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Spawning Abundance of Chinook Salmon in the Chickamin River in 2005

by

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November 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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ABSTRACT

The escapement of Chinook salmon *Oncorhynchus tshawytscha* returning to the Chickamin River in 2005 was estimated for a fifth 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. The estimated escapement of large (≥660 mm MEF) Chinook salmon in 2005 was 4,257 (SE = 591) fish. This estimate was 4.60 (SE = 0.64) times the peak aerial survey count. The average of similar annual expansion factors for the Chickamin River (1996 and 2001–2005) is 4.75 (SE = 0.70; CV = 15.6%). We estimated the escapement of medium-sized (580–659 mm MEF) Chinook salmon to be 624 (SE = 201) fish. The combined estimate for all Chinook salmon ≥580 mm MEF was 4,881 (SE = 624) fish, of which 1,834 (SE = 266) were large females. Age-1.3 fish from the 2000 year class composed an estimated 67% of the total escapement estimate for Chinook salmon ≥580 mm (MEF), followed by age-1.2 fish (21%), and age-1.4 fish (11%).

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. Chinook salmon <660 mm MEF can not be readily distinguished from other species of salmon, primarily chum salmon *Oncorhynchus keta*, during aerial surveys. These index counts are used by the 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 2005.

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 index, mark–recapture 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, approximately 17% of spawning occurred in small unnamed tributaries of the upper Chickamin River, and no salmon were tracked into British Columbia (Pahlke 1997). On the basis of these studies the expansion factor 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, the ADF&G

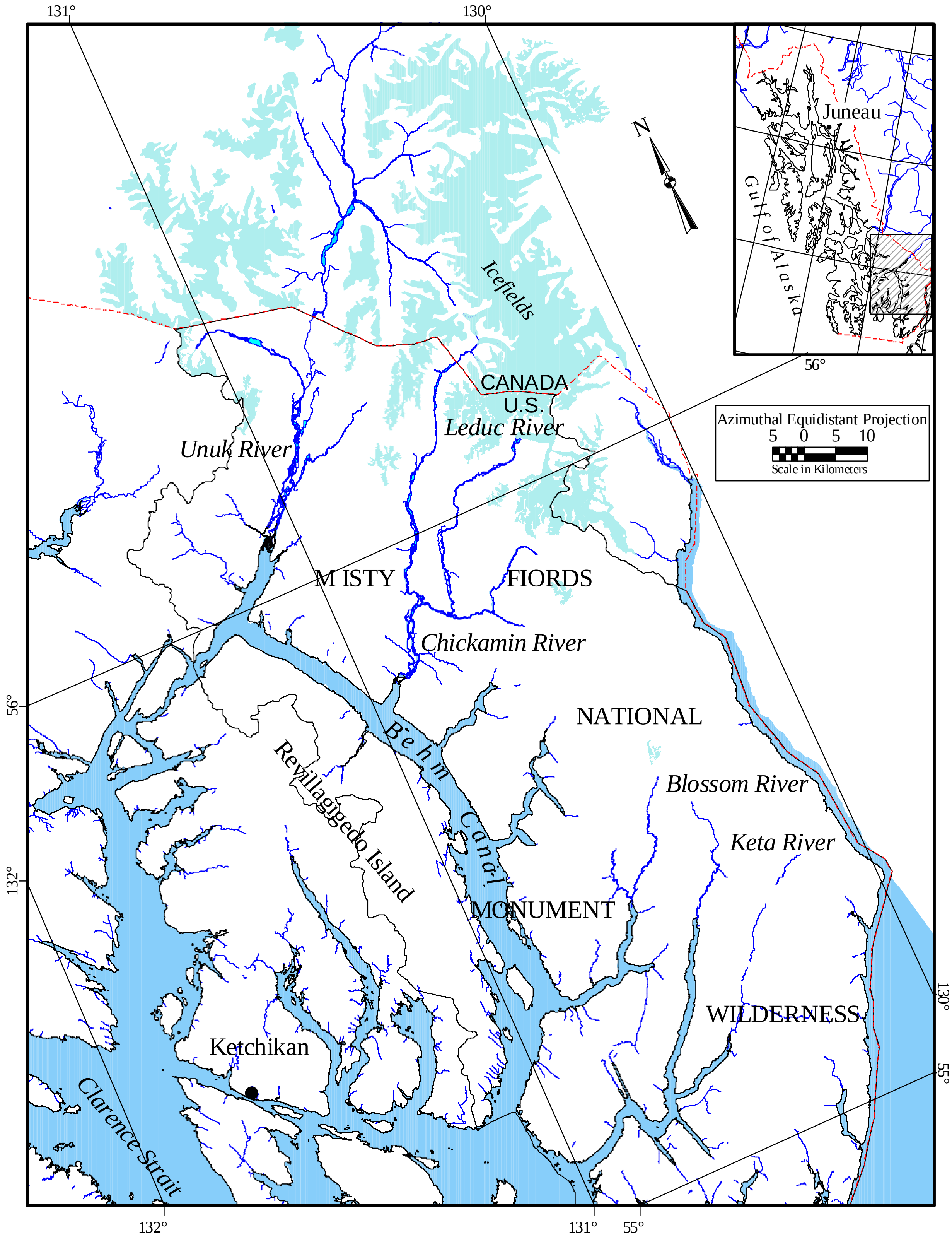

Figure 1.–Major Chinook salmon-producing river systems within the Misty Fjords National Monument that flow into Behm Canal in Southeast Alaska.

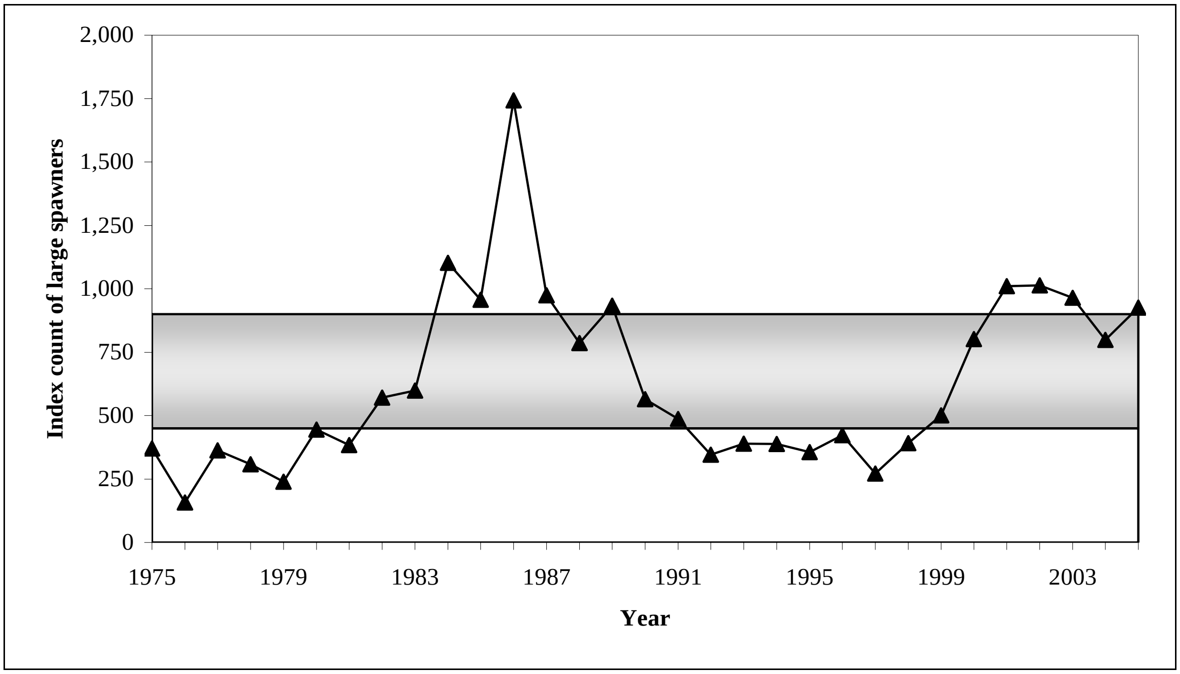

Figure 2.–Index counts of large Chinook salmon spawners in the Chickamin River from 1975 to 2005, compared to the biological escapement goal range established in 1997 (shaded area; McPherson and Carlile 1997).

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 (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 to:

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

In 2001, the estimated escapement of large Chinook salmon was 5,177 (SE = 972), 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, 4,579 (SE = 592) and 4.75 (SE = 0.61) in 2003, and 4,268 (SE = 893) and 5.35 (SE

= 1.12) in 2004 (Freeman and McPherson 2004, 2005; Freeman et al. 2007).

An estimate of escapement in 2005 allows calculation of an expansion factor for a fifth consecutive year (and seventh 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 2005 was conducted to 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 2002–2005, 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).

Research on the Chickamin River in 2005 had the following objectives:

1. estimate the total escapement of large (length ≥660 mm MEF) Chinook salmon in the Chickamin River in 2005;
2. estimate an expansion factor for converting peak aerial survey counts in the Chickamin River in 2005 to escapement; and
3. estimate the age and sex composition of large Chinook salmon spawning in the Chickamin River in 2005.

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 2005. In the first event, set gillnets were used at three locations below the Leduc River to capture fish (Figure 3). 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 from 2001 to 2004 (Freeman and McPherson 2003, 2004, 2005; Freeman et al. 2007) 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 three sites: 1) At SN3D, located on the mainstem along the west

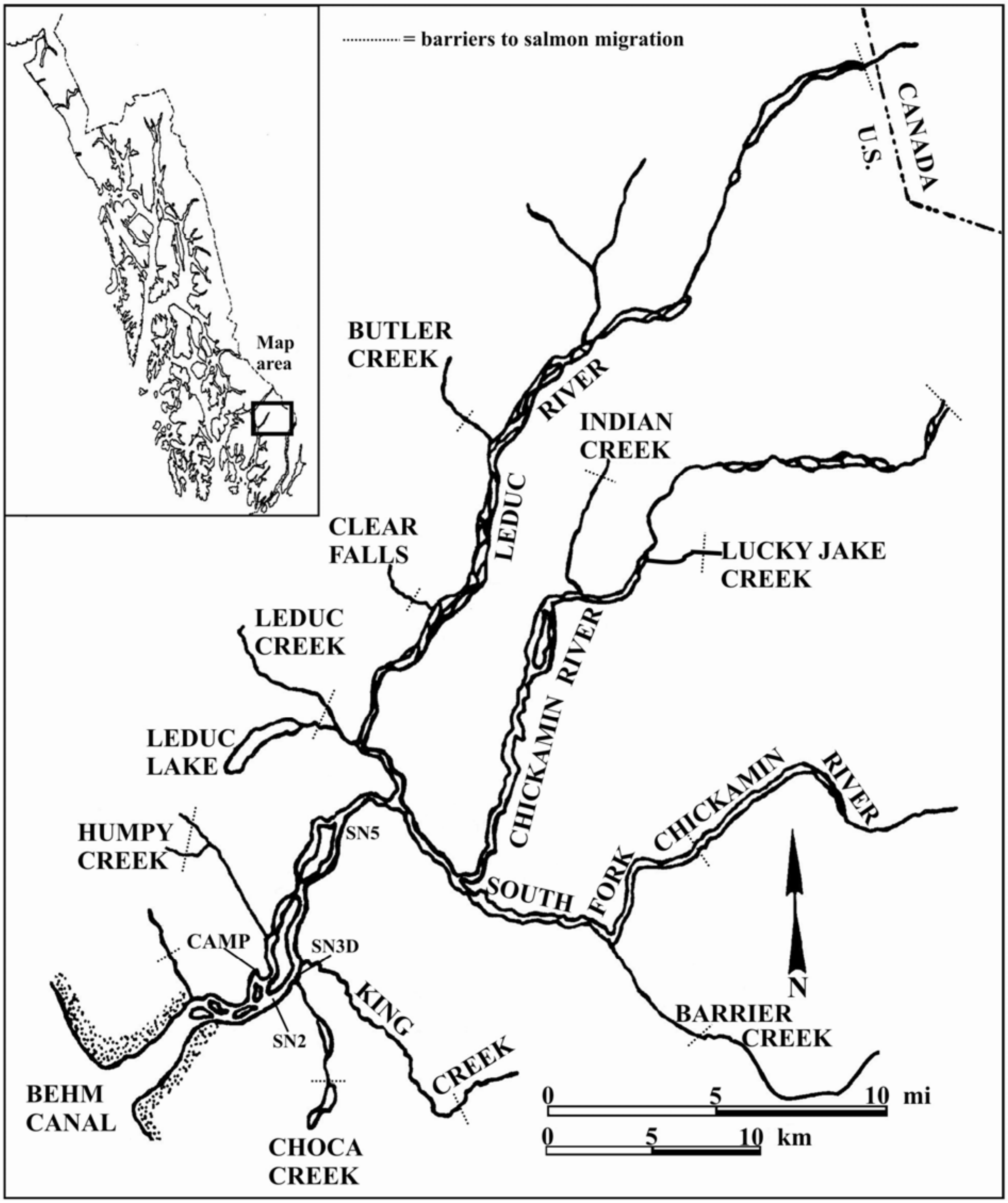

Figure 3.–Chickamin River drainage, showing major tributaries, ADF&G setnet (SN) sites, and barriers to salmon migration.

bank at river km (RK) 10.0, just below the Choca Creek confluence, 2) at SN5, located on the mainstem along the east bank 0.5 km below the Leduc River confluence at RK16.8, and 3) at SN2, located on the mainstem along the west bank at RK6.4, directly in front of camp (Figure 3). Previously fished sites were discontinued because of sediment aggradations, changes in flow, limitations from tidal influence, snags or low catches.

Setnets 36.5 m (120 ft) long, 5.5 m (18 ft) deep, of 18.5 cm (7¼") stretch mesh, were fished at varying tidal stages in an effort to maximize Chinook catches while maintaining a roughly consistent level of effort. Tides influenced set netting at SN2 and SN3D, but ended well below SN5. Two 2-person crews typically fished 12 shifts per week, with a target of 6 hours of setnet fishing time per shift. During each week, 5 days were spent fishing two shifts, and 2 non-consecutive days were spent fishing one shift. The goal was to fish 6 shifts per week at SN5 and 6 shifts per week at SN3D. If SN3D was found to be unproductive, effort would shift to SN2 instead. Gillnets were watched continuously and a fish was removed from the net as soon as bobbing corks were observed. If fishing time was lost because of entanglements, snags, cleaning the net, or tidal impacts, the lost time (processing time) was added to the end of the shift to bring fishing time to 6 hours. For each Chinook salmon captured, 1 minute 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), gender, and presence of the adipose fin (indicating the fish was marked with a coded wire tag). Fish in good condition were marked with a uniquely-numbered spaghetti tag. 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™ 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, and the tag was applied by punching the tip of the 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 were applied (to control for primary tag loss) and included a 0.6-cm punch in the left upper operculum (LUOP) and removal of the left axillary appendage (LAA). Five scales were taken from each fish, mounted onto gummed cards, and impressions were made in cellulose acetate (Clutter and Whitesel 1956). The impressions were magnified 70× and the age of each fish was determined from annual growth patterns of circuli (Olsen 1992).

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. Upon first encounter, all sampled fish were given a left lower operculum punch (LLOP) to prevent double sampling. Each fish was closely examined for the presence of a spaghetti tag, LUOP, LLOP, and LAA, 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 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) 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, <u>or</u> that every fish had an equal probability of being captured in the second event, <u>or</u> 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 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 was 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 experience gained when conducting previous 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 estimated 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 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 usually yields 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 2005. Several recovered large fish had lost their spaghetti tags, and in some instances the tag number or date of tagging was ambiguous because of data recording errors (Event 1 temporal stratum). Exclusion of these recoveries in the Darroch model, because tagging date could not be determined, would likely bias the abundance estimate high (Freeman et al. 2007). We selected a primary model, as described above, using a transition matrix constructed by assigning these ambiguous recoveries to Event 1 strata proportionally to the occurrence of recaptured fish with known marking dates within Event 2 strata. Then several "candidate" transition matrices were constructed, one for each plausible "true" distribution of the ambiguous recoveries among Event 1 strata, using the primary model's structure of Event 1 and 2 strata. The SPAS software was used to calculate a maximum-likelihood estimate of abundance ($\tilde{N}_i$) and variance ($v\hat{a}r(\tilde{N}_i)$) for each of these "candidate" models. The probability of each candidate model occurring was calculated as the product of the binomial or multinomial probability for the distribution of ambiguous recoveries within each of the Event 2 strata where ambiguous recoveries occurred, based on the distribution of recoveries among Event 1 strata of recoveries with known marking dates:

$$\hat{N}_L = \sum_i \tilde{N}_i \, p(\tilde{N}_i)\,. \tag{1}$$

Variance for the abundance estimator (equation 1) was estimated using Bayesian methods (Carlin and Louis 2000). Using Markov Chain Monte-Carlo (MCMC) techniques, a posterior distribution for $\hat{N}_L$ was generated by collecting 100,000 simulated values of $\hat{N}_{(b)}$. Each iteration of the simulation was conducted in two steps. First, a candidate model was selected based on an empirical approach. Within each Event 2 strata where ambiguous recoveries occurred, the distribution among Event 1 strata for ambiguous recoveries was modeled using a binomial or multinomial model based on the empirical distribution of unambiguous recoveries among Event 1 strata. The MCMC realization from each of these Event 2 strata in combination defined one of the "candidate" transition matrices described above with its associated abundance ($\tilde{N}_i$) and variance ($v\hat{a}r(\tilde{N}_i)$) estimates. Second, $N_{(b)}$ was modeled using a Normal distribution with mean ($\tilde{N}_i$) and variance ($v\hat{a}r(\tilde{N}_i)$), and $\hat{N}_{(b)}$ was the MCMC realization from this distribution.

At the end of the iterations, the following statistics were calculated:

$$\overline{N} = \frac{\sum_{b=1}^{100,000} \hat{N}_{(b)}}{100,000} \tag{2}$$

and,

$$v\hat{a}r(\hat{N}_L) = \frac{\sum_{b=1}^{100,000} (\hat{N}_{(b)} - \overline{N})^2}{100,000 - 1} \tag{3}$$

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):

$$\hat{N}_M = \frac{(n_1+1)(n_2+1)}{m_2+1} - 1 \tag{4}$$

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;

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

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

Throughout the remainder of this report, references to medium Chinook salmon indicate those salmon 580–659 mm MEF. Variance for the estimator (equation 4) was estimated using empirical Bayesian methods (Carlin and Louis 2000). Using MCMC techniques, a posterior distribution for $\hat{N}_M$ was generated by collecting 100,000 simulated values of $\hat{N}_{(b)}$ which were calculated using equation (4) from simulated values of equation parameters. Simulated values were modeled from observed data using a multinomial distribution of $\hat{N}_M$ experimental fish with the multinomial components: (n_1 - m_2), (n_2 - m_2), (m_2), and ($\hat{N}_M$ - n_1 - n_2 + m_2). At the end of the iterations, the variance estimate was calculated as described in equations (2) and (3).

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). The eight index tributaries of the Chickamin River are South Fork, Barrier, Butler, Leduc, Indian, Humpy, Clear Falls, and King creeks (Figure 3). During years when both M–R estimates and aerial counts were available (1995, 1996, and 2001–2005), an abundance-to-count annual expansion factor ($\hat{\pi}_t$) was estimated:

$$\hat{\pi}_i = \hat{N}_i / C_i \quad (5)$$

$$var(\hat{\pi}_t) = var(\hat{N}_i) / C_i^2 \quad (6)$$

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.

For return years when M–R estimates were not available, a long-term expansion factor is used to estimate total escapement of large Chinook salmon. The long-term observed expansion factor ($\bar{\pi}$) is estimated as:

$$\bar{\pi} = \frac{\sum_{y=1}^{k} \hat{\pi}_y}{k} \quad (7)$$

$$v\hat{a}r(\bar{\pi}) = v\hat{a}r_B(\hat{\pi}) - \frac{\sum_{y=1}^{k} v\hat{a}r(\hat{\pi}_y)}{k} + v\hat{a}r_B(\bar{\pi}) \quad (8)$$

where k is the number of years with both counts and M–R estimates and $\hat{\pi}_y$ is the observed expansion factor in year y. The estimate of $v\hat{a}r(\bar{\pi})$ is the appropriate term for predicting a new value of π, and the measurement error within years (i.e., the mark–recapture induced error in escapement estimation) has been removed (See Appendix A3 for details).

The estimator for expanding peak survey counts into estimates of spawning abundance in year t without a M–R estimate is:

$$\hat{N}_t = \bar{\pi}\ C_t \quad (9)$$

$$var(\hat{N}_t) = C_t^2\ var(\bar{\pi}) \quad (10)$$

where C_t is the peak aerial survey count in year t.

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:

$$\hat{p}_{ij} = \frac{n_{ij}}{n_i} \quad (11)$$

$$var(\hat{p}_{ij}) = \frac{\hat{p}_{ij}(1-\hat{p}_{ij})}{n_i - 1} \quad (12)$$

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 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:

$$\hat{N}_j = \sum_i (\hat{p}_{ij}\hat{N}_i) \quad (13)$$

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

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:

$$\hat{p}_j = \frac{\hat{N}_j}{\hat{N}} \quad (15)$$

$$\text{var}(\hat{p}_j) = \frac{\sum_i (\text{var}(\hat{p}_{ij})\hat{N}_i^2 + \text{var}(\hat{N}_i)(\hat{p}_{ij} - \hat{p}_j)^2)}{\hat{N}^2} \quad (16)$$

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

From 17 June to 24 August 2005, 360 Chinook salmon ≥401 mm MEF were captured, sampled, and released with numbered tags and secondary marks; an additional 6 fish were captured but were either sacrificed to retrieve coded wire tags (5) or died (1) as a result of handling induced stress (Table 1). All five sacrificed fish had Chickamin River coded wire tag codes. Catches were relatively low until 7 July (Figure 4). Of 360 fish marked, 21 were smaller than 580mm MEF, 44 were medium-sized (580-659 mm MEF), 288 were large (≥660 mm MEF), and 7 were not measured (Table 1). The release group was comprised of eight medium and 45 large fish tagged at SN3D, 21 medium and 113 large fish tagged at SN2, and 15 medium and 130 large fish tagged at SN5 below the Leduc River confluence (Table 1).

Event 1 effort remained relatively constant through 2 August, after which effort was halved in response to fiscal considerations and a shift in focus to a mark–recapture feasibility study to estimate the coho salmon escapement. As a result of relatively poor catches at SN3D, site SN2 was used as the primary lower river capture location beginning 8 July (Figure 5).

From 3 August to 9 September 2005, a total of five Chinook salmon ≤ 400 mm MEF, 88 fish 401-579 mm MEF, 124 medium (580–659 mm MEF) and 995 large (≥660 mm MEF) fish were captured on the spawning grounds and inspected for marks (Table 2). Eight medium fish and 68 large fish had been marked in Event 1 (five of the marked large fish had lost their spaghetti tag and the tag number from one marked large fish was mis-recorded and consequently unknown). 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 = 0.1, P

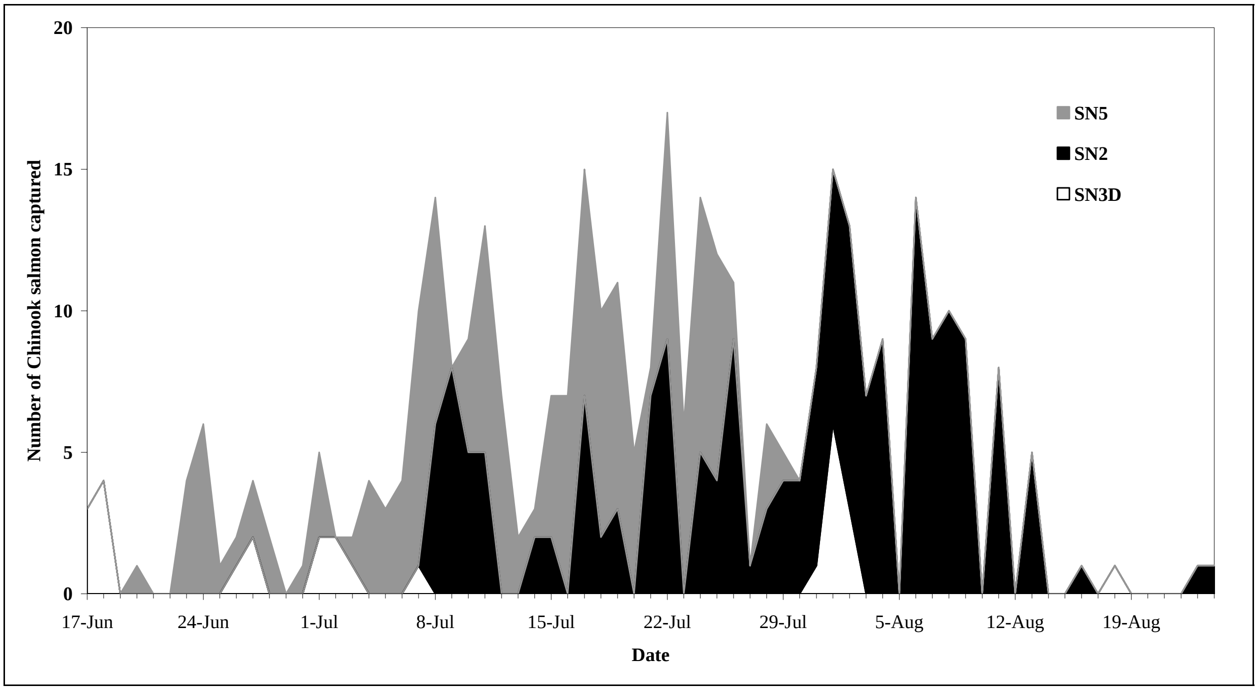

Figure 4.–Daily catches of Chinook salmon captured in set gillnets in the lower Chickamin River, by setnet location, 2005.

Table 1.–Catch of Chinook salmon 401–579 mm MEF, 580–659 mm MEF (medium-sized), ≥660 mm MEF (large-sized), and unmeasured fish that were marked in Event 1, by set gillnet location on the Chickamin River, 2005.

Site		401–579 mm MEF	Medium 580–659 mm MEF	Large ≥660 mm MEF	Not measured	Total
SN2	Catch	12	23	115	1	151
	Marked	12	21	113	1	147
	Mortalities [a]		2	2		4
SN3D	Catch	6	8	45	6	65
	Marked	5	8	45	6	64
	Mortalities [a]	1				1
SN5	Catch	4	15	131		150
	Marked	4	15	130		149
	Mortalities [b]			1		1
Total	Catch	22	46	291	7	366
	Marked	21	44	288	7	360
	Mortalities		2	3	0	6

[a] Fish were sacrificed to recover coded wire tags implanted in their heads.

[b] Mortality resulted from handling-induced stress.

= 0.353; Figure 6). 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 = 0.157, P = 0.076; Figure 6). These results indicate the setnets 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).

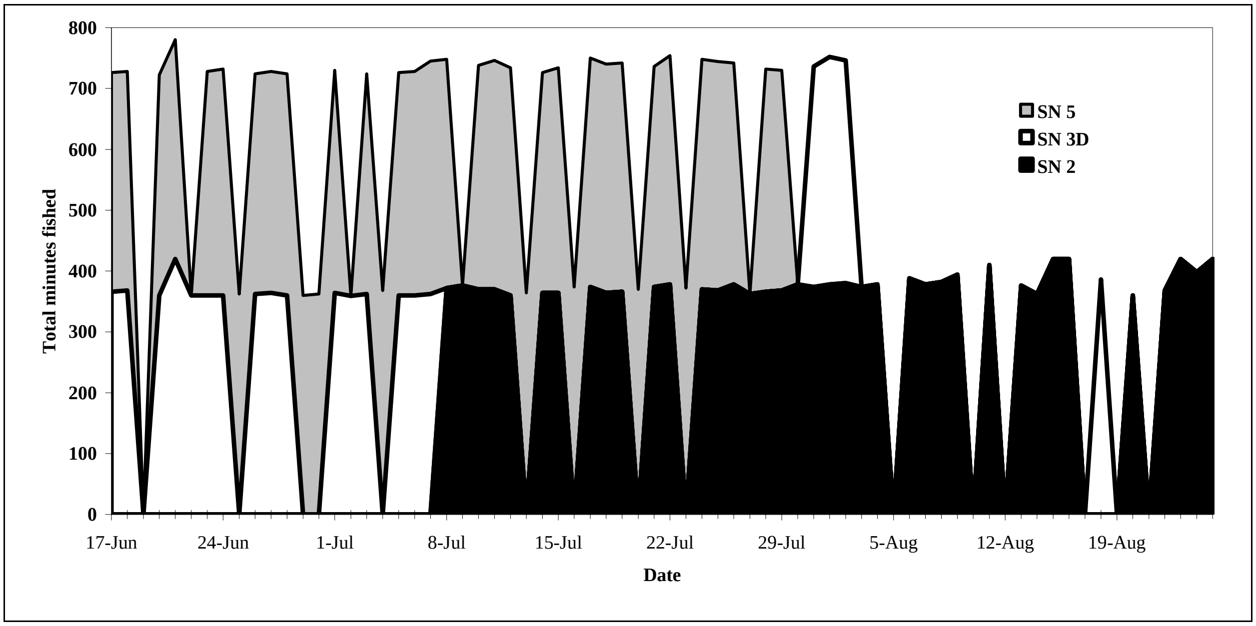

Figure 5.–Total daily effort (in minutes) of set gillnets in the lower Chickamin River, by setnet location and date, 2005.

Table 2.–Numbers of Chinook salmon ≤400 mm MEF, 401–579 mm MEF, 580–659 mm MEF (medium-sized), and ≥660 mm MEF (large-sized) marked in the lower Chickamin River and inspected for marks on the spawning grounds, 2005.

	≤ 400 mm MEF	401–579 mm MEF	580–659 mm MEF (Medium)	≥ 660 mm MEF (Large)	Total
Marked during Event 1 (M)		21	44	288	353
Inspected during Event 2 (C)	5	88	124	995	1,212
Recaptured during Event 2 (R)			8	68	76
R/C (%)			6.5	6.8	6.3

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 = 0.323, P = 0.360). 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 = 0.413, P = 0.134). 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 recaptured was independent of whether it was <580 mm or ≥580 mm MEF and rejected this hypothesis (χ^2 = 4.354, df = 1, P = 0.037). We also tested the hypothesis that the probability 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 = 5.900, df = 1, P = 0.015). As a result of these tests, we concluded that we should only attempt to estimate the abundance of Chinook salmon ≥580 mm MEF.

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 = 0.162, P = 0.970; Figure 7). Similarly, no difference was detected between fish inspected for marks on the spawning grounds and those marked fish

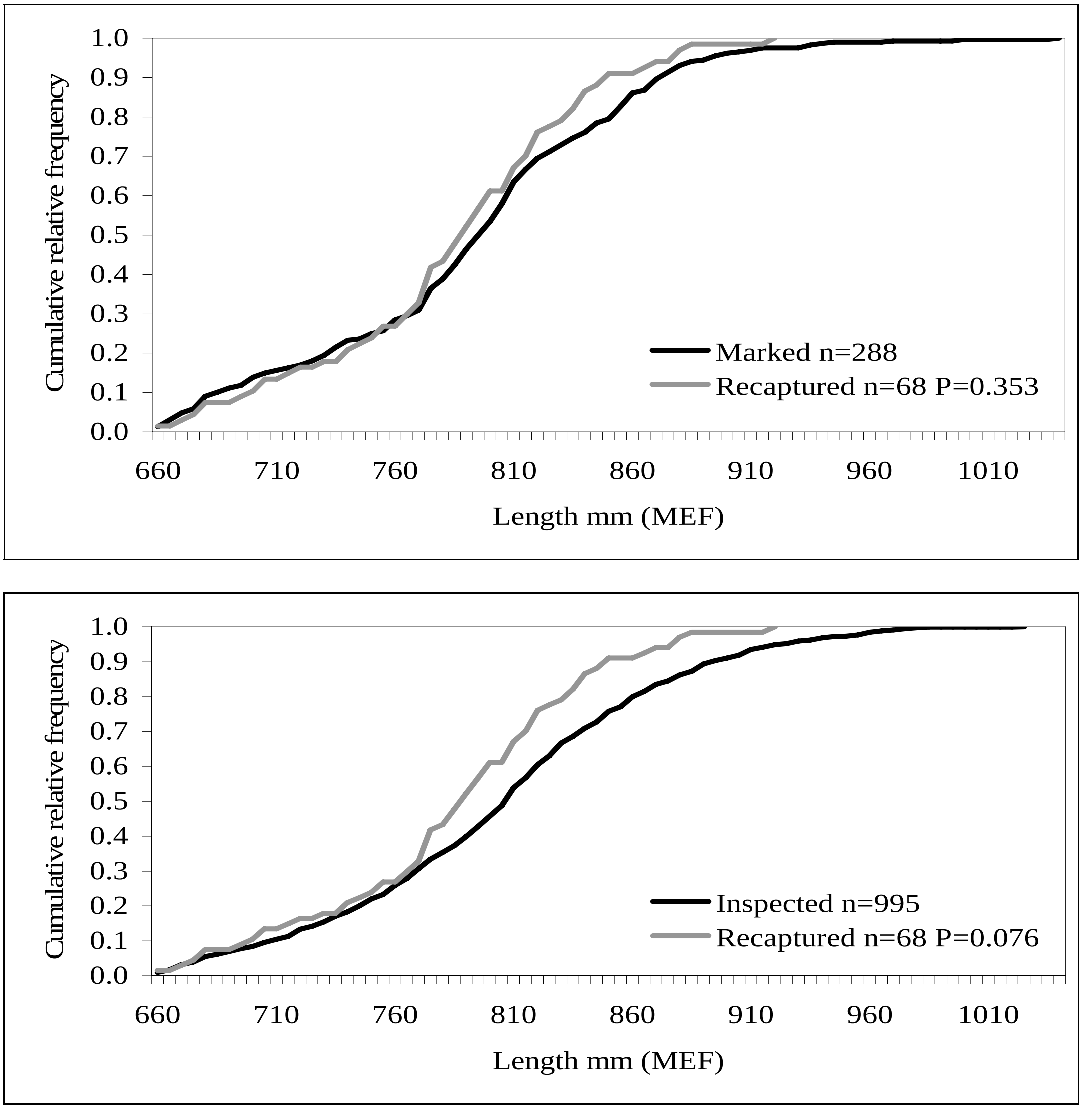

Figure 6.–Cumulative relative frequencies of large (≥660 mm MEF) Chinook salmon marked in Event 1 and recaptured in Event 2 (upper graph), and inspected and recaptured in Event 2 (lower graph) in the Chickamin River, 2005.

recaptured on the spawning grounds (D-value = 0.148, P = 0.992; Figure 7). These results indicate that size-biased 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. The hypothesis that the probability a fish inspected during Event 2 was marked was independent of sampling location was rejected (χ^2 = 24.687., df = 7, P < 0.001, Table 3). Further, the hypothesis that the probability that a marked fish was recaptured during Event 2 was independent of the time it was marked during Event 1 was also rejected (χ^2 = 10.848, df = 2, P = 0.004, Table 3). 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. The hypothesis that the probability a fish inspected during Event 2 was marked was independent of

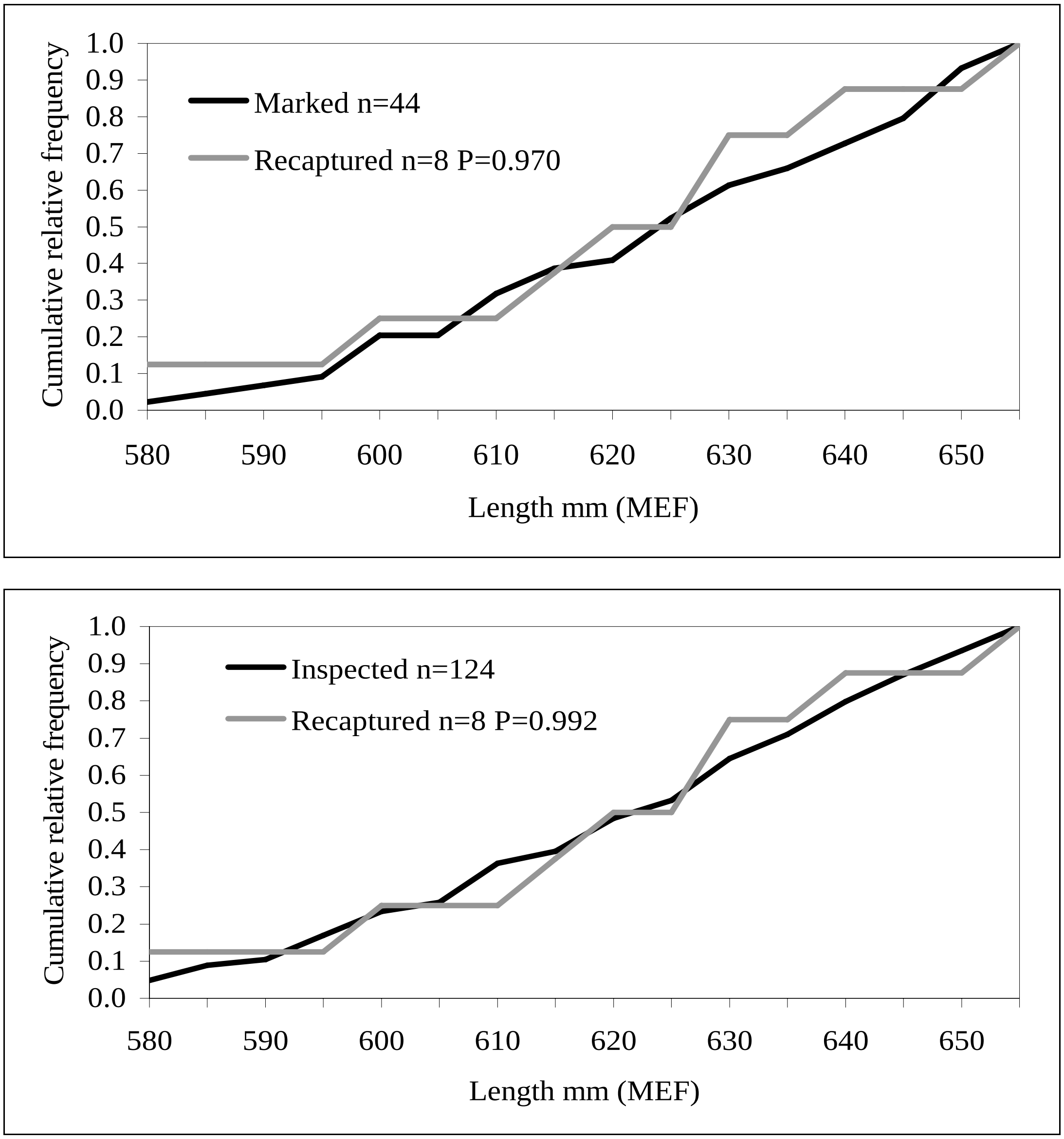

Figure 7.–Cumulative relative frequencies of medium (580–659 mm MEF) Chinook salmon marked in Event 1 and recaptured in Event 2 (upper graph), and inspected and recaptured in Event 2 (lower graph) in the Chickamin River, 2005.

sampling location was not rejected (χ^2 = 2.466, df = 2, P = 0.291, Table 4). Similarly, the hypothesis that the probability that a marked fish was recaptured during Event 2 was independent of the time it was marked during Event 1 was not rejected (χ^2 = 0.116, df = 2, P = 0.944, Table 4). Based on these test results, a Petersen-type model was appropriate to estimate abundance of medium fish (Appendix A2).

The abundance of large fish was estimated at 4,257 (SE = 591). Several stratification schemes using the Darroch (1961) model were tested. The stratification that yielded an admissible abundance estimate and the best GOF statistics used geographic stratification for Event 2 sampling and temporal stratification for Event 1 marking (Table 3). Five recovered large fish lost their spaghetti tags and the tag number of one recovered large fish was mis-recorded. Exclusion of these recoveries because the tagging date could not be determined would have likely biased the abundance estimate high (Freeman et al. 2007), so models were created to provide point estimates and standard errors from 18 possible (“candidate”) transition matrices.

Table 3.–Numbers of marked large (≥660 mm MEF) Chinook salmon released in the Chickamin River in 2005, by marking period, and the number inspected for marks and recaptured at each recovery location, with recoveries of unknown marking date assigned proportionally to the distribution of recoveries with known marking dates.

Marking dates	Number marked	Recovery location: King Creek	Humpy Creek	Leduc Creek	Clear Creek Falls	Butler Creek	Indian Creek	Lucky Jake Creek	South Fork/ Barrier Creek combined [a]	Total recovered	Estimated fraction recovered
17 June–3 July	31				1.33	1.5		2		4.83	0.156
4 July–24 July	142	4.67	1	3	2.67	4.5	12	6	11	44.84	0.316
25 July–25 Aug.	115	9.33	7						1	17.33	0.151
Total/proportion	288	14	8	3	4	6	12	8	12	67	0.233
Number inspected		179	134	84	71	177	77	44	229	995	
Fraction marked		0.078	0.060	0.036	0.056	0.034	0.156	0.182	0.052	0.067	

[a] 4 July–24 July recoveries are from South Fork (10) and Barrier Creek (1), 25 July–25 August recovery is from Barrier Creek. Number examined for marks in South Fork and Barrier Creek was 198 and 31, respectively.

The abundance of medium-sized fish was estimated at 624 (SE = 201) using a Chapman estimator. The combined estimate for all Chinook salmon ≥580 mm was 4,881 (SE = 624, 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, two marked fish recaptured during Event 2 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 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-1.3 Chinook salmon from the 2000 brood year were dominant (66.7%, SE = 3.1%) in the Chickamin River in 2005 (Table 5). Males composed 62.4% (SE = 2.3%) of the escapement of fish ≥580 mm MEF. There were an estimated 1,834 (SE = 266) females in the spawning population, and age-1.3 fish were the most abundant age class amongst 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. All medium-sized fish sampled were males and 94.1% (SE = 2.4%) were age-1.2. Of the 867 scale samples from Event 2 that were successfully aged, 863 (99.5%) were age-1. fish from yearling smolt; the remaining four fish were age-2.

Average length-at-age generally increased with saltwater age for both male and female Chinook salmon sampled (Table 6, Figure 8). Within age-1.3 fish, females were on average 24 mm longer than males, whereas age-1.4 males averaged an estimated 13 mm longer than their female counterparts. Summary statistics for ages of all fish sampled in setnets and from the spawning grounds are shown in Appendix A4.

Expansion Factor

The combined peak count for the eight index tributaries of the Chickamin River was 926 large Chinook salmon. Indian Creek was surveyed on 8 August; Barrier, Humpy, and King creeks were surveyed on 16 and 25 August; Butler, Clear Falls, and Leduc creeks were surveyed on 9 and 16 August; and South Fork Creek was surveyed on 9, 16, and 25 August. The estimated expansion factor in 2005 was 4.60 (SE = 0.64), and the mean expansion factor, using the latter six years (1996 and 2001–2005), is 4.75 (SE = 0.70; range 3.76 to 5.35; Table 7). 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 six most recent estimates is 15.6% (range 12.5% to 20.9%), which is acceptable relative to the benchmark 20% precision guideline in USCTC (1997).

Table 4.–Numbers of marked medium (580-659 mm MEF) Chinook salmon released in the Chickamin River in 2005, by marking period, and the number inspected for marks and recaptured at each recovery location.

		Recovery location													
		Lower tributaries			Leduc River tributaries				Upper-middle tributaries						
Marking dates	Number marked	King Creek	Humpy Creek	Subtotal	Leduc Creek	Clear Creek Falls	Butler Creek	Subtotal	Indian Creek	Lucky Jake Creek	South Fork	Barrier Fork	Subtotal	Total	Estimated fraction recovered
17 June–3 July	5								1				1	1	0.200
4 July–24 July	16						1	1	1		1		2	3	0.188
25 July–25 August	23	4		4										4	0.174
Total/proportion	44	4		4			1	1	2		1		3	8	0.182
Number inspected		42	6	48	7	4	36	47	8	5	14	2	29	124	
Fraction marked		0.095		0.083			0.028	0.021	0.250		0.071		0.103	0.065	

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, 2005. Estimates are from Chinook salmon sampled on the spawning grounds in Event 2.

		Brood year and age class							
		2001	2000	2000	1999	1999	1998	1998	
		1.2	2.2	1.3	2.3	1.4	2.4	1.5	Total
PANEL A: AGE COMPOSITION OF MEDIUM CHINOOK SALMON (580-659 mm MEF)									
Males	Sample size	95		6					101
	p_{ijk} x100	94.1		5.9					100.0
	SE(p_{ijk}) x100	2.4		2.4					
	N_{ijk}	587		37					624
	SE(N_{ijk})	190		18					201
Females	Sample size								
	p_{ijk} x100								
	SE(p_{ijk}) x100								
	N_{ijk}								
	SE(N_{ijk})								
Total	Sample size	95		6					101
	p_{ij} x100	94.1		5.9					100.0
	SE(p_{ij}) x100	2.4		2.4					
	N_{ij}	587		37					624
	SE(N_{ij})	190		18					201
PANEL B: AGE COMPOSITION OF LARGE CHINOOK SALMON (≥660 mm MEF)									
Males	Sample size	76	1	316		39	2	2	436
	p_{ijk} x100	9.9	0.1	41.3		5.1	0.3	0.3	56.9
	SE(p_{ijk}) x100	1.1	0.1	1.8		0.8	0.2	0.2	1.8
	N_{ijk}	422	6	1,756		217	11	11	2,423
	SE(N_{ijk})	74	6	255		45	8	8	345
Females	Sample size	2		263	1	60		4	330
	p_{ijk} x100	0.3		34.3	0.1	7.9		0.5	43.1
	SE(p_{ijk}) x100	0.2		1.7	0.1	1.0		0.3	1.8
	N_{ijk}	11		1,462	6	333		22	1,834
	SE(N_{ijk})	8		215	6	62		11	266
Total	Sample size	78	1	579	1	99	2	6	766
	p_{ij} x100	10.2	0.1	75.6	0.1	12.9	0.3	0.8	100.0
	SE(p_{ij}) x100	1.1	0.1	1.6	0.1	1.2	0.2	0.3	0.0
	N_{ij}	433	6	3,218	6	550	11	33	4,257
	SE(N_{ij})	76	6	451	6	92	8	14	591
PANEL C: AGE COMPOSITION OF MEDIUM AND LARGE CHINOOK SALMON COMBINED									
Males	Sample size	171	1	322		39	2	2	537
	p_{ik} x100	20.7	0.1	36.7		4.4	0.2	0.2	62.4
	SE(p_{ik}) x100	3.4	0.1	2.1		0.7	0.2	0.2	2.3
	N_{jk}	1,009	6	1,793		217	11	11	3,047
	SE(N_{jk})	204	6	256		45	8	8	399
Females	Sample size	2		263	1	60		4	330
	p_{ik} x100	0.2		29.9	0.1	6.8		0.5	37.6
	SE(p_{ik}) x100	0.2		2.0	0.1	0.9		0.2	2.3
	N_{jk}	11		1,462	6	333		22	1,834
	SE(N_{jk})	8		215	6	62		11	266
Total	Sample size	173	1	585	1	99	2	6	867
	p_j x100	20.9	0.1	66.7	0.1	11.3	0.2	0.7	100.0
	SE(p_j) x100	3.4	0.1	3.1	0.1	1.2	0.2	0.3	
	N_j	1,020	6	3,253	6	550	11	33	4,881
	SE(N_j)	204	6	452	6	92	8	14	624

Table 6.–Average length by sex and age of Chinook salmon sampled in the Chickamin River, 2005. Estimates include all Chinook salmon sampled and successfully aged from the spawning grounds.

		Brood year and age class									
		2002	2001	2001	2000	2000	1999	1999	1998	1998	
		1.1	2.1	1.2	2.2	1.3	2.3	1.4	2.4	1.5	Total
Males	Sample size	50	2	193	1	320		39	2	2	609
	Avg. length	456	430	641	680	795		888	895	850	723
	SD	41	50	57		69		66	50	148	130
	SE	6	35	4		4		11	35	105	5
Females	Sample size			2		261	1	59		4	327
	Avg. length			715		819	770	875		941	829
	SD			28		44		54		15	53
	SE			20		3		7		7	3
Total	Sample size	50	2	195	1	581	1	98	2	6	936
	Avg. length	456	430	642	680	805	770	881	895	911	760
	SD	41	50	57		61		59	50	82	121
	SE	6	35	4		3		6	35	34	4

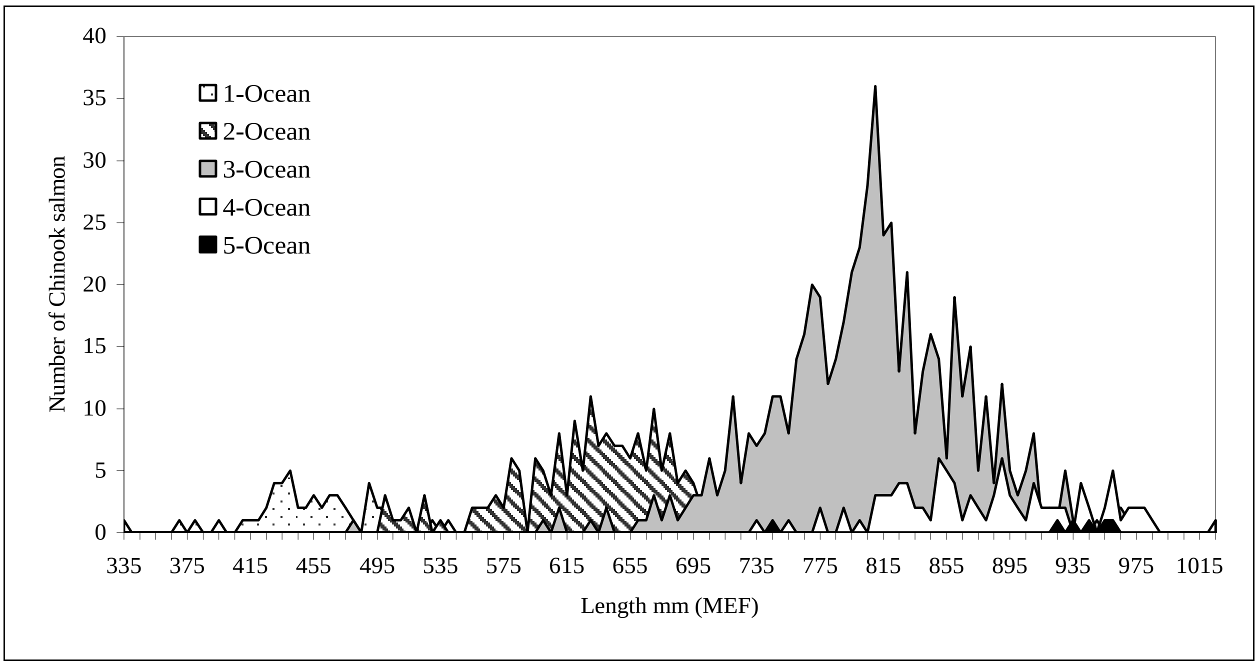

Figure 8.–Numbers of Chinook salmon by ocean age from samples taken in Event 2, Chickamin River, 2005.

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 4,257 large Chinook salmon in 2005 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 seventh consecutive year (since 1998) that the peak index survey counts met or exceeded the present escapement goal (index count of 450–900 fish; McPherson and Carlile 1997).

The two primary setnet sites fished from 2002–2004 (SN3D and SN5) were again fished in 2005. While the SN5 site remained productive, changes in riverine topography rendered the SN3D site less productive than in previous years, and SN3D

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 2001–2005.

	Year							1996–2005
	1995	1996	2001	2002	2003	2004	2005	Average
Survey count	356	422	1,010	1,013	964	798	926	856
Mark–recapture estimate (M–R)	2,309	1,587	5,177	5,007	4,579	4,268	4,257	4,146
M–R standard error	723	199	972	738	592	893	591	664
95% RP M–R estimate (%)	61.4	24.6	36.8	28.9	25.3	41.0	27.2	31.4
M–R lower 95% C.I.	1,388	1,279	3,780	3,892	3,481	2,519	3,099	3,008
M–R upper 95% C.I.	4,650	2,089	7,573	6,742	5,134	6,018	5,415	5,495
Survey count/(M–R) (%)	15.4	26.6	19.5	20.2	21.1	18.7	21.8	21.3
Expansion factor (EF)	6.49	3.76	5.13	4.94	4.75	5.35	4.60	4.75
SE (EF)	2.03	0.47	0.96	0.73	0.61	1.12	0.64	0.70
CV (EF)	31.3	12.5	18.8	14.7	12.9	20.9	13.9	14.7

was eventually abandoned in favor of SN2 midway through the run.

Tagging goals were met and spawning ground sampling (Event 2) goals were exceeded in 2005. Crew efficiency coupled with mostly favorable weather and stream conditions in August yielded 995 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 and the 1,006 fish captured in 2004 using similar staffing and effort as was used in 2005. The number of fish 401–659 mm MEF that were captured during both Events 1 and 2 was similar to previous years, however as in 2004, only marked fish 580 mm MEF and larger were recaptured. As in 2004, we concluded that fishing by sight on the spawning grounds limits our ability to capture medium-sized fish, especially the smaller ones. 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 upper Chickamin mainstem areas (Lucky Jake and Indian Creek) in 2005 was the primary reason for the failure of the statistical test of equal marked fractions across spatial recovery strata. In 2004 the same failure was due to the relatively high proportion of recoveries from Indian Creek and the South Fork. In both years, most of the fish recaptured in the upper Chickamin mainstem and South Fork were tagged at SN5. Based on limitations of suitable setnet sites within the drainage, SN5 is a proven and necessary site to ensure that tagging goals are reached in Event 1. Also, SN5 may be a staging or milling area for Chinook salmon bound for the South Fork and upper Chickamin mainstem, a likely consequence of its location just downstream of the first major fork in the river (Leduc) encountered by returning adults. That a lower proportion of fish bound for the Leduc River tributaries are captured at SN5 may be due to the presence of side sloughs connecting the Leduc to the mainstem below SN5, as well as to the location of SN5 on the bank contiguous with the South Fork/upper Chickamin River (Figure 3).

The relatively low proportion of fish marked in the early and latter stages of the run was the primary reason for the failure of the statistical test of equal marked fractions across temporal marking strata. The decreased efficiency of SN3 probably contributed to the low marked fractions in the early stage of the run. The halving of effort after 2 August is one likely reason for the low marked proportion in the latter stage of the run.

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 (>850 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.

CONCLUSIONS AND RECOMMENDATIONS

This is the final year of Chinook salmon mark–recapture studies on the Chickamin River. We recommend that the peak survey expansion factor of 4.0 that was established in 1997 be revised to 4.75 based on the mean of the six estimates for 1996 and 2001–2005. We also recommend annual sampling of at least 900 adults on the spawning grounds through 2012 to recover and sample enough coded-wire-tagged fish to precisely estimate adult production, exploitation rates, and smolt abundance by brood year.

ACKNOWLEDGMENTS

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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

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.

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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-

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

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

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]

Area/time	Time/area where recaptured				Not recaptured
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.–Predicting escapement from index counts using an expansion factor.

The expansion factor provides a means of predicting escapement in years where only an index count of the escapement is available, i.e. no weir counts or mark–recapture experiments were conducted. The expansion factor is the average over several years of the ratio of the escapement estimate (or weir count) to the index count.

Systems where escapement is known

On systems where escapement can be completely enumerated with weirs or other complete counting methods, the expansion factor is an estimate of the expected value of the "population" of annual expansion factors (π's) for that system:

$$\bar{\pi} = \frac{\sum_{y=1}^{k} \pi_y}{k} \quad (1)$$

where $\pi_y = N_y / C_y$ is the observed expansion factor in year *y*, N_y is the known escapement in year *y*, C_y is the index count in year *y*, and *k* is the number of years for which these data are available to calculate an annual expansion factor.

The estimated variance for expansion of index counts needs to reflect two sources of uncertainty for any predicted value of π, (π_p). First is an estimate of the process error (*var*(π)-the variation across years in the π's, reflecting, for example, weather or observer-induced effects on how many fish are counted in a survey for a given escapement), and second is the sampling variance of $\bar{\pi}$ (*var*($\bar{\pi}$)), which will decline as we collect more data pairs.

The variance for prediction will be estimated (Neter et al. 1990):

$$v\hat{a}r(\pi_p) = v\hat{a}r(\pi) + v\hat{a}r(\bar{\pi}) \quad (2)$$

where

$$v\hat{a}r(\pi) = \frac{\sum_{y=1}^{k} (\pi_y - \bar{\pi})^2}{k-1} \quad (3)$$

and

$$v\hat{a}r(\bar{\pi}) = \frac{\sum_{y=1}^{k} (\pi_y - \bar{\pi})^2}{k(k-1)} \quad (4)$$

such that

$$v\hat{a}r(\pi_p) = \frac{\sum_{y=1}^{k} (\pi_y - \bar{\pi})^2}{k-1} + \frac{\sum_{y=1}^{k} (\pi_y - \bar{\pi})^2}{k(k-1)} \quad (5)$$

-continued-

Systems where escapement is estimated

On systems where escapement is estimated, the expansion factor is an estimate of the expected value of the "population" of annual expansion factors (π 's) for that system:

$$\overline{\pi} = \frac{\sum_{y=1}^{k} \hat{\pi}_y}{k} \tag{6}$$

where $\hat{\pi}_y = \hat{N}_y / C_y$ is the estimate of the expansion factor in year *y*, $\hat{N}_y$ is the estimated escapement in year *y*, and other terms are as described above.

The variance for prediction will again be estimated:

$$v\hat{a}r(\pi_p) = v\hat{a}r(\pi) + v\hat{a}r(\overline{\pi}) \tag{7}$$

The estimate of *var*(π) should again reflect only process error . Variation in $\hat{\pi}$ across years, however, represents process error **plus** measurement error within years (e.g. the mark–recapture induced error in escapement estimation) and is described by the relationship (Mood et al. 1974):

$$V(\hat{\pi}) = V[E(\hat{\pi})] + E[V(\hat{\pi})] \tag{8}$$

This relationship can be rearranged to isolate process error, that is:

$$V[E(\hat{\pi})] = V[\hat{\pi}] - E[V(\hat{\pi})] \tag{9}$$

An estimate of *var*(π) representing only process error therefore is:

$$v\hat{a}r(\pi) = v\hat{a}r(\hat{\pi}) - \frac{\sum_{y=1}^{k} v\hat{a}r(\hat{\pi}_y)}{k} \tag{10}$$

where $v\hat{a}r(\hat{\pi}_y) = v\hat{a}r(\hat{N}_y) / C_y^2$ and $v\hat{a}r(\hat{N}_y)$ is obtained during the experiment when N_y is estimated.

We can calculate:

$$v\hat{a}r(\hat{\pi}) = \frac{\sum_{y=1}^{k} (\hat{\pi}_y - \overline{\pi})^2}{k-1} \tag{11}$$

and we can estimate $var(\overline{\pi})$ similarly to as we did above:

$$v\hat{a}r(\overline{\pi}) = \frac{\sum_{y=1}^{k} (\hat{\pi}_y - \overline{\pi})^2}{k(k-1)} \tag{12}$$

where both process and measurement errors need to be included.

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For large k (k > 30), equations (11) and (12) provide reasonable parameter estimates, however for small k the estimates are imprecise and may result in negative estimates of variance when the results are applied as in equation (7).

Because k is typically < 10, we will estimate $var(\hat{\pi})$ and $var(\overline{\pi})$ using parametric bootstrap techniques Efron and Tibshirani 1993. The sampling distributions for each of the $\hat{\pi}_y$ are modeled using Normal distributions with means $\hat{\pi}_y$ and variances $v\hat{a}r(\hat{\pi}_y)$. At each bootstrap iteration, a bootstrap value $\hat{\pi}_{y(b)}$ is drawn from each of these Normal distributions and the bootstrap value $\hat{\pi}_{(b)}$ is randomly chosen from the k values of $\hat{\pi}_{y(b)}$. Then, a bootstrap sample of size k is drawn from the k values of $\hat{\pi}_{y(b)}$ by sampling with replacement, and the mean of this bootstrap is the bootstrap value $\overline{\pi}_{(b)}$. This procedure is repeated B = 1,000,000 times. We can then estimate $var(\hat{\pi})$ using:

$$v\hat{a}r_B(\hat{\pi}) = \frac{\sum_{b=1}^{B}(\hat{\pi}_{(b)} - \overline{\hat{\pi}_{(b)}})^2}{B-1} \tag{13}$$

where

$$\overline{\hat{\pi}_{(b)}} = \frac{\sum_{b=1}^{B}\hat{\pi}_{(b)}}{B} \tag{14}$$

and we can calculate $var_B(\overline{\pi})$ using equations (13) and (14) with appropriate substitutions. The variance for prediction is then estimated:

$$v\hat{a}r(\pi_p) = v\hat{a}r_B(\hat{\pi}) - \frac{\sum_{y=1}^{k}\mathrm{v\hat{a}r}(\hat{\pi}_y)}{k} + v\hat{a}r_B(\overline{\pi}) \tag{15}$$

As the true sampling distributions for the $\hat{\pi}_y$ are typically skewed right, using a Normal distribution to approximate these distributions in the bootstrap process will result in estimates of $var(\hat{\pi})$ and $var(\overline{\pi})$ that are biased slightly high, but simulation studies using values similar to those realized for this application indicated that the bias in equation (15) is < 1%.

Predicting Escapement

In years when an index count (C_p) is available but escapement (N_p) is not known, it can be predicted:

$$\hat{N}_p = \overline{\pi}\, C_p \tag{16}$$

and

$$v\hat{a}r(\hat{N}_p) = C_p^2 v\hat{a}r(\pi_p) \tag{17}$$

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 the spawning grounds, Chickamin River, 2005.

PANEL A: EVENT 1 (SET GILLNETS) SAMPLES

			Brood year and age class									
			2002	2001	2001	2000	2000	1999	1999	1998	1998	
			1.1	2.1	1.2	2.2	1.3	2.3	1.4	2.4	1.5	Total
Large	Male	Sample size			25		103		6		1	135
		Percent			11.3		46.6		2.7		0.5	61.1
	Female	Sample size					72		13		1	86
		Percent					32.6		5.9		0.5	38.9
	Total	Sample size			25		175		19		2	221
		Percent			11.3		79.2		8.6		0.9	
Medium	Male	Sample size			31		3					34
		Percent			91.2		8.8					100.0
	Total	Sample size			31		3					34
		Percent			91.2		8.8					
Small	Male	Sample size	13		7							20
		Percent	65.0		35.0							100.0
	Total	Sample size	13		7							20
		Percent	65.0		35.0							
Total	Male	Sample size	13		63		106		6		1	189
		Percent	4.7		22.9		38.5		2.2		0.4	68.7
	Female	Sample size					72		13		1	86
		Percent					26.2		4.7		0.4	31.3
	Total	Sample size	13		63		178		19		2	275
		Percent	4.7		22.9		64.7		6.9		0.7	

PANEL B: EVENT 2 (SPAWNING GROUNDS) SAMPLES

			Brood year and age class									
			2002	2001	2001	2000	2000	1999	1999	1998	1998	
			1.1	2.1	1.2	2.2	1.3	2.3	1.4	2.4	1.5	Total
Large	Male	Sample size			76	1	316		39	2	2	436
		Percent			9.92	0.1	41.3		5.1	0.3	0.3	56.9
	Female	Sample size					263	1	60		4	330
		Percent			0.3		34.3	0.1	7.8		0.5	43.1
	Total	Sample size			78	1	579	1	99	2	6	766
		Percent			10.2	0.1	75.6	0.1	12.9	0.3	0.8	
Medium	Male	Sample size			95		6					101
		Percent			94.1		5.9					100.0
	Total	Sample size			95		6					101
		Percent			94.1		5.9					
Small	Male	Sample size	50	2	22		1					75
		Percent	66.7	2.7	29.3		1.3					100.0
	Total	Sample size	50	2	22		1					75
		Percent	66.7	2.7	29.3		1.3					
Total	Male	Sample size	50	2	193	1	323		39	2	2	612
		Percent	5.3	0.2	20.5	0.1	34.3		4.1	0.2	0.2	65.0
	Female	Sample size			2		263	1	60		4	330
		Percent			0.2		27.9	0.1	6.4		0.4	35.0
	Total	Sample size	50	2	195	1	586	1	99	2	6	942
		Percent	5.3	0.2	20.7	0.1	62.2	0.1	10.5	0.2	0.6	

-continued-

Appendix A4.–Page 2 of 2.

PANEL C: EVENT 1 (SET GILLNETS) AND EVENT 2 (SPAWNING GROUNDS) SAMPLES COMBINED												
			Brood year and age class									
			2002	2001	2001	2000	2000	1999	1999	1998	1998	
			1.1	2.1	1.2	2.2	1.3	2.3	1.4	2.4	1.5	Total
Large	Male	Sample size			101	1	419		45	2	3	571
		Percent			10.2	0.1	42.5		4.6	0.2	0.3	57.9
	Female	Sample size			2		335	1	73		5	416
		Percent			0.2		33.9	0.1	7.4		0.5	42.1
	Total	Sample size			103	1	754	1	118	2	8	987
		Percent			10.4	0.1	76.4	0.1	12.0	0.2	0.8	
Medium	Male	Sample size			126		9					135
		Percent			93.3		6.7					100.0
	Total	Sample size			126		9					135
		Percent			93.3		6.7					
Small	Male	Sample size	63	2	29		1					95
		Percent	66.3	2.1	30.5		1.1					100.0
	Total	Sample size	63	2	29		1					95
		Percent	66.3	2.1	30.5		1.1					
Total	Male	Sample size	63	2	256	1	429		45	2	3	801
		Percent	5.2	0.2	21.0	0.1	35.3		3.7	0.2	0.2	65.8
	Female	Sample size			2		335	1	73		5	416
		Percent			0.2		27.5	0.1	6.0		0.4	34.2
	Total	Sample size	63	2	258	1	764	1	118	2	8	1,217
		Percent	5.2	0.2	21.2	0.1	62.8	0.1	9.7	0.2	0.7	

Appendix A5.–Computer files used to estimate the spawning abundance and age, sex, and length data for Chinook salmon in the Chickamin River in 2005.

File name	Description
05Chix41A.xls	Spreadsheets containing Tables 1–7, Figures 2 and 8, and Appendix A4.
05ChixEF.calc.xls	Spreadsheet containing expansion factor calculations.
Chix41ASL2005.xls	Spreadsheet containing mark–recapture data file.
Chixeffort01-05.xls	Spreadsheet containing Effort data from 2001–2005 and Figures 4 and 5.
KSN1M2.xls	Spreadsheet containing Kolmogorov-Smirnov two-sample test results for large fish marked and recaptured during the M–R study and upper portion of Figure 6.
KSN2M2.xls	Spreadsheet containing Kolmogorov-Smirnov two-sample test results for large fish inspected and recaptured during the M–R study and lower portion of Figure 6.
KSM580N1M2.xls	Spreadsheet containing Kolmogorov-Smirnov two-sample test results for medium fish marked and recaptured during the M–R study and upper portion of Figure 7.
KSM580N2M2.xls	Spreadsheet containing Kolmogorov-Smirnov two-sample test results for medium fish inspected and recaptured during the M–R study and lower portion of Figure 7.