Abundance of the Chinook Salmon Escapement in the Taku River, 1989 to 1990

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ABSTRACT: An interagency study was conducted to estimate, through mark-recapture methods, the abundance of *large* (≥660 mm MEF), spawning chinook salmon *Oncorhynchus tshawytscha* in the Taku River in 1989 and 1990. Fish were captured with fish wheels from May through July in the lower river at Canyon Island in Southeast Alaska. All fish were marked with back-sewn spaghetti tags, and some were additionally fitted with radiotags. Chinook salmon recaptured in Canadian tributaries showed that fish bound for the Nahlin River generally passed Canyon Island first, those bound for the Nakina River passed next, and fish bound for Tatsatua and Kowatua Rivers passed last. The 1984 year class predominated samples in both 1989 and 1990. Little or no size- or sex-selective sampling among larger fish was evident in samples taken from tributaries. Because many recaptured fish had lost their spaghetti tags, the marked population used for estimating abundance was defined as only those fish with radiotags that had been tracked to their spawning grounds. Recapture proportions were similar among tributaries. Abundance of large fish was estimated at 40,329 (SE = 5,646) for 1989 and 52,142 (SE = 9,326) for 1990. Estimates of abundance from aerial surveys of the Taku River were considerably smaller than estimates from mark-recapture experiments in both 1989 and 1990, a trend repeated in studies at other transboundary rivers in later years.

INTRODUCTION

Chinook salmon *Oncorhynchus tshawytscha* returning to the Taku River represent 1 of the largest and most important populations of chinook salmon in Southeast Alaska (Figure 1). Prior to the mid 1970s these fish were exploited in directed commercial fisheries in Alaska, annual harvests reaching 15,000 fish (Kissner 1978). As part of a program to rebuild stocks of chinook salmon throughout Southeast Alaska, the directed gillnet fishery was suspended in 1976. Presently adult chinook salmon from the Taku River are caught incidentally in U.S. gillnet fisheries targeting other salmon species near the mouth of the river and in a Canadian inriver gillnet fishery targeting sockeye salmon *O. nerka*. Taku River chinook salmon are also exploited in marine sport fisheries near Juneau and in freshwater sport fisheries in Canada.

The Taku River, a transboundary river with a drainage of over 16,000 km^2, originates in northern British Columbia and flows into the Pacific Ocean 48 km east of Juneau, Alaska (Figure 1). Flows range from 40 m^3/s in winter to 2,489 m^3/s in summer and average 740 m^3/s in June (McGregor and Clark 1989). Sudden increases in discharge in the lower river are caused by a release of glacially impounded waters from Tulsequah Lake, an event that usually occurs once or twice a year between May and August. During floods, water levels fluctuate dramatically and the river carries a tremendous load of debris (McGregor and Clark 1989). Principal tributaries include the Sloko, Nakina, Sheslay, Inklin, and Nahlin Rivers. The upper Taku River, in Canada, is extremely remote and has no road access

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and few year-round residents. All chinook salmon spawn in tributaries of the upper drainage, mostly in the Nakina, Nahlin, Dudidontu, Tatsatua, Hackett, and Kowatua Rivers and Tseta Creek.

Since 1975 escapements to the Taku River have been assessed from helicopters by counting chinook salmon on the spawning grounds (Pahlke 1993). Only *large* chinook salmon, typically ages .3, .4, and .5 that

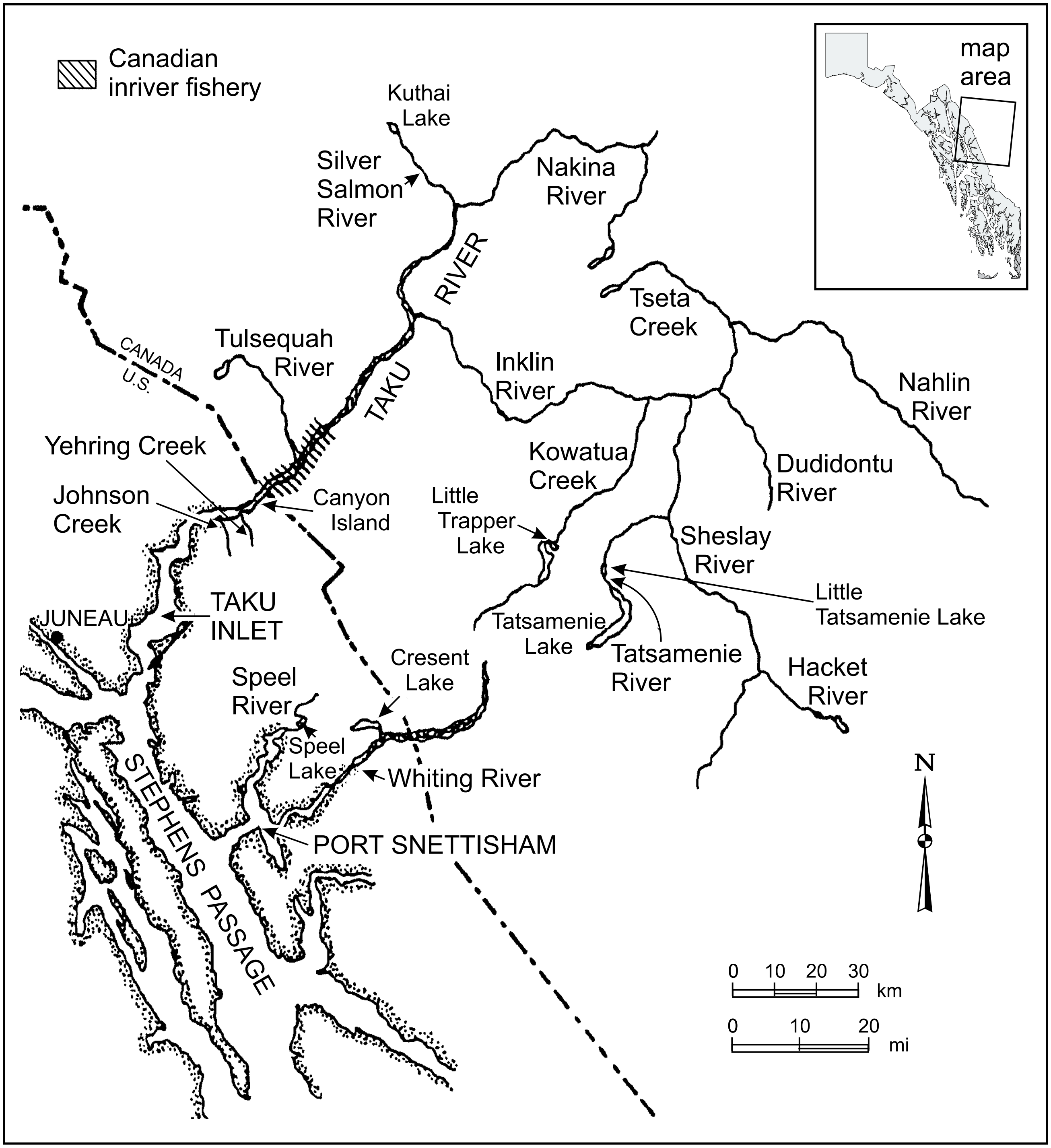

Figure 1. Watershed of the Taku River and Taku Inlet.

Table 1. Numbers of chinook salmon released with tags at Canyon Island and inspected for tags and fin clips in upriver tributaries during 1989 and 1990 by length group (MEF).

	1989 Number Tagged			1990 Number Tagged		
	Total	≥ 660 mm	< 660 mm	Total	≥ 660 mm	< 660 mm
Tagged and Released at Canyon Island:						
Spaghetti-tagged	1,235	822	413	912	637	275
Radio-tagged	429	389	40	372	372	0
Number of Fish Inspected at:						
Nahlin River (live weir)	542	493	49	2,240	1,992	248
Nakina River (carcass weir)	4,347	3,540	807	2,527	2,094	433
Kowatua River (carcass weir)	721	601	120	938	559	379
Tatsatua System						
River (carcass weir)	834	636	198	883	752	131
Tatsamenie Lake (live weir)	1,051			434	356	78
Total Inspected	6,444[a]	5,270	1,174	6,084[b]	5,194[b]	890[b]

[a] Samples taken at the live weir below Tatsamenie Lake in 1989 were not included in the total because not all samples were examined for missing tags or were measured.
[b] Samples taken at Kowatua River in 1990 were not included in the total because this sample was not used in the mark-recapture experiment.

are ≥660 mm long (mid eye to fork of tail; MEF), were counted during these aerial surveys. No attempt was made to accurately count smaller age-.1 and most age-.2 fish (Pahlke 1993) because they are difficult to distinguish from smaller species, such as pink *O. gorbuscha* and sockeye salmon. Survey counts of large chinook salmon were expanded to account for unobserved fish and unsurveyed spawning areas (Mecum and Kissner 1989) using expansion formulas, established in 1981 without knowledge of actual escapements to the Taku River (ADF&G 1981). In 1988 a feasibility study showed it was possible to mark and recapture enough large chinook salmon in the Taku River to estimate escapement (McGregor and Clark 1989).

In 1989 and 1990 the Commercial Fisheries Division of the Alaska Department of Fish and Game (ADF&G) tagged adult chinook salmon in the Taku River in an effort to estimate the abundance of spawners in the watershed. This project was 1 of a group of cooperative projects between the National Marine Fisheries Service (NMFS), the Canadian Department of Fisheries and Oceans (CDFO), and ADF&G to obtain information on spawning and harvested Taku River chinook salmon. Using tag and recovery information, we were to estimate inriver spawning abundance by age and sex, information against which concurrent aerial surveys could be calibrated. If disparate estimates were found, we believed they could lead to reevaluation of escapement estimates and the methods used to provide such estimates, as well as possibly alter exploitation rate estimates, escapement goals, and even stock status.

METHODS

Tagging and Sampling

Migrating adult salmon were captured with 2 fish wheels set 200 m apart along opposite banks of the river at Canyon Island (Figure 1; McGregor et al. 1991). Fish wheels operated continuously, except during extreme high or low water velocities and during maintenance and sampling. All uninjured chinook salmon ≥440 mm in length (MEF) caught in the fish wheels were tagged (McGregor and Clark 1989); those <440 mm were generally too small to tag readily and would not have been effectively recovered on the spawning grounds with the recovery methods available to us.

Salmon were dipnetted from a live box to a tagging trough partially filled with river water. Carefully

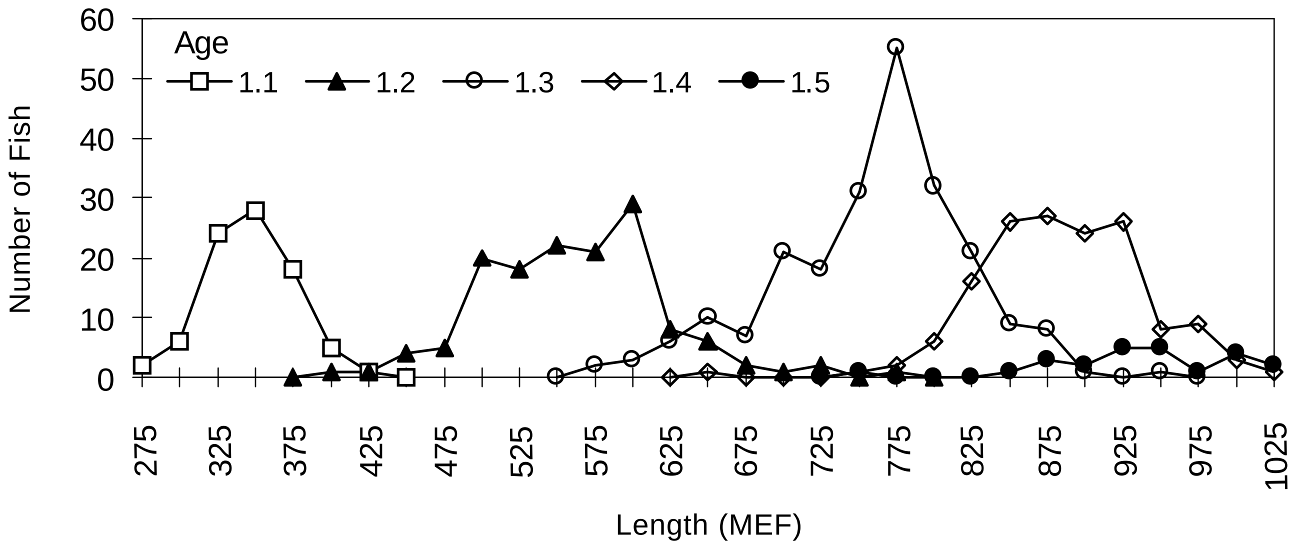

Figure 2. Length frequency (MEF), by age class, of chinook salmon sampled at the Nakina River carcass weir, 1989.

handled with bare hands or neoprene gloves to reduce injury, fish were measured for length and their sex was determined from secondary sex characteristics. A sample of 4 scales was taken from the *preferred area* (INPFC 1963) of each fish, and age was determined based on the circuli pattern (Olsen 1992) on magnified acetate impressions of the scales (Clutter and Whitesel 1956).

Spaghetti tags (Floy Tag and Manufacturing, Inc., Seattle, WA[1]) were sewn through the dorsal musculature immediately below the dorsal fin with a 15-cm metal needle and the ends tied with a single overhand knot. Individually numbered tags were made of PVC tubing (approximately 2 mm in diameter and 30 cm in length). Gray tags were used to reduce susceptibility to predation and scavenging on marked fish. Radio-transmitters at frequencies of 150–151 MHz (Advanced Telemetry Systems[1]) were orally inserted into the stomachs of 10 to 15 large (≥660 mm MEF), spaghetti-tagged chinook salmon each day (Eiler et al. 1988). Transmitters used in this study were equipped with motion (mortality) sensors that doubled the pulse rate to 2 pulses/s following 3–4 h of inactivity (Eiler 1990). Although no secondary mark was used to determine tag loss in 1989, in 1990 the posterior 3 rays of the dorsal fin were clipped approximately 1 cm above the back (Shaul 1994). Chinook salmon judged by inspection to be <440 mm MEF were counted but not sampled or tagged in 1989; in 1990 these fish were measured but not tagged.

In 1989 chinook salmon were sampled for tags at the Nakina, Tatsatua, Kowatua, and Nahlin Rivers and Tseta Creek, and in 1990 at the Nakina, Tatsatua, Kowatua, Nahlin and Dudidontu Rivers (Figure 1). In 1989, samples were collected using carcass weirs at the Nakina, Tatsatua, and Kowatua Rivers; with a live weir at the Tatsamenie River (a Tatsatua tributary); and during a foot survey of carcasses on the Nahlin River and Tseta Creek. Samples were collected in 1990 in the same manner, except live fish were collected at a weir on the Nahlin River and carcasses were taken during a foot survey on the Dudidontu River. All sampled fish were closely examined for tags, and their length and sex were noted; 4 scales were collected from the preferred area of each fish for age determination. Because few fish were collected during foot surveys at Tseta Creek (117) and the Dudidontu River (108), samples taken from these locations were not included in mark-recapture estimates.

Analysis

Abundance of the spawning population of large chinook salmon was estimated using Chapman's modified Petersen mark-recapture estimator (Seber 1982). A contingency table (chi-square statistic) was used to test whether fish sampled at various spawning locations had been marked at similar rates. Failure to reject the null hypothesis of equal probabilities of capture at Canyon Island satisfied the criteria listed in Seber

[1] Mention of a trade name is included for scientific completeness and does not imply endorsement by the author or the Alaska Department of Fish and Game.

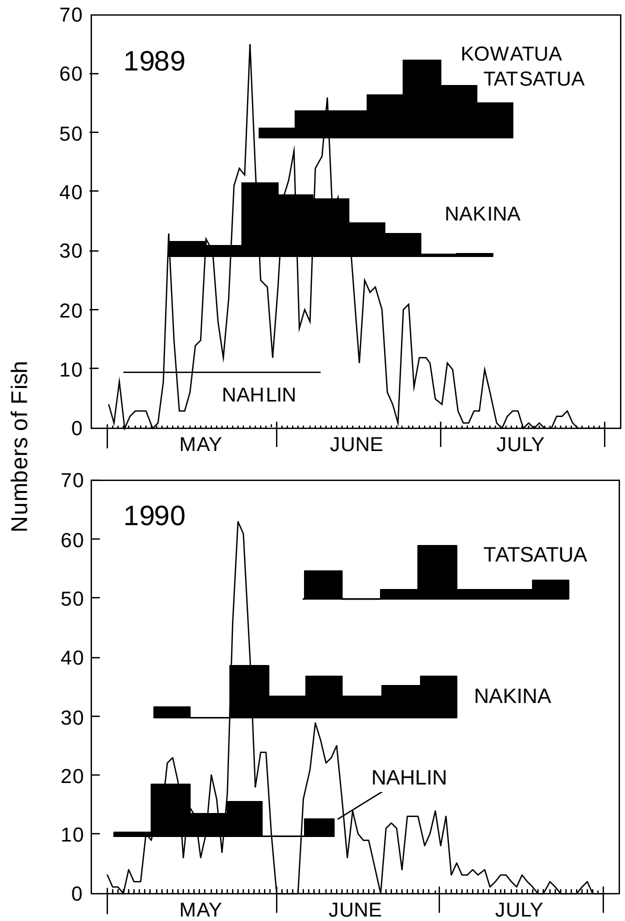

Figure 3. Weekly numbers of chinook salmon mark recaptures in the Nahlin, Nakina, Kowatua, and Tatsatua Rivers in 1989 and 1990 (bar graphs), set against daily catches in fish wheels at Canyon Island (line graph). So few fish were recaptured in the Nahlin River in 1989 that only the range across the first and last recaptured fish to pass Canyon Island is reported. Data on fish recaptured in the Kowatua and Tatsatua Rivers in 1989 were also combined because of few numbers. No fish were recaptured in the Kowatua River in 1990.

(1982) for pooling stratified data to produce a consistent estimate using the Petersen estimator. Whether large fish of different sizes were recaptured in the tributaries with equal probability was tested using a Kolmogorov-Smirnov 2-sample test on the length distribution of marked versus recaptured fish. Failure to reject the null hypothesis indicated no stratification by size of fish was needed to avoid bias in estimates of abundance. Confidence intervals were estimated based on frequency percentiles of 1,000 bootstrapped estimates generated using procedures in Buckland and Garthwaite (1991) for resampling data from mark-recapture experiments. Relative bias in estimated abundance was estimated with the same bootstrap simulations (Efron and Tibshirani 1993).

Age and sex compositions of chinook salmon on the spawning grounds were estimated from samples taken from each tributary sampled and, by inference, for fish age 1.2 and older on all spawning grounds in the watershed. Because salmon did not grow between being marked at Canyon Island and being recaptured on the spawning grounds, a Kolmogorov-Smirnov 2-sample test was used to detect size-selective sampling on the spawning grounds. Because marine age and chinook size are positively correlated, this test was also used to infer age-selective sampling, or the lack thereof. Contingency tables were used to detect sex-selective sampling on the spawning grounds. In the absence of size-, age-, or sex-selective sampling, proportions of each population by age and sex group were estimated without a correction for sampling from finite populations (Cochran 1977).

Statistics were calculated for each tributary and for the entire watershed based on information pooled across sampled tributaries. Age and sex composition of spawners for the watershed was estimated in numbers as well as in proportions as $\hat{N}_{a,s} = \hat{N}_{mr}\,\hat{p}_{a,s}\left(1-\hat{p}_{1.2}\right)^{-1}$, where N is abundance, p is a proportion, mr signifies an estimate from the mark-recapture experiment, and a,s signifies each age/sex group. For these calculations, large chinook salmon (≥660 mm MEF) were considered to be age 1.3 and older as determined by McGregor and Clark (1989). The estimate *var* $\left[\hat{p}_{a,s}(1-\hat{p}_{1.2})^{-1}\right]$ was approximated with the delta method, and *var* $\left(\hat{N}_{a,s}\right)$ was calculated as the product of 2 independent variables (Goodman 1960). No statistics were calculated for age-1.1 fish because the smallest fish caught at Canyon Island were not marked and could not be included in tests for size- or sex-selective sampling.

RESULTS

First Year: 1989

In 1989 we marked and released 1,235 chinook salmon at Canyon Island and sampled 7,495 chinook salmon upstream (Table 1). Water levels and flows were relatively stable throughout the project. Considerable overlap in the migratory timing of salmon passing Canyon Island was evident, but generally fish bound for the Nahlin River passed first, those bound for the Nakina River passed next, and those headed for the Kowatua and Tatsatua Rivers passed last (Figure 3).

Table 2. Age and sex composition of spawning chinook salmon in 1989 and 1990 estimated from data pooled across 1,989 and 2,580 samples, respectively, taken at the Nahlin, Nakina, Kowatua, and Tatsatua Rivers.

	Both Sexes				Males				Females			
	1989		1990		1989		1990		1989		1990	
Age[a]	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE
1.2	0.21	0.009	0.12	0.006	0.21	0.009	0.12	0.006	0.00	0.001	0.00	0.001
1.3	0.52	0.011	0.35	0.009	0.33	0.011	0.23	0.008	0.19	0.009	0.12	0.006
1.4	0.24	0.010	0.51	0.010	0.10	0.007	0.18	0.008	0.14	0.008	0.33	0.009
1.5	0.03	0.004	0.02	0.003	0.01	0.003	0.01	0.002	0.02	0.003	0.01	0.002

[a] Because age 1.1 could not be included in tests for size- or sex-selectivity of sampling, this age group was excluded from the table. Because only a few age-2. chinook salmon were sampled, these age groups were also excluded.

Age-1.3 chinook salmon predominated all samples (Figure 4; Table 2) and relative frequencies for ages-1.3 and older salmon (generally those fish ≥660 mm MEF) were similar across all tributaries. Males predominated overall and younger males (age 1.1 and 1.2) at the Nakina and Kowatua Rivers, where samples were collected exclusively with carcass weirs, were more abundant than at other rivers. Lengths of fish recaptured in the tributaries were similar to lengths of fish released with tags at Canyon Island (Kolmogorov-

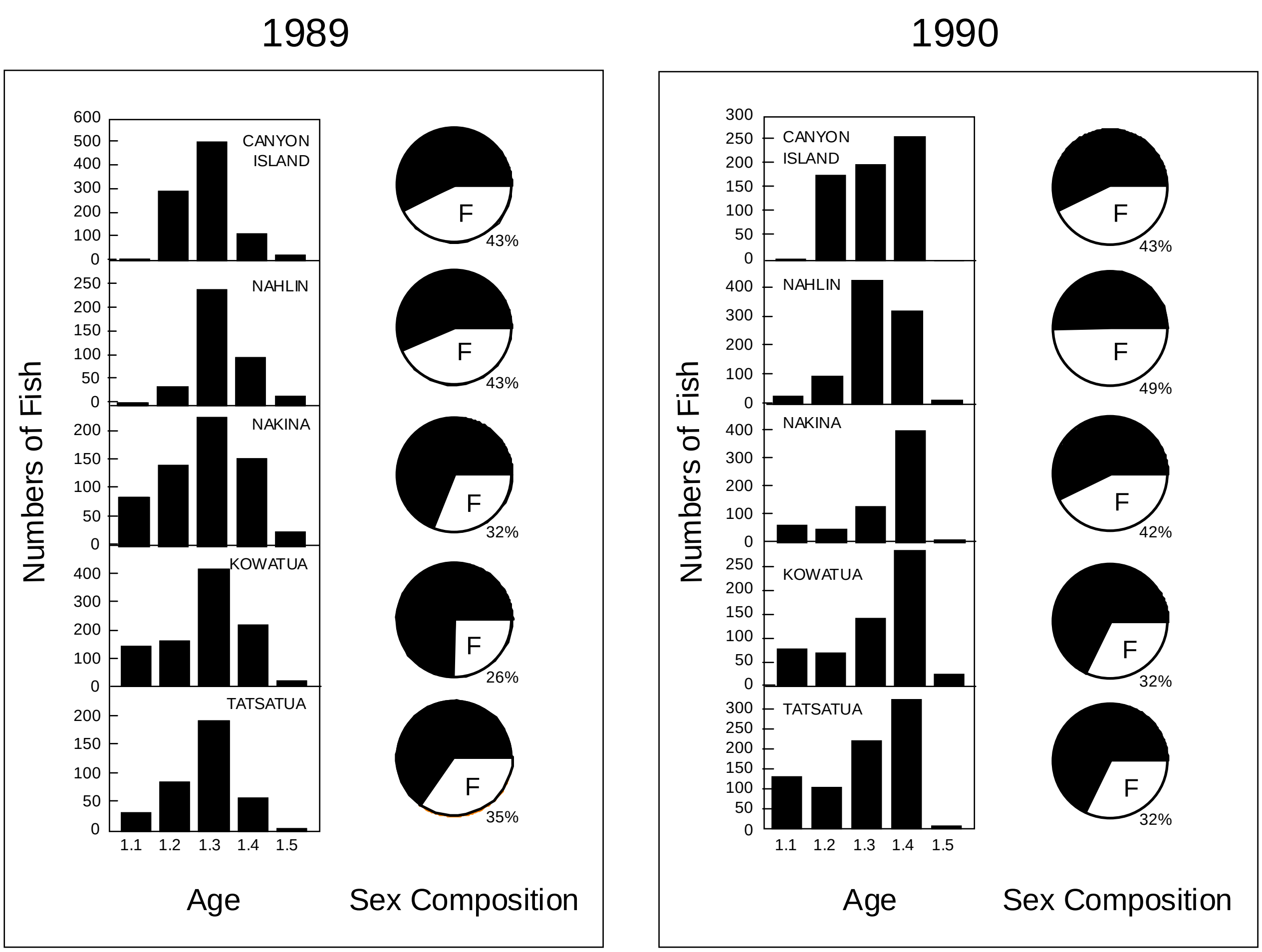

Figure 4. Age (numbers) and sex composition (proportions) of samples taken in 1989 and 1990 at Canyon Island and at the Nahlin, Nakina, Kowatua, and Tatsatua Rivers. Age-2. fish are excluded.

Smirnov 2-sample test; *P* = 0.64; Figure 5), indicating that sampling in tributaries was not size-selective. Because few age-1.1 fish were marked at Canyon Island, this test is germane only for salmon age 1.2 and older. Similar recapture rates, 8.1% for females and 8.6% for males, indicated no sex or size selectivity in sampling for these older fish.

Inspection of recaptured salmon indicated that an estimated 38% of the recaptured marked fish had lost their spaghetti tags: 19 of 49 recaptured salmon with radiotags had lost their spaghetti tags and 7 others had wounds indicative of having been tagged. Considering this high loss of spaghetti tags and lack of secondary marks, only large fish carrying radiotags that had reached the spawning grounds were used in the mark-recovery abundance estimate. Of 389 large fish fitted with radiotags, 328 were tracked onto spawning grounds, and these formed the tagged population (Figure 6). Radiotagged fish that did not make it to the spawning grounds were excluded from the tagged population and not included in the mark-recapture analysis (hereafter referred to as *censored* fish). Of the 61 censored fish, 5 were recovered in marine commercial and sport fisheries in Taku Inlet, 10 disappeared (signal lost) below Canyon Island, 27 regurgitated their tags or died near Canyon Island, and 19 were recaptured in an inriver gillnet fishery targeting sockeye salmon. The 40 fish <660 mm MEF tagged with

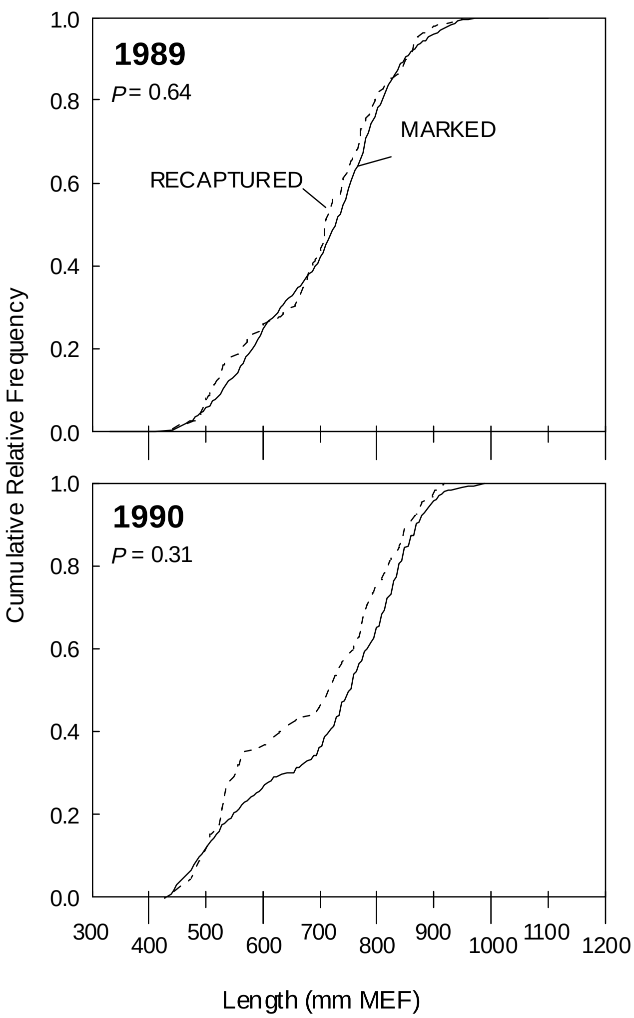

Figure 5. Cumulative relative frequencies of chinook salmon marked at Canyon Island in 1989 and 1990 and subsequently recaptured during sampling in tributaries (Nahlin, Nakina, Kowatua, and Tatsatua Rivers). *P* values are from Kolmogorov-Smirnov's test for differences between 2 distributions.

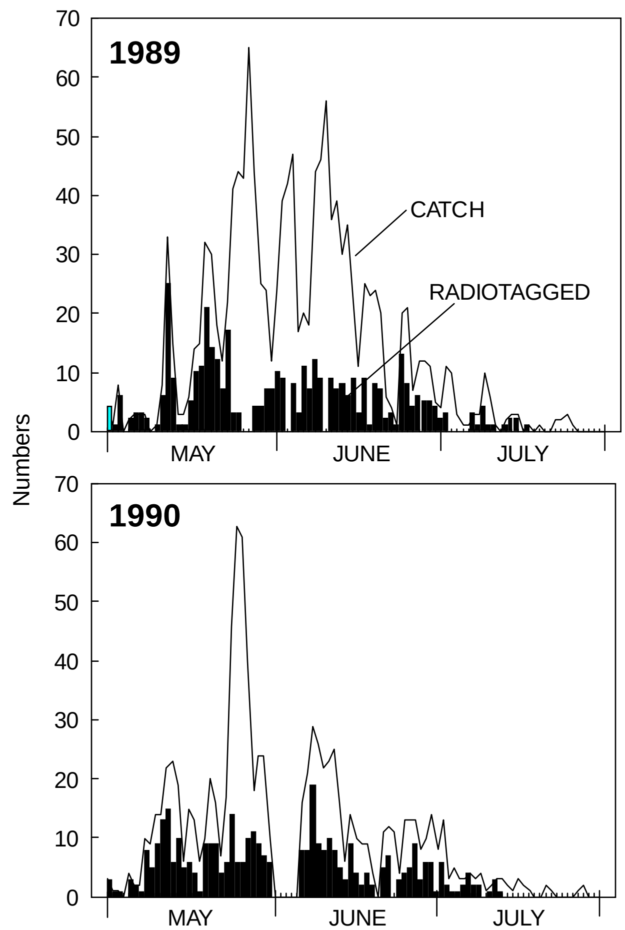

Figure 6. Daily numbers of chinook salmon implanted with radiotags and released at Canyon Island in 1989 and 1990 versus daily catches in fish wheels.

Table 3. Numbers of radiotagged large (≥660 mm MEF) chinook salmon recaptured in tributaries of the Taku River in 1989 and 1990 during carcass surveys or at carcass (C) and live (L) weirs.

	Nahlin River		Nakina River		Kowatua River	Tatsatua River		
Total	Survey	Weir(L)	Survey	Weir(C)	Weir(C)	Weir(C)	Weir(L)	Total Recoveries
1989	3			28	5	6		42
1990		14	0	8	0	1	3	26

radiotags were also excluded from the mark-recovery estimate.

The abundance of chinook salmon ≥660 mm MEF on the spawning grounds in 1989 was estimated at 40,329 (SE = 5,646), based on 5,270 large fish inspected for tags at 4 tributaries (Table 1) and 42 recaptured fish (Table 3). Based on the proportion of tributary recaptures to captures at Canyon Island, the estimated mark-recapture probabilities were 0.008 (28/3,540) for large fish bound for the Nakina River, 0.009 (6/636) for the Tatsatua River, 0.008 (5/601) for the Kowatua River, and 0.006 (3/493) for the Nahlin River. Similarity among these estimated probabilities (χ^2 = 0.23, df = 2, P = 0.89 with data from Nahlin and Kowatua Rivers pooled for the test) met criteria listed in Seber (1982) for pooling stratified data in a mark-recapture experiment to produce a consistent estimate of abundance with the Petersen estimator. The estimated 95% confidence interval was 30,936 to 56,995 for large fish, and the relative bias in estimated abundance was estimated to be 2.1%. Estimated abundance of large fish on the spawning grounds was 40,329, and estimated abundance of large chinook salmon passing Canyon Island was at most 41,255 (SE = 5,646), the sum of the estimated abundance of spawners and harvest in the inriver fishery. This estimate is a maximum because no estimate of age composition is available for the inriver harvest, and some portion of that harvest consisted of fish <660 mm MEF.

Second Year: 1990

In 1990 we tagged and released 920 chinook salmon at Canyon Island and sampled 6,084 chinook salmon upstream (Table 1). Unlike the previous year, a flood originating from Tulsequah Lake stopped operation of the fish wheels for almost 4 d (Figure 6). Migratory timing of stocks within the Taku River followed the pattern observed in 1989: fish bound for the Nahlin River generally passed Canyon Island first, those bound for the Nakina River passed next, and fish headed for the Tatsatua River passed last (Figure 3). Age-1.4 salmon and males predominated all samples, except those taken at the Nahlin River live weir (Figure 4; Table 2). Estimates of age composition had a similar pattern across other tributaries with considerable representation by young males. Most samples taken at the Nakina, Kowatua, and Tatsatua Rivers were taken at carcass weirs. Fish captured at Canyon Island were again excluded from this comparison because smaller males were not sampled as rigorously as larger fish. Lengths of fish recaptured in the tributaries were marginally dissimilar to lengths of fish released with tags at Canyon Island (Figure 5), but not significantly (Kolmogorov-Smirnov 2-sample test, P = 0.31), indicating that sampling in tributaries was not significantly size-selective. Because few age-1.1 salmon were tagged at Canyon Island, this test is germane only for salmon age .2 and older. Recapture rates between males and females were marginally dissimilar (5.3% for females and 8.2% for males, χ^2 = 2.70, df = 1, P = 0.11), indicating there was mild, but not significant, selectivity against females in the tributaries sampled.

In 1990 a significant percentage of the fish again shed their spaghetti tags: 6 of 26 (23%) recaptured salmon carried radiotags and no spaghetti tags and 6 of 52 (12%) recaptured fish with secondary marks (dorsal finclip) had no tags of any kind. Considering this loss of spaghetti tags and the disparity in the indicated rates of loss, only fish carrying radiotags were used to estimate abundance of large fish on the spawning grounds. Of 372 radiotagged fish ≥660 mm MEF (Figure 6), 102 were censored: 10 were captured in marine commercial and sport fisheries in Taku Inlet, 12 disappeared (signal lost) below Canyon Island, 53 regurgitated their tags or died near Canyon Island, and 27 were recaptured in the inriver gillnet fishery targeting sockeye salmon. The 270 that were tracked onto spawning grounds composed the marked population (Table 3).

Abundance of large chinook salmon on the spawning grounds in 1990 was estimated at 52,142 (SE = 9,326), based on 5,194 large fish inspected for marks on 3 tributaries (Table 1) and 26 recaptured, radiotagged fish (Table 3). The estimated 95% confidence interval was 37,072 to 80,784, and the relative bias in estimated abundance was estimated to be 3.7%. The estimated mark-recapture probability (as described for 1989) was 0.007 (=14/1,992) for the Nahlin River, 0.004 (=4/1,108) for the Tatsatua River, and 0.004

Table 4. Estimated abundance by age group and sex for chinook salmon spawning in the Taku River in 1989 and 1990.

	Both Sexes				Males				Females			
	1989		1990		1989		1990		1989		1990	
Age[a]	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE
1.2	10,569	1,589	7,095	1,338	10,441	2,525	7,049	1,329	128	79	46	33
1.3	26,715	3,819	20,848	3,779	17,068	3,998	13,799	2,513	9,647	2,298	7,049	1,313
1.4	12,053	1,770	30,124	5,434	5,016	1,236	10,929	2,003	7,037	1,700	19,195	3,472
1.5	1,561	294	1,171	264	665	225	666	170	896	281	505	139
Totals	50,898	7,149	59,238	10,603	33,190	2,540	32,443	4,679	17,708	4,827	26,795	5,831

[a] Because age 1.1 could not be included in tests for size- or sex-selectivity of sampling, this age group was excluded from the table. Because only a few age-2. chinook salmon were sampled, these age groups were also excluded.

(=8/2,094) for the Nakina River. Although estimated probabilities of capture were higher for fish bound for the Nahlin River, this difference was not significant ($\chi^2 = 2.65$, df = 1, $P = 0.11$ with data from the 2 latter tributaries pooled). Thirteen large chinook salmon with radiotags were tracked into the Kowatua River. Because none of these radiotags were recovered among the 559 large fish sampled, probability of capture at Canyon Island could not be estimated for this stock and the sample was excluded from the experiment. Failure to reject the null hypothesis of equal probabilities of capture at Canyon Island again met criteria listed in Seber (1982) for pooling of stratified data to produce a consistent estimate using the Petersen estimator.

Estimates of abundance by age group and sex are listed in Table 4. The Canadian inriver catch was 1,258 large fish and 128 jacks. The maximum estimate of abundance for large chinook salmon passing Canyon Island in 1990 was 53,400 (SE = 9,326), the sum of the mark-recapture estimate and inriver catch.

DISCUSSION

In our study, downstream migratory retreat of newly marked chinook salmon could have biased mark-recapture abundance estimates in the Taku River. Fish that moved downstream from Canyon Island had a greater chance of being caught in both the recreational marine fishery that begins in May and in commercial fisheries that begin in June. If this downstream movement is not a natural phenomenon of chinook salmon but a consequence of handling, tagged fish would suffer greater mortality than untagged fish. This retreat of tagged chinook salmon has been observed in other studies (Milligan et al. 1984; Johnson et al. 1992, 1993; Bendock and Alexandersdottir 1993). Because we monitored our tagged population with radio transmitters, we knew the actual number of tagged fish present when sampling was conducted on the spawning grounds. Therefore, migratory retreat of some tagged fish did not bias abundance estimates. Exclusion of samples taken from the Kowatua River in 1990 would have biased the estimate for that year if the probability of capturing large, Kowatua-bound chinook salmon at Canyon Island had been different than the probabilities for other stocks. Although we do not have an estimate of this probability for fish returning to the Kowatua River in 1990 (no radiotags were recovered during sampling in the Kowatua River that year), that bias is probably negligible based on the relative size of this stock. In 1989, 24 of 328 and in 1990, 13 of 270 large fish tracked to the spawning grounds were tracked to the Kowatua River.

We found that hollow-core plastic spaghetti tags sewn through the back of chinook salmon are an unsuitable primary mark to estimate their abundance in the Taku River. Living fish incurred unacceptably high rates of tag loss and carcasses even higher rates. Wounds from tags were not distinct enough to be recognized with certainty.

High tag loss does not necessarily invalidate a mark-recapture experiment as long as it can be measured. Tag loss rates in this study appeared to vary between sexes and sampling strata, making it very difficult to measure. The secondary mark, a shallow excision of the posterior margin of dorsal fin included in the 1990 program, was also unreliable, especially on abraded carcasses. Without the fortuitous use of radio transmitters in chinook salmon in 1989 and 1990, there would have been no estimates of abundance for either year. Radiotags were especially effective because they were unlikely to be lost once they reached the spawning grounds; recaptured fish without their spaghetti tags presented no additional information with which to estimate abundance (see Seber 1982, pp. 94–96 for consequences when only 1 of 2 types of marks are lost).

The success of mark-recapture experiments on the Taku River in 1989 and 1990 depended heavily on tagging chinook salmon at Canyon Island at a rate proportional to their passing abundance. According to Seber (1982), for our estimates of abundance to be unbiased (consistent) 1 of 3 requirements must have been satisfied: (1) every fish must have had an equal chance of being tagged at Canyon Island, (2) every fish on the spawning grounds must have had an equal chance of being sampled, or (3) marked and unmarked fish must have mixed completely before arriving at their spawning grounds. Fish in tributaries other than the Nahlin, Nakina, Kowatua, and Tatsatua Rivers were not inspected for marks, and differences in migratory timing of fish bound for different tributaries prevented complete mixing of tagged and untagged fish. Only by tagging fish in proportion to their relative abundance as they passed Canyon Island could all migrating fish have had an equal probability of being captured and tagged.

Flow-related changes in catchability of chinook salmon in fish wheels, protocols for selecting fish to carry radiotags, and censoring of radiotagged fish caught in gillnet fisheries all affected our ability to proportionally tag chinook salmon. Although there is little evidence of disproportionate sampling at Canyon Island in 1989, a Tulsequah River flood in May 1990 probably hampered proportionate sampling of chinook salmon bound for the Nakina, Kowatua, and Tatsatua Rivers. Still, our data passed the test of consistency (Seber 1982), indicating that our marking had been proportional, or nearly so, in both years. Although the power of these tests was not great, neither were the differences in marked fractions among samples. Because our samples came from populations that represented the earliest through the latest fish to pass Canyon Island (McGregor and Clark 1989), our estimates of abundance pertained to all chinook salmon spawning in the Taku River watershed.

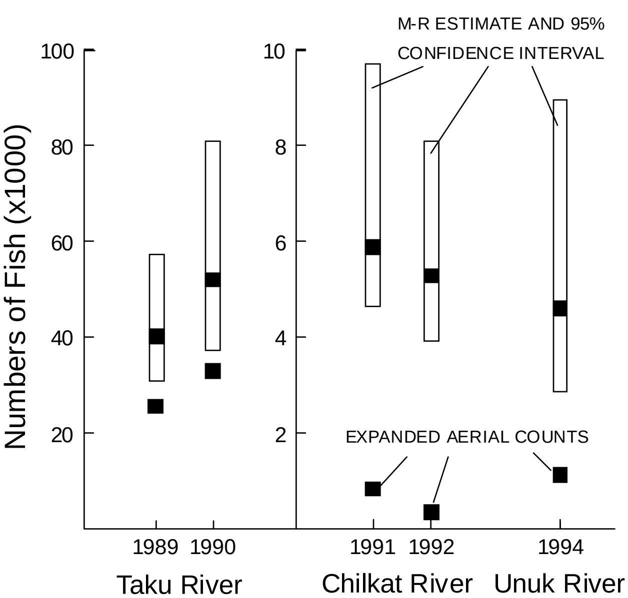

Figure 7. Comparison between abundance of large chinook salmon (≥660 mm MEF) estimated through expansion of counts from aerial surveys and through mark-recapture experiments. Methods of expansions in surveys are described in Pahlke (1993). Mark-recapture experiments on the Chilkat River in 1991 and 1992 are described in Johnson et al. (1992, 1993), and the experiment on the Unuk River in 1994 is described in Pahlke et al. (1996).

Success of mark-recapture experiments in the Taku River also depended on sex and size composition of samples being representative of the spawning population. Methods used to sample populations in the tributaries were undoubtedly sex- and size (age)-selective. Hubartt and Kissner (1987) found that most female chinook salmon in the Taku River died in shallow water near their redds, whereas males tended to wash downstream in a moribund condition, which is typical for males and females of other species of Pacific salmon (Peterson 1954; Ward 1959; Eames and Hino 1981). Therefore, males would be more likely to wash against carcass weirs, and females would be more likely to remain on the streambed and be encountered during a carcass survey. Because male chinook salmon tend to be younger and smaller than females, this sexual-sampling disparity would also influence estimates of age and size composition. Meehan (1961) showed that fish wheels on the Taku River were size-selective, catching higher proportions of smaller and younger fish than were present on the spawning grounds. Yet with all this potential for size- and sex-selective sampling in mark-recapture experiments, such selection was not statistically detected in our recaptures; most fish marked at Canyon Island were age 1.2 and older, making the problematic sampling of age-1.1 males irrelevant. Because the marked population (large, radiotagged fish on the spawning grounds) used to estimate abundance was almost exclusively age-1.3 and older fish, best evidence is that sampling for experiments was representative, again avoiding bias in our estimates of abundance.

The abundance of large chinook salmon in the Taku River has been estimated annually by flying slowly over spawning grounds in a helicopter and counting the large fish (Pahlke 1993). These counts have been expanded for fish missed in the survey of each tributary and for the fraction of large spawners returning to the Taku River that were bound for each tributary. Factors used in the expansions have been based mostly on professional opinions of the ability to see large fish during aerial surveys and on the distribution of spawners in the watershed. Expanded aerial counts of 25,604 for 1989 and 32,779 for 1990 (Pahlke 1993) were well below mark-recapture estimates of 41,255 for 1989 and 53,400 for 1990; the aerial counts were even below the lower ends of the 95% CIs for the mark-recapture estimates. A similar difference has also been observed for chinook salmon returning to smaller Southeast Alaska transboundary rivers (Johnson et al. 1992; Pahlke et al. 1996; Figure 7). In light of these comparisons, expansions used in aerial stock assessment are being reevaluated, and past estimates of escapements to these transboundary rivers are being changed to higher, more realistic levels, which will lower associated estimates of exploitation rates. These changes will result in reevaluation of escapement goals and overall stock status.

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