Fishery Data Series No. 99-14

A Mark-Recapture Experiment to Estimate the Escapement of Chinook Salmon in the Unuk River, 1998

by

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and

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August 1999

Alaska Department of Fish and Game

Division of Sport Fish

Symbols and Abbreviations

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Weights and measures (metric)

Centimeter	cm
Deciliter	dL
Gram	g
hectare	ha
kilogram	kg
kilometer	km
liter	L
meter	m
metric ton	mt
milliliter	ml
millimeter	mm

Weights and measures (English)

cubic feet per second	ft^3/s
foot	ft
gallon	gal
inch	in
mile	mi
ounce	oz
pound	lb
quart	qt
yard	yd
Spell out acre and ton.	

Time and temperature

Day	d
Degrees Celsius	°C
Degrees Fahrenheit	°F
hour (spell out for 24-hour clock)	h
minute	min
second	s
Spell out year, month, and week.	

Physics and chemistry

all atomic symbols	
alternating current	AC
ampere	A
calorie	cal
direct current	DC
hertz	Hz
horsepower	hp
hydrogen ion activity	pH
parts per million	ppm
parts per thousand	ppt, ‰
volts	V
watts	W

General

All commonly accepted abbreviations.	e.g., Mr., Mrs., a.m., p.m., etc.
All commonly accepted professional titles.	e.g., Dr., Ph.D., R.N., etc.
and	&
at	@
Compass directions:	
east	E
north	N
south	S
west	W
Copyright	©
Corporate suffixes:	
Company	Co.
Corporation	Corp.
Incorporated	Inc.
Limited	Ltd.
et alii (and other people)	et al.
et cetera (and so forth)	etc.
exempli gratia (for example)	e.g.,
id est (that is)	i.e.,
latitude or longitude	lat. or long.
monetary symbols (U.S.)	$, ¢
months (tables and figures): first three letters	Jan,...,Dec
number (before a number)	# (e.g., #10)
pounds (after a number)	# (e.g., 10#)
registered trademark	®
trademark	™
United States (adjective)	U.S.
United States of America (noun)	USA
U.S. state and District of Columbia abbreviations	use two-letter abbreviations (e.g., AK, DC)

Mathematics, statistics, fisheries

alternate hypothesis	H_A
base of natural logarithm	e
catch per unit effort	CPUE
coefficient of variation	CV
common test statistics	F, t, χ^2, etc.
confidence interval	C.I.
correlation coefficient	R (multiple)
correlation coefficient	r (simple)
covariance	cov
degree (angular or temperature)	°
degrees of freedom	df
divided by	÷ or / (in equations)
equals	=
expected value	E
fork length	FL
greater than	>
greater than or equal to	≥
harvest per unit effort	HPUE
less than	<
less than or equal to	≤
logarithm (natural)	ln
logarithm (base 10)	log
logarithm (specify base)	log_2, etc.
mideye-to-fork	MEF
minute (angular)	'
multiplied by	x
not significant	NS
null hypothesis	H_O
percent	%
probability	P
probability of a type I error (rejection of the null hypothesis when true)	α
probability of a type II error (acceptance of the null hypothesis when false)	β
second (angular)	"
standard deviation	SD
standard error	SE
standard length	SL
total length	TL
variance	Var

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This investigation was partially financed by the Federal Aid in Sport Fish Restoration Act (16 U.S.C. 777-777K) under Projects F-10-13 and F-10-14, Job No. S-1-8.

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This document should be cited as:
Jones, Edgar L. III, and Scott A. McPherson. 1999. A mark-recapture experiment to estimate the escapement of chinook salmon in the Unuk River, 1998. Alaska Department of Fish and Game, Fishery Data Series No. 99-14 , Anchorage.

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ABSTRACT

The abundance of medium and large chinook salmon *Oncorhynchus tshawytscha* that returned to spawn in the Unuk River in 1998 was estimated using a two-event mark-recapture experiment. Fish were captured in the lower Unuk River using set gillnets from June through July, and each healthy fish was individually marked with a solid-core spaghetti tag sewn through its back and was given two secondary batch marks in the form of an upper-left operculum punch and removal of the left axillary appendage. Spawning grounds sampling took place from July through August to estimate the fraction of the escapement that had been marked.

During this study, 610 chinook salmon were captured in the lower Unuk River, and 555 of these were marked and released alive. Of the marked and released fish, 466 were considered large (≥660 mm mid eye to fork [MEF]), 87 were medium (401–659 mm MEF) and 3 were small (≤400 mm MEF) in size. On the spawning grounds, 924 fish were sampled; 707 were considered large fish, and of these, 79 were recaptures that had been previously marked in the lower river with spaghetti tags. Two hundred seventeen (217) medium fish were sampled, and 15 of these were recaptures. Thirty-two (32) small fish were sampled, of which 2 were age-1.0 fish ("mini-jacks"), 225 mm and 250 mm MEF in size.

A modified Petersen model was used to estimate that 4,132 (SE = 413, $M = 466$, $C = 707$, $R = 79$) large, 1,198 (SE = 290, $M = 87$, $C = 217$, $R = 15$) medium, and 5,330 (SE = 497) fish >400 mm MEF in length immigrated into the Unuk River in 1998. An estimated 27% of this immigration was sampled during the project. Peak survey counts in August totaled 840 large chinook salmon, about 20% of the mark-recapture estimate of large fish, a trend seen in similar studies. Of the spawning population >400 mm MEF, 49% were estimated to be age-1.3 fish from the 1993 brood year, 23% were estimated to be age-1.4 fish, and 24% were estimated to be age-1.2 fish.

Key words: spawning abundance, large and medium chinook salmon, Unuk River, mark-recapture, set gillnets, spaghetti tags, operculum punch, axillary appendage, Petersen model, peak survey counts.

INTRODUCTION

The Unuk, Chickamin, Blossom, and Keta rivers are index streams for the chinook salmon *Oncorhynchus tshawytscha* escapement estimation program in Southeast Alaska (Pahlke 1997a). These systems traverse the Misty Fjords National Monument and flow into Behm Canal, a narrow saltwater passage east of Ketchikan (Figure 1). Peak single-day survey counts of "large" chinook salmon ≥660 mm mid eye to fork of tail (MEF) are used as indices of escapement in each of these systems. These indices are roughly dome-shaped when plotted against time (since 1975) with peak values occurring between 1987 and 1990 (Pahlke 1997a). Peak 1987–1990 values of escapement are two to five times greater than the "baseline" (1975–1980) or current values of the index.

In 1992, recent low survey counts generated concern for the health of the Behm Canal chinook stocks. Historical data for the two largest Behm Canal systems, the Unuk and Chickamin rivers, were reviewed to evaluate the status of these two stocks. It was not clear what had caused recent declines in escapement. In response, the Division of Sport Fish began a research program on the largest chinook salmon producer in Behm Canal, the Unuk River. Goals of the program were to estimate fall fry or smolt production, escapement, total run size, exploitation rates, harvest distribution, and marine survival.

The current escapement goal for the Unuk River is 650–1,400 large fish counted in surveys, or about 3,000–7,000 total escapement of large fish (McPherson and Carlile 1997). Only large fish are counted in aerial surveys, because they can be distinguished with more confidence from other species that may be present and their size increases their visibility from the air. For our purposes, chinook salmon ≥660 mm MEF are

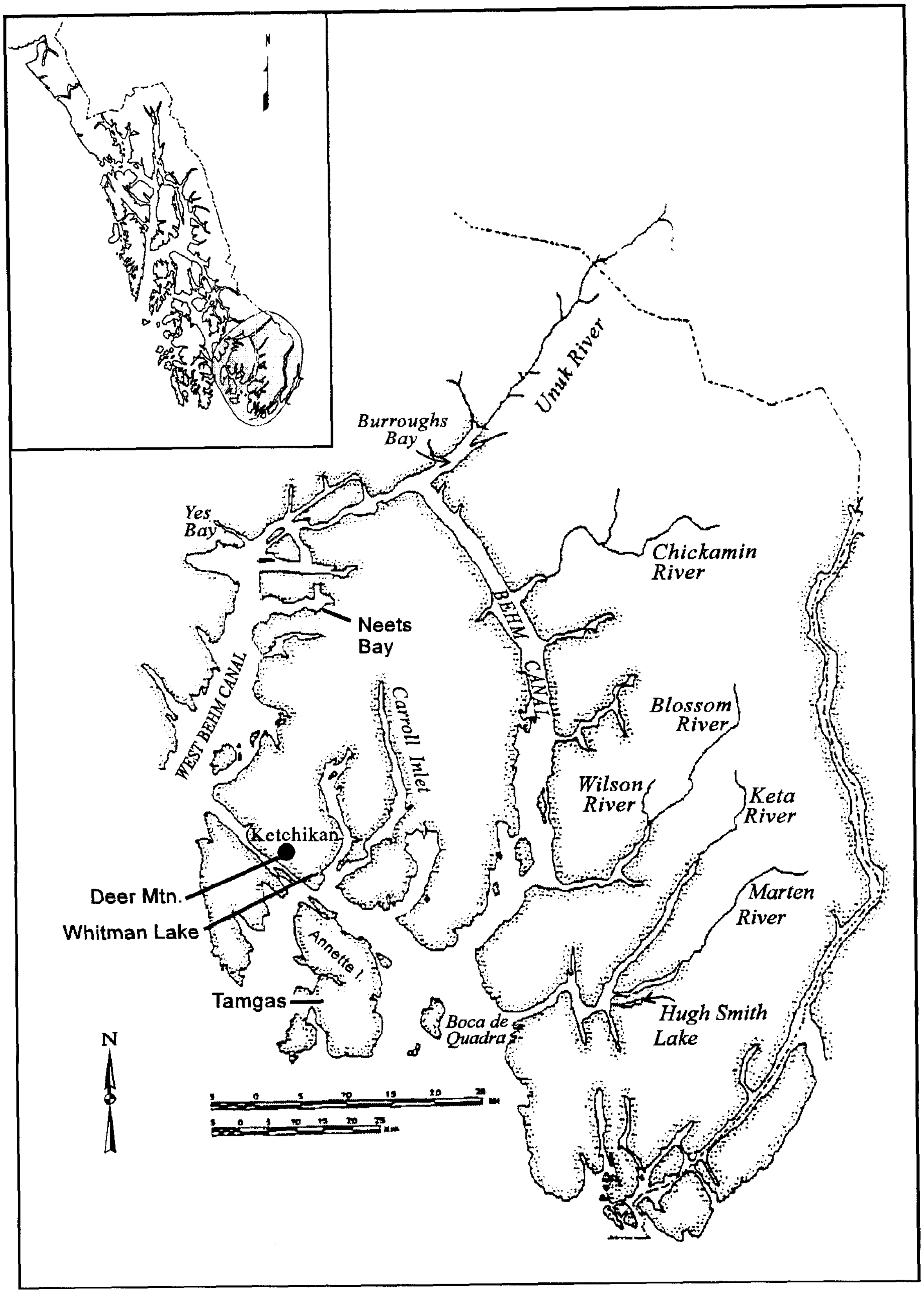

Figure 1.–Behm Canal area in Southeast Alaska and location of major chinook salmon systems and hatcheries.

considered large fish and generally consist of fish 3-ocean age or older. Chinook salmon 401 mm–659 mm MEF are considered medium fish, and chinook salmon ≤400 mm MEF are considered small fish. Indices of escapement on the Unuk River are determined each year by summing the peak observer aerial and foot survey counts of large spawners observed in six tributaries; i.e., Cripple, Gene's Lake, Kerr, Clear, and Lake creeks plus the Eulachon River (Pahlke 1997a).

In an attempt to validate these indices of escapement and to estimate the fraction counted in the surveys, a radio telemetry study in 1994 and mark-recapture experiments in 1994 and 1997 were conducted (Pahlke et al. 1996; Jones et al. 1998). The 1994 radio telemetry study indicated that 83% (SE = 9%) of all spawning occurred in the six tributaries surveyed. The mark-recapture experiment in 1994 estimated 4,623 large chinook salmon entered the river: the survey count of 711 fish represented 15% of this estimate. The mark-recapture experiment in 1997 estimated 2,970 large chinook salmon entered the river: the survey count of 636 fish represented 21% of this estimate. The highest survey count on record occurred in 1986 and was 2,126 large fish (Pahlke 1997a). Average peak survey counts in the six index tributaries of the Unuk River from 1977–1998 are distributed as follows: Cripple Creek (435 fish, 39%), Gene's Lake Creek (326 fish, 30%), Eulachon River (186 fish, 15%), Clear Creek (97 fish, 9%), Lake Creek (26 fish, 3%), and Kerr Creek (37 fish, 4%). Cripple Creek and Gene's Lake Creek are not surveyed from the air because of heavy canopy cover; survey counts in these areas are made on foot. All other index areas are surveyed by helicopter or on foot (Pahlke et al. 1996).

Other studies on the Unuk River were based on coded wire tags (CWTs) inserted in chinook salmon juveniles of the 1982–1986 broods (Pahlke 1995). Indications from this research are that commercial and sport harvest rates on the Unuk River chinook salmon stock (age-1.1–1.5) ranged between 14% and 24%; however, the precision of the harvest estimates was low, and escapement was inferred from the 1994 mark-recapture study expansion of 15% and an alternative expansion of 25% of spawners counted.

Beginning in 1993, chinook salmon fall fingerlings, or young-of-the-year (YOY), and spring smolt were tagged with CWTs on the Unuk River. Fall YOY tagging efforts were 13,789 in 1993, 18,826 in 1994, 40,206 in 1995, 39,177 in 1996, 61,905 in 1997, and 33,888 in 1998. Spring smolt tagging efforts were 2,642 in 1994, 3,227 in 1995, 7,456 in 1996, 12,517 in 1997, and 17,121 in 1998 (Appendix A1). The first returns of large fish from this effort (age-1.3 fish from the 1992 brood year) returned in 1997.

The current stock assessment program for adult chinook salmon returning to the Unuk River has three primary goals: (1) to estimate escapement; (2) to estimate age distribution in the escapement; and (3) to sample escapement for the fraction of fish possessing CWTs by brood year. The results are essential to estimate the marked fraction of each brood for CWTd fish and to estimate harvest of this stock in current and future sport and commercial fisheries. These harvest and escapement data will enable us to estimate total run size, exploitation rates, harvest distribution, and marine survival for this important chinook salmon indicator stock in southern Southeast Alaska.

STUDY AREA

The Unuk River originates in a heavily glaciated area of northern British Columbia and flows for 129 km where it empties into Burroughs Bay, 85 km northeast of Ketchikan, Alaska. The river drainage encompasses an area of approximately 3,885 km^2 (Pahlke et al. 1996). The lower 39 km of the river are in Alaska (Figure 2). In most years, the Unuk River is the fourth or fifth largest producer of king salmon in Southeast Alaska. Radio telemetry results from the 1994 study showed that 83% of all chinook salmon spawning occurred in the six surveyed tributaries, all of which are within the United States (Pahlke et al. 1996). Fish trapping efforts in the CWT project indicate that most chinook salmon rear in the lower 39 km of the river.

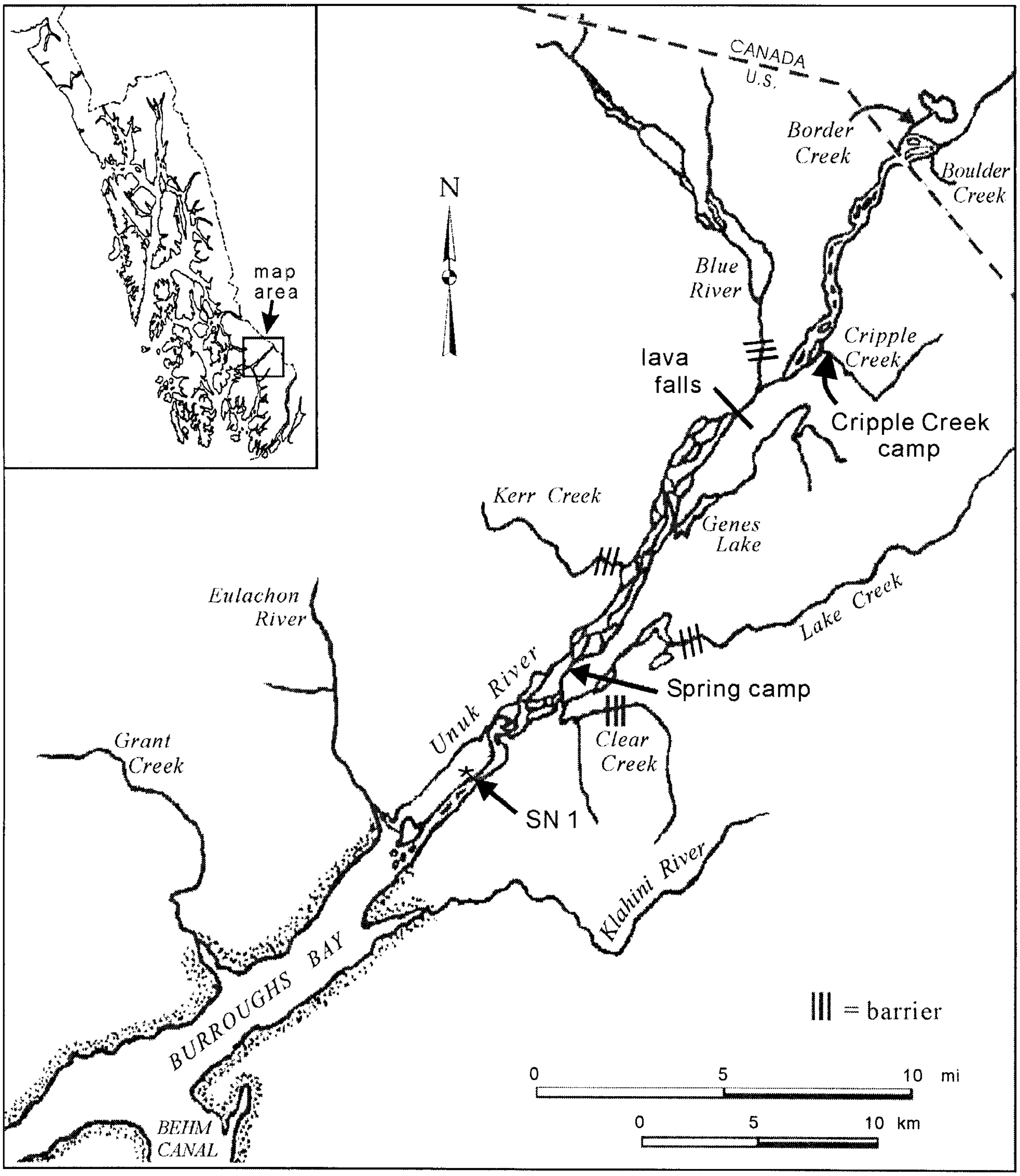

Figure 2.–Unuk River area in Southeast Alaska, showing major tributaries, barriers to chinook salmon migration, and location of ADF&G research sites. Dog Salmon Creek (not shown) flows into the Unuk River about 2 miles upstream of Gene's Lake on the opposite shore.

METHODS

A two-event mark-recapture experiment for a closed population was used to estimate the number of immigrant medium and large chinook salmon to the Unuk River in 1998. Fish were captured using set gillnets in the lower river for the first event and were sampled for marks with a variety of gear types on the spawning grounds for the second event.

EVENT 1: SAMPLING IN THE LOWER RIVER

Adult chinook salmon were captured using set gillnets as they immigrated into the lower Unuk River between 7 June and 15 August 1998. The set gillnets were 37 m (120 ft) long by 4 m (14 ft) deep with 18 cm (7¼") stretch mesh. During the 1997 mark-recapture experiment, the highest catches of adult chinook salmon occurred at one site and this site was used exclusively in 1998. This site (SN1) is located approximately 2 miles upstream on the south channel or mainstem of the lower Unuk River well below all known spawning areas, with the exception of the Eulachon River (Figure 3).

Using two back-to-back shifts of personnel, two set gillnets were fished at SN1 (Figure 4) twelve hours per day, six days per week. One net (essentially a cross net) was attached to the shore and ran directly across a small slough to a fixed buoy placed just downstream of a small island (perpendicular to the main flow of the Unuk River). Another net (essentially a lead net) was then attached to the same fixed buoy and allowed to trail downstream along the eddy line formed between the Unuk River mainstem and the side slough.

All fish captured, regardless of health, were sampled for age, sex, and length (ASL) prior to release. Length in MEF was measured to the nearest 5 mm and sex was estimated from secondary maturation characteristics. Four scales were taken about 1" apart from the preferred area on the left side of the fish. The preferred area is two to three rows above the lateral line and between the posterior terminus of the dorsal fin and the anterior margin of the anal fin (Welander 1940). Scales were mounted on gum cards which held scales from ten fish, as described in ADF&G (1993). The age of each fish was later determined from the pattern of circuli (Olsen 1992), seen on images of scales impressed into acetate cards magnified 70× (Clutter and Whitesel 1956). The presence or absence of an adipose fin was also noted for each sampled fish. Those fish missing adipose fins were sacrificed, and their heads were sent to the ADF&G Tag Lab for detection and decoding of CWTs.

All captured fish judged healthy and possessing adipose fins were given three different marks: a uniquely numbered solid-core spaghetti tag, a clip of the left axillary appendage (LAA), and a left upper operculum punch (LUOP) 0.63 cm (¼") in diameter then released. The two fin clips enable the detection of primary tag loss. The spaghetti tag consisted of a 5.71 cm (2¼") section of laminated Floy tubing shrunk onto a 38 cm (15") piece of 80-lb test monofilament fishing line. The monofilament was sewn through the back just behind the dorsal fin and secured by crimping both ends of the mono-filament in a line crimp. Excess monofilament was then trimmed off. Each spaghetti tag was individually numbered and stamped with an ADF&G phone number.

EVENT 2: SAMPLING ON THE SPAWNING GROUNDS

Chinook salmon of all sizes were sampled on Cripple, Gene's Lake, Clear, Kerr, Dog Salmon, Lake, and Boundary creeks and the Eulachon River in 1998 (Figure 2). Various methods were used to capture these fish, including rod and reel, spear, dip net, set gillnet, and random carcass pickups. Use of a variety of gear types has been shown to produce unbiased estimates of age, sex, and length composition (McPherson et al. 1997; Jones et al. 1998). All inspected fish were given a left lower operculum punch (LLOP) to prevent double sampling. These fish were closely examined for the presence of the primary tag, the LUOP, the LLOP, and the LAA, for the absence of their adipose fin, and were sampled for ASL data using the same techniques employed in the lower river. Foot survey counts were also performed on each of the sampled tributaries on

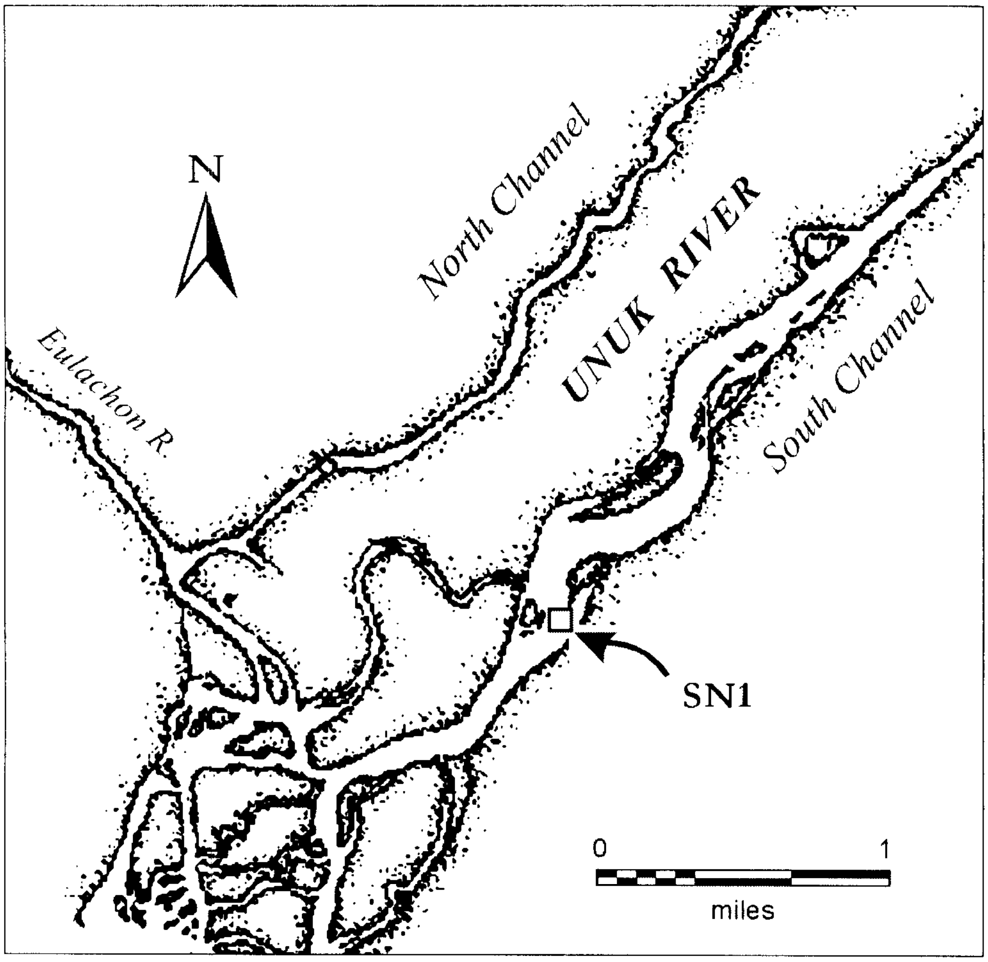

Figure 3.–Location of the set gillnet site (SN1) on the lower Unuk River in 1998.

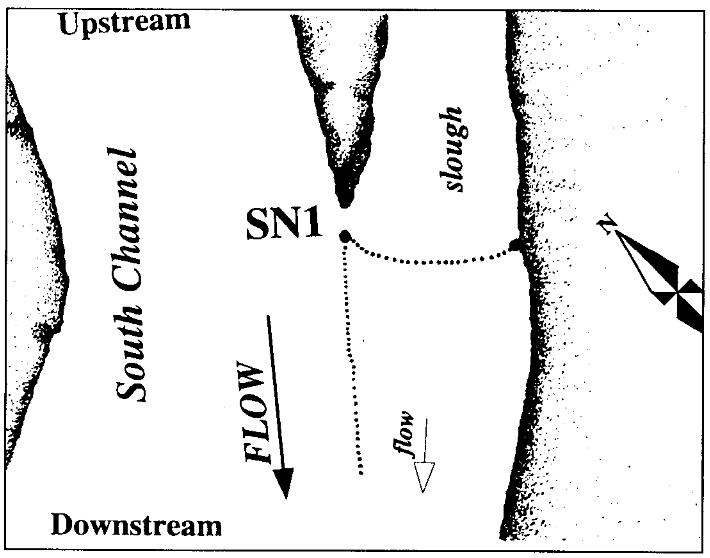

Figure 4.–Detailed drawing of the net placement used at the set gillnet site (SN1) on the lower Unuk River in 1998.

at least one occasion. These counts were spaced approximately one week apart and coincided with the historical peak observed abundance.

ABUNDANCE BY SIZE

Abundances of medium (401–659 mm MEF) and large (≥660 mm MEF) fish were estimated separately, using Chapman's modification of the Petersen estimate (Seber 1982). Estimated abundance ($\hat{N}_i$) for each group was calculated:

$$\hat{N}_i = \frac{(M_i + 1)(C_i + 1)}{(R_i + 1)} - 1 \qquad (1)$$

where M_i is the number of fish of size *i* sampled and marked during event 1, C_i is the number of fish of size *i* inspected for marks during event 2, and R_i is the number of C_i that possessed unique marks applied during event 1. General assumptions (Seber 1982) that must hold for $\hat{N}_i$ to be a suitable estimate of abundance may be cast as follows:

- *(a)* every fish has an equal probability of being marked in event 1, or every fish has an equal probability of being captured in event 2, or marked fish mix completely with unmarked fish;
- *(b)* both recruitment and death (emigration) do not occur between sampling events;
- *(c)* marking does not affect the catchability of an animal;
- *(d)* animals do not lose their marks in the time between the two events;
- *(e)* all marks are reported on recovery in event 2; and
- *(f)* double sampling does not occur.

To provide evidence that assumption *a* was met, two chi-square tests were performed: (1) for equal proportions of marks by capture in event 2; and (2) equal probabilities of recapture in event 2 independent of the stratum of origin. If the null hypothesis of either test was accepted, the pooled Petersen estimator (equation 1) was or would be used to model the mark-recapture data; otherwise a temporally or spatially stratified estimator would be employed. Tests were made separately using the SPAS software program (Arnason et al. 1996).

The possibility of size and sex selective sampling was also investigated, because assumption *a* can also be violated in this manner. The hypothesis that fish of different sizes were captured with equal probability was tested by using two Kolmogorov-Smirnov (K-S) 2-sample tests ($\alpha = 0.05$). These hypotheses tests and adjustments for bias are described in Appendix A.4. Because sampling in the lower river spanned the entire known immigration of fish into the Unuk River and continued without interruption, the experiment is, due to the life history of the fish, closed to recruitment (assumption *b*). We were not able to test assumption *c*; however, we were careful to not harm or stress fish and we did not mark obviously injured fish. Radio telemetry studies in 1994 and 1996 have shown that chinook salmon survive and spawn using this type of capture method (Pahlke et al. 1996; Pahlke 1997b). The effect of tag loss (assumption *d*) is virtually eliminated by using the two secondary marks, and all fish captured during event 2 were inspected for marks (assumption *e*). Double sampling (assumption *f*) of fish was avoided by marking all sampled fish during event 2 with a LLOP.

Variance, bias, and confidence intervals for $\hat{N}_i$ were estimated with modifications of bootstrap procedures in Buckland and Garthwaite (1991). Fish were divided into four capture histories (Table 1). A bootstrap sample was built by drawing with replacement a sample of size $\hat{N}_i$ from the empirical distribution defined by capture histories. A new set of statistics was generated from each bootstrap sample $\{\hat{M}_i^*, \hat{C}_i^*, \hat{R}_i^*\}$, along with a new estimate for abundance $\hat{N}_i^*$, and 1,000 such bootstrap samples were drawn, creating the empirical distribution $\hat{F}(\hat{N}_i^*)$, which is an estimate of F($\hat{N}_i$). The difference between the average $\hat{N}_i^*$

Table 1.–Capture histories for medium and large chinook salmon in the population spawning in the Unuk River in 1998 (notation explained in text).

Capture history	Medium	Large	Source of statistics
Marked and not sampled in tributaries	72	387	$\hat{M}_i - R_i$
Marked and recaptured in tributaries	15	79	R_i
Not marked, but captured in tributaries	202	628	$C_i - R_i$
Not marked and not sampled in tributaries	909	3,038	$\hat{N}_i - \hat{M}_i - C_i + R_i$
Effective population for simulations	1,198	4,132	$\hat{N}_i^+$

of bootstrap estimates and $\hat{N}_i$ is an estimate of statistical bias in the latter statistic (Efron and Tibshirani 1993, Section 10.2). Confidence intervals were estimated from $\hat{F}(\hat{N}_i^*)$ with the percentile method (Efron and Tibshirani 1993, Section 13.3).

Variance was estimated as

$$v(\hat{N}_i^*) = (B-1)^{-1}\sum_{b=1}^{B}(\hat{N}_{i(b)}^* - \overline{\hat{N}}_i^*)^2 \qquad (2)$$

where B is the number of bootstrap samples.

AGE AND SEX COMPOSITION

The proportion of the spawning population composed of a given age within medium or large fish was estimated as a binomial variable from fish sampled on the spawning grounds:

$$\hat{p}_{ij} = \frac{n_{ij}}{n_i} \qquad (3)$$

where $\hat{p}_{ij}$ is the estimated proportion of the population of age j in sized group i, n_{ij} is the number of chinook salmon of age j of size group i, and n_i is the number of chinook salmon in the sample n of size group i taken on the spawning grounds.

Information gathered using the lower river set gillnets was not used to estimate age or sex composition of the spawning population, because of the difficulty in sexing fish (many are ocean-bright and do not possess distinct secondary maturation characteristics). Samples gathered at each spawning grounds tributary were pooled together because investigations showed sampling on the spawning grounds had not been size-selective within a size group (Jones et al. 1998). Sample variance was calculated as:

$$v(\hat{p}_{ij}) = \frac{\hat{p}_{ij}(1-\hat{p}_{ij})}{n_i - 1} \qquad (4)$$

Numbers of spawning fish by age were estimated as the summation of products of estimated age composition and estimated abundance within a size category:

$$\hat{N}_j = \sum_i \left(\hat{p}_{ij}\hat{N}_i\right) \qquad (5)$$

with a sample variance calculated according to procedures in Goodman (1960):

$$v(\hat{N}_j) = \sum_i \begin{pmatrix} v(\hat{p}_{ij})\hat{N}_i^{\,2} + v(\hat{N}_i)\hat{p}_{ij}^2 \\ - v(\hat{p}_{ij})v(\hat{N}_i) \end{pmatrix} \qquad (6)$$

The proportion of the spawning population >400 mm MEF composed of a given age was estimated as the summed totals across size categories:

$$\hat{p}_j = \frac{\hat{N}_j}{\hat{N}} \qquad (7)$$

with a variance approximated according to procedures in Seber (1982, p. 8-9):

$$v(\hat{p}_j) = \frac{\sum_i \left(v(\hat{p}_{ij})\hat{N}_i^2 + v(\hat{N}_i)(\hat{p}_{ij} - \hat{p}_j)^2\right)}{\hat{N}^2} \qquad (8)$$

Sex composition and age-sex composition for the entire spawning population and its associated variances were also estimated with the equations above by first redefining the binomial variables in samples to produce estimated proportions by sex $\hat{p}_k$, where k denotes gender (male or female), such that $\sum_k \hat{p}_k = 1$, and by age-sex $\hat{p}_{jk}$, such that $\sum_{jk} \hat{p}_{jk} = 1$.

RESULTS

Tagging, Recovery and Abundance

Of 610 chinook salmon sampled in the lower river, 556 were tagged and released (Table 2). Ninety-five percent of the catches occurred between 10 June and 21 July. Six fish were considered unhealthy upon capture and were not tagged. Of the 556 fish tagged, 3 were small, 87 were medium, and 466 were large. Forty-nine (49) fish sampled in the gillnets were missing adipose fins and were sacrificed. Of these, 65% were males. In general, the numbers of recaptures sampled on the spawning grounds in each tributary and the dates when they were first marked occurred in rough proportion to numbers seen in the daily gillnet catches (Figure 5).

The length distributions of marked medium, large, and medium and large fish combined were not significantly different than length distributions for fish *recaptured* on the spawning grounds (P = 0.99, P = 0.73, and P = 0.85; Figure 6). Thus, sampling on the spawning grounds was not size selective and the mark-recapture data did not need length stratification. However, for our purposes the experiment was stratified by size, because we desired $\hat{N}_{lg}$ for comparison with the aerial survey counts. In contrast, length distributions of marked chinook salmon were comparable to those fish *inspected* on the spawning grounds for large fish (P = 0.77), but not for and medium and large fish (P = 0.01) and medium fish (P<0.001; Figure 7). Also, the fractions of medium and large chinook salmon with marks were significantly different (P = 0.07), indicating that medium fish were less likely to be captured in the lower river set gillnets. Thus, only ages from event 2 were used to calculate age and length compositions.

Tests to determine if temporal or spatial stratification was needed were conducted by stratifying the mark-recapture data by three time and recovery periods as follows:

Medium chinook salmon

Time	Marks	Cripple Creek	Gene's Lake Creek	All others
Stratum 1	19	2	0	3
Stratum 2	25	2	0	1
Stratum 3	43	3	1	3
	$U_{i.}$	77	67	58

Large chinook salmon

Time	Marks	Cripple Creek	Gene's Lake Creek	All others
Stratum 1	152	8	5	11
Stratum 2	161	9	7	12
Stratum 3	153	13	5	9
	$U_{i.}$	263	185	180

where $U_{i.}$ is the number not marked.

A test for equal proportions of marks in event 2 by area suggests different fractions (χ^2 = 4.90, df = 2, P = 0.09) among medium fish inspected in the various tributaries (Cripple Creek: 0.083; Gene's Lake Creek: 0.014; Clear/Kerr/Boundary/Dog Salmon/Lake creeks/Eulachon River pooled: 0.109). The test for equal proportions of marks from each marking stratum suggests equal fractions (χ^2 = 1.61, df = 2, P = 0.45), so the pooled Petersen estimate was acceptable for medium fish. For large fish, marginally equal fractions were marked (χ^2 = 5.09, df = 2, P = 0.08) in the tributaries (Cripple Creek: 0.113; Gene's Lake Creek: 0.089; Clear/Kerr/Boundary/Dog Salmon/Lake creeks and Eulachon River pooled: 0.156); sufficient evidence therefore exists for use of the pooled Petersen estimate for large fish as well.

Because observer survey counts of escapement are of large chinook salmon, estimates of abundance were stratified into medium and large fish to calculate an expansion factor for large fish. Estimated abundance of medium fish ($\hat{N}_{med}$) on the spawning grounds in 1998 was 1,198 (SE = 290), based on 87 fish marked in the lower river ($\hat{M}_{med}$), 217 fish inspected for marks

Table 2.–Numbers of chinook salmon marked in the lower Unuk River and inspected for marks on the spawning grounds of the Unuk River in 1998 by size group.

	Length (MEF)			
	0–400 mm	401–659 mm	≥660 mm	Total
A. Released in event 1 with marks (*M*)	3	87	466	**556**
B. Inspected at:				
1. Cripple Creek				
Inspected (C)	13	84	293	**390**
Recaptured (R)	0	7	30	**37**
Recaptured/captured	0	0.083	0.102	**0.095**
2. Gene's Lake Creek				
Inspected (C)	11	69	202	**282**
Recaptured (R)	0	1	17	**18**
Recaptured/captured	0	0.014	0.084	**0.064**
3. All others[a]				
Inspected (C)	8	64	212	**284**
Recaptured (R)	0	7	32	**39**
Recaptured/captured	0	0.109	0.151	**0.137**
Total inspected				
Inspected (C)	32	217	707	**956**
Recaptured (R)	0	15	79	**94**
Recaptured/captured	0	0.069	0.112	**0.098**

[a] Includes Kerr, Clear, Boundary, Dog Salmon, and Lake creeks and the Eulachon River.

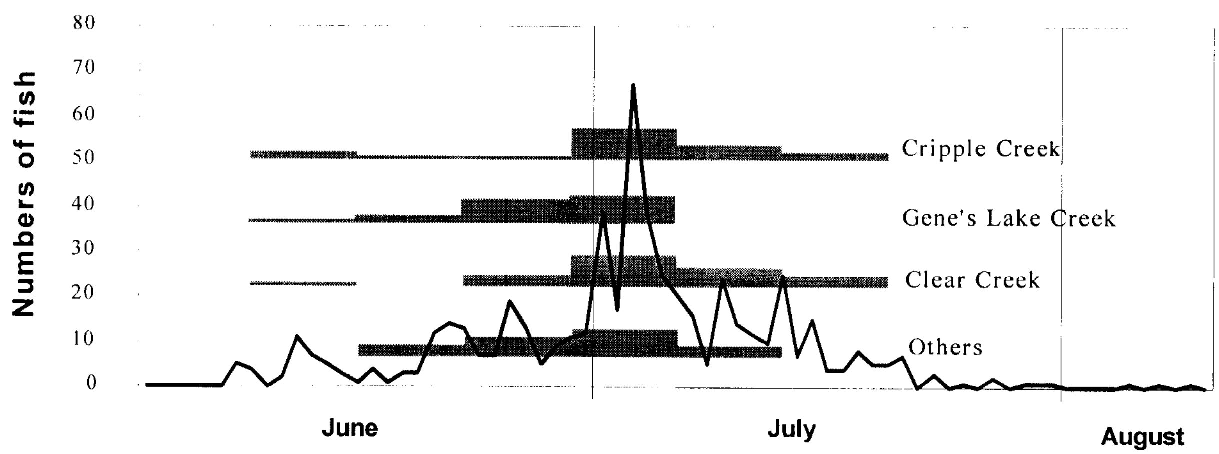

Figure 5.–Weekly numbers of marked chinook salmon sampled in 1998 at eight locations (bar graphs) and associated time of marking, set against the daily set gillnet catches in the lower Unuk River (line graph). X-axis pertains to time of marking; 'others' include Kerr, Boundary, Dog Salmon, and Lake creeks and the Eulachon River.

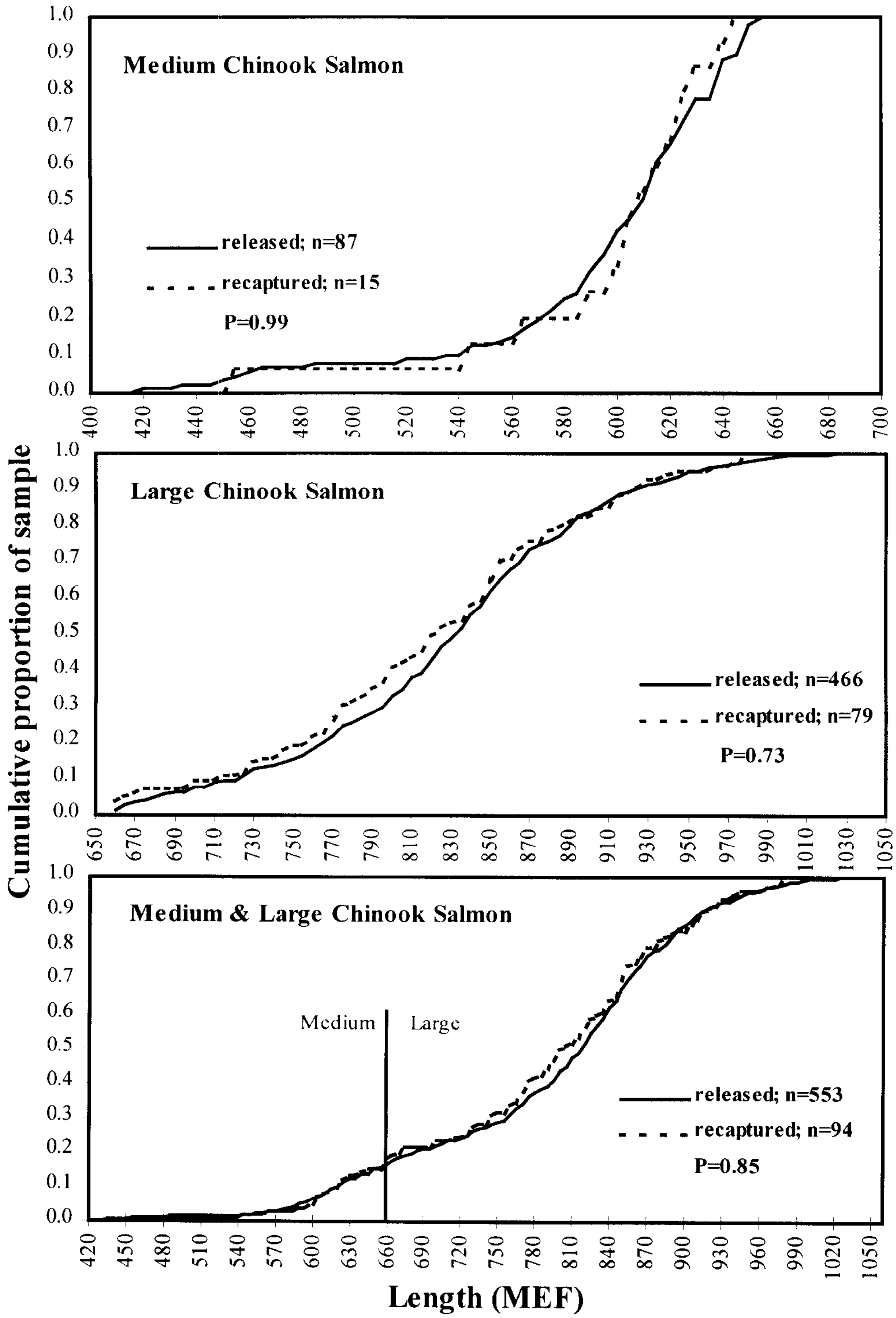

Figure 6.–Cumulative relative frequencies of medium, large, and medium and large chinook salmon (combined) marked in the lower Unuk River in 1998 versus those recaptured on the spawning grounds at eight tributary sampling sites.

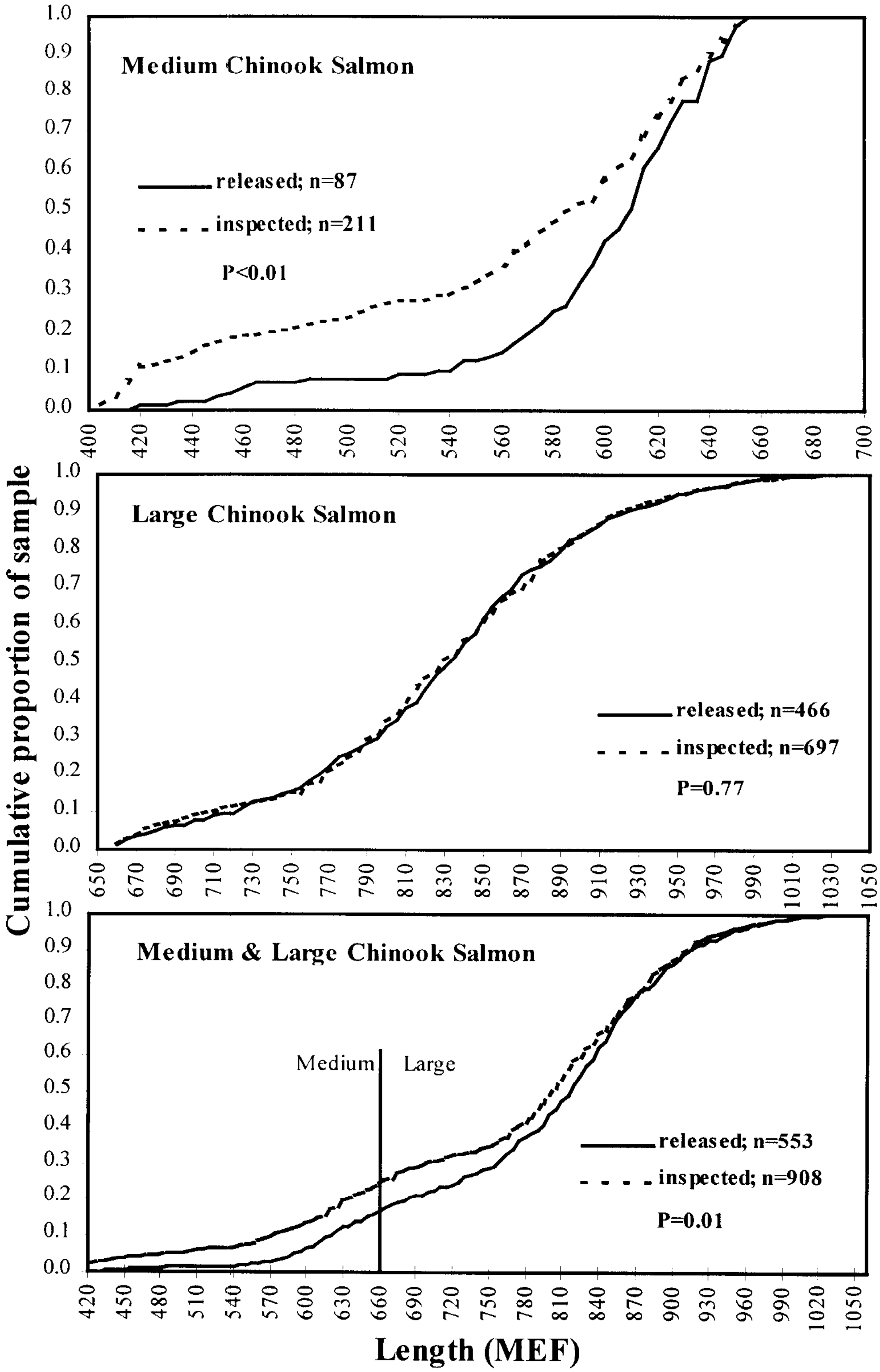

Figure 7.–Cumulative relative frequencies of medium, large, and medium and large chinook salmon (combined) marked in the lower Unuk River in 1998 versus those inspected on the spawning grounds at eight tributary sampling sites.

($\hat{C}_{med}$) on the spawning grounds, and 15 recaptured fish ($\hat{R}_{med}$) (Table 2). With a bias of 3.0%, the 95% confidence interval for the estimated abundance of medium fish is 815 to 1,903.

Estimated abundance of large fish ($\hat{N}_{lg}$) on the spawning grounds in 1998 was 4,132 (SE = 413) based on 466 fish marked in the lower river ($\hat{M}_{lg}$) and 707 fish inspected for marks ($\hat{C}_{lg}$) on the spawning grounds, and 79 recaptured fish ($\hat{R}_{lg}$) (Table 2). With a bias of 0.6%, the 95% confidence interval for the estimated abundance of large fish is 3,433 to 4,974. Only five (5%) of the 94 recovered medium and large fish had lost the primary tag, and these were detected as marked fish from the presence of the left upper operculum punch (LUOP) and a missing left axillary appendage (LAA). In addition to the 924 medium and large fish sampled on the spawning grounds, 32 small fish were sampled none of which were previously marked in the lower river. Six of these fish were missing adipose fins and were subsequently sacrificed.

With a bias of 1.13%, the estimated abundance of all fish >400 mm MEF ($\hat{N} = \hat{N}_{med} + \hat{N}_{lg}$) for 1998 was 5,330 (SE = 497), with a 95% confidence interval of 4,492 to 6,374.

Estimates of Age and Sex Composition

Age-1.2, age-1.3 and age-1.4 chinook salmon dominated the age compositions of fish >400 mm MEF (Appendix A3). However, 29% of all fish sampled on the spawning grounds were age-1.1 and age-1.2. Age-1.2 fish composed 24% (SE = 3.3%), age-1.3 fish 49% (SE = 2.9%), and age-1.4 fish 23% (SE = 1.7%) of the escapement of medium and large fish; 61% (SE = 3.7%) were males (Table 3). Age-1.2 fish composed 78% (SE = 2.8%) of the medium fish (Figure 8), which, except for 1 fish, were 100% males. Age-1.3 fish accounted for 62% (SE = 1.8%), and age-1.4 fish for 29% (SE = 1.7%) of all large fish in the escapement; 50% (SE = 1.9%) were males, and an estimated 2,092 (SE = 294) were spawning females.

In the gillnet sampling in the lower river, mostly large fish were captured consisting of 5% age-1.2 fish, 68% age-1.3 fish, and 27% age-1.4 fish (Appendix A3). Among medium fish sampled, 88% were age-1.2, 6% were age-1.1, and 6% were age-1.3 fish. In general, sex compositions of large fish sampled in the lower river were the same as those from the combined spawning grounds samples (males 50%). Table 4 and Figure 8 show lengths by age of all fish sampled for length and successfully aged on the spawning grounds. In general, length compositions were very similar between samples gathered in the lower river and on the spawning grounds, within sex and age class.

DISCUSSION

At the inception of this study, we were concerned that fish bound for the various spawning tributaries might be unevenly distributed across lower river entry channels and that fish bound for some areas (i.e., Eulachon River) may be disproportionately sampled. In the 1994 study, two set gillnet sampling sites were used to capture and mark fish. Radio telemetry and spaghetti tag recoveries from that study showed that fish bound for the various spawning tributaries were tagged in nearly equal proportions at two different set gillnet sites (Pahlke et al. 1996). In the 1997 study only one set gillnet site was used to capture fish (Jones et al. 1998). It was evident from that study that fish bound for the various spawning tributaries, including the Eulachon River, were tagged in nearly equal proportions using this one site. Therefore, this year we again used only one sampling site, located on the mainstem of the lower Unuk River. As was the case in the 1994 and 1997 studies, fish bound for the Eulachon River migrated into and matured in the Unuk mainstem and thus were susceptible to capture. As was the case in 1997, the marked fraction of fish sampled from the Eulachon River (25%) appeared higher than the average marked fraction observed in other sampling sites combined (11%), although these values were not significantly different ($\chi^2 = 1.71$, df = 1, P = 0.19).

Predators such as bald eagles *Haliaeetus leucocephalus*, harbor seals *Phoca vitulina*,

Table 3.–Age and sex composition of medium (401 mm–659 mm MEF) and large (≥660 mm MEF) chinook salmon escapement in the Unuk River in 1998, determined using data gathered from the spawning grounds.

		BROOD YEAR AND AGE CLASS						
		1995	1994	1993	1993	1992	1991	
		1.1	1.2	2.2	1.3	1.4	1.5	Total
PANEL A. AGE COMPOSITION OF MEDIUM CHINOOK SALMON								
Males	n	40	167	1	5			213
	%	18.8	78.4	0.5	2.3			99.5
	SE of %	2.7	2.8	0.5	1.0			0.5
	Escapement	224	935	6	28			1,192
	SE of esc.	23	32	8	13			289
Females	n				1			1
	%				100.0			0.5
	SE of %				0.0			0.5
	Escapement				6			6
	SE of esc.				2			20
Sexes combined	n	40	167	1	6			214
	%	18.7	78.0	0.5	2.8			100.0
	SE of %	2.7	2.8	0.5	1.1			0.0
	Escapement	224	935	6	34			1,198
	SE of esc.	23	32	8	13			290
PANEL B. AGE COMPOSITION OF LARGE CHINOOK SALMON								
Males	n		57		235	56	1	349
	%		16.3		67.3	16.0	0.3	49.5
	SE of %		2.0		2.5	2.0	0.3	1.9
	Escapement		334		1377	328	6	2,045
	SE of esc.		31		40	31	11	291
Females	n				201	150	5	356
	%				56.5	42.1	1.4	50.5
	SE of %				2.6	2.6	0.6	1.9
	Escapement				1,178	879	29	2,086
	SE of esc.				40	38	17	294
Sexes combined	n		57		436	206	6	705
	%		8.1		61.8	29.2	0.9	100.0
	SE of %		1.0		1.8	1.7	0.3	0.0
	Escapement		334		2,555	1,207	35	4,132
	SE of esc.		43		64	58	24	413
PANEL C. AGE COMPOSITION OF MEDIUM AND LARGE CHINOOK SALMON								
Males	n	40	224	1	240	56	1	562
	%	6.9	39.2	0.2	43.4	10.1	0.2	61.2
	SE of %	0.8	2.6	0.2	2.7	0.8	0.2	2.2
	Escapement	224	1,269	6	1,405	328	6	3,238
	SE of esc.	23	45	8	42	31	11	410
Females	n				202	150	5	357
	%				56.6	42.0	1.4	38.8
	SE of %				0.7	0.7	0.3	0.8
	Escapement				1,184	879	29	2,092
	SE of esc.				40	38	17	294
Sexes combined	n	40	224	1	442	206	6	919
	%	4.2	23.8	0.1	48.6	22.7	0.7	100.0
	SE of %	0.9	3.3	0.2	2.9	1.7	0.5	0.0
	Escapement	224	1,269	6	2,589	1,207	35	5,330
	SE of esc.	23	45	8	58	49	20	497

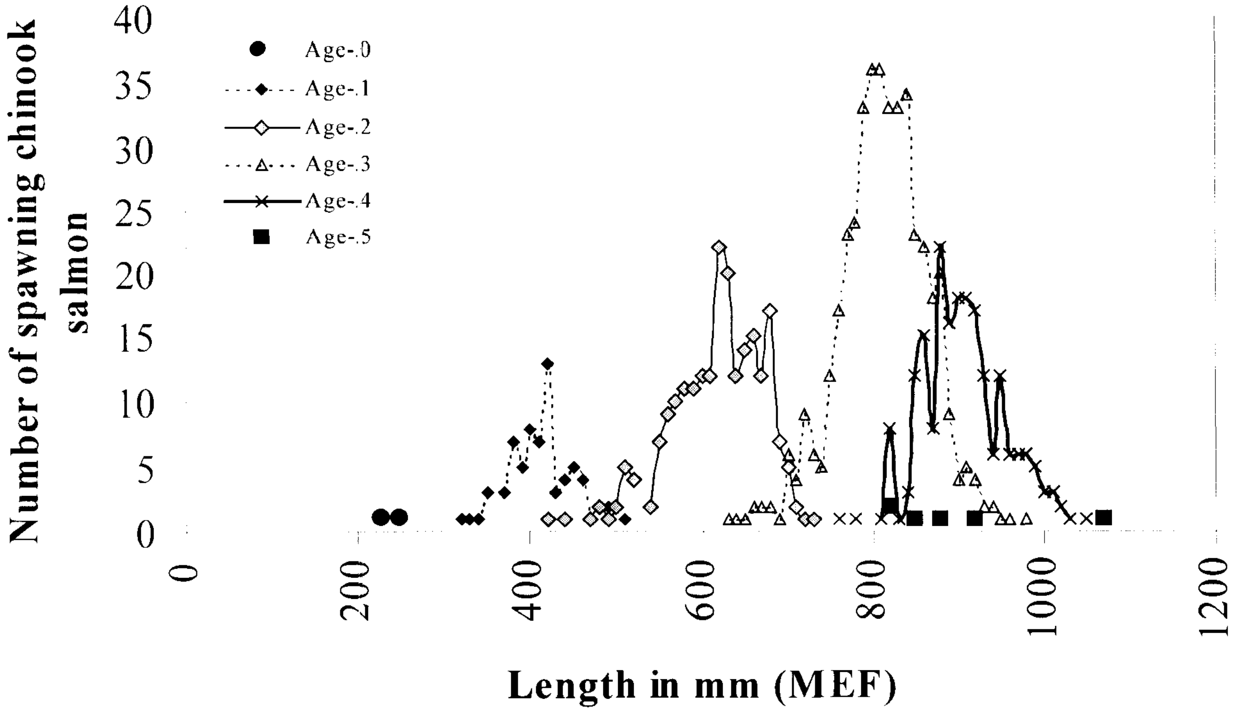

Figure 8.–Numbers of chinook salmon sampled by length and ocean-age at all eight tributary spawning sites on the Unuk River in 1998.

brown bears *Ursus arctos*, black bears *U. americana*, and river otters *Lutra canadensis* were again commonly seen in the study area in 1998. In response to the presence of predators, fish may benefit from milling in the deep glacial waters, pools, or in lake areas of the Unuk River for extended periods of time while ripening prior to spawning in order to minimize contact with predators. This would provide one explanation for the higher ratio of marked/unmarked fish observed in the Eulachon River, as this spawning site is one of the closest to the gillnet site. The 1994 study noted such behavior by fish tagged with radio transmitters. In some cases, the fish remained in the lower Unuk River for extended periods of time or even returned to the ocean or backed-down prior to moving upriver (Pahlke et al. 1996). This backing-down phenomenon of tagged chinook salmon has been observed in other studies (Milligan et al. 1984; Johnson et al. 1992; Bendock and Alexandersdottir 1993; Johnson 1993; Eiler et al. *In prep*).

In the 1994 study, 86% of fish tagged with radio transmitters were successfully tracked to the spawning grounds, although some fish displayed a "sulking" behavior or a delay in upstream migration (Pahlke et al. 1996). Such behavior may have been present in this year's study; however, we feel confident that over the long term marked and unmarked fish died at the same rate, and that the estimated abundance is therefore unbiased (Seber 1982). Loss of primary tags was not a problem in this study, as only four large males and one large female were captured missing a primary tag. In all cases, secondary tags were clearly visible on recaptured fish, once in hand.

The success of this mark-recapture experiment rests largely on the assumptions that fish were marked in proportion to their passing abundance, and that every fish had an equal chance of being inspected. The statistical tests performed and the output from SPAS (Arnason et al. 1996) suggest that large fish were marked in proportion to their abundance and that medium fish marked at

Table 4.–Estimated average length (MEF in mm) by age and sex of chinook salmon sampled on the Unuk River in 1998.

		BROOD YEAR AND AGE CLASS						
		1995	1994	1993	1993	1992	1991	
		1.1	1.2	2.2	1.3	1.4	1.5	Total
PANEL A. LENGTH COMPOSITION OF MEDIUM AND LARGE CHINOOK SALMON SAMPLED USING GILLNETS IN THE LOWER UNUK RIVER								
Males	n	5	103		192	47		347
	Avg. length	447	621		800	914		757
	SD	20	46		68	74		112
	SE	9	4		5	11		6
Females	n		2		158	92	3	255
	Avg. length		695		815	896	913	844
	SD		49		44	45	35	87
	SE		35		3	5	20	5
Sexes combined	n	5	105		350	139	3	602
	Avg. length	447	622		806	902	913	794
	SD	20	46		59	57	35	102
	SE	9	5		3	5	20	4
PANEL B. LENGTH COMPOSITION OF MEDIUM AND LARGE CHINOOK SALMON SAMPLED ON THE UNUK RIVER SPAWNING GROUNDS								
Males	n	40	218	1	234	56	1	550
	Avg. length	433	616	470	801	918	1070	712
	SD	24	54	0	59	61	0	104
	SE	4	4	0	4	8	0	4
Females	n				200	148	5	353
	Avg. length				821	899	855	854
	SD				44	43	45	77
	SE				3	4	20	4
Sexes combined	n	40	218		434	204	6	902
	Avg. length	433	616	470	810	904	891	768
	SD	24	54	0	54	49	97	135
	SE	4	4		3	3	39	4

Table 5.–Peak survey counts compared to mark-recapture estimates of abundance and other statistics for large chinook salmon (≥660 mm MEF) in the Unuk River (1994, 1997, and 1998) and the Chickamin River (1995 and 1996).

	Chickamin River		Unuk River			
	1995	1996	1994	1997	1998	Average
Survey count	356	422	711	636	840	595
Mark-recapture estimate (M-R)	2,309	1,587	4,623	2,970	4,132	3,124
Survey count/(M-R) (%)	**15**	**27**	**15**	**21**	**20**	**19**
M-R CV	31%	13%	27%	9%	10%	
95% RP	61	25	54	18	20	35

different times were captured with equal probabilities at different recovery locations. Thus, our estimates of abundance pertain to all chinook salmon spawning in the Unuk River, including the Eulachon River.

As was the case in 1997, use of gillnets in the lower river appeared to be selective toward bigger medium fish, yet almost all sizes of large fish were captured. In 1997, not a single age-1.1 fish was captured in the gillnets; however, this year age-1.1 fish were substantially larger than those seen on the spawning grounds in 1997 and consequently five age-1.1 fish were captured in the gillnets.

For large fish, very little difference in age and sex composition occurred between gillnet and spawning ground samples (Appendix A3, panels C and D). In addition, there was no significant difference between the length distributions of large fish tagged versus those fish recaptured or inspected (Figures 6 and 7).

Female chinook salmon tend to die on or near their redds whereas males usually drift downstream in a moribund state after spawning (Kissner and Hubartt 1986). Because of this behavior, estimates of age, sex, and size composition for fish sampled in carcass-only surveys tend to be biased towards females, which are also larger fish on average. To help compensate for this we used various sampling techniques such as rod and reel snagging and lure fishing, spear, gillnet, dip net, and carcass-only surveys during sampling on the spawning grounds. Using various types of gear has been shown to reduce bias in age, sex, and length compositions (McPherson et al. 1997; Jones et al. 1998). Foot surveys of abundance were used to approximate the amount of effort required to sample various spawning sites in proportion to abundance. Therefore, when estimating abundance and age and sex composition for the watershed, it was presumed that the combined samples from the various spawning tributaries for medium and large fish were representative of the total population.

The 95% relative precision (RP) of mark-recapture estimates of abundance has been shown to improve in consecutive years of study. On the Chickamin River, RPs of ±61% and ±25% occurred in 1995 and 1996 (Pahlke 1996, 1997b). On the Unuk River, RPs of ±54% and ±17% occurred in 1994 and 1997. These results suggest that knowledge gained from previous mark-recapture studies is beneficial and positively influences the success of future studies. This year our goal was to achieve results similar to those obtained during 1997 (Jones et al. 1998), and a 95% RP of ±20% (CV = 10%) was obtained, an excellent level of precision for a detailed stock assessment study.

As was the case in the 1997 study, the estimated abundance of large fish was considerably greater than corresponding estimates obtained from the peak survey counts. Observer bias resulting in underestimation of the actual abundance is a common pattern seen in other studies of chinook salmon in Southeast Alaska and in northern British Columbia (Johnson et al. 1992; Pahlke et al. 1996; McPherson et al. 1997; Jones et al. 1998) and of salmon in general (Jones 1995). This year, about 20% (840) of the estimated 4,132 large fish immigrating to the Unuk River were counted in the peak survey count. This percentage is similar to that of the 1994 and 1997 studies and the 1995 and 1996 Chickamin River studies (Table 5) (Pahlke 1996, 1997b, Pahlke et al. 1996; Jones et al. 1998).

This ongoing study is designed to estimate the escapement of chinook salmon in the Unuk River and is an integral part of a larger full stock assessment program which estimates the total run size, exploitation rate, harvest distribution, marine survival, and other population parameters for these fish. Fall juvenile and spring chinook salmon smolt have been tagged with CWTs since the fall of 1993 (1992 brood year). Good numbers of these fish returned in 1997 and 1998 as evidenced by the 50 CWTs recovered in 1997 (Jones et al. 1998) and the 102 recovered in 1998 (Appendix A1). Since juvenile and smolt tagging was initiated, greater numbers of fish have been tagged with CWTs in each subsequent brood year (Appendix A1). This has translated into a higher ratio of marked:unmarked adults sampled from each of these brood years: the ratio for the 1992 brood year was 3.5% vs. 9.6% for the 1993 brood year (Appendix A1).

In recent years, peak survey counts of escapement have been at or below the 20-year average of 1,106 large fish: 711 in 1994, 772 in 1995, 1,167 in 1996, 636 in 1997, and 840 in 1998. The escapement goal range, expressed in survey counts, for this stock is 650 to 1,400 large spawners (McPherson and Carlile 1997). The recent survey counts have generally been in the lower half of this range, but our recent work indicates that returns in the near future may be larger. An estimated 1,269 (SE = 45) age-1.2 (1994 brood year) fish returned to the Unuk River in 1998 (Table 3). This unusually high percentage (24%) and number of fish in the overall escapement was similar to that seen in 1997 (25%; Jones et al. 1998) and nearly doubles the percentage (13%) seen in 1994 (Pahlke et al. 1996). Also, the 1993 brood year produced an estimated 2,589 age-1.3 fish in 1998. In 1999, age-1.3 and age-1.4 fish will be returning from the 1993 and 1994 brood years, and if the brood year strength seen in 1998 continues, we should expect the 1999 escapement to be larger than that seen in 1998.

CONCLUSIONS AND RECOMMENDATIONS

Because this project will be performed again in 1999, we recommend some strategies for continued success. As in 1997 and 1998, at least the same number of medium and large fish should be tagged in both the marking and recapturing events. SN1 will continue to be used as the marking site. Knowledge of run timing gathered in 1994, 1997, and 1998 should be used as an indicator of peak spawning abundance and optimum sampling periods.

In 1997 and 1998, very few fish lost their primary tags, and we feel that this is mainly due to the use of the stronger, more durable 80-lb test monofilament in spaghetti tags and to increased efficiency in their application. Therefore, we will use the same primary tag and the same secondary marks in 1999.

We recommend that survey counts continue in a similar manner as those made in the past and that observers attempt to maintain consistency in counting efficiency from year to year.

Finally, the age, sex, and length composition estimates from the 1997 and 1998 studies have been relatively unbiased, which is primarily attributable to the use of multiple capture gear during spawning grounds sampling. Thus, we will be continuing this practice in future years.

ACKNOWLEDGMENTS

We thank Brett Hiatt, Eric Raitanen, Tim Schantz, and Schyler Winnen of ADF&G for operating the gillnets used to capture and tag fish in the lower Unuk River and for their efforts in capturing tagged and untagged fish on the spawning grounds; Cliff Kemmerling for his help during gillnet tagging; Jim Andel for help with the spawning grounds sampling; Amy Holm for helping plan the project, logistic support, daily camp communication, and an outstanding job in expediting equipment and materials needed to run this project; Keith Pahlke for performing the aerial counts of spawning abundance and for project planning and assistance; Bob Marshall for his biometric support; Dale Brandenburger for assistance in data entry; and Alma Seward for preparation of the final manuscript.

LITERATURE CITED

ADF&G (Alaska Department of Fish and Game). 1993. Length, sex, and scale sampling procedure for sampling using the ADF&G adult salmon age-length mark-sense form version 3.0. Commercial Fisheries Management and Development Division, Douglas.

Arnason, A. N., C. W. Kirby, C. J. Schwarz, and J. R Irvine. 1996. Computer analysis of data from stratified mark-recovery experiments for estimation of salmon escapements and other populations. Canadian Technical Report of Fisheries and Aquatic Sciences. 2106: 37 p.

Bendock, T. and M. Alexandersdottir. 1993. Hooking mortality of chinook salmon released in the Kenai River, Alaska. North American Journal of Fisheries Management 13:540-549.

Buckland, S. T. and P. H. Garthwaite. 1991. Quantifying precision of mark-recapture estimates using the bootstrap and related methods. Biometrics 47:255-268.

Clutter, R. and L. Whitesel. 1956. Collection and interpretation of sockeye salmon scales. Bulletin of the International Pacific Salmon Fisheries Commission 9, New Westminster, British Columbia.

Efron, B. and R. J. Tibshirani. 1993. An introduction to the bootstrap. Chapman and Hall, New York.

Eiler, J., M. M. Masuda, J. Pella, H. R. Carlson, R. F. Bradshaw, and B. D. Nelson. *In prep.* Stock composition, escapement estimate, and timing of chinook salmon returns in the Taku River, Alaska and British Columbia.

Goodman, L. A. 1960. On the exact variance of products. Journal of the American Statistical Association 55:708-713.

Johnson, R. E. 1993. Chilkat River chinook salmon studies, 1992. Alaska Department of Fish and Game, Division of Sport Fish, Fishery Data Series 93-50, Anchorage.

Johnson, R. E., R. P. Marshall, and S. T. Elliott. 1992. Chilkat River chinook salmon studies, 1991. Alaska Department of Fish and Game, Division of Sport Fish, Fishery Data Series 92-49, Anchorage.

Jones, E. L. III. 1995. Observer variability and bias in estimation of Southeast Alaska pink salmon escapement. Master's thesis, University of Alaska Fairbanks, Juneau.

Jones, E. L. III, S. A. McPherson, and D. L. Magnus. 1998. A mark-recapture experiment to estimate the escapement of chinook salmon in the Unuk River, 1997. Alaska Department of Fish and Game, Fishery Data Series No. 98-23, Anchorage.

Kissner, P. D., Jr. and D. J. Hubartt. 1986. A study of chinook salmon in Southeast Alaska. Alaska Department of Fish and Game, Annual Report 1985-1986, Project F-10-1, 27 (AS-41).

McPherson, S. A. and J. K. Carlile. 1997. Spawner-recruit analysis of Behm Canal chinook salmon stocks. Alaska Department of Fish and Game, Division of Commercial Fisheries Management and Development, Regional Information Report 1J97-08, Juneau.

McPherson, S. A., D. R. Bernard, M. S. Kelley, P. A. Milligan, and P. Timpany. 1997. Spawning abundance of chinook salmon in the Taku River in 1996. Alaska Department of Fish and Game, Fishery Data Series No. 97-14, Anchorage.

Milligan, P. A., W. O. Rublee, D. D. Cornett, and R. A. C. Johnston. 1984. The distribution and abundance of chinook salmon in the upper Yukon River basin as determined by a radio-tagging and spaghetti tagging program: 1982–1983. Department of Fisheries and Oceans, Yukon River Basin Study, Technical Report 35. Whitehorse, Yukon Territory.

Olsen, M. A. 1992. Abundance, age, sex and size of chinook salmon catches and escapements in Southeast Alaska in 1987. Alaska Department of Fish and Game, Division of Commercial Fisheries, Technical Fishery Report 92-07, Juneau.

Pahlke, K. A. 1995. Coded-wire tagging studies of chinook salmon on the Unuk and Chickamin rivers, 1983-1993. Alaska Department of Fish and Game, Alaska Fishery Research Bulletin Series 2(2):93-113.

Pahlke, K. A. 1996. Abundance of the chinook salmon escapement on the Chickamin River, 1995. Alaska Department of Fish and Game, Division of Sport Fish, Fishery Data Series No. 96-37, Anchorage.

Pahlke, K. A. 1997a. Escapements of chinook salmon in Southeast Alaska and transboundary rivers in 1996. Alaska Department of Fish and Game, Division of Sport Fish, Fishery Data Series No. 97-33, Anchorage.

Pahlke, K. A. 1997b. Abundance and distribution of the chinook salmon escapement on the Chickamin River, 1996. Alaska Department of Fish and Game, Division of Sport Fish, Fishery Data Series No. 97-28, Anchorage.

Pahlke, K. A., S. A. McPherson, and R. P. Marshall. 1996. Chinook salmon research on the Unuk River, 1994. Alaska Department of Fish and Game, Division of Sport Fish, Fishery Data Series No. 96-14, Anchorage.

Seber, G. A. F. 1982. On the estimation of animal abundance and related parameters, second edition. MacMillan and Company, New York.

Welander, A. D. 1940. A study of the development of the scale of the chinook salmon (*Oncorhynchus tshawytscha*). Master's thesis, University of Washington, Seattle.

APPENDIX A

Appendix A1.–Numbers of adult chinook salmon examined for CWTs, CWTs recovered, marked fractions, and numbers marked as fall fry and spring smolt, 1992 brood year to present.

PANEL A. NUMBERS OF ADULT CHINOOK SALMON SAMPLED, AD-CLIPPED FISH SAMPLED, AND THE ASSOCIATED MARKED FRACTION

Year sampled	Brood year	Number examined	Ad-clipped fish	Marked fraction (%)	Spawning grounds or gillnet
1996	1992	33	0	0.0	spawning grounds
1997	1992	162	7	4.3	gillnet
1997	1992	324	7	2.2	spawning grounds
1998	1992	139	6	4.3	gillnet
1998	1992	206	9	4.4	spawning grounds
1992 BROOD YEAR TOTAL		**864**	**29**	**3.4**	
1996	1993	4	1	25.0	spawning grounds
1997	1993	106	9	8.5	gillnet
1997	1993	211	23	10.9	spawning grounds
1998	1993	350	32	9.1	gillnet
1998	1993	443	33	7.4	spawning grounds
1993 BROOD YEAR TOTAL		**1,114**	**98**	**8.6**	
1997	1994	56	4	7.1	spawning grounds
1998	1994	105	9	8.6	gillnet
1998	1994	225	20	8.9	spawning grounds
1994 BROOD YEAR TOTAL		**386**	**33**	**8.5**	
1998	1995	8	1	12.5	gillnet
1998	1995	67	14	20.9	spawning grounds
1995 BROOD YEAR TOTAL		**75**	**15**	**20.0**	

-continued-

Appendix A1.–(Page 2 of 2).

PANEL B. TOTAL NUMBERS OF FALL AND SPRING CHINOOK JUVENILES AND SMOLT TAGGED BY YEAR AND SUMMED BY BROOD YEAR

Year tagged	Fall/ spring	Brood year	Tag code	Number tagged	Valid tagged
1993	Fall	1992	043803	10,316	10,263
1993	Fall	1992	043804	441	433
1993	Fall	1992	043805	3,202	3,093
1994	Spring	1992	044206	2,653	2,642
		1992 BROOD YEAR TOTAL			**16,431**
1994	Fall	1993	043350	11,152	11,139
1994	Fall	1993	043557	7,688	7,687
1995	Spring	1993	044213	3,228	3,227
		1993 BROOD YEAR TOTAL			**22,053**
1995	Fall	1994	043556	11,540	11,476
1995	Fall	1994	043558	11,654	11,645
1995	Fall	1994	043559	10,825	10,825
1995	Fall	1994	044231	6,324	6,260
1996	Spring	1994	044207	6,143	6,099
1996	Spring	1994	044208	1,362	1,357
		1994 BROOD YEAR TOTAL			**47,662**
1996	Fall	1995	044712	24,252	24,224
1996	Fall	1995	044236	11,202	11,200
1996	Fall	1995	044218	3,755	3,753
1997	Spring	1995	043829	12,521	12,517
		1995 BROOD YEAR TOTAL			**51,694**
1997	Fall	1996	044713	24,309	24,176
1997	Fall	1996	044714	22,996	22,583
1997	Fall	1996	044715	15,401	15,146
1998	Spring	1996	044646	11,193	11,134
1998	Spring	1996	044339	5,991	5,987
		1996 BROOD YEAR TOTAL			**79,026**
1998	Fall	1997	040139	22,389	22,366
1998	Fall	1997	040140	11,664	11,522
		1997 BROOD YEAR TOTAL			**33,888**

Appendix A2.–Detection of size-selectivity in sampling and its effects on estimation of size composition.

Results of hypothesis tests (K-S and χ^2 on lengths of fish MARKED during the fish first event and RECAPTURED during the second event	Results of hypothesis tests (K-S) on lengths of CAPTURED during the first event and CAPTURED during the second event
Case I:	
"Accept" H_O	"Accept" H_O
There is no size-selectivity during either sampling event.	
Case II:	
"Accept" H_O	Reject H_O
There is no size-selectivity during the second sampling event but there is during the first.	
Case III:	
Reject H_O	"Accept" H_O
There is size-selectivity during both sampling events.	
Case IV:	
Reject H_O	Reject H_O
There is size-selectivity during the second sampling event; the status of size-selectivity during the first event is unknown.	

Case I: Calculate one unstratified abundance estimate, and pool lengths, sexes, and ages from both sampling events to improve precision of proportions in estimates of composition.

Case II: Calculate one unstratified abundance estimate, and only use lengths, sexes, and ages from the second sampling event to estimate proportions in compositions.

Case III: Completely stratify both sampling events, and estimate abundance for each stratum. Add abundance estimates across strata to get a single estimate for the population. Pool lengths, ages, and sexes from both sampling events to improve precision of proportions in estimates of composition, and apply formulae to correct for size bias to the pooled data (p. 17).

Case IV: Completely stratify both sampling events and estimate abundance for each stratum. Add abundance estimates across strata to get a single estimate for the population. Use lengths, ages, and sexes from only the second sampling event to estimate proportions in compositions, and apply formulae to correct for size bias to the data from the second event.

Whenever the results of the hypothesis tests indicate that there has been size-selective sampling (Case III or IV), there is still a chance that the bias in estimates of abundance from this phenomenon is negligible. Produce a second estimate of abundance by not stratifying the data as recommended above. If the two estimates (stratified and unbiased vs. biased and unstratified) are dissimilar, the bias is meaningful, the stratified estimate should be used, and data on compositions should be analyzed as described above for Cases III or IV. However, if the two estimates of abundance are similar, the bias is negligible in the UNSTRATIFIED estimate, and analysis can proceed as if there were no size-selective sampling during the second event (Cases I or II).

Appendix A3.–Age composition by sex and age for chinook salmon sampled in the Unuk River in 1998 by size group, location, and gear type.

				BROOD YEAR AND AGE CLASS						
				1995	1994	1993	1993	1992	1991	
				1.1	1.2	2.2	1.3	1.4	1.5	Total
PANEL A: SPAWNING GROUNDS SAMPLING BY SITE										
Spawning grounds Cripple Creek Event 2	medium- and large-sized	Males	n	15	81	1	103	22	1	223
			%	6.7	36.3	0.4	46.2	9.9	0.4	59.3
		Females	n				91	61	2	154
			%				59.1	39.6	1.3	41.0
		Total	n	15	81		194	83	3	376
			%	4.0	21.5		51.6	22.1	0.8	100.0
Spawning grounds Gene's Lake Creek Event 2	medium- and large-sized	Males	n	15	71		68	8		162
			%	9.3	43.8		42.0	4.9		60.4
		Females	n				70	36		106
			%				66.0	34.0		39.6
		Total	n	15	71		138	44		268
			%	5.6	26.5		51.5	16.4		100.0
Spawning grounds All other tributaries [a] Event 2	medium- and large-sized	Males	n	10	72		69	26		177
			%	5.6	40.7		39.0	14.7		64.6
		Females	n				41	53	3	97
			%				42.3	54.6	3.1	35.4
		Total	n	10	72		110	79	3	274
			%	3.6	26.3		40.1	28.8	1.1	100.0
PANEL B: SPAWNING GROUNDS SAMPLING BY GEAR										
Spawning grounds Gear = rod and reel Event 2	medium- and large-sized	Males	n	21	175		178	41	1	416
			%	3.6	26.3		40.1	28.8	1.1	63.6
		Females	n				120	115	3	238
			%				50.4	48.3	1.3	36.4
		Total	n	21	175		298	156	4	654
			%	3.2	26.8		45.6	23.9	0.6	100.0
Spawning grounds Gear = spear Event 2	medium- and large-sized	Males	n	11	15		11	3		40
			%	27.5	37.5		27.5	7.5		60.6
		Females	n				16	10		26
			%				61.5	38.5		39.4
		Total	n	11	15		27	13		66
			%	16.7	22.7		40.9	19.7		100.0
Spawning grounds Gear = gillnet Event 2	medium- and large-sized	Males	n				5			5
			%				100.0			23.8
		Females	n				13	3		16
			%				81.3	18.8		76.2
		Total	n				18	3		21
			%				85.7	14.3		100.0
Spawning grounds Gear = dip net Event 2	medium- and large-sized	Males	n	5	16		21	8		50
			%		32.0		42.0	16.0		79.4
		Females	n				6	6	1	13
			%				46.2	46.2	7.7	20.6
		Total	n	5	16		27	14	1	63
			%	7.9	25.4		42.9	22.2	1.6	100.0
Spawning grounds Gear = carcass pickup Event 2	medium- and large-sized	Males	n	3	18		24	4		49
			%		36.7		49.0	8.2		43.4
		Females	n				47	16	1	64
			%		0.0		73.4	25.0		56.6
		Total	n	3	18		71	20	1	113
			%	2.7	15.9		62.8	17.7	0.9	100.0

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Appendix A3.–(Page 2 of 2).

PANEL C: ALL TRIBUTARIES COMBINED										
Spawning grounds Event 2	medium-sized	Males	n	40	167	1	5			213
			%	18.8	78.4	0.5	2.3			99.5
		Females	n				1			1
			%				100.0			0.5
		Total	n	40	167	1	6			214
			%	18.7	78.0	0.5	2.8			100.0
Spawning grounds Event 2	large-sized	Males	n		57		235	56	1	349
			%		16.3		33.3	7.9	0.1	49.5
		Females	n				201	150	5	356
			%				56.5	42.1	1.4	50.5
		Total	n		57		436	206	6	705
			%		8.1		61.8	29.2	0.9	100.0
Spawning grounds Event 2	medium- and large-sized	Males	n	40	224	1	240	56	1	562
			%	7.1	39.9	0.2	26.1	6.1	0.1	61.2
		Females	n				202	150	5	357
			%				56.6	42.0	1.4	38.8
		Total	n	40	224	1	442	206	6	919
			%	4.4	24.4	0.1	48.1	22.4	0.7	100.0
PANEL D: LOWER UNUK RIVER GILLNET SAMPLES										
Lower Unuk River Gillnet samples Event 1	medium-sized	Males	n	5	81		5			91
			%	5.5	89.0		5.5			100.0
		Females	n							0
			%							0.0
		Total	n	5	81		5			91
			%	5.5	89.0		5.5			100.0
Lower Unuk River Gillnet samples Event 1	large-sized	Males	n		22		187	47		256
			%		8.6		36.6	9.2		50.1
		Females	n		2		158	92	3	255
			%		0.8		62.0	36.1	1.2	49.9
		Total	n		24		345	139	3	511
			%		4.7		67.5	27.2	0.6	100.0
Lower Unuk River Gillnet samples Event 1	medium- and large-sized	Males	n	5	103		192	47		347
			%	1.4	29.7		55.3	13.5		57.6
		Females	n		2		158	92	3	255
			%		0.8		62.0	36.1	1.2	42.4
		Total	n	5	105		350	139	3	602
			%	0.8	17.4		58.1	23.1	0.5	100.0

[a] Includes Kerr, Clear, Boundary, Dog Salmon, and Lake creeks and the Eulachon River.

Appendix A4.–Computer files used to estimate the spawning abundance of chinook salmon in the Unuk River in 1998.

FILE NAME	DESCRIPTION
98unk41.xls	Spreadsheet containing all the mark-recapture data with various pivot table results, Tables 1 - 5, Figures 5 and 8, Appendices A2 – A3, abundance estimates, SPAS results, bootstrap results, and chi-squared analyses.
99unkks.xls	Spreadsheet containing the Kolmogorov-Smirnov (K-S) 2-sample test results and various figures and data sets used in these calculations. Figures 6 and 7 used in 98unk41a.doc are also included.
98unk41a.doc	WORD 7.0 (Windows) file of this FDS report.
BootVar.exe	BASIC compiled program for bootstrapping abundance estimates to estimate variance and bias.
98unklg.dat	Data file for large chinook salmon for BootVar.exe.
98unkmd.dat	Data file for medium chinook salmon for BootVar.exe.
SPAS.exe	Stratified Population Analysis System (SPAS) lets the user perform computer analysis of 2-sample mark-recovery data where each sample is from a geographically or temporally stratified population.
Spaslg.dat	Data file containing the data on large chinook salmon used in SPAS.exe.
Spasmd.dat	Data file containing the data on medium chinook salmon used in SPAS.exe.
Spaslg.out	Output from SPAS.exe on large chinook salmon.
Spasmd.out	Output from SPAS.exe on medium chinook salmon.