Fishery Data Series No. 07-13

Spawning Abundance of Chinook Salmon in the Chickamin River in 2004

by

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March 2007

Alaska Department of Fish and Game **Divisions of Sport Fish and Commercial Fisheries**

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
milliliter	mL
millimeter	mm

Weights and measures (English)	
cubic feet per second	ft^3/s
foot	ft
gallon	gal
inch	in
mile	mi
nautical mile	nmi
ounce	oz
pound	lb
quart	qt
yard	yd

Time and temperature	
day	d
degrees Celsius	°C
degrees Fahrenheit	°F
degrees kelvin	K
hour	h
minute	min
second	s

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

General	
Alaska Department of Fish and Game	ADF&G
Alaska Administrative Code	AAC
all commonly accepted abbreviations	e.g., Mr., Mrs., AM, PM, etc.
all commonly accepted professional titles	e.g., Dr., Ph.D., R.N., etc.
at	@
compass directions:	
east	E
north	N
south	S
west	W
copyright	©
corporate suffixes:	
Company	Co.
Corporation	Corp.
Incorporated	Inc.
Limited	Ltd.
District of Columbia	D.C.
et alii (and others)	et al.
et cetera (and so forth)	etc.
exempli gratia (for example)	e.g.
Federal Information Code	FIC
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
registered trademark	®
trademark	™
United States (adjective)	U.S.
United States of America (noun)	USA
U.S.C.	United States Code
U.S. state	use two-letter abbreviations (e.g., AK, WA)

Measures (fisheries)	
fork length	FL
mideye-to-fork	MEF
mideye-to-tail-fork	METF
standard length	SL
total length	TL

Mathematics, statistics	
all standard mathematical signs, symbols and abbreviations	
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	CI
correlation coefficient (multiple)	R
correlation coefficient (simple)	r
covariance	cov
degree (angular)	°
degrees of freedom	df
expected value	*E*
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.
minute (angular)	'
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
variance	
population	Var
sample	var

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March 2007

Development and publication of this manuscript were partially financed by the Federal Aid in Sport Fish Restoration Act (16 U.S.C.777-777K) under Project F-10-19, Job No. S-1-8; and NOAA Grants No. NA17FP2457 and NA03NMF4380248 appropriated by U.S. Congress for implementation of the U.S. Chinook Letter of Agreement.

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This document should be cited as:
Freeman, G. M., S. A. McPherson, and D. J. Reed. 2007. Spawning abundance of Chinook salmon in the Chickamin River in 2004. Alaska Department of Fish and Game, Fishery Data Series No. 07-13, Anchorage.

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ABSTRACT

The escapement of Chinook salmon *Oncorhynchus tshawytscha* returning to the Chickamin River in 2004 was estimated for a fourth consecutive year as part of an effort to determine an expansion factor to apply to future and historical peak aerial survey counts. The escapement of spawning salmon, an expansion factor for peak aerial survey counts, and age, sex, and length composition of the population were estimated. Escapement was estimated using a two-event mark–recapture experiment. Fish were captured with set gillnets, marked with uniquely numbered spaghetti tags, and given two secondary marks. During Event 2, spawning and pre-spawning fish were captured on the spawning grounds using rod-and-reel gear and dip nets, examined for marks, and sampled for age (scales), sex, and length. The escapement of large (≥660 mm MEF) Chinook salmon in 2004 was 4,268 (SE = 893) fish. This estimate was 5.35 (SE = 1.12) times the peak aerial survey count. The average of similar annual expansion factors for the Chickamin River (1996 and 2001–2004) is 4.79 (SE = 0.78; CV = 15.9%). We estimated the escapement of medium-sized (580–659 mm MEF) Chinook salmon to be 507 (SE = 50) fish. The combined estimate for all Chinook salmon ≥580 mm MEF was 4,775 (SE = 894) fish, of which 1,754 (SE = 374) were large females. Age-1.4 fish from the 1998 year class composed an estimated 38% of the total escapement estimate for Chinook salmon ≥580 mm (MEF), followed by age-1.2 fish (32%), and age-1.3 fish (26%). Brood years from 1997 to 2000 were represented in the abundance estimate, and most successfully aged fish originating from age-1. (yearling) smolt. Age 1.1 fish from the 2001 brood year were encountered in both sampling events, but were not included in the abundance estimate due to their size (<580 mm).

Key words: Chinook salmon, *Oncorhynchus tshawytscha*, abundance, escapement, Chickamin River, mark–recapture, Darroch model, Petersen estimator, peak survey count, expansion factor, age, sex, length composition, Behm Canal, Southeast Alaska

INTRODUCTION

The Chickamin River flows into Behm Canal in the Misty Fjords National Monument Wilderness in southern Southeast Alaska (SEAK; Figure 1). The Chickamin River produces the second largest run of Chinook salmon *Oncorhynchus tshawytscha* in southern SEAK, and is one of four Behm Canal index streams for the Chinook salmon escapement estimation program (Pahlke 1998). In response to depressed Chinook salmon stocks in many SEAK streams in the mid-1970s, a fisheries management program was implemented to rebuild stocks. Peak counts of large (≥660 mm MEF length) Chinook salmon serve as an index of abundance and have been collected annually by helicopter since 1975 using a standardized method (time and area). In SEAK, large Chinook salmon are generally fish that are saltwater-age-.3 or older. These index counts are used by Alaska Department of Fish and Game (ADF&G) and the Chinook Technical Committee (CTC) of the Pacific Salmon Commission (PSC) to evaluate stock status and implement abundance-based management. Expansion factors for the peak counts are being developed for the four Behm Canal systems and, after review, will provide estimates of total escapement of large spawners as they do in the other seven Chinook systems in SEAK where escapement is estimated annually using expansions of aerial survey counts.

Peak counts of Chinook salmon in the Chickamin River have exhibited marked trends, ranging from lows of fewer than 450 Chinook salmon annually during the PSC base period (1975–1980) to highs of over 900 fish (with broad inter-annual fluctuations) during the 1980s, then a return to lower counts through the 1990s (Figure 2). Peak counts increased again in 1999 and continued this general trend through 2004.

From 1981 to 1994, it was assumed that the sum of index counts on eight tributaries represented 62.5% of the total annual escapement to the Chickamin River (Pahlke 1997). In order to validate the ongoing escapement index, studies were conducted to estimate the escapement of large Chinook salmon. In 1995 and 1996, estimated escapements of large Chinook salmon were 2,309 (SE = 723; Pahlke 1996) and 1,587 (SE = 199; Pahlke 1997). In addition, radiotelemetry studies in 1996 estimated that approximately 83% of all spawning occurred in the eight index streams and no salmon were tracked into British Columbia (Pahlke 1997). On the basis of these studies the expansion factor

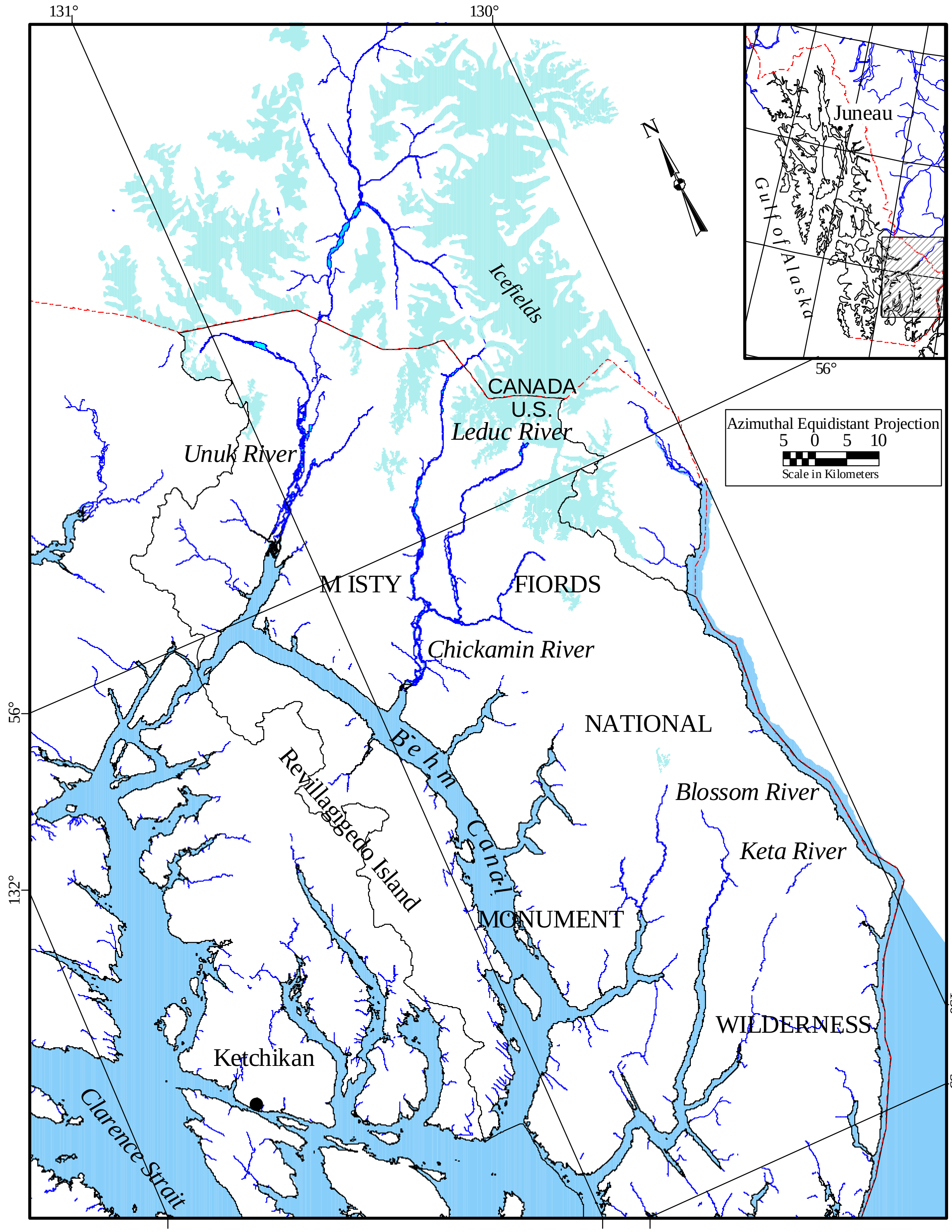

Figure 1.–Major Chinook salmon-producing river systems within the Misty Fjords National Monument that flow into Behm Canal in Southeast Alaska.

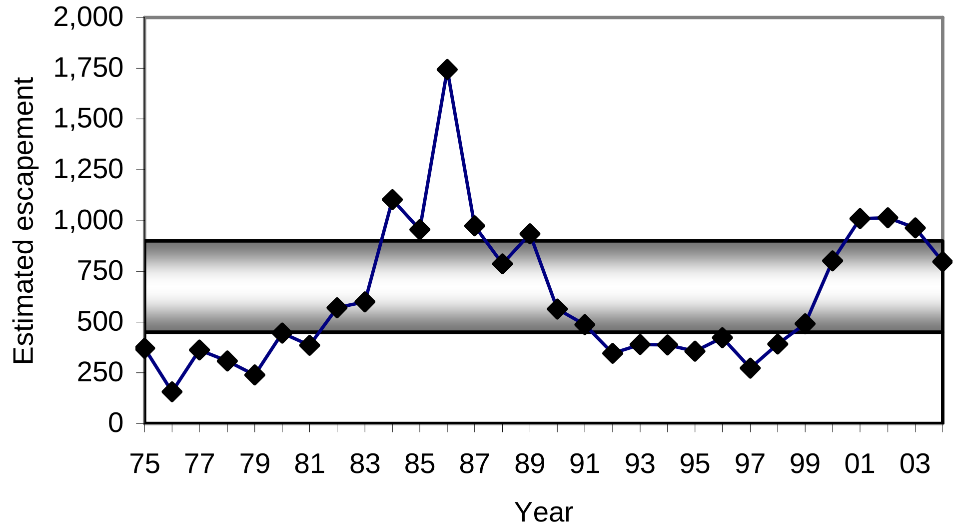

Figure 2.–Estimated escapements of large Chinook salmon spawners in the Chickamin River from 1975 to 2004, compared to 1997 survey biological escapement goal range (shaded area).

applied to peak aerial survey counts to estimate total escapement of large fish was revised to 4.0 (Pahlke 1998).

As part of the State of Alaska's commitment to a coastwide rebuilding program, ADF&G Division of Sport Fish obtained funding to conduct expanded research on the Chickamin River beginning in 2001 to estimate abundance and age, sex, and length composition of spawners. Funding for this program was approved by the Chinook Technical Committee (CTC) using monies appropriated by the U.S. Congress to implement abundance-based management of Chinook salmon from Oregon to Alaska, as detailed in "*The 1996 U.S. Letter of Agreement*," signed by U.S. parties in the Pacific Salmon Treaty arena, and as detailed in the 1999 Pacific Salmon Treaty Agreement.

The U.S. section of the CTC (PSC 1997) developed data standards for stock-specific assessments of escapement, terminal runs, and forecasts of total returns. The standard for escapement is as follows:

> *"Escapement. Annual age- and sex-specific estimates of total escapement should be available. Point estimates should be accompanied by variance estimates, and both should be based on annual sampling data. Factors used to expand the escapement from index areas (or counts of components of the escapement) should be initially verified a minimum of three times. Those expansion factors that have moderate to large amounts of inter-annual variability (a coefficient of variation of more than 20%) should be monitored annually."*

The CTC concluded that the Chickamin River stock-assessment program needed improvements:

1) To estimate total escapement in additional years;
2) To estimate an expansion factor converting historical survey counts into estimates of total escapement; and
3) To estimate the escapement by sex and age annually.

In 2001, the estimated escapement was 5,177 (SE = 972) large Chinook salmon, and the expansion factor for the peak aerial survey count was 5.1 (SE = 199; Freeman and McPherson 2003). The estimated escapements and expansion factors were 5,007 (SE = 738) and 4.94 (SE = 0.73) in 2002, and 4,579 (SE = 592) and 4.75 (SE = 0.61) in 2003 (Freeman and McPherson 2004, 2005).

An estimate of escapement in 2004 allows calculation of an expansion factor for a fourth consecutive year (and sixth overall), provides data to determine if U.S. CTC escapement data standards (PSC 1997) were met, and provides an additional data point to re-estimate total escapements from expanded aerial survey counts dating back to 1975. Peak counts of large fish for individual systems can be expanded to estimates of total escapement if a valid river specific expansion factor has been estimated for three or more years with a CV of ≤20% (PSC 1997). Research on the Chickamin River in 2004 (and in future years) will confirm whether the present expansion factor (4.0) for survey counts is indicative of the true spawning magnitude in the Chickamin River.

In addition, funding from the Southeast Sustainable Salmon Fund was used to re-implement a coded wire tagging program on juvenile Chinook and coho salmon on the Chickamin River beginning in the fall of 2001. Tagging was continued each spring and fall in 2002–2004, and is scheduled to continue until spring 2007. Recoveries of the Chinook salmon tags will be used to revise estimates of harvest and production of Chinook salmon in the Chickamin River. Presently the biological escapement goal range for the Chickamin River stock is a survey index count of 450 to 900 large spawners (McPherson and Carlile 1997). Additional years of spawning escapement estimates will facilitate the ability of ADF&G to convert the escapement goal to a range of total escapement of large spawners.

Research on the Chickamin River in 2004 had the following objectives:

1. Estimate the total escapement of large (length ≥660 mm MEF) Chinook salmon in the Chickamin River in 2004;
2. Estimate an expansion factor for converting peak aerial survey counts in the Chickamin River in 2004 to escapement; and
3. Estimate the age and sex composition of large Chinook salmon spawning in the Chickamin River in 2004.

A secondary task of the research was to estimate the abundance and mean length-at-age of medium-sized (length 401–659 mm MEF) Chinook salmon.

STUDY AREA

The Chickamin River is a transboundary river that originates in a heavily glaciated area of northern British Columbia and flows into Behm Canal in the Misty Fjords National Monument Wilderness approximately 65 km northeast of Ketchikan, Alaska. Although the Chickamin River is a transboundary river, no Chinook salmon spawning areas have been documented in Canada. Many of its anadromous spawning tributaries flow clear, however, the mainstem flows mostly turbid during summer from glacial influence. The lower river flows through a broad valley bordered by steep-sided mountains. The lower river channel has a relatively flat bottom, with fine riverbed sediments, exposed bars, low gradient with braided channels, and large, bedrock-controlled pools. Moving upstream, the river is narrower, with progressively coarser substrates, more bedrock, steeper gradient, and more logjams.

METHODS

OVERVIEW

A two-event mark–recapture (M-R) experiment for a closed population (Seber 1982) was again conducted on the Chickamin River in 2004. In the first event, set gillnets were used at two locations below the Leduc River to capture fish. Rod-and-reel snagging, dipnetting, and carcass recovery were employed on the spawning grounds for the second event. ADF&G studies in 1995 and 1996 (Pahlke 1996, 1997) and in 2001 and 2002 (Freeman and McPherson 2003, 2004) used similar sampling methods to estimate population parameters in the Chickamin River. The river was accessed from camp by boat downstream to the mouth and upstream to log jams or other impedance barriers located on the lower Leduc River, on the mainstem near Indian Creek, and on the South Fork to the Barrier Creek confluence (Figure 3).

CAPTURE OF CHINOOK SALMON

Gillnet sampling during Event 1 (the marking event) occurred primarily at two sites: in the mainstem along the west bank at river km (RK) 5, just below the Choca Creek confluence (SN3) and in the mainstem along the east bank 0.5 km below the Leduc River confluence (SN5, RK16; Figure 3). Previously fished sites at the confluence of Humpy Slough (SN1; RK3.5) and others were discontinued because of sediment aggradations, limitations from tidal influence, snags or low catches. These discontinued sites included those located just above camp at RK4 (west bank); just upstream of the King Creek confluence at RK6 (east bank); across the river from SN5 (RK 16, west bank); and at the Leduc River confluence (SN6, RK17, west bank).

Set nets 36.5 m (120 ft) long, 5.5 m (18 ft) deep, of 18.5 cm (7¼") stretch mesh, were fished throughout the day and tide stages in an effort to maximize Chinook catches while using roughly constant daily effort. Tides influenced set netting at SN3 but ended well below SN5. Two 2-person crews typically fished 12 shifts per week, with a target of 6 hours of set net fishing time per shift. During each week, 5 days were spent fishing two shifts, and 2 non-consecutive days were spent fishing one shift. Often, during 2-shift days, one net was fished at SN3 and one at SN5. However, both crews did occasionally fish at opposite riverbanks at SN3 when conditions were favorable. Gillnets were watched continuously and a fish was removed from the net as soon as bobbing corks were observed. If fishing time was lost from entanglements, snags, cleaning the net, or tidal impacts, the lost time (processing time) was added on to the end of the shift to bring fishing time to 6 hours. For each Chinook salmon captured, 2 minutes of processing time was added to the shift.

MARKING AND SAMPLING

All fish captured in Event 1 were sampled for scales, length to the nearest 5 mm (MEF), sex, presence of the adipose fin (indicating the fish was marked with a coded wire tag), and coloration. Fish in good condition were marked with a uniquely numbered spaghetti tag. Five scales were taken from each fish and mounted onto gummed cards. The age of each fish was determined from annual growth patterns of circuli (Olsen 1992) on images of scales impressed onto acetate and magnified 70× (Clutter and Whitesel 1956). Uniquely numbered spaghetti tags were inserted just below the posterior end of the dorsal fin. Each tag consisted of a 5.7-cm section of blue, laminated Floy™ [1] tubing shrunk onto a 38-cm piece of 80 lb-test (36.3 kg) monofilament fishing line. The monofilament end of the tag was pushed into a hollow needle. The tag was then applied to the fish by first punching the tip portion of the hollow needle through the fish approximately 1.5 cm below the posterior end of the dorsal fin, so as to anchor it in front of the last two fin rays, and then withdrawing the needle. A metal leader sleeve was used to secure the ends of the tag line across the fish, and the excess line was cut 0.5 cm above the crimp. Secondary marks applied (to control for primary loss) included a 0.6-cm punch in the left upper operculum (LUOP) and removal of the left axillary appendage (LAA).

SPAWNING GROUNDS SAMPLING

Rod-and-reel snagging, dipnetting, and carcass recovery were employed to capture fish on or near the spawning grounds during the recapture event of the M-R experiment. Fish were captured and sampled within tributaries and mainstem areas previously identified as key spawning areas, including all eight spawning areas that compose the aerial survey indices. All sampled fish were given a left lower operculum punch (LLOP) upon their first encounter to prevent double sampling. Each fish was closely examined for the presence of the primary tag, LUOP, LLOP, and LAA, for the absence of the adipose fin, and stage of maturity, after which they were sampled for length, sex, and age using the same techniques employed during Event 1. The tag number of each fish marked in Event 1 and recaptured in Event 2 was recorded.

ABUNDANCE ESTIMATION

Abundance of large and medium-sized Chinook salmon were estimated separately by design. This practice allowed us to obtain comparable M-R estimates (within and across streams in SEAK)

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[1] Product names used in this report are included for scientific completeness, but do not constitute a product endorsement.

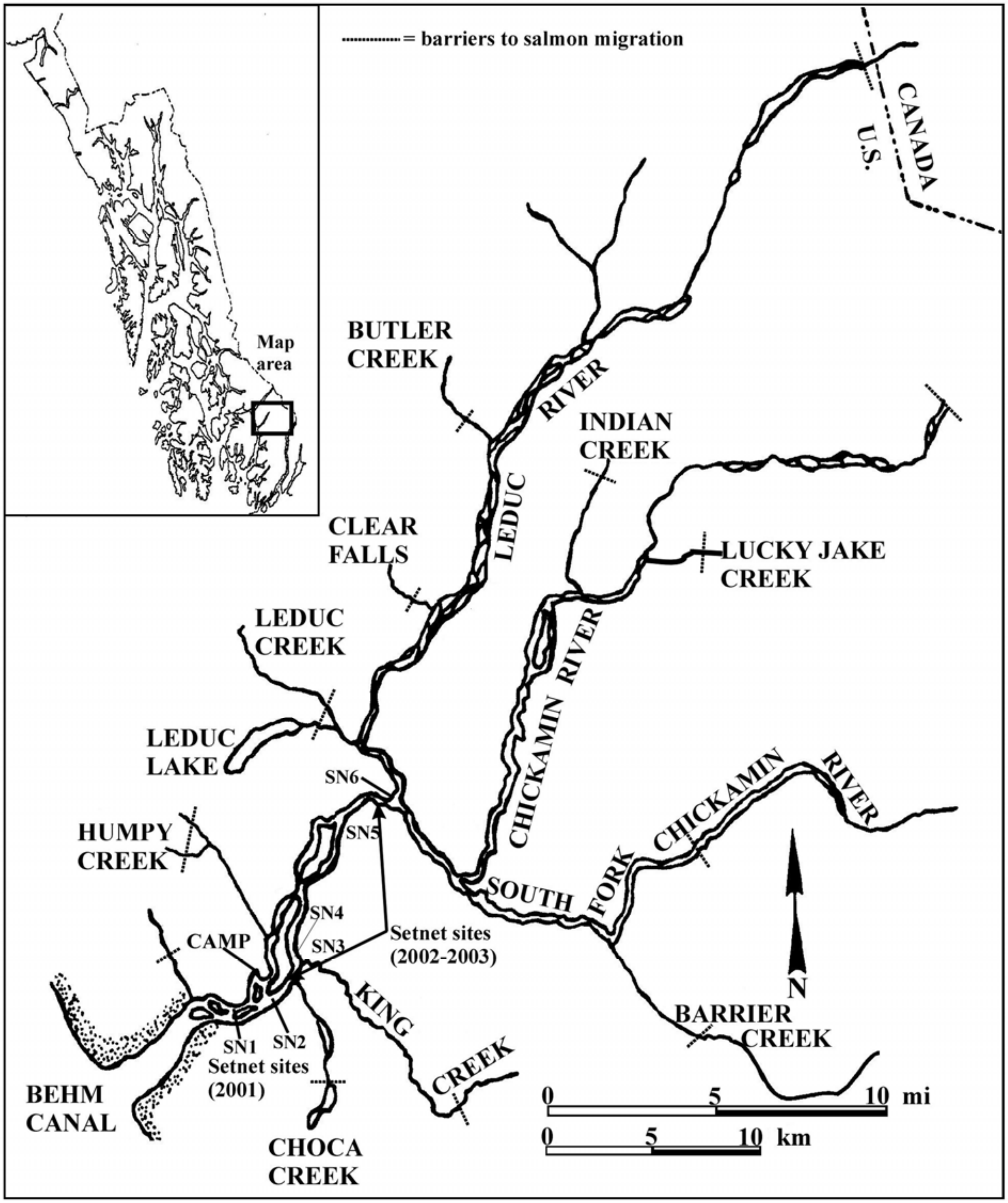


Figure 3.–Chickamin River drainage, showing major tributaries, ADF&G set net (SN) sites, and barriers to salmon migration.

each year for large fish. The estimates for large fish were also compared to annual aerial survey counts of large fish to determine expansion factors. This experiment was designed so that escapements could be estimated using the Chapman's modification to the Petersen estimator (Chapman 1951) if assumptions of the model were met:

Necessary conditions for accurate use of a Petersen-type estimator (Seber 1982) included:

(a) Every fish had an equal probability of being marked in the first event, or that every fish had an equal probability of being captured in the second event, or that marked fish mixed completely with unmarked fish;

(b) Both recruitment and mortality did not occur between events;

(c) Marking did not affect the catchability of a fish;

(d) Fish did not lose their marks in the time between the two events;

(e) All marks were reported on recovery in the second event; and,

(f) Double sampling did not occur.

Condition (a) may be violated if size- or sex-selective sampling occurs. Kolmogorov-Smirnov (K-S, Conover 1980) two-sample tests were used to test the hypothesis that fish of different lengths were captured with equal probability during both first and second sampling events. These test procedures are described in Appendix A1, as well as corrective measures (stratification) based on diagnostic test results that will minimize bias in estimation of abundance and composition parameters. Tests for gender bias were not conducted because of errors detected in gender classification during first event sampling.

Three consistency tests (Appendix A2) described by Seber (1982) were used to test for temporal and/or spatial violations of condition (a). Contingency table analyses were used to test three null hypotheses: 1) the probability that a marked fish is recovered during Event 2 is independent of when it was marked; 2) the probability that a fish inspected during Event 2 is marked is independent of when/where it was caught during the second event; and 3) for all marked fish recovered during Event 2, time of marking is independent of when/where recovery occurs. If all three hypotheses were rejected, the "partially" stratified abundance estimator described by Darroch (1961) was necessary to estimate abundance. Failure to reject at least one of these three hypotheses is sufficient to conclude that at least one of assumptions in conditions (a) was satisfied, and a Petersen-type model was appropriate to estimate abundance.

The experiment was assumed closed to recruitment because first event sampling spanned the entire immigration. Marking was assumed to have little effect on behavior of released fish or the catchability of fish on the spawning grounds because only fish in good condition were tagged and released, and because the 1996 Chickamin study and other radio telemetry studies conducted in SEAK indicated minimal mortality from handling in the marking event for Chinook salmon (Pahlke 1997). The use of multiple marks during Event 1, careful inspection of all fish captured during Event 2, and additional marking of all fish inspected helped to ensure assumptions (d), (e), and (f) were met.

When geographic and/or temporal stratification was required, estimation of abundance followed procedures described by Darroch (1961) using the computer program SPAS (Arnason et al. 1996). The contingency tables described in Appendix A2 were further analyzed to identify a) first event strata (individual or contiguous groupings of temporal/geographic categories) where probability of recapture during the second event was homogeneous within strata and different between strata; and b) second event strata where marked/ unmarked ratios were homogeneous within strata and different between strata. Temporal categories generally consist of groupings of sample data collected by week, and geographic categories consist of groupings of sample data by location. Stratification was also guided by environmental conditions encountered during data collection (river stage height and rainfall) and by previous experience gained when conducting mark–recapture experiments on this system. If the initial stratification failed to result in an admissible maximum-likelihood (ML) estimate of abundance, further stratification was necessary before an admissible estimate could be calculated. Non-admissible estimates included failure of convergence of the ML algorithm in SPAS, or convergence to estimators with estimated negative capture probabilities or negative abundance within stratum. Goals in this case were always that observations within the pooled stratum should be as homogeneous as possible with respect to capture, migration, and recapture (Arnason et al. 1996).

A Goodness of Fit (GOF) test (provided in SPAS) comparing the observed and predicted statistics suggested the adequacy of a stratified model. Once a stratification was identified that resulted in an admissible estimate of abundance, GOF was evaluated. Further stratification was evaluated, according to the guidelines described above, to produce a model and abundance estimate with a satisfactory GOF. The model selected was that which provided an admissible estimate of abundance, where no stratification guidelines were violated, no significant evidence of lack of fit was detected, and the smallest number of strata parameters were estimated for the model. The model with these characteristics will usually yield the smallest ML estimate of variance for the abundance estimate.

As a result of diagnostic tests, the Darroch (1961) model was used to estimate abundance of large (length ≥660 mm MEF) Chinook salmon returning to the Chickamin River in 2004 and the maximum likelihood variance estimate for this abundance estimator was used to assess precision.

For medium Chinook salmon, no marked fish were recovered smaller than 580mm MEF, so we estimated abundance of only those returns of length 580–659 mm MEF and used Chapman's formula to calculate an abundance estimate and variance (Seber 1982):

$$\hat{N}_M = \frac{(n_1+1)(n_2+1)}{m_2+1} - 1 \quad (1)$$

$$\hat{V}\left[\hat{N}_M\right] = \frac{(n_1+1)(n_2+1)(n_1-m_2)(n_2-m_2)}{(m_2+1)^2(m_2+2)} \quad (2)$$

where:

$\hat{N}_M$ = estimated abundance of medium (length 580–659 mm MEF) Chinook salmon in the Chickamin River;

n_1 = the number of medium Chinook salmon tagged and released during the first sampling event = *M*;

n_2 = the number of medium Chinook salmon inspected for marks during the second sampling event = *C*; and,

m_2 = the number of marked medium Chinook salmon detected during second event sampling = *R*.

Throughout the remainder of this report, references to medium Chinook salmon indicate those salmon 580–659 mm MEF.

EXPANSION FACTOR

Standardized, low altitude helicopter surveys have been used to count large Chinook salmon in index tributaries of the Chickamin River since 1975 (Pahlke 1998). During years when both M-R estimates and aerial counts were available (1995, 1996, and 2001–2004), an abundance-to-count annual expansion factor ($\hat{\pi}_t$) was calculated:

$$\hat{\pi}_i = \hat{N}_i / C_i \quad (3)$$

$$var(\hat{\pi}_t) = var(\hat{N}_i)/C_i^2 \quad (4)$$

where $\hat{N}_i$ is the mark-recapture estimate of large Chinook in year *i* and C_i is the peak aerial survey count in year *i*.

When M-R estimates were not available, a long-term expansion factor was used. The long-term observed expansion factor ($\hat{\pi}$) was estimated as:

$$\hat{\pi} = \sum_{i=1}^{k} \hat{\pi}_i \; / \; k \quad (5)$$

$$var(\hat{\pi}) = \sum_{i=1}^{k} \left(\hat{\pi}_i - \overline{\pi}\right)^2 / \; (k-1) \quad (6)$$

where k is the number of years with both counts and M-R estimates. Simulation studies suggest that measurement error in the M-R experiment does not need to be considered in this variance.

The estimator for expanding peak survey counts into estimates of spawning abundance in year *t* without a M-R estimate was then:

$$\hat{N}_t = \hat{\pi}\ C_t \quad (7)$$

$$var(\hat{N}_t) = C_t^2\ var(\hat{\pi}) \quad (8)$$

AGE AND SEX COMPOSITION

The proportion of the spawning population composed of a given age *j* within each of the medium or large fish groups (*i*) was estimated as a binomial variable:

$$\hat{p}_{ij} = \frac{n_{ij}}{n_i} \quad (9)$$

$$var(\hat{p}_{ij}) = \frac{\hat{p}_{ij}(1-\hat{p}_{ij})}{n_i - 1} \quad (10)$$

where $\hat{p}_{ij}$ is the estimated proportion of the population of age *j* in size 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* within size group *i*. Information gathered during Event 1 was not used to estimate age or sex composition of *large* fish because sampling in Event 1 was biased towards catching larger fish and sex was inaccurately determined. Samples gathered at each spawning tributary were pooled together because no differences in age composition were apparent between tributaries sampled. Numbers of spawning fish by age were estimated as the sum of the products of estimated age composition and estimated abundance within a size category:

$$\hat{N}_j = \sum_i (\hat{p}_{ij}\hat{N}_i) \quad (11)$$

$$var(\hat{N}_j) = \sum_i \begin{pmatrix} var(\hat{p}_{ij})\hat{N}_i^2 + var(\hat{N}_i)\hat{p}_{ij}^2 \\ -var(\hat{p}_{ij})var(\hat{N}_i) \end{pmatrix} \quad (12)$$

where the variance is for a product of two independent variables (Goodman 1960).

The proportion of the spawning population (over a stated length) composed of a given age was estimated as the summed totals across size categories:

$$\hat{p}_j = \frac{\hat{N}_j}{\hat{N}} \quad (13)$$

$$\mathrm{var}(\hat{p}_j) = \frac{\sum_i (\mathrm{var}(\hat{p}_{ij})\hat{N}_i^2 + \mathrm{var}(\hat{N}_i)(\hat{p}_{ij} - \hat{p}_j)^2)}{\hat{N}^2} \quad (14)$$

where variance is approximated by the delta method (Seber 1982):

Sex composition and age-sex composition for the entire spawning population and its associated variances were also estimated using the above equations 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

MARKING, CAPTURE, RECAPTURE, AND ABUNDANCE ESTIMATION

In Event 1, from 20 June to 18 August 2004, 387 Chinook salmon ≥401 mm MEF were captured, sampled, and released with numbered tags and secondary marks. Catches were relatively low until July 1, after which most of the catch occurred (Figure 4). Peak daily catches of 23 and 22 fish occurred on 17 July and on 24 July, respectively (Figure 4). Seven fish 401–659 mm MEF and 6 large fish were captured but not marked because they had missing adipose fins (coded wire tags) and were sent to ADF&G Mark, Tag and Age Laboratory in Juneau for processing. Of the fish 401–659 mm MEF, 6 were from Chickamin River releases and 1 was from the Unuk River. Among large recoveries, 4 were from the Chickamin River, 1 from the Unuk River, and 1 from Anita Bay. Of the 387 fish marked in Event 1, 14 were smaller than 580 mm MEF, 91 were medium-sized (580–659 mm MEF) and 282 were large (Table 1). Forty-three medium and 109 large fish were tagged at SN3 below Choca Creek, and 48 medium and 173 large fish were captured at SN5 below the Leduc River confluence (Table 2; Appendix A3).

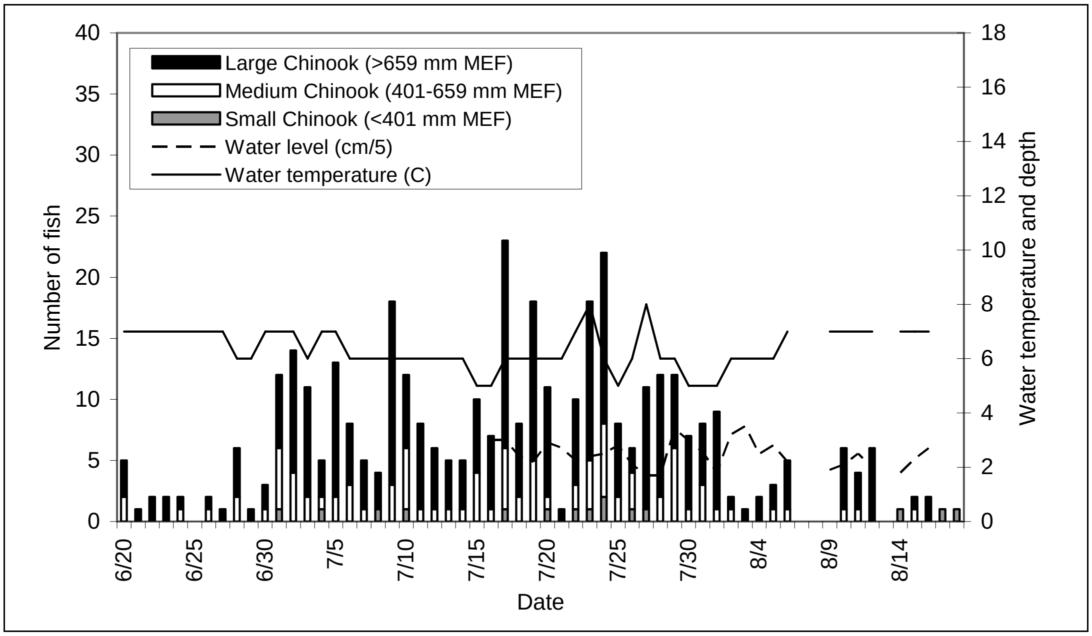


Figure 4.–Daily catches of Chinook salmon (by size class) captured in set gillnets and daily water temperature and depth in the lower Chickamin River, 2004.

In Event 2, from 2 August to 1 September 2004, a total of 66 Chinook salmon 401–579 mm MEF, 242 medium and 1,006 large fish were captured on the spawning grounds and inspected for marks (Table 1). Twenty-three medium fish and 86 large fish had been marked in Event 1 (2 of the marked large fish and 1 marked medium fish had lost their primary tag). The cumulative relative frequencies (crfs) for lengths of *large* fish marked in Event 1 and those recaptured on the spawning grounds were not significantly different (K-S test, D-value = 0.092, P = 0.578; Figure 5). However, lengths of all large fish inspected for marks on the spawning grounds were significantly different compared to those of marked fish recaptured on the spawning grounds (D-value = 0.149, P = 0.053; Figure 5). These results indicate the set nets were size selective against the largest fish, while sampling gear on the spawning grounds was not. This selectivity led us to use only the spawning grounds samples to estimate age and sex composition of the escapement *within the large size group* (Case III, Appendix A1).

Table 1.–Numbers of Chinook salmon 401–579 mm MEF, and in medium (580–659 mm MEF), and large (≥660 mm MEF) size strata marked in the lower Chickamin River and inspected for marks on the spawning grounds, 2004.

	401–579 mm	580–659 mm	≥660 mm	Total
A. Event 1: Released with marks (*M*)	14	91	282	387
B. Event 2: Captured (C)	66	242	1,006	1,314
Recaptured (*R*)	0	23	86	109
R/C (%)	0.0%	9.5%	8.5%	8.3%

During the initial analysis of Chinook salmon 401–659 mm MEF, no significant difference was detected between crfs of fish marked in Event 1 and those recaptured on the spawning grounds (D-value = 0.142, P = 0.776). Similarly, no difference was detected between fish inspected for marks on

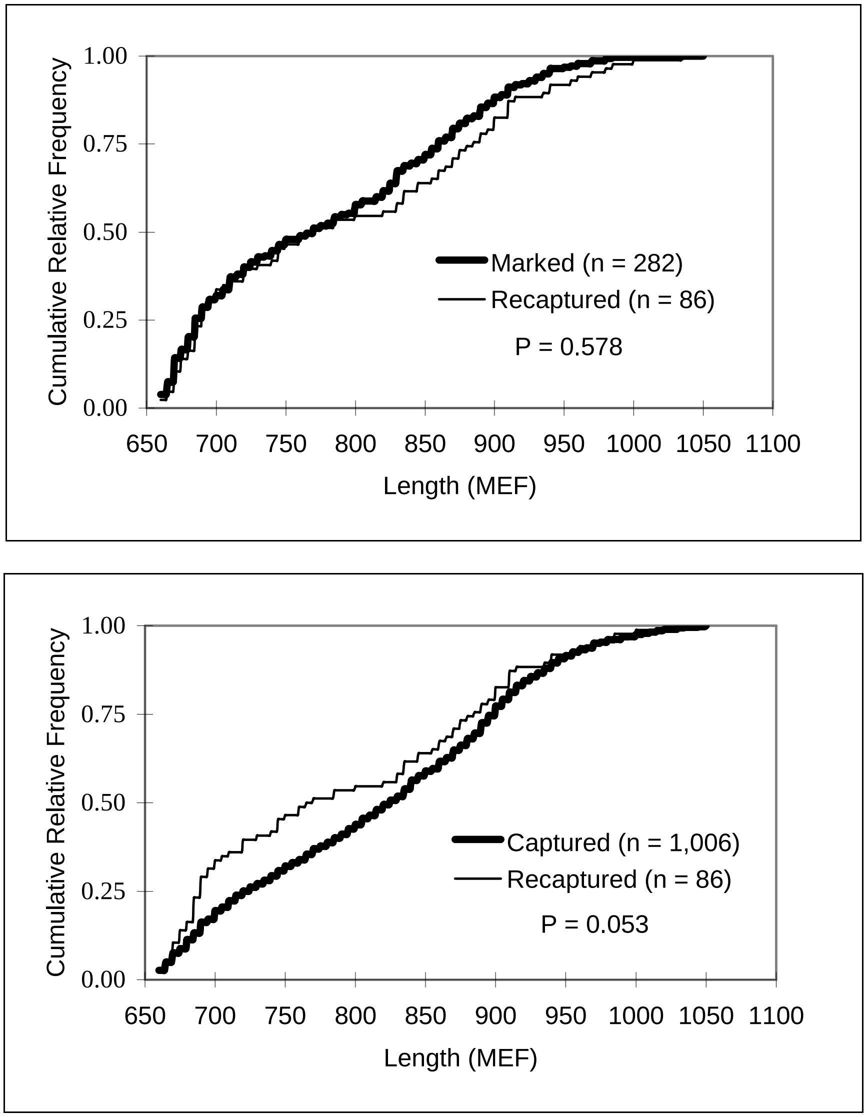


Figure 5.–Cumulative relative frequencies of large (≥660 mm MEF) Chinook salmon marked in Event 1 and recaptured in Event 2 (upper graph), and captured and recaptured in Event 2 (lower graph) in the Chickamin River, 2004.

the spawning grounds and those marked fish recaptured on the spawning grounds (D-value = 0.236, P = 0.158). These results suggest little evidence of size bias sampling for fish in this size range during either sampling event. However, our failure to observe any recaptured fish smaller than 580 mm MEF during second event sampling suggested further examination was necessary. We used contingency table analysis to evaluate the hypothesis that probability of a marked fish being recapturedwas independent of whether it was <580 mm or ≥580 mm MEF and rejected this hypothesis (χ^2 = 4.531, df = 1, P = 0.033). We also tested the hypothesis that the probability that a fish inspected during Event 2 sampling was marked was independent of whether it was <580 mm or ≥580 mm MEF and rejected this hypothesis (χ^2 = 6.779, df = 1, P = 0.009). As a result of these tests, we concluded that we should only attempt to estimate the abundance of Chinook salmon ≥580 mm MEF.

Table 2.–Catch of medium (580–659 mm MEF) and large (≥660 mm MEF) Chinook salmon marked with tags in Event 1, by set net site, Chickamin River, 2004.

	Medium	Large	Total
Choca Creek site (SN3)			
Catch	46	112	158
Tagged	43	109	152
Mortalities[a]	3	3	6
Below Leduc River site (SN5)			
Catch	51	176	227
Tagged	48	173	221
Mortalities	3	3	6
Total, both sites			
Catch	97	288	385
Tagged	91	282	373
Mortalities	6	6	12

[a] All fish shown as mortalities had missing adipose fins and were dispatched for tag sampling at the ADF&G Mark, Tag, and Age Laboratory. One additional fish <580 mm MEF with a missing adipose fin was also sacrificed.

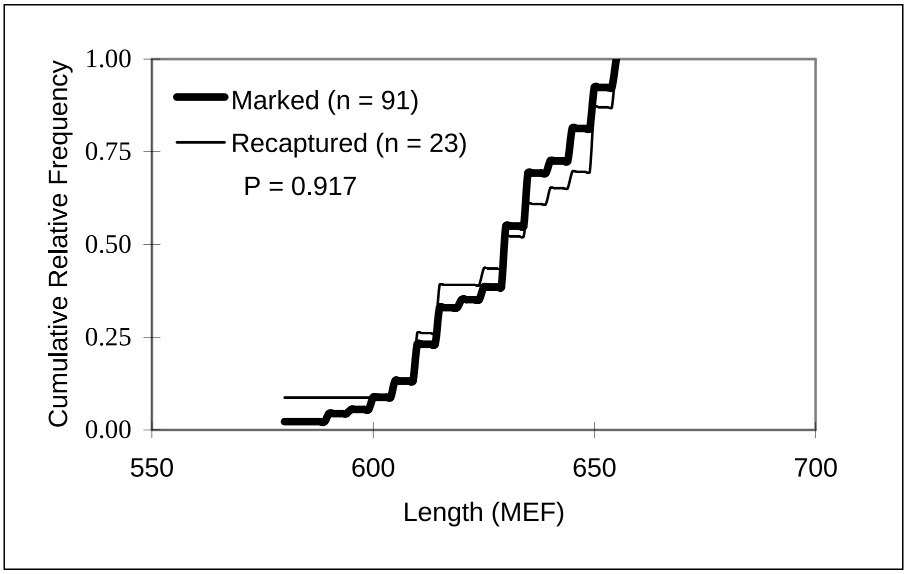
When evaluating size bias for medium-sized (580–659 mm MEF) Chinook salmon, no significant difference was detected between crfs of fish marked in Event 1 and those recaptured on the spawning grounds (D-value = 0.118, P = 0.917; Figure 6). Similarly, no difference was detected between fish inspected for marks on the spawning grounds and those marked fish recaptured on the spawning grounds (D-value = 0.098, P = 0.984; Figure 6). These results indicate that size bias sampling did not occur during either event for medium-sized fish (Case I, Appendix A1).

Temporal and spatial stratification were required to estimate abundance of large fish. When evaluating the null hypothesis that sampling location was independent of the probability that a fish inspected during Event 2 sampling was marked, we rejected this hypothesis (χ^2 = 24.090, df = 5, P < 0.001, Table 3). When evaluating the null hypothesis that the time when a fish was marked during Event 1 was independent of the probability that a marked fish was recaptured during Event 2, we rejected this hypothesis (χ^2 = 26.192, df = 7, P < 0.001, Table 4). The test for complete mixing between sampling events (Appendix A2) was not conducted because of the large number of small contingency table cell counts, and by inspection there was no evidence to indicate that complete mixing may have occurred.

Temporal and/or spatial stratification were not required prior to estimating abundance of medium fish. When evaluating the null hypothesis that sampling location was independent of the probability that a fish inspected during Event 2 sampling was marked, we reject this hypothesis (χ^2 = 12.875, df = 5, P = 0.025, Table 3). However, when evaluating the null hypothesis that the time when a fish was marked during Event 1 was independent of the probability that a marked fish was recaptured during Event 2, we failed to reject this hypothesis (χ^2 = 1.626, df = 4, P = 0.804, Table 4). Based on this test result, a Petersen-type model was appropriate to estimate abundance of medium fish (Appendix A2).

We tried several stratification schemes using the Darroch (1961) model when attempting to estimate the abundance of large Chinook salmon. The only stratification that yielded an admissible abundance estimate with satisfactory GOF statistics used geographic stratification for Event 2 sampling, and both geographic (set net site) and temporal stratification for Event 1 sampling (Table 4, Panel C). No stratification scheme that relied only on temporal stratification for Event 1 sampling could be identified that would yield an estimate. The difficulties encountered when trying to fit simpler stratification schemes resulted primarily from a lack of independence between both where and when a fish was tagged and the spawning stream that a fish was destined for.

The abundance of large fish was estimated at 4,268 (SE = 893). Two of the 86 recovered large fish (2.3%) had lost their primary tags, both of which were recovered in the South Fork. These two fish were not used in the Darroch model because a time and location of tagging could not be assigned. Consequently, the abundance estimate was likely biased high. To evaluate the potential for the size of the bias, we evaluated all possible combinations of potential Event 1 strata for these two fish, re-ran the model, and assigned probabilities for each combination based on the distribution among Event 1 strata of the other 43 tagged fish recaptured during Event 2 sampling in the South Fork. As a result of these sensitivity



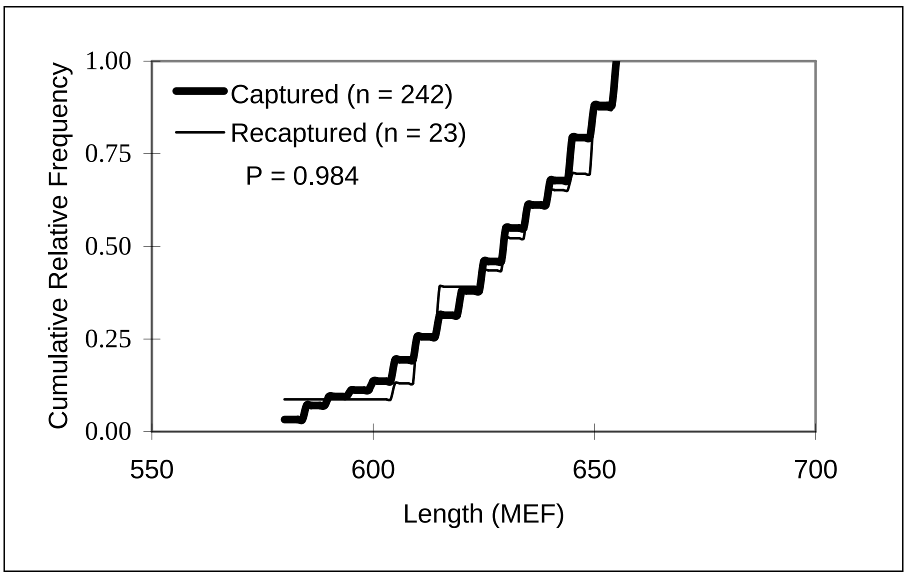


Figure 6.–Cumulative relative frequencies of medium (580–659 mm MEF) Chinook salmon marked in Event 1 and recaptured in Event 2 (upper graph), and captured and recaptured in Event 2 (lower graph) in the Chickamin River, 2004.

analyses, we projected a 79% chance that the bias was < 1% and an 86% chance that the bias was < 3%. There was a 14% chance that the real point estimate should be 3,700 to 3,800 (SE = 750 to 800).

The abundance of medium-sized (580–659 mm MEF) fish was estimated at 507 (SE = 50) using a Chapman estimator. The combined estimate for all Chinook salmon ≥580 mm was 4,775 (SE = 894, Table 5).

ESTIMATES OF AGE, SEX, AND LENGTH COMPOSITION

No evidence of size selective sampling was detected during Event 2, while size selectivity was detected during Event 1 (see diagnostic results above). In addition, 85 marked fish were recaptured and sexed in Event 2, and three of these fish (3.5%) had been assigned the opposite sex in Event 1. This infers error in sex assignment of fish in Event 1, and a lack of confidence in

Table 3.–Numbers of Chinook salmon ≥580 mm (MEF) sampled by size, location, and mark status during spawning ground surveys, Chickamin River, 2004.

	Captures		Recaptures		Marked rate	
Location	Medium	Large	Medium	Large	Medium	Large
Lower tributaries:						
Humpy	40	122		3	0.000	0.025
King	48	312	8	17	0.167	0.054
Subtotal Lower combined	88	434	8	20	0.091	0.046
Leduc River tributaries**:**						
Leduc	33	75	1	6	0.030	0.079
Clear Falls	1	1			0.000	0.000
Butler	52	134	5	8	0.096	0.060
Subtotal Leduc combined	86	210	6	14	0.070	0.067
Middle-upper tributaries:						
Indian	11	49	3	7	0.273	0.143
Lucky Jake		2				0.000
South Fork.	57	311	6	45	0.105	0.144
Middle-upper combined	68	362	9	52	0.132	0.144
Total	242	1,006	23	86	0.095	0.085

Table 4.–Number of large and medium-sized Chinook salmon ≥580 mm MEF marked by period and recovered during spawning ground sampling in the lower Chickamin River, 2004.

Panel A. Medium Chinook salmon (580–659 mm MEF)

Marking dates	Number marked	Number recovered	Recovery rate
6/20 to 7/4	19	3	0.157
7/5 to 7/14	18	4	0.222
7/15 to 7/20	18	4	0.222
7/21 to 7/28	19	6	0.316
7/29 to 8/18	17	5	0.294
Total	91	22 [a]	0.242

Panel B. Large Chinook salmon (≥660 mm MEF)

Marking dates	Number marked	Number recovered	Recovery rate
6/20 to 7/2	34	7	0.206
7/3 to 7/8	35	5	0.143
7/9 to 7/12	33	10	0.303
7/13 to 7/17	37	11	0.297
7/18 to 7/22	36	19	0.528
7/23 to 7/26	35	18	0.514
7/27 to 7/31	37	8	0.216
8/1 to 8/18	35	6	0.171
Total	282	84 [a]	0.298

Panel C. Partial Stratification for Large Chinook salmon (≥660 mm MEF)

	Event 1 (Marking) Strata					
Event 2 Strata	Setnet 3 6/20 to 7/17	Setnet 3 7/18 to 7/24	Setnet 3 7/25 to 8/16	Setnet 5 6/20 to 7/9	Setnet 5 7/10 to 8/16	Unmarked
Humpy	1	1	0	0	1	119
King	1	3	8	0	5	295
Leduc/Clear Falls	0	4	0	0	2	70
Butler	3	3	0	1	1	126
South Fork	2	4	2	4	31	268
Indian/Lucky Jake	0	0	0	3	4	44
Not recaptured	28	6	43	51	70	

[a] One medium fish recovered at Butler Creek and two large fish at South Fork with missing spaghetti tags were excluded from this table.

comparing sex compositions in Event 1 and Event 2. As a result, only samples from Event 2 were used for estimating age and sex composition, and mean length at age and sex (Appendix A1). When discrepancies occurred in lengths of recaptured fish between Events 1 and 2, Event 1 lengths were used for diagnostic tests and estimates of abundance and composition.

Age-1.4 Chinook salmon from the 1998 brood year were dominant (38.1%, SE = 1.7%) on the Chickamin River in 2004 (Table 5). Unlike previous years, the run was composed of fewer age-1.3 fish than either age-1.2 or age-1.4 fish. Males composed 59.3% (SE = 1.5%) of the escapement of fish ≥580 mm MEF. There were an estimated 1,757 (SE = 374) females in the spawning population, and age-1.4 fish were the most abundant age class among females. Note that the escapement of age-1.1 and age-1.2 fish <580 mm MEF are not estimated because we could not sample these fish as effectively as larger fish during either sampling event. None of the marked fish <580 mm MEF were recaptured and only one age-1.3 fish < 580mm MEF was encountered during event 2 sampling. Nearly all medium-sized fish sampled were males (99.0%, SE = 0.7%), and 97.9% (SE = 1.0%) were age-1.2. Of the 1,105 scale samples from Event 2 that were successfully aged, 1,102 or 99.7% were age-1. fish from yearling smolt; one fish was age-0 and two were age-2 (Table 6).

Average length-at-age generally increased with saltwater age for both male and female Chinook salmon sampled (Table 6, Figure 7). Within age-1.3 fish, females were on average 35 mm longer than males, whereas age-1.4 males averaged an estimated 27 mm longer than their female counterparts. Summary statistics for ages of all fish sampled in set nets and from the spawning grounds are shown in Appendix A4.

EXPANSION FACTOR

At least two surveys were made to count spawning fish in each of the eight tributaries surveyed annually on the Chickamin River. The combined peak count for these tributaries was 798 large Chinook salmon. The upper-middle tributaries were surveyed on 8, 12, and 17 August, and the lower tributaries were surveyed on 12 and 26 August and on 1 September. The expansion factor for 2004 was estimated at 5.35 (SE = 1.12), as compared with 6.49 in 1995, 3.76 in 1996, 5.13 in 2001, 4.94 in 2002, and 4.75 in 2003 (Table 7). The mean expansion factor is 4.79 (range 3.76 to 5.35), using the latter five years (1996 and 2001–2004). We did not use the initial year (1995) because of the low sample size and poor precision of the mark–recapture estimate. The mean coefficient of variation (CV) of the five most recent estimates is 15.9% (range 12.5% to 20.9%), which is acceptable relative to the benchmark 20% precision guideline in USCTC (PSC 1997). Computer files of worksheets containing the data and analyses used for estimates in this document are reported in Appendix A5.

DISCUSSION

The estimated escapement of 4,268 large Chinook salmon in 2004 was below the 2001–2003 estimates of 5,177, 5,007, and 4,579 fish, respectively, though well above the 1995 and 1996 estimates of 2,309 and 1,587 large fish (Table 7). This year marked the sixth consecutive year (since 1998) that the peak index survey counts met or exceeded the present escapement goal (798 fish in 2004; index count of 450–900 fish; McPherson and Carlile 1997).

The two primary set net sites fished in 2002 and 2003 (SN3 off Choca Creek and SN5 11 km upstream – below the Leduc River confluence, Figure 3) were again fishable and productive in 2004. However, SN5 produced higher catches than SN3 in 2004. The year-to-year consistency of these two sites allowed the crews more uninterrupted fishing time in proven waters.

Similar to 2003, crew efficiency coupled with mostly favorable weather and stream conditions in August yielded over 1,000 large fish sampled during the recovery event. This compares favorably to 883 large fish captured in 2001 utilizing more staffing and effort, and to the 623 large fish captured in 2002 using similar staffing and effort. A relatively higher number of fish 401–659 mm MEF were captured during both Events 1 and 2 than in previous years, however only marked fish 580mm MEF and larger were recaptured. We concluded that sight fishing on the spawning grounds limits our ability to capture medium-sized fish, especially the smaller ones.

Table 5.–Estimated age and sex composition, and escapement of medium (580–659 mm MEF) and large (≥660 mm MEF) Chinook salmon in the Chickamin River, 2004. Estimates are from Chinook salmon sampled on the spawning grounds in Event 2.

Panel A: Medium Chinook salmon (580–659 mm MEF)

		BROOD YEAR AND AGE CLASS								
		2001	2000	1999	1999	1999	1998	1997	1997	
		1.1	1.2	1.3	0.4	2.2	1.4	1.5	2.3	Total
Males	Sample size		189	4						193
	Percent		96.9	2.1						99.0
	SE of percent		1.2	1.0						0.7
	Escapement		311	7						318
	SE of esc.		49	3						50
Females	Sample size		2							2
	Percent		1.0							1.0
	SE of percent		0.7							0.7
	Escapement		3							3
	SE of esc.		2							2
Total	Sample size		191	4						195
	Percent		97.9	2.1						100.0
	SE of percent		1.0	1.0						0.0
	Escapement		314	7						507
	SE of esc		49	3						50

Panel B: Large Chinook salmon (≥660 mm MEF)

		BROOD YEAR AND AGE CLASS								
		2001	2000	1999	1999	1999	1998	1997	1997	
		1.1	1.2	1.3	0.4	2.2	1.4	1.5	2.3	Total
Males	Sample size		226	153		1	114		1	496
	Percent		26.8	18.2		0.1	13.5		0.1	58.9
	SE of percent		1.5	1.3		0.1	1.2		0.1	1.7
	Escapement		1146	776		5	578		5	2,514
	SE of esc.		248	171		5	131		5	531
Females	Sample size		9	88	1		245		3	346
	Percent		1.1	10.5	0.1		29.1		0.4	41.1
	SE of percent		0.4	1.1	0.1		1.6		0.2	1.7
	Escapement		46	446	5		1,242		20	1,754
	SE of esc.		18	103	5		268		11	374
Total	Sample size		35	241	1	1	359		4	842
	Percent		27.9	28.6	0.1	0.1	42.6		0.5	100.0
	SE of percent		1.5	1.6	0.1	0.1	1.7		0.2	0.0
	Escapement		1,191	1,222	5	5	1,820		20	4,268
	SE of esc.		257	264	5	5	389		11	893

Panel C: Medium and Large Chinook salmon combined

		BROOD YEAR AND AGE CLASS								
		2001	2000	1999	1999	1999	1998	1997	1997	
		1.1	1.2	1.3	0.4	2.2	1.4	1.5	2 .3	
Males	Sample size		415	157		1	114	1	1	689
	Percent		30.5	16.4		0.1	12.1	0.1	0.1	59.3
	SE of %		1.5	1.2		0.1	1.1	0.1	0.1	1.5
	Escapement		1,457	782		5	578	5	5	2,832
	SE of Esc.		253	172		5	131	5	5	533
Females	Sample size		11	88	1		245	3		348
	Percent		1.0	9.3	0.1		26	0.3		36.8
	SE of %		0.3	1.0	0.1		1.5	0.2		1.7
	Escapement		49	446	5		1,242	15		1,757
	SE of Esc.		18	103	5		268	9		374
Total	Sample size		426	245	1	1	359	4	1	1,037
	Percent		31.5	25.7	0.1	0.1	38.1	0.4	0.1	100.0
	SE of %		1.5	1.5	0.1	0.1	1.7	0.2	0.1	0.0
	Escapement		1,506	1,228	5	5	1,820	20	5	4,775
	SE of Esc.		262	264	5	5	387	11	5	894

The 18.5 cm mesh nets were better suited to catching large fish; however, they were hung loosely to help reduce bias towards larger fish.

The relatively high proportion of marked large Chinook salmon recovered in the South Fork and Indian Creek areas in 2004 primarily resulted in failure of the statistical test of equal marked fractions across spatial recovery strata. Most of the fish recaptured in the South Fork were tagged at SN5, the same side of the mainstem that the South Fork enters. Based on limitations of suitable set net sites within the drainage, SN5 is a proven and necessary site to ensure that minimums are reached in Event 1. Also, SN5 may be a staging or milling area for Chinook salmon bound for South Fork and Indian Creek.

Relative to the Unuk River and other Chinook salmon systems studied in SEAK, the lower Chickamin River lacks obvious holding areas or easily detected migration routes, and high bycatch of pink and chum salmon are inevitable. Finding effective set net sites on this system has proven challenging such that multiple sites (and possibly at different locations on a given year) must be fished to capture the necessary minimum in Event 1. Despite some limitations (differential marking rates), the combination of the two primary sites fished in 2002–2004 seems to be our best option on the Chickamin River. Other sites have been tested and proven ineffective over the long term because of variable stream conditions, debris loading, snags, or high bycatches.

Table 6.–Average length by sex and age of Chinook salmon sampled in the Chickamin River, 2004. Estimates include all Chinook salmon sampled and successfully aged from the spawning grounds.

		Brood year								
		2001	2000	1999	1999	1999	1998	1997	1997	
		1.1	1.2	1.3	0.4	2.2	1.4	1.5	2.3	Total
Males	Sample size	47	436	158		1	113	1	1	757
	Avg. length	430	658	787		690	925	1,050	815	
	SD	43	52	70			76			
	SE	6	3	6			7			
Females	Sample size		11	88	1		245	3		348
	Avg. length		722	822	905		898	955		
	SD		62	43			47	13		
	SE		19	5			3	8		
Sexes combined	Sample size	47	447	246	1	1	358	4	1	1,105
	Avg. length	430	659	799	905	690	906	979	815	
	SD	43	53	64			59	49		
	SE	6	3	4			3	24		

Table 7.–Peak survey counts, mark–recapture estimates of escapement, and estimated expansion factors for large (≥660 mm MEF) Chinook salmon in the Chickamin River in 1995, 1996, and 2001–2004.

	Year						1996–2004 Average
	1995	1996	2001	2002	2003	2004	
Survey count	356	422	1,010	1,013	964	798	841
Mark-recapture estimate (M-R)	2,309	1,587	5,177	5,007	4,579	4,268	4,124
M-R standard error	723	199	972	738	592	893	
M-R 95% relative precision	61.4%	24.6%	36.8%	28.9%	25.3%	41.0%	31.3%
M-R lower 95% C.I.	1,388	1,279	3,780	3,892	3,481	2,519	
M-R upper 95% C.I.	4,650	2,089	7,573	6,742	5,134	6,018	
Survey count/(M-R)(%)	15.4	26.6	19.5	20.2	21.1	18.7	21.7
Expansion factor	6.49	3.76	5.13	4.94	4.75	5.35	4.79
SE[expansion factor]	2.03	0.47	0.96	0.73	0.61	1.12	0.78
CV of expansion factor (%)	31.3	12.0	18.0	14.0	12.0	20.0	15.0

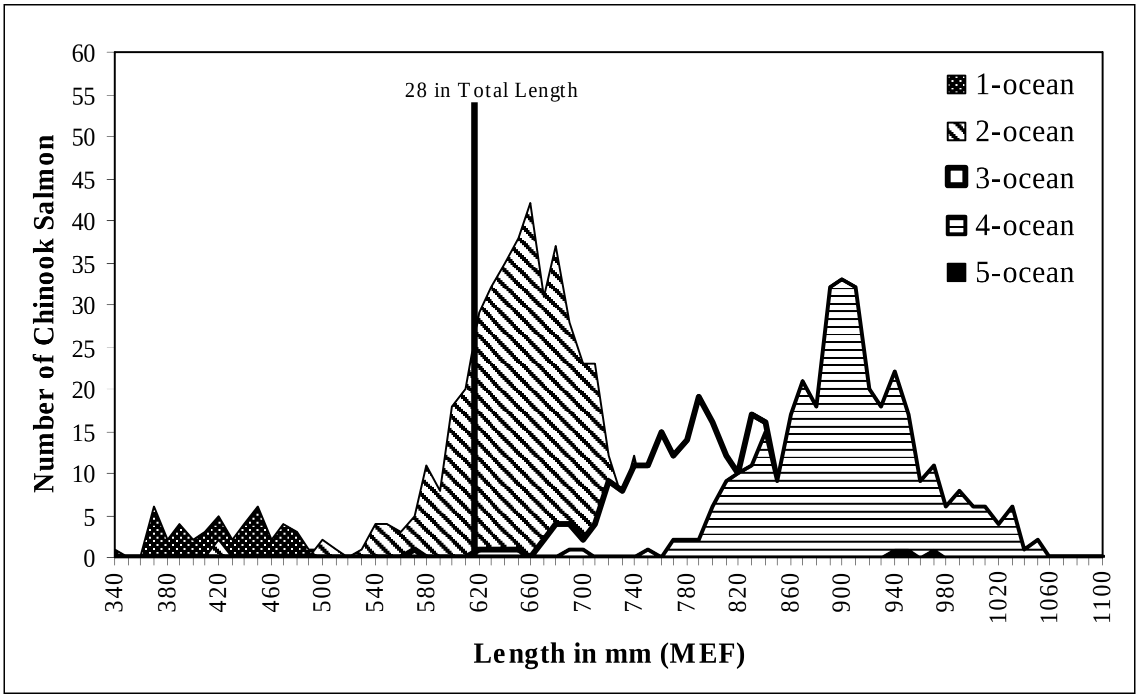


Figure 7.–Numbers of Chinook salmon by ocean age from samples taken in Event 2, Chickamin River, 2004. (Based on regulations for Southeast Alaska, 28 inches is the minimum total length of Chinook salmon permitted for harvest in the sport fishery.)

The escapement was marked by a relatively high number of 2-ocean fish and a relatively low number of 3-ocean fish. Furthermore, it is likely that not all 2-ocean fish were represented in our abundance estimate and composition estimates excluded fish < 580 mm MEF. This finding was consistent among many SEAK streams investigated in 2004. Barring unforeseen survival issues, the 3-ocean component of the 2005 return should be strong.

Once the small and medium-sized fish were segregated, sampling size selectivity was less of an issue with large fish. We concluded (using our KS tests for large fish) that sampling was not size selective in Event 2 but was selective against the largest fish in Event 1 (P = 0.053). This is to be expected given that the largest Chinook salmon (>860 mm MEF) are caught at a lower rate in the 18.5 cm mesh gillnets than they are with the gear used on the spawning grounds. The effects of size-selective sampling over the medium and large size classes were substantially reduced using our size-stratified study design.

Direct evidence of handling or stress-related mortality of Chinook salmon was not observed in the gillnet catches. Low mortality using these methods was reported by Pahlke (1997), who observed that over 90% of gillnet-caught and radio-tagged Chinook salmon were tracked upstream to spawning areas in 1996. Some net mortality of pink and chum salmon was observed during the peak bycatch period in late July. Mortality was minimized because crews maintained a constant watch on the nets, and responded quickly to free entangled fish.

CONCLUSIONS AND RECOMMENDATIONS

We should continue to try to reduce the differences in the fractions of Chinook salmon bound for the three general spawning areas (lower, South Fork and Indian, and Leduc tributaries) that are marked. Further refinement of the timing of sampling at each location in each event may help in this endeavor, as will trying to catch more fish along the west bank near SN5 or SN6. If successful, similar marked fractions in the tributaries may make future experiments more robust.

We recommend that the previously established expansion factor (4.0) for aerial surveys conducted on the Chickamin River be revised to 4.79, based on the mean of the five estimates for 1996 and 2001–2004. A continuation of this project will provide a better estimate of the expansion factor, and a more reliable base from which to estimate past and future escapements through aerial index surveys. We also recommend that the mark–recapture project be continued. Otherwise, annual sampling of at least 400 adults on the spawning grounds will be necessary to recover and sample enough coded-wire-tagged fish in future returns to precisely estimate total return by age and brood year, adult production, exploitation rates, and smolt abundance.

ACKNOWLEDGMENTS

We thank Jason Leavitt, Alex Blaine, Richard Duncan, Jesse Morris, David Magnus, and Andrew Morphis for conducting fieldwork and collecting data while operating from the Chickamin River field camp. Amy Holm in Ketchikan provided comprehensive logistics support and data entry. Dave Magnus assisted in data collection and helped train the crew. Keith Pahlke conducted aerial surveys and provided assistance in logistics for escapement sampling. Sue Millard completed aging of the Chinook salmon scales collected during this project. Mike Wood provided mapping assistance. John H. Clark, Dave Bernard, Gary Freitag and other members of the U.S. CTC, and Dave Cantillon (NOAA-NFMS) helped obtain funding approval for this project. John Derhovanisian provided critical review and editorial improvements to this manuscript and Judy Shuler prepared the final manuscript for publication.

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APPENDIX A

Appendix A1.–Detection of size- and/or sex-selective sampling during a two-sample mark–recapture experiment and its effects on estimation of population size and population composition.

Size selective sampling: The Kolmogorov-Smirnov two sample test (Conover 1980) is used to detect significant evidence that size selective sampling occurred during the first and/or second sampling events. The second sampling event is evaluated by comparing the length frequency distribution of all fish marked during the first event (M) with that of marked fish recaptured during the second event (R) by using the null test hypothesis of no difference. The first sampling event is evaluated by comparing the length frequency distribution of all fish inspected for marks during the second event (C) with that of R. A third test that compares M and C is then conducted and used to evaluate the results of the first two tests when sample sizes are small. Guidelines for small sample sizes are <30 for R and <100 for M or C.

Sex selective sampling: Contingency table analysis (Chi^2-test) is generally used to detect significant evidence that sex selective sampling occurred during the first and/or second sampling events. The counts of observed males to females are compared between M&R, C&R, and M&C using the null hypothesis that the probability that a sampled fish is male or female is independent of sample. If the proportions by gender are estimated for a sample (usually C), rather an observed for all fish in the sample, contingency table analysis is not appropriate and the proportions of females (or males) are then compared between samples using a two sample test (e.g. Student's t-test).

M vs. R	**C vs. R**	**M vs. C**
Case I:		
Fail to reject H_o	Fail to reject H_o	Fail to reject H_o
There is no size/sex selectivity detected during either sampling event.		
Case II:		
Reject H_o	Fail to reject H_o	Reject H_o
There is no size/sex selectivity detected during the first event but there is during the second event sampling.		
Case III:		
Fail to reject H_o	Reject H_o	Reject H_o
There is no size/sex selectivity detected during the second event but there is during the first event sampling.		
Case IV:		
Reject H_o	Reject H_o	Either result possible
There is size/sex selectivity detected during both the first and second sampling events.		
Evaluation Required:		
Fail to reject H_o	Fail to reject H_o	Reject H_o

-continued-

Sample sizes and powers of tests must be considered:

A. If sample sizes for M vs. R and C vs. R tests are not small and sample sizes for M vs. C test are very large, the M vs. C test is likely detecting small differences which have little potential to result in bias during estimation. *Case I* is appropriate.

B. If a) sample sizes for M vs. R are small, b) the M vs. R p-value is not large (~0.20 or less), and c) the C vs. R sample sizes are not small and/or the C vs. R p-value is fairly large (~0.30 or more), the rejection of the null in the M vs. C test was likely the result of size/sex selectivity during the second event which the M vs. R test was not powerful enough to detect. *Case I* may be considered but *Case II* is the recommended, conservative interpretation.

C. If a) sample sizes for C vs. R are small, b) the C vs. R p-value is not large (~0.20 or less), and c) the M vs. R sample sizes are not small and/or the M vs. R p-value is fairly large (~0.30 or more), the rejection of the null in the M vs. C test was likely the result of size/sex selectivity during the first event which the C vs. R test was not powerful enough to detect. *Case I* may be considered but *Case III* is the recommended, conservative interpretation. D. If a) sample sizes for C vs. R and M vs. R are both small, and b) both the C vs. R and M vs. R p-values are not large (~0.20 or less), the rejection of the null in the M vs. C test may be the result of size/sex selectivity during both events which the C vs. R and M vs. R tests were not powerful enough to detect. *Cases I, II, or III* may be considered but *Case IV* is the recommended, conservative interpretation

Case I. Abundance is calculated using a Petersen-type model from the entire data set without stratification. Composition parameters may be estimated after pooling length, sex, and age data from both sampling events.

Case II. Abundance is calculated using a Petersen-type model from the entire data set without stratification. Composition parameters may be estimated using length, sex, and age data from the first sampling event without stratification. If composition is estimated from second event data or after pooling both sampling events, data must first be stratified to eliminate variability in capture probability (detected by the M vs. R test) within strata. Composition parameters are estimated within strata, and abundance for each stratum needs to be estimated using a Petersen-type formula. Overall composition parameters are estimated by combining stratum estimates weighted by estimated stratum abundance according to the formulae below.

Case III. Abundance is calculated using a Petersen-type model from the entire data set without stratification. Composition parameters may be estimated using length, sex, and age data from the second sampling event without stratification. If composition is estimated from first event data or after pooling both sampling events, data must first be stratified to eliminate variability in capture probability (detected by the C vs. R test) within strata. Composition parameters are estimated within strata, and abundance for each stratum needs to be estimated using a Petersen-type type formula. Overall composition parameters are estimated by combining stratum estimates weighted by estimated stratum abundance according to the formulae below.

Case IV. Data must be stratified to eliminate variability in capture probability within strata for at least one or both sampling events. Abundance is calculated using a Petersen-type model for each stratum, and estimates are summed across strata to estimate overall abundance. Composition parameters may be estimated within the strata as determined above, but only using data from sampling events where stratification has eliminated variability in capture probabilities within strata. If data from both sampling events are to be used, further stratification may be necessary to meet the condition of capture homogeneity within strata for both events. Overall composition parameters are estimated by combining stratum estimates weighted by estimated stratum abundance.

If stratification by sex or length is necessary prior to estimating composition parameters, then an overall composition parameters (p_k) is estimated by combining within stratum composition estimates using:

-continued-

$$\hat{p}_k = \sum_{i=1}^{j} \frac{\hat{N}_i}{\hat{N}_\Sigma} \hat{p}_{ik} \qquad (1)$$

and,

$$\hat{V}[\hat{p}_k] \approx \frac{1}{\hat{N}_\Sigma^2} \left(\sum_{i=1}^{j} \hat{N}_i^2 \hat{V}[\hat{p}_{ik}] + (\hat{p}_{ik} - \hat{p}_k)^2 \hat{V}[\hat{N}_i] \right) \qquad (2)$$

where: j = the number of sex/size strata;

$\hat{p}_{ik}$ = the estimated proportion of fish that were age or size *k* among fish in stratum *i*;

$\hat{N}_i$ = the estimated abundance in stratum *i*; and,

$\hat{N}_\Sigma$ = sum of the $\hat{N}_i$ across strata.

Appendix A2.–Tests of consistency for the Petersen estimator (from Seber 1982, page 438).

Tests of consistency for Petersen estimator

Of the following conditions, at least one must be fulfilled to meet assumptions of a Petersen estimator:

1. Marked fish mix completely with unmarked fish between events;
2. Every fish has an equal probability of being captured and marked during event 1;

   or,
3. Every fish has an equal probability of being captured and examined during event 2.

To evaluate these three assumptions, the chi-square statistic will be used to examine the following contingency tables as recommended by Seber (1982). At least one null hypothesis needs to be accepted for assumptions of the Petersen model (Bailey 1951, 1952; Chapman 1951) to be valid. If all three tests are rejected, a temporally or geographically stratified estimator (Darroch 1961) should be used to estimate abundance.

I.-Test for complete mixing [a]

	Time/Area Where Recaptured				Not Recaptured
Area/Time Where Marked	1	2	…	t	(n_1-m_2)
1					
2					
…					
s					

II.-Test for equal probability of capture during the first event [b]

	Area/Time Where Examined			
	1	2	…	t
Marked (m_2)				
Unmarked (n_2-m_2)				

III.-Test for equal probability of capture during the second event [c]

	Area/Time Where Marked			
	1	2	…	s
Recaptured (m_2)				
Not Recaptured (n_1-m_2)				

[a] This tests the hypothesis that movement probabilities (θ) from time or area i (i = 1, 2, ...s) to section j (j = 1, 2, t) are the same among sections: H_0: $\theta_{ij} = \theta_j$.

[b] This tests the hypothesis of homogeneity on the columns of the 2-by-t contingency table with respect to the marked to unmarked ratio among time or area designations: H_0: $\Sigma_i a_i\theta_{ij} = kU_j$, where k = total marks released/total unmarked in the population, U_j = total unmarked fish in stratum j at the time of sampling, and a_i = number of marked fish released in stratum i.

[c] This tests the hypothesis of homogeneity on the columns of this 2-by-s contingency table with respect to recapture probabilities among time or area designations: H_0: $\Sigma_j\theta_{ij}p_j = d$, where p_j is the probability of capturing a fish in section j during the second event, and d is a constant.

Appendix A3.–Set net catch and effort records on the Chickamin River, 2004.

Date	Setnet Site	Start time	End Time	Time fished (hrs)	MEF ≥660	MEF 401–659	MEF ≤400	No. pink	No. chum	No. coho	No. sockeye	Water depth (cm)	Water temp (`C)
6/20/04	5	1115	1723	6	3	1							7
6/20/04	3	1045	1647	6		1							7
6/21/04	5	1044	1646	6	1								7
6/21/04	3	1005	1605	6									7
6/22/04	5	1038	1640	6	1								7
6/22/04	3	1005	1607	6	1								7
6/23/04	5	955	1559	6	2					2			7
6/24/04	3	1035	1639	6	1	1			2				7
6/25/04	5	1200	1800	6									7
6/25/04	3	1155	1755	6					1				7
6/26/04	5	1129	1733	6	1	1							7
6/26/04	3	1145	1745	6									7
6/27/04	5	1150	1752	6	1								7
6/28/04	5	1130	1740	6	4	1			1				6
6/28/04	3	1110	1712	6		1			1				6
6/29/04	5	1115	1717	6	1				3				6
6/29/04	3	1113	1713	6					1				6
6/30/04	5	1125	1733	6	2	1			3		1		7
7/01/04	5	1310	1926	6	5	3			5				7
7/01/04	3	1315	1923	6	1	3			4				7
7/02/04	5	1140	1756	6	7	1							7
7/02/04	3	1145	1757	6	3	3		2	7				7
7/03/04	5	1050	1700	6	4	1		1	4		1		6
7/03/04	3	1035	1647	6	5	1		8					6
7/04/04	3	1045	1645	6	4	1			3				7
7/05/04	5	1100	1724	6	10	2		1	3				7
7/05/04	3	1047	1651	6	2			1	5				7
7/06/04	5	1100	1714	6	5	2		2	8				6
7/06/04	3	1035	1437	6		1			3				6
7/07/04	5	1047	1659	6	4	3		1	6				6
7/08/04	5	1030	1636	6	3			1	9				6
7/08/04	3	1035	1637	6			1		4				6
7/09/04	5	1050	1706	6	6	2			3				6
7/09/04	3	1255	1917	6	9	2		3	22				6
7/10/04	5	1133	1753	6	4	6		3	10				6
7/10/04	3	1245	1849	6	2				11				6
7/11/04	5	1155	1811	6	7	1		3	11				6
7/12/04	5	1105	1716	6	5			1	3		1		6
7/12/04	3	1111	1713	6		1		6	9				6
7/13/04	5	1017	1621	6	1	1		2	9				6
7/13/04	3	803	1411	6	3	1		10	20				6
7/14/04	5	1105	1715	6	4	1		4	8				6
7/15/04	5	1110	1726	6	5	3		13	21				5
7/15/04	3	920	1524	6	1	1		31	15				5
7/16/04	5	1040	1648	6	4			18	22		2	15	5
7/16/04	3	950	1556	6	2	1		20	29			15	5
7/17/04	5	1050	1726	6	15	3		29	20		1	15	6
7/17/04	3	1020	1630	6	2	3		65	37		1	15	6
7/18/04	5	1115	1731	6	6	2		22	12		1	12	6
7/19/04	5	1115	1744	6	11	3		30	11			11	6
7/19/04	3	935	1541	6	2	2		122	17			11	6
7/20/04	5	1058	1715	6	6	1		81	10		1	14.5	6
7/20/04	3	1029	1640	6	5	1						14.5	6

-continued-

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Date	Setnet Site	Start time	End Time	Time fished (hrs)	MEF ≥660	MEF 401–659	MEF ≤400	No. pink	No. chum	No. coho	No. sockeye	Water depth (cm)	Water temp (`C)
7/21/04	5	1200	1500	6	1			35	10			13.5	6
7/22/04	5	1111	1813	6		1		37	9			11.25	7
7/22/04	3	1110	1730	6	7	2		229	34			11.25	7
7/23/04	5	1028	1656	6	11	2		43	15			12	8
7/23/04	3	842	1454	6	3	3		487	25			12	8
7/24/04	5	1300	1926	6	9	4		86	28	1		12.5	6
7/24/04	3	1146	1811	6	6	5		405	34			12.5	6
7/25/04	5	1120	1736	6	6	2		148	27			14	5
7/26/04	5	1220	1826	6	1	2		130	25			10.5	6
7/26/04	3	1154	1800	6	2	1		555	27			10.5	6
7/27/04	5	1118	1732	6	6	1		90	21			8.5	8
7/27/04	3	912	1520	6	4			605	29			8.5	8
7/28/04	5	1200	1800	6	10	2		72	26			8.5	6
7/29/04	5	1300	1908	6	1	3		88	29			17	6
7/29/04	3	1248	1904	6	6	2		141	17			17.25	6
7/30/04	5	957	1307	6				91	7			17	5
7/30/04	3	1335	1639	6				23	1			12.5	5
7/30/04	3	1200	1814	6	5	1		188	11			12.75	5
7/31/04	3	935	1542	6				90	2			12.75	5
7/31/04	3	920	1530	6	4	2		136	25				5
8/01/04	3	1050	1710	6	9	1		116	17			9	6
8/02/04	3	1115	1718	6	1	1		34	12			16	6
8/03/04	3	835	1440	6	1			44	14			17.5	6
8/04/04	3	945	1717	7	2			65	15			12.5	6
8/05/04	3	1200	1808	6	2	1		47	12			14	6
8/06/04	5	925	1540	6	2	1		54	2			11	7
8/06/04	3	1230	1834	6	2			12	9			11	7
8/09/04	3	927	1526	6				33	13			9.5	7
8/10/04	3	1108	1708	6								10.5	7
8/10/04	3	1053	1707	6	5	2		32	11			10.5	7
8/11/04	3	1101	1709	6	3	1		30	16	11		12.5	7
8/12/04	3	1225	1717	6	6			48	16			10	7
8/14/04	3	1002	1604	6		1		45	29	7		9	7
8/15/04	3	1140	1748	6	1	1		23	18			11.5	7
8/16/04	5	1135	1743	6	1			30	10			14.5	7
8/16/04	3	1130	1730	6	1			30	10			12.5	7
8/18/04	3	1105	1705	6		1		50	9	17		12.5	7
8/19/04	3	1115	1730	6				31	3	24			7
8/22/04	3	1101	1801	6				45	6	36		7	
8/24/04	3	1035	1735	6						40	1	7	
8/29/04	3	1100	1800	6				24	3		2		
8/31/04	5	1000	1648	6		1				23		4	5
9/02/04	3	1010	1642	6						25		4	5
9/05/04	5	1100	1800	6				2	3	53		11.5	7
9/07/04	3	1020	1720	6				1	4	77		10	
9/09/04	5	1050	1708	6						9		1	7
9/11/04	3	1045	1745	6						46		10	
9/13/04	5	1130	1830	6						72		10	
9/13/04	3	900	1600	6						40		10	
9/22/04	3	950	1550	6			1			21		25	6

Appendix A4.–Age by sex of large (≥660 mm MEF), medium (580–659 mm MEF), and all smaller (<580 mm MEF) Chinook salmon sampled in set gillnets and from spawning grounds, Chickamin River, 2004.

PANEL A. Chinook salmon sampled in Event 1 (set gillnets)

			Age class								
			1.1	1.2	1.3	0.4	2.2	1.4	1.5	2.3	Total
Large fish	Males	Sample		79	49	1		20			149
		Percent		53.0	32.9	0.7		13.4			69.3
	Females	Sample		1	17			47	1		66
		Percent		1.5	25.8			71.2	1.5		30.7
	Total	Sample		80	66	1		67	1		215
		Percent		37.2	30.7	0.5		31.2	0.5		
Medium fish	Males	Sample		68	2						70
		Percent		97.1	2.9						100
	Total	Sample		68	2						70
		Percent		97.1	2.9						
Smaller fish	Males	Sample	5	6							11
		Percent	45.5	54.5							100
	Total	Sample	5	6							11
		Percent	45.5	54.5							
Set Gillnets–all Chinook	Males	Sample	5	153	51	1		20			230
		Percent	2.2	66.5	22.2	0.4		8.7			77.7
	Females	Sample		1	17			47	1		66
		Percent		1.5	25.8			71.2	1.5		22.3
	Total	Sample	5	154	68	1		67	1		296
		Percent	1.7	52.0	23.0	0.3		22.6	0.3		

PANEL B. Chinook salmon sampled in Event 2 (spawning grounds)

			Age class								
			1.1	1.2	1.3	0.4	2.2	1.4	1.5	2.3	Total
Large fish	Males	Sample		226	153		1	114	1	1	496
		Percent		45.6	30.8		0.2	23.0	0.2	0.2	58.9
	Females	Sample		9	88	1		245	3		346
		Percent		2.6	25.4	0.3		70.8	0.9		41.1
	Total	Sample		235	241	1	1	359	4	1	842
		Percent		27.9	28.6	0.1	0.1	42.6	0.5	0.1	
Medium fish	Males	Sample		189	4						193
		Percent		97.9	2.1						99.0
	Females	Sample		2							2
		Percent		100							1.0
	Total	Sample		191	4						195
		Percent		97.9	2.1						
Smaller fish	Males	Sample	47	22	1						70
		Percent	67.1	31.4	1.4						100
	Total	Sample	47	22	1						13
		Percent	67.1	31.4	1.4						
Spawning Grounds–all Chinook	Males	Sample	47	437	158		1	114	1	1	759
		Percent	6.2	57.6	20.8		0.1	15.0	0.1	0.1	68.6
	Females	Sample		11	88	1		245	3		348
		Percent		3.2	25.3	0.3		70.4	0.9		31.4
	Total	Sample	47	448	246	1	1	359	4	1	1,107
		Percent	4.2	40.5	22.2	0.1	0.1	32.4	0.4	0.1	

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PANEL C. Chinook salmon sampled in Event 1 (set gillnets) and Event 2 (spawning grounds) combined												
			Age class									
			1.1	1.2	1.3	0.4	2.2	1.4	1.5	2.3	Total
Large fish	Males	Sample		280	184	1	1	123	1	1	591
		Percent		47.4	31.1	0.2	0.2	20.8	0.2	0.2	60.0
	Females	Sample		10	102	1		277	4		394
		Percent		2.5	25.9	0.3		70.3	1.0		40.0
	Total	Sample		290	286	2	1	400	5	1	985
		Percent		29.4	29.0	0.2	0.1	40.6	0.5	0.1	
Medium fish	Males	Sample		241	5						246
		Percent		98.0	2.0						99.2
	Females	Sample		2							2
		Percent		100%							0.8%
	Total	Sample		243	5						248
		Percent		86.4	2.1						
Smaller fish	Males	Sample	52	28	1						81
		Percent	64.2	34.6	1.2						100.0
	Total	Sample	52	28	1						81
		Percent	64.2	34.6	1.2						
Set gillnets & spawning grounds–all Chinook	Males	Sample	52	549	190	1	1	123	1	1	918
		Percent	5.7	59.8	20.7	0.1	0.1	13.4	0.1	0.1	69.9
	Females	Sample		12	102	1		277	4		396
		Percent		3.0	25.8	0.3		69.9	1.0		30.1
	Total	Sample	52	561	292	2	1	400	5	1	1,314
		Percent	4.0	42.7	22.2	0.2	0.1	30.4	0.4	0.1	

Appendix A5.–Computer files used to estimate the spawning abundance and age, sex, and length data for Chinook salmon in the Chickamin River in 2004.

File name	Description
Chickamin King 04.xls	Spreadsheets containing mark-recapture data, summary tables, chi-square test results, Kolmogorov-Smirnov (K-S) 2-sample test results, abundance estimation, age, and sex composition data, selected report tables and figures.