two major lakes in the Taku River drainage that support sockeye salmon (Transboundary Technical Committee 1988); this would decrease the expected yield of sockeye smolts in 1989. Mass migration of age-0 sockeye juveniles to the lower river and the reduced contribution of smolts from Tatsamenie Lake could explain why our estimate of sockeye smolts was only one-third of the expected number.

The summer migration of age-0 salmon to the lower Taku River differs from the typical pattern in other studies. Spring and fall are the usual periods of downstream movement, whereas summer is a time of stasis (Murphy et al. 1984). The summer migration in the Taku River may be caused by nomadic behavior and shrinking habitat as river discharge drops between June and November. Because carrying capacity for coho and sockeye juveniles is a function of lake or pool volume (Murphy et al. 1986; Koenings and Burkett 1987), a decrease in water level could cause them to migrate. Thus, downstream areas of the river probably provide critical habitat for migrants leaving dewatered habitat upriver.

"Sea-type" sockeye salmon, which go to sea at age 0, make up about 13% of the adult sockeye salmon returning to the Taku River (McPherson et al. 1988). Juvenile sea-type sockeye salmon appeared to migrate mostly in early summer, and the estimated number of migrants in only 2 weeks in early summer could account for the river's total return of sea-type sockeye salmon. The sudden onset of migration and increase in size of age-0 sockeye juveniles in mid-June indicated the' migration of a distinct group of fish that had reared upriver for several months. This migration pattern appears to recur each year. In both 1987 and 1989, the number and size of age-0 sockeye migrants increased sharply in June, and mean FL was nearly the same both years (Murphy et al. 1988). Based on an adult return of 22,000 sea-type sockeye salmon (McPherson et al. 1988) and an assumed marine survival of 15% (see footnote 2), the expected number of age-0 sea-type migrants is about 150,000. By our estimate, age-0 sockeye migrants in only 16 days in late June should account for the river's adult return of sea-type sockeye salmon.

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[3]J. M. Lorenz. 1990. Auke Bay Laboratory, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA, 11305 Glacier Highway, Juneau, AK 99801. Unpubl. data.

In conclusion, downstream migrations of juvenile salmon in the Taku River have an important role in the river's salmon production. Lower than expected smolt yields from the upper river and a comparative abundance of age-0 migrants indicate that a large proportion of the age-0 salmon spawned in the upper river migrate to the lower river where they rear until going to sea the following year. More data are needed, however, to verify results of this study. Future research should partition smolt yield between the upper and lower river to better evaluate these areas as summer nurseries and wintering habitats for juvenile salmon.

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