Regional Operational Plan SF.3F.2016.07

Chinook Salmon Escapement in the Chena and Salcha Rivers and Coho Salmon Escapement in the Delta Clearwater River, 2016–2018

by

Lisa Stuby

and

Matt Tyers

May 2016

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

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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 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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by

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May 2016

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Title	Name	Signature	Date
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ABSTRACT

Salmon enumeration projects in the Tanana River drainage will be conducted by the Alaska Department of Fish and Game (ADF&G) on the Chena, Salcha, and Delta Clearwater rivers. The primary purpose of these projects is to estimate spawning escapement abundance and determine whether or not the established escapement goals for these 3 rivers are met. Chinook salmon *Oncorhynchus tshawytscha* escapement for the Chena and Salcha rivers will be estimated using tower-counting and sonar techniques and coho salmon *O. kisutch* escapement in the Delta Clearwater River will be estimated by a visual boat survey at peak escapement.

Key words: Chinook salmon, *Oncorhynchus tshawytscha,* chum salmon, *O. keta*, coho salmon, *O. kisutch*, Chena River, Delta Clearwater River, Salcha River, counting tower, escapement.

PURPOSE

The Yukon River is 1 of 12 indicator stocks chosen by the Alaska Department of Fish and Game (ADF&G) in the *Chinook Salmon Stock Assessment and Research Plan* (ADF&G Chinook Research Team 2013) as a stock for which additional information on stock productivity is desired. Age-structured production models that are widely used to understand a stock's dynamics require information about processes like escapement, recruitment, and mortality. The Chena and Salcha rivers are among the largest spawning populations of Chinook salmon *Oncorhynchus tshawytscha* in the Alaskan side of the Yukon River drainage, while the Delta Clearwater River (DCR) supports the largest spawning population of coho salmon *O. kisutch* in the Yukon River drainage.

The primary purpose of this project is to estimate spawning escapement abundance and determine whether or not the established escapement goals on these 3 rivers are met. To accomplish this objective, counting tower and DIDSON sonar techniques will be used to enumerate the Chinook salmon escapements in the Chena and Salcha rivers, and visual boat surveys will be used to estimate coho salmon escapement in the Delta Clearwater River. The monitoring programs provide information on run magnitude and timing, which allows managers to modify fishing regulations to achieve the established escapement goals.

BACKGROUND

The Chena and Salcha rivers are among the largest spawning populations of Chinook salmon within the Alaska side of the Yukon River. Likewise, the Delta Clearwater River (DCR) supports a significant spawning population of coho salmon. The Goodpaster, Chatanika, and Nenana rivers also support important, albeit comparatively smaller spawning populations of Chinook and coho salmon.

In 2001 the Alaska Board of Fisheries (BOF) adopted escapement goals for the Chena, Salcha, and Delta Clearwater rivers. Biological escapement goals (BEGs) of 2,800–5,700 Chinook salmon in the Chena River and 3,300–6,500 in the Salcha River were established to provide for maximum sustained yield (Evenson 2002). A sustainable escapement goal (SEG) of 5,200–17,000 coho salmon in the Delta Clearwater River was established because the spawner-recruit information required to establish a BEG is not available (ADFG 2004).

Chinook salmon enumeration and escapement composition (age, sex, length) projects have been conducted annually by ADF&G since 1986 in the Chena River making it, along with the Salcha

River (projects conducted since 1987), the longest continuous Chinook salmon escapement data set in the Yukon River drainage. The monitoring programs provide information on run magnitude and timing, which allows managers to modify fishing regulations to achieve the established escapement goals. Annual Chinook salmon escapement assessments are important to further examine the spawner-recruit relationship, to evaluate whether the escapement goal was met, and to provide inseason information on run strength to modify fishing regulations through emergency order (EO) if needed to achieve the goal. The establishment of meaningful escapement goals are only possible with long, unbroken data strings of escapement and composition estimates. The current BEG is evaluated every 3 years during the BOF with all additional years of acquired data. Boat survey counts of coho salmon in the Delta Clearwater have been conducted annually by ADF&G since 1980 during the peak of the run.

This operational plan describes the procedures for the Chena and Salcha rivers Chinook salmon and Delta Clearwater River coho salmon escapement monitoring projects for the 2016–2018 field seasons. This will be the first year ADF&G will be enumerating Chinook salmon on the Salcha River since 1998. An attempt will be made to incorporate DIDSON sonar to enumerate Salcha River Chinook salmon on days missed due to high water events, similar to what has been done for the Chena River since 2008. The first season (2016) will determine the efficacy of using sonar technology and if successful, funding will be requested for following years.

OBJECTIVES

The objectives for 2016–2018 are to:

1. estimate the total escapement of Chinook salmon in the Chena and Salcha rivers using tower-counting techniques such that the estimates will be within 15% of the true values 95% of the time and the potential for bias is minimized;
2. estimate age, sex, and length compositions of the escapement of Chinook salmon in the Chena and Salcha rivers such that estimated proportions are within 6 percentage points of the true proportions 95% of the time;
3. count coho salmon in the Delta Clearwater River from a drifting river boat during peak spawning to estimate minimum escapement;
4. deploy and maintain 2 dual-frequency identification sonars (DIDSON produced by Sound Metrics Corp.) each in the Chena and Salcha rivers to enumerate passing salmon during periods of high-water when tower counts cannot be completed; and,
5. count chum salmon in the Chena and Salcha rivers throughout the duration of the Chinook salmon run.

METHODS

Study Area and Sampling Design

Chena and Salcha Rivers Chinook salmon

Daily escapements of Chinook and chum salmon will be estimated by expansion of timed visual counts of fish as they pass over white fabric panels located on the river bottom on the upstream side of the Moose Creek Dam on the Chena River (Figure 1) and approximately 1 km upriver of

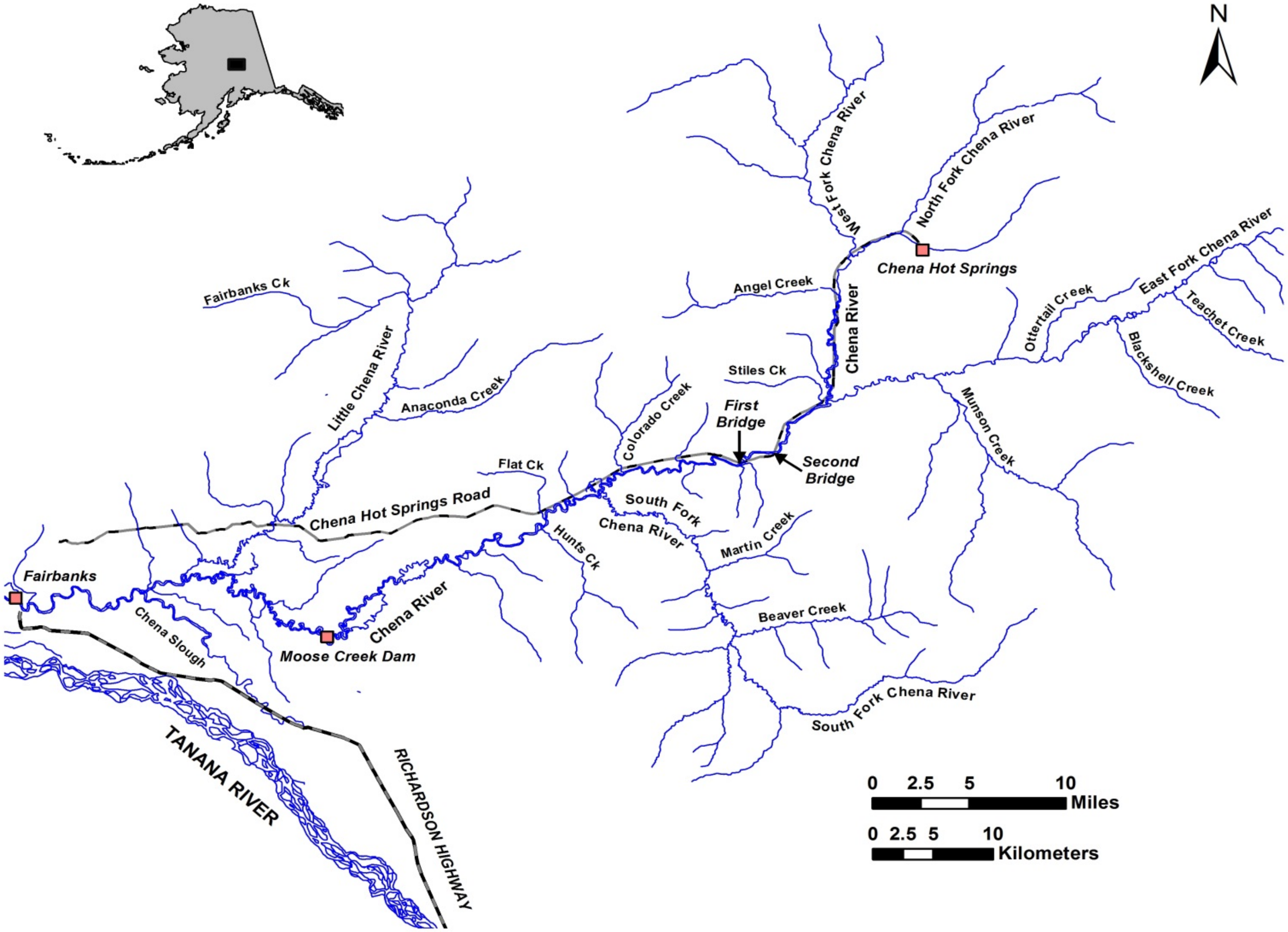

Figure 1.–Map of the Chena River demarcating the Moose Creek Dam (river km 72) and the first bridge on Chena Hot Springs Road (river km 161).

the Richardson Highway Bridge (Figure 2) on the Salcha River. Personnel will stand on top of scaffolding towers and count all salmon passing upstream and downstream for 20-min intervals every hour over the course of the run. Lights will be suspended over the panels to provide illumination during periods of low ambient light, and they will remain on for the duration of each counted hour in which they are used. Counting will begin on or about 25 June and will continue until there are 3 continuous days with no net upstream passage of Chinook salmon (typically around August 5). The majority of Chinook salmon spawning occurs upstream of these sites and no harvest of salmon is allowed on this section of the Chena River and 4km upstream of the Richardson Highway Bridge, so final estimates will represent total escapement in these 2 drainages.

Five technicians will be assigned to each river to enumerate the salmon escapement. Each day will be divided into three 8.0-h shifts. Shift I begins at 0000 (midnight) and ends at 0759; Shift II begins at 0800 and ends at 1559; Shift III begins at 1600 and ends at 2359. Salmon will be counted for 20 min of every hour. The start time for all counts will begin at the top of the hour.

In conjunction with the counting towers, 2 DIDSON sonars will be deployed upstream of the white fabric panels on the Salcha and Chena rivers to estimate the number of migrating salmon during periods of high-water (>2 consecutive days) when tower counts cannot be completed. Ranges up to 30 m are needed to insonify the entire river profile, and Burwen et al. (2007) established that standard DIDSON sonar units can precisely measure fish length up to 12 m away from the sonar unit. For this reason, each sonar will cover half of the river and will be positioned such that the beams do not overlap and record a salmon twice. Images will be recorded 24 hours a day, 7 days a week. The sonars will be mounted to portable aluminum stands that can be moved manually to adjust for water depth. Weir structures will be deployed behind each unit to ensure migrating salmon pass through the sonar beam. These counts will be used during extended periods of high-water (> 2 days) when tower counts cannot be completed. When daily visual counts are available, they will be used to evaluate the effectiveness of the sonar in filling in for missing visual count days.

During and post-season, all fish >400 mm in length in the DIDSON sonar images will be measured and recorded using Echotastic, a software program developed to process sonar images (Pfisterer 2010). Historical length distributions of chum and Chinook salmon from the Chena and Salcha rivers illustrate that no salmon are less than 400 mm in length. The estimated lengths from the sonar images, along with the associated dates of tower passage, will be used in a Bayesian mixture model that uses historical length and run-timing data for Chinook and chum salmon to apportion and estimate numbers of Chinook and chum salmon from the total sonar count. Burwen et al. (2007) showed in a tethered-fish experiment that measured fish lengths from DIDSON sonar images are a good predictor of actual fish lengths. For the Chena River, DIDSON has proved a valuable technology for estimating Chinook and chum salmon passage on days when visual counts could not be recorded due to high, muddy water. In 2007, a single DIDSON unit was deployed on the Chena River and a mixture model based on length of the Chinook and chum salmon was used to allocate the total count of salmon passing the sonar into numbers of Chinook and chum salmon (Huang 2012). Typically, the Chinook salmon run is earlier than the chum salmon run and Chinook salmon are larger than chum salmon and the mixture model uses this information to apportion the total count by species. Apportioned counts using the mixture model were compared to actual tower counts on the Chena River during 2015

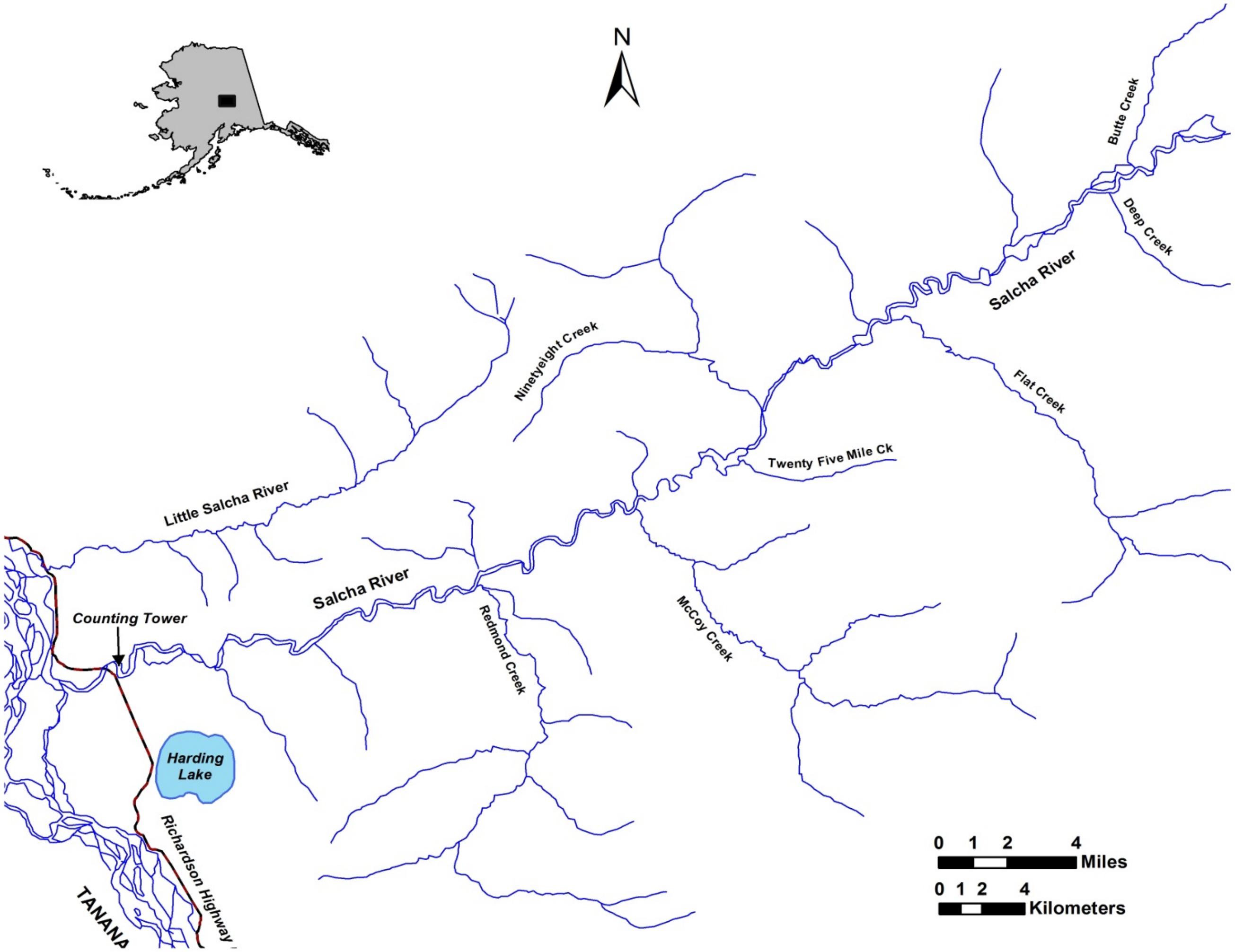

Figure 2.–Map of the Salcha River demarcating the counting tower.

during days of good visibility and results suggested this methodology is an appropriate means to estimate passage when conditions prohibit tower counts (Stuby and Tyers *In prep*).

In addition to the tower and sonar counts, carcasses of spawned-out Chinook salmon will be collected during the last week of July through the first 2 weeks of August from river km 72 to 161 (Figure 1) of the Chena River and from the Richardson Highway Bridge (rkm 2) to Butte Creek (75 rkm) on the Salcha River to estimate age, length, and sex composition of the escapement. Ages will be determined from scale patterns as described by Mosher (1969). Three scales will be removed from the left side of the fish approximately 2 rows above the lateral line along a diagonal line downward from the posterior insertion of the dorsal fin to the anterior insertion of the anal fin (Welander 1940). If no scales are present in the preferred area due to decomposition, scales will be removed from the same area on the right side of the fish or if necessary, from any location where there are any scales remaining, other than along the lateral line. Scales will be stored in coin envelopes and mounted on gum cards in the lab. Sex will be determined from external and internal characteristics. Length and sex will also be recorded for chum salmon. This information will be added to the mixture model that will be used to apportion Chinook from chum salmon in the sonar data.

Two riverboats with 3 people in each boat (1 operator and 2 people collecting carcasses) will be used to collect Chinook salmon carcasses. Chinook salmon carcasses will be speared from the boats and collected along banks and gravel bars. All deep pools and eddies that can be safely explored will be inspected to find and sample as many Chinook salmon carcasses as possible. After collection, the carcasses will be placed in a large tub onboard the boat. Once the tub is full, the boat will land on a gravel bar and the carcasses will be laid out in rows of 10 with their left sides facing up.

Objective criteria for age, sex, and length compositions were established to maintain the integrity of the spawner-recruit data used to set the BEGs. To estimate age compositions with the desired level of precision, a minimum of 416 Chinook salmon carcasses will be sampled for scales assuming 15% data loss due to unreadable scales (Thompson 1987).

Delta Clearwater River Coho Salmon

Previous aerial surveys of the Delta Clearwater River drainage have shown that an average of 20% of the coho escapement is found in areas inaccessible to a boat survey; therefore, counts of adult coho salmon will be conducted to obtain a minimum estimate of escapement. This estimate will be used to evaluate whether or not the SEG was met.

Two persons (a boat operator and a counter) will conduct the survey from a drifting river boat equipped with a 5 ft elevated platform. The survey is typically done during peak spawning times over the course of 1 to 2 days. The survey will be conducted along the lower 18 miles of the Delta Clearwater River to within 1.0 mile of the Clearwater Lake outlet (Figure 3). The total number of coho salmon observed (both dead and alive) will be recorded every mile at mile markers posted on the river bank. The sum of the section counts equals the estimate of minimum escapement.

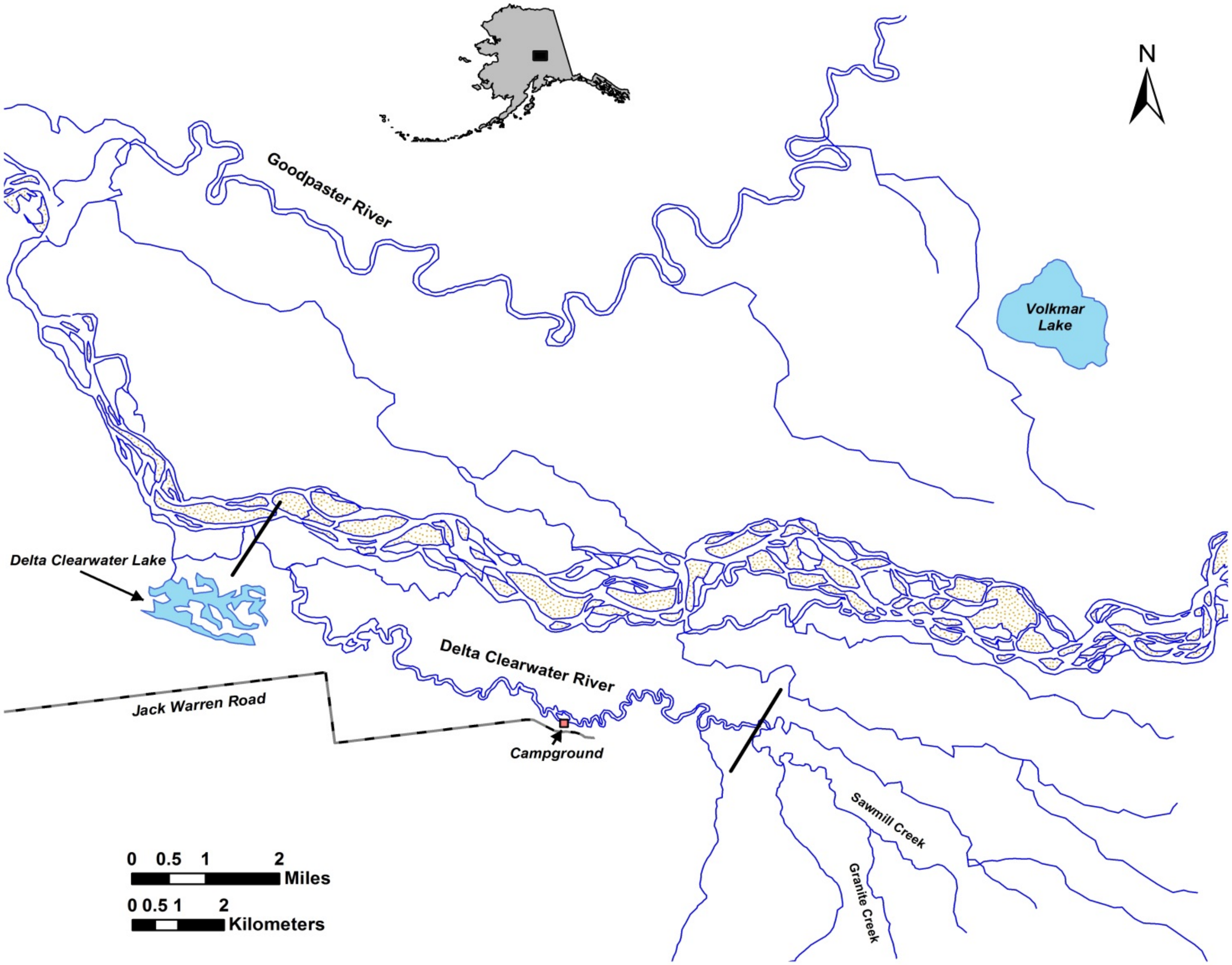

Figure 3.–Map of the Delta Clearwater River demarcating the survey area (bold lines).

Data Collection

Chena and Salcha Rivers Chinook Salmon

The numbers of Chinook and chum salmon passing upstream and downstream across the panels and water clarity rating (Table 1) will be recorded on field forms (Appendix A1) at the end of each 20-min count. Only counts with an associated water clarity rating of 3 or lower will be used in the estimate of escapement. A count with an associated water clarity rating of 4 or 5 is considered as no count. Each day, the data sheets from the previous day will be returned to the project leader at the end of Shift 1.

All recorded images from the sonars will be stored on an external hard drive capable of holding large data files. The technicians will ensure the sonar is running at the end of every 20-min tower count and that the proper sonar angle has been maintained. They will be responsible for any adjustments necessary due to water level and/or debris.

All fish collected during carcass surveys will be sampled for age, sex, and length (Appendix A2). After sampling, all carcasses will be cut in a distinctive manner through the left orbit to avoid resampling and returned to the river.

Table 1.–Water clarity ratings**.**

Rating	Description	Salmon Viewing	Water Condition
1	Excellent	All passing salmon are observable	Virtually no turbidity or glare, “drinking water” clarity; all routes of passage observable
2	Good	All passing salmon are observable	Minimal to moderate levels of turbidity or glare; all routes of passage observable
3	Fair	Possible, but not likely, that some passing salmon may be missed	Moderate to high levels of turbidity or glare; a few likely routes of passage are partially obscured
4.	Poor	Likely that some passing salmon may be missed	Moderate to high levels of turbidity or glare; some-many likely routes of passage are obscured
5	Un-observable	Passing fish are not observable	High level of turbidity or glare; ALL routes of passage obscured

Delta Clearwater River Coho Salmon

The person counting coho salmon will stand on the elevated platform and count fish along each mile section of river. The observer will wear polarized glasses to facilitate viewing into the water and record the number of coho salmon on tally counters. The number of coho salmon observed will be recorded at the end of each mile section and the tally counters will be zeroed at the start of the next section. The survey conditions will also be recorded.

Data Reduction

Chena and Salcha Rivers Chinook Salmon

Recorded data will be entered into a Microsoft Excel spreadsheet for data analysis. The spreadsheet calculates daily estimates of Chinook salmon escapement and the associated variance plus summary tables documenting counting effort and daily and cumulative Chinook and chum salmon passage.

Recorded data from the DIDSONs will be stored on an external hard drives. Similar to 2015, an attempt will be made to measure the lengths of all fish recorded by the 4 DIDSONs in order to examine and compare paired estimates (counting tower and sonar) to test the efficacy of sonar as a tool for future years when high-water events result in large data gaps from the counting tower.

When all data are compiled in the spreadsheet, a copy of the file and the scale cards will be sent to Commercial Fisheries Division (CFD) in Anchorage. The scale samples will be imprinted on acetate cards and aged, and the ages will be entered into the spreadsheet listing the sex and length for each fish. The completed file will be used by CFD for assessment and reporting purposes; and, a copy returned to Fairbanks for final analysis and contribution to the final FDS report, and archiving. Final copies of the spreadsheet file will be provided with the completed report when it is submitted for review to be archived in a regional Sport Fish Division repository.

Delta Clearwater River Coho Salmon

Field notebooks and raw survey data will be archived in the Delta Junction area office. Results will be reported to the project leader and presented in the annual FDS Report.

Data Analysis

Chena and Salcha Rivers Chinook Salmon

Counting Towers

Estimates of Chinook salmon escapement will be stratified by day, and daily estimates will be summed to estimate total escapement. Daily escapement will be estimated 1 of 5 ways depending on the frequency of successful counts. The following criteria will be used to determine the equations (1-13) used to estimate the daily escapement and its variance:

1. when 2 or more 8-hr shifts per day are considered complete (i.e. a minimum of 4 counting periods per shift are sampled) escapement for that day will be estimated using equations 1-3 and variance will be estimated using equations 4-8;
2. when only one 8-hr shift per day is considered complete but at least 4 counting periods are sampled, escapement for that day will be estimated using equations 1-3 and variance will be estimated using equation 13;

3. when no 8-hr shifts are considered complete on a given day, interpolation techniques described in equations 14 and 15 will be used to estimate escapement, and equation 13 will be used to estimate variance for inseason reporting of escapement estimates. This approach will only be used when no 8-hr shifts for 1 or 2 consecutive days of counting are considered complete. Post-season, escapement for these dates will be estimated using the mixture model that apportions the DIDSON sonar counts of salmon by species (Huang 2012, Stuby and Tyers *In prep*);
4. when all 8-hr shifts on 3 or more but fewer than 10 consecutive days are considered incomplete, no inseason daily escapement values will be reported and postseason daily escapement values will be assessed using a mixture model that apportions the DIDSON sonar counts of salmon by species (Huang 2012, Stuby and Tyers *In prep*); and,
5. when visual counting cannot be conducted for an excessive number of days during the run (e.g., more than 10 consecutive days or more than 20 total days), or when neither visual counts or sonar counts can be conducted for 3 or more consecutive days (i.e., high water and inoperative sonar equipment), a Bayesian hierarchical model will be used to estimate escapement for the missed days using characteristics of the run-timing curve (Hansen et al. 2016).

Although diel migratory patterns have been noted for other systems (Taras and Sarafin 2005), no distinct diel migratory pattern has been documented for Chena or Salcha River Chinook salmon (Stuby 2001, J. Savereide, ADF&G, Fairbanks, unpublished data)

Daily estimates of escapement will be considered a two-stage direct expansion where the first stage is 8-h shifts within a day and the second stage is 20 min counting periods within a shift. The second stage is considered systematic sampling because the 20 min counting periods were not chosen randomly.

The formulas necessary to calculate escapement from counting tower data are taken directly or modified from those provided in Cochran (1977). The expanded shift escapement on day *d* and shift *i* will be calculated by:

$$\hat{Y}_{di} = \frac{M_{di}}{m_{di}} \sum_{j=1}^{m_{di}} y_{dij} \ . \tag{1}$$

The average shift escapement for day *d* will be:

$$\bar{Y}_d = \frac{\sum_{i=1}^{h_d} \hat{Y}_{di}}{h_d} \, . \tag{2}$$

The expanded daily escapement will be:

$$\hat{N}_d = \bar{Y}_d H_d . \tag{3}$$

The period sampled is systematic because the same period is sampled every hour in a shift. The sample variance associated with periods will be approximate using the successive difference approach (Wolter, 1985):

$$s_{2di}^2 = \frac{1}{2\left(m_{di}-1\right)} \sum_{j=2}^{m_{di}} \left(y_{dij} - y_{di(j-1)}\right)^2 . \tag{4}$$

All shifts will be sampled unless water clarity conditions prohibit counts. If 2 or more shifts are not sampled on a given day, then the moving average technique (described below) will be used to estimate the daily passage and its variance. If 1 shift is not sampled then the between shift sample variance will be calculated as:

$$s_{1d}^2 = \frac{1}{h_d - 1} \sum_{i=1}^{h_d} \left(\hat{Y}_{di} - \bar{Y}_d\right)^2 . \tag{5}$$

The variance for the expanded daily escapement will be estimated by (Eq. 11.24; Cochran, 1977):

$$\hat{V}\left(\hat{N}_d\right) = \left[\left(1 - f_{1d}\right) H_d^2 \frac{s_{1d}^2}{h_d}\right] + \left[\frac{1}{f_{1d}} \sum_{i=1}^{h_d} \left(\left(1 - f_{2di}\right) M_{di}^2 \frac{s_{2di}^2}{m_{di}}\right)\right] \tag{6}$$

where:

$$f_{1d} = \frac{h_d}{H_d} \text{; and,} \tag{7}$$

$$f_{2di} = \frac{m_{di}}{M_{di}} \tag{8}$$

and

d = day;

i = *8-h shift;*

j = *20-min counting period;*

y_{dij} = *observed 20-min period count;*

$\hat{Y}_{di}$ = *expanded shift escapement estimate;*

m_{di} = *number of 20-min counting periods sampled within a shift;*

M_{di} = *total number of possible 20-min counting periods within a day (24 would indicate a full day);*

h_d = *number of 8-h shifts sampled within a day;*

H_d = *total number of possible 8-h shifts within a day,*

D = *total number of possible days*.

f_1 = fraction of 8-h shifts sampled; and,

f_2 = fraction of 20 min counting periods sampled.

Total escapement and variance estimates are the sum of all daily estimates:

$$\hat{N} = \sum_{d=1}^{D} \hat{N}_d \text{ ; and,} \tag{9}$$

$$\hat{V}\left(\hat{N}\right) = \sum_{d=1}^{D} \hat{V}(\hat{N}_d)\,. \tag{10}$$

Equation 5, the sample variance across shifts, requires data from more than 1 shift per day. In the event that water conditions and/or personnel constraints do not permit at least 2 shifts during a day, a coefficient of variation (CV) will be calculated using all days when more than 1 shift was worked. The average CV will then be used to approximate the daily variation for those days when fewer than 2 shifts were worked. The coefficient of variation is used because it is independent of the magnitude of the estimate and is relatively constant throughout the run (Evenson 1995). The daily CV is calculated as:

$$CV_d = SE_d \big/ \hat{N}_d\,. \tag{11}$$

For all L days of the run where more than one shift is worked, an average CV will be calculated as:

$$\overline{CV} = \sum_{l=1}^{L} CV_l \bigg/ L\,, \tag{12}$$

and variance of the escapement for days where one or zero shifts is worked will be estimated as:

$$\text{var}\left(\hat{N}_d\right) = (\overline{CV}\,\hat{N}_d)^2\,. \tag{13}$$

When k consecutive days are not sampled due to adverse viewing conditions, the moving average estimate for the missing day i will be calculated as:

$$\hat{N}_i = \frac{\sum_{j=i-k}^{i+k} I(day\, j\ \ was\, sampled)\hat{N}_j}{\sum_{j=i-k}^{i+k} I(day\ j\, was\, sampled)} \tag{14}$$

where:

$$I(Condition) = \begin{cases} 1 & Condition\, is\, true \\ 0 & otherwise \end{cases} \tag{15}$$

is an indicator function. The moving average procedure will only be applied for data gaps that do not exceed 3 days for inseason daily estimate reporting (9 consecutive 8-hr shifts).

Postseason, all data gaps will be assessed using a mixture model (Huang 2012, Stuby & Tyers *In prep*) applied to the DIDSON sonar data for final estimates.

Carcass Surveys

Biased estimates of sex composition have been noted during sampling when sex ratios of Chinook salmon collected during carcass surveys were compared with those estimated with mark-recapture methods. In the mark-recapture studies, the ratio of the abundance estimates of females to total abundance is used to estimate the percent females in the population. Diagnostic testing associated with the analysis of the mark-recapture data dictated whether first event samples (taken with electrofishing gear), second event samples (collected from carcasses), or both samples were used to estimate sex and age compositions, and whether those estimates could be considered unbiased. A comparison of sex composition estimates from mark-recapture methods to straight sample proportions from carcass surveys revealed that carcass surveys tended to overestimate the proportions of females in the population (and conversely tended to underestimate the proportion of males). A "correction factor" was developed to apply to sex composition estimates (specifically the proportion of females) in years when only a carcass survey was conducted based on the average of ratios of unbiased estimates from mark-recapture experiments to estimates from carcass samples over those years when mark-recapture studies were conducted. Mark-recapture data are available for 9 years from the Chena River (1989–1992, 1995–1997, 2000, and 2002) and 7 years from the Salcha River (1987–1992, 1996).

The escapement estimate will be apportioned by sex prior to apportioning by age categories within each sex. Age compositions will be reported using the European notation that includes the number of freshwater and ocean years of residence. For example, age 1.2 symbolizes 1 year of freshwater residence and 2 years in the ocean (4 years total age). The estimated proportions of males and females from carcass surveys will be calculated using (Cochran 1977):

$$\hat{p}_{sc} = \frac{y_{sc}}{n_c}; \tag{16}$$

with variance:

$$\hat{V}\left[\hat{p}_{sc}\right] = \frac{\hat{p}_{sc}\left(1-\hat{p}_{sc}\right)}{n_c - 1}; \tag{17}$$

where y_{sc} is the number of salmon of sex s observed during carcass surveys and n_c is the total number of salmon of either sex observed during carcass surveys for $s = m$ or f.

The adjustment factor necessary to compensate for the gender bias is $\hat{R}_p$ = 0.708 with $\hat{V}(\hat{R}_p)$ = 0.018 for the Chena River and $\hat{R}_p$ = 0.867 with $\hat{V}(\hat{R}_p)$ = 0.030 for the Salcha River (Doxey 2014).

The bias-corrected estimate and variance (Goodman 1960) of the proportion of females, $\tilde{p}_{fe}$, is:

$$\tilde{p}_{fe} = \hat{p}_{fc}\hat{R}_p \text{ with } \hat{V}(\tilde{p}_{fe}) = \hat{p}_{fc}^2\hat{V}(\hat{R}_p) + \hat{R}_p^2\hat{V}(\hat{p}_{fc}) - \hat{V}(\hat{R}_p)\hat{V}(\hat{p}_{fc}). \tag{18}$$

The bias-corrected estimates and variance of the proportion of males are:

$$\tilde{p}_{me} = 1 - \tilde{p}_{fe} \text{ and } \hat{V}(\tilde{p}_{me}) = \hat{V}(\tilde{p}_{fe}).$$

Escapement of each sex is then estimated by:

$$\hat{N}_s = \tilde{p}_{se}\hat{N} \tag{19}$$

The variance for $\hat{N}_s$ in this case is (Goodman 1960):

$$\hat{V}\left(\hat{N}_s\right) = \hat{V}(\tilde{p}_{se})\hat{N}^2 + \hat{V}\left(\hat{N}\right)\tilde{p}_{se}^2 - \hat{V}(\tilde{p}_{se})\hat{V}\left(\hat{N}\right). \tag{20}$$

The proportion of fish at age *k* by sex *s* for samples collected solely for age, sex, and length will be calculated as:

$$\hat{p}_{sk} = \frac{y_{sk}}{n_s} \tag{21}$$

where: $\hat{p}_{sk} =$ the estimated proportion of Chinook salmon that are age *k*; y_{sk} = the number of Chinook salmon sampled that are age *k* and sex *s*; and, n_s = the total number of Chinook salmon sampled of sex *s*.

The variance of this proportion will be estimated as:

$$\hat{V}[\hat{p}_{sk}] = \frac{\hat{p}_{sk}(1 - \hat{p}_{sk})}{n_s - 1} \tag{22}$$

Mean lengths and associated variances are calculated for each sex and associated age class using:

$$\bar{l}_j = \frac{\sum_{j-1}^{n} l_j}{n_s}; \text{ and,} \tag{23}$$

$$V[\bar{l}_j] = \frac{\sum_{j=1}^{n}(l_j - \bar{l}_j)}{n(n-1)} \tag{24}$$

Escapement at age *k* for each sex is then estimated by:

$$\hat{N}_{sk} = \hat{p}_{sk}\hat{N}_s \tag{25}$$

The variance for $\hat{N}_{sk}$ in this case is (Goodman 1960):

$$\hat{V}\left(\hat{N}_{sk}\right) = \hat{V}(\hat{p}_{sk})\hat{N}_s{}^2 + \hat{V}\left(\hat{N}_s\right)\hat{p}_{sk}^2 - \hat{V}(\hat{p}_{sk})\hat{V}\left(\hat{N}_s\right). \tag{26}$$

DIDSON Mixture Model

The proportions of Chinook and chum salmon in the total sonar counts are estimated using a mixture model with fish length being the discriminating information, weakly informed by run timing. The probability density function (pdf) of length of fish *i* (y_i) will be modeled using a weighted mixture model,

$$f(y_i) = p_{c,i}f_c(y_i) + p_{k,i}f_k(y_i), \tag{27}$$

$$0 \le p_{c,i}, p_{k,i} \le 1, \text{ and } p_{c,i} + p_{k,i} = 1$$

where $f_c(y)$ is the length distribution of chum salmon and $f_k(y)$ is the length distribution of Chinook salmon; weights $p_{c,i}$ and $p_{k,i}$ are the probabilities of fish i being a chum or Chinook salmon, respectively.

There is a moderate difference in length between male and female Chinook and chum salmon. The length distribution (pdf) of either species can be expressed with a two-component sex mixture model as shown below,

$$f_c(y) = \theta_{c1} f_{c1}(y) + \theta_{c2} f_{c2}(y)$$

$$f_k(y) = \theta_{k1} f_{k1}(y) + \theta_{k2} f_{k2}(y) \tag{28}$$

where θ_{c1} and θ_{c2} are the proportions of male and female chum salmon, respectively; $and\ \theta_{k1}$ and θ_{k2} are the proportions of male and female Chinook salmon, respectively. The proportions of males and females add up to 1 for each species. Distributions $f_{cs}(y)$ and $f_{ks}(y)$ are assumed to be normal for both sexes,

$$f_{cs}(y) \sim N(\mu_{cs}, \sigma_{cs}^2)$$

$$f_{ks}(y) \sim N(\mu_{ks}, \sigma_{ks}^2) \tag{29}$$

Prior information about the length means (μ) and variances (σ^2) in equation (29) were found in other fishery research publications. For this study, prior information for Chinook and chum salmon length distributions were taken from the Arctic-Yukon-Kuskokwim (AYK) Database Management System. In addition, prior information for chum salmon length distribution was provided by Clark (1993).

Actual individual fish length (y) was not measured directly from individual fish and therefore was considered an unobserved variable. Instead, fish length was measured from DIDSON images. A linear relationship was assumed between DIDSON length ($y_{obs,i}$) and the actual fish length (y_i) for fish i. The DIDSON fish length ($y_{obs,i}$) was modeled as a normal variable whose mean was a linear function of actual fish length (y_i) (Equation 30).

$$y_{obs,i} = \beta_1 + \beta_2 y_i + \varepsilon_i \tag{30}$$

where y_{obs} refers to observed DIDSON length, which are the fish length measurements obtained from the DIDSON sonar images; y_i refers to the actual fish length; the intercept β_1 and slope β_2 are unknown parameters of the linear relationship between $y_{obs,i}$ and y_i. Paired data used to inform the relationship between $y_{obs,i}$ and y_i were obtained from a tethered-fish experiment (conducted by D. Burwen and S. Fleischman, ADF&G, personal communication).

The mixture model (equations 27–30) contains unknown parameters including species probability parameters p_c and p_k, sex proportion parameters θs, intercept parameter β_1, and slope parameter β_2. In order to estimate these unknown parameters, the mixture model was fitted using Markov Chain Monte Carlo (MCMC) as implemented in the statistical software package JAGS (Plummer 2003), called through the statistical software R (R Core Team 2014) using R package R2jags (Su and Yajima 2015).

According to Bayes's Theorem, the posterior distributions of the unknown parameters are proportional to the likelihood of the data multiplied by the prior distributions of the parameters.

The likelihood of the data collected follows the mixture model density function (Equation 27). The prior distributions of the sex ratio parameters θs were assigned a Dirichlet (α,γ) distribution. It has been noted since this project's inception that the Chinook salmon run starts earlier and will usually peak before or during the early portion of the chum salmon run and that the proportion of the total run comprised of Chinook salmon has followed an approximate logistic trend over the course of the run. Therefore, species proportions parameters $p_{c,d}$ and $p_{k,d}$ for run day x_d were assigned diffuse Dirichlet priors (η_d,ζ_d) that were calculated by run date according to:

$$\log\left(\frac{\eta_d}{\eta_d - 1}\right) = b_0 + b_1 x_d$$

$$\zeta_t = 1 - \eta_t ; \tag{31}$$

Hyperparameters b_0 and b_1 are estimated using logistic regression to model the relationship between run-timing and species in historical data. Because some variability in this relationship exists between years, the values of b_0 and b_1 that will be used in the model will either be calculated from available visual counts in the year the data gap exists, or the average values across historic data, depending on the magnitude of the data gap. Chinook and chum salmon lengths are assigned normal priors, using data from the AYK Database Management System, as well as Clark (1993). The historic data used for model priors suggests that male and female chum salmon lengths are similar. Female chum salmon mean length was 553.0 mm (SE=1.1 mm) and male chum salmon mean length was 583.6 mm (SE=1.3 mm). Chinook salmon lengths vary moderately between sexes; female Chinook salmon had a mean length of 851.4 mm (SE=0.8 mm) and male Chinook salmon had a mean length of 703.9 mm (SE=1.3 mm). The regression parameters β_1 and β_2 were assigned diffuse normal priors. The Bayesian MCMC was conducted using JAGS with 3 chains and 100,000 iterations in each chain. The first 50,000 iterations in each chain were considered as burn-in and discarded.

Species totals were calculated every iteration of the MCMC procedure, thus giving posterior distributions of the escapement for each species. Escapement estimates and respective standard errors were then obtained by calculating the median and standard deviation of the posterior draws of species totals.

JAGS code for model fitting can be found in Appendix B.

Bayesian Hierarchical model

In the event visual counting cannot be conducted for an excessive number of days during the run (e.g., more than 10 consecutive days or more than 20 total days), or when neither visual counts or sonar counts can be conducted for 3 or more consecutive days (i.e., high water and inoperative sonar equipment), a Bayesian hierarchical model will be used to estimate escapement for the missed days using characteristics of the run-timing curve (Hansen et al. 2016).

For this, estimated daily counts for day d within year k are assumed to be normally distributed around either a lognormal, extreme-value, or log-logistic trends by date.

$$\widehat{N}_{k[d]} \sim N(\theta_{k[d]}, {\sigma_\theta}^2) \tag{32}$$

The run-timing trends of year k are determined by 3 parameters: a_k describes the amplitude of the run peak, μ_k describes the location by date of the run peak, and b_k describes the width of the run peak. The functional forms are given below for the lognormal, extreme-value, and log-logistic trends, respectively, for run day $x_{k[d]}$.

$$\theta_{k[d]} = a_k e^{\left(-0.5\left(\frac{ln\left(\frac{x_{k[d]}}{\mu_k}\right)}{b_j}\right)^2\right)} \tag{33}$$

$$\theta_{k[d]} = a_k e^{\left(-e^{\left(-\frac{x_{k[d]}-\mu_k}{b_k}\right)}-\left(\frac{x_{k[d]}-\mu_k}{b_k}\right)+1\right)} \tag{34}$$

$$\theta_{k[d]} = a_k \left(\frac{\left(\frac{b_k}{\mu_k}\right)\left(\frac{x_{k[d]}}{\mu_k}\right)^{(b_k-1)}}{\left(1+\left(\frac{x_{k[d]}}{\mu_k}\right)^{b_k}\right)^2}\right) \tag{35}$$

Amplitude parameters a_k for each year are considered independent between years, and are each given flat, noninformative priors. However, μ_k and b_k for each year are treated as normally distributed from common distributions, according to:

$$\mu_k \sim N(\mu_0, {\sigma_\mu}^2) \tag{36}$$

$$b_k \sim N(b_0, {\sigma_b}^2) \tag{37}$$

with uninformative priors placed on parameters μ_0, ${\sigma_\mu}^2$, b_0, and ${\sigma_b}^2$. All available years' data will be incorporated into the model, in order to fine-tune parameter estimates.

Because Chinook salmon spawning in the Chena and Salcha rivers have been observed to follow very similar run-timing profiles each year, timing parameters μ_k for each river and b_k for each river will be treated as correlated, allowing the model to have greater predictive power, particularly if counts are available for one river while a data gap exists for the other. This will likely be done by specifying multivariate normal distributions in the hierarchical component, or by adding a level of hierarchy.

JAGS code for a current version of this model is provided in Appendix C.

DCR Coho Salmon

The minimum escapement of coho salmon will be estimated by:

$$E_{\min} = \sum_{i=1}^{s} C_i \tag{38}$$

where: C_i = count of coho salmon in each mile section and s = number of mile sections.

SCHEDULE AND DELIVERABLES

Results from this project will be summarized annually in a Fishery Data Series Report for which a draft will be submitted to the Research Supervisor by 1 March each year; all 3 of these FDS reports will be uploaded to the AKSSF website as project deliverables. Semiannual reports will also be submitted online each year to satisfy the AKSSF and Yukon Panel R&M fund reporting requirements. Probable dates for sampling activities are summarized below.

Sampling = (S), Mobilization = (M), Demobilization = (D), Analysis = (A), Reports = (R)

Date	Chena/Salcha Towers and sonar	Chena/Salcha Carcass Surveys	DCR Coho	Data Analysis/Reports
May				R
June 13–26	M			
June 27–July 3	S			
July 4–10	S			
July 11–17	S			
July 18–24	S			
July 25–July 31	S	S		
August 1–August 7	S/D	S		
August 8–August 14		S		
October–November				A
Oct. 24–Nov. 6			M/S	
December				R
March				R

RESPONSIBILITIES

Lisa Stuby, *Fisheries Biologist II*. Project Leader. Responsible for supervision of all aspects of the Chena and Salcha rivers Chinook salmon counting tower and DIDSON sonar projects, managing the project budgets, and writing all reports.

James Savereide, *Fisheries Biologist III*. General project support and editing of annual report.

Virgil Davis, *Fish & Wildlife Technician III*. Chena River Crew leader. Oversees Chena River counting tower operations, mobilization, day-to-day project tasks, all aspects of field work, demobilization.

Chad Bear, *Fish & Wildlife Technician IV*. Salcha River Crew leader. Oversees Salcha River counting tower operations, mobilization, day-to-day project tasks, all aspects of field work, demobilization.

Loren St. Amand, *Fish & Wildlife Technician III*. Chena and Salcha Rivers Carcass Surveys Crew leader. Oversees and prepares for carcass sampling surveys on Chena and Salcha rivers, mobilization, day-to-day project tasks, all aspects of field work, demobilization.

Carmen Daggett, *Fish & Wildlife Technician III*. Chena River Crew leader. Oversees DIDSON sonar operations for Chena River, mobilization, day-to-day project tasks, all aspects of field work, demobilization.

Allison Matter, *Fish & Wildlife Technician III*. Salcha River Crew leader. Oversees DIDSON sonar operations for Salcha River, mobilization, day-to-day project tasks, all aspects of field work, demobilization.

Matt Stoller, *Fish & Wildlife Technician II*. Chena River Crew Member. Mobilization, day-to-day project tasks, all aspects of field work, demobilization.

Eric Nakalsky, *Fish & Wildlife Technician II*. Salcha River Crew Member. Mobilization, day-to-day project tasks, all aspects of field work, demobilization.

David Spencer, *Fish & Wildlife Technician II (Non Perm*). Chena River Crew Member. Mobilization, day-to-day project tasks, all aspects of field work, demobilization.

Quinn Evenson, *Fish & Wildlife Technician II (Non Perm)*. Chena River Crew Member. Mobilization, day-to-day project tasks, all aspects of field work, demobilization.

Brett George, *Fish & Wildlife Technician II.* Salcha River Crew Member. Mobilization, day-to-day project tasks, all aspects of field work, demobilization.

Kipp Wilkinson, *Fish & Wildlife Technician II (Non Perm*). Salcha River Crew Member. Mobilization, day-to-day project tasks, all aspects of field work, demobilization.

Mary Webb, *College Intern II*. Chena River Crew Member. Mobilization, day-to-day project tasks, all aspects of field work, demobilization.

Brandy Baker, *Fishery Biologist II*. Responsible for conducting boat counts of the Delta Clearwater River coho salmon escapement and updating long - term data sets.

Ellie Mason, *Fish and Wildlife Technician III*. Assist in conducting boat counts of the Delta Clearwater River coho salmon escapement.

RESPONSIBILITIES (CONTINUED)

Matt Tyers, *Biometrician II*. Assist with project design and data analysis.

Matt Evenson, *Fishery Biologist IV*. Final report editing and project support.

CFD Staff: Age scales collected from carcass survey and provide these data to the project leader.

REFERENCES CITED

ADF&G Chinook Salmon Research Team. 2013. Chinook salmon stock assessment and research plan, 2013. Alaska Department of Fish and Game, Special Publication 13-01, Anchorage.

ADF&G (Alaska Department of Fish and Game). 2004. Escapement goal review of select AYK Region salmon stocks. Alaska Department of Fish and Game, Division of Commercial Fisheries Regional Information Report 3A04-01, Anchorage.

Burwen, D. L., S. J. Fleischman, and J. D. Miller. 2007. Evaluation of a dual-frequency imaging sonar for estimating fish size in the Kenai River. Alaska Department of Fish and Game, Fishery Data Series, No. 06-61, Anchorage.

Clark, R. A. 1993. Abundance and age-sex-size composition of chum salmon escapements in the Chena and Salcha rivers, 1992. Alaska Department of Fish and Game, Fishery Data Series No. 93-13, Anchorage, Alaska, USA.

Cochran, W. G. 1977. Sampling Techniques. 3rd edition, John Wiley, New York.

Doxey, Mike 2004. Salmon studies in the Chena, Chatanika, Delta Clearwater, and Salcha Rivers, 2001. Alaska Department of Fish and Game, Fishery Data Series No. 04-01, Anchorage.

Evenson, M. J. 1995. Salmon studies in Interior Alaska, 1994. Alaska Department of Fish and Game, Fishery Data Series No. 95-5, Anchorage.

Evenson, M. J. 2002. Optimal production of Chinook salmon from the Chena and Salcha rivers. Alaska Department of Fish and Game, Fishery Manuscript No. 02-1, Anchorage.

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

Hansen, T. R., B. J. Blain, D. V. Taylor, and Z. W. Liller. 2016. Salmon escapement monitoring in the Kuskokwim Area, 2014. Alaska Department of Fish and Game, Fishery Data Series No. 16-03, Anchorage.

Huang, J. 2012. Sonar-based Chena River Salmon Assessment 2008. Alaska Department of Fish and Game, Fishery Data Series No. 12-39, Anchorage.

Mosher, K. H. 1969. Identification of Pacific salmon and steelhead trout by scale characteristics. United States Department of the Interior, U.S. Fish and Wildlife Service, Bureau of Commercial Fisheries, Washington, D.C., Circular 317.

Pfisterer, C. 2010. Echotastic 2.0 User Manual. Alaska Department of Fish and Game, Fairbanks Alaska.

Plummer, M. 2003. JAGS: A program for analysis of Bayesian graphical models using Gibbs Sampling.

R Core Team. 2014. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. www.R-project.org/.

Stuby, L. 2001. Salmon studies in interior Alaska, 2000. Alaska Department of Fish and Game, Fishery Data Series No. 01-24, Anchorage.

Stuby, L. and M. Tyers. *In prep*. Chinook salmon escapement in the Chena, Salcha, and Goodpaster Rivers and coho salmon escapement in the Delta Clearwater River, 2015. Alaska Department of Fish and Game, Fishery Data Series No. 16-XX, Anchorage.

Su, Y. and Yajima, M. 2015. R2jags: A package for running jags from R. R package version 0.05-0.01. http://CRAN.R-project. Org/package=R2jags.

Taras, B. D. and D. R. Sarafin. 2005. Chinook salmon escapement in the Gulkana River, 2002. Alaska Department of Fish and Game, Fishery Data Series No. 05-02, Anchorage.

Thompson, S. K. 1987. Sample size for estimating multinomial proportions. The American Statistician, 41:42-46.

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

Wolter, K. M. 1985. Introduction to variance estimation. Springer-Verlag, New York.

APPENDIX A

CHENA RIVER DAILY COUNT FORMS AND CARCASS SAMPLE FORM

Appendix A1.–Field Forms used to record daily 20-minute visual tower counts and DIDSON sonar counts for the Salcha and Chena rivers.

VISUAL TOWER COUNTS

RIVER:

DATE:

Total Salmon = Number up minus number down

OBSERVER:

	Chinook			**Chum**			**VIS**
Time	**Up**	**Down**	**Total**	**Up**	**Down**	**Total**	
0000							
0100							
0200							
0300							
0400							
0500							
0600							
0700							
TOTAL							

Chum Tag	
White	**Other?**

Weather (circle one): Clear---Partly Cloudy---Mostly Cloudy---Rain:

OBSERVER:

	Chinook			**Chum**			**VIS**
Time	**Up**	**Down**	**Total**	**Up**	**Down**	**Total**	
0800							
0900							
1000							
1100							
1200							
1300							
1400							
1500							
TOTAL							

Chum Tag	
White	**Other?**

Weather (circle one): Clear---Partly Cloudy---Mostly Cloudy---Rain:

OBSERVER:

	Chinook			**Chum**			**VIS**
Time	**Up**	**Down**	**Total**	**Up**	**Down**	**Total**	
1600							
1700							
1800							
1900							
2000							
2100							
2200							
2300							
TOTAL							

Chum Tag	
White	**Other?**

Weather (circle one): Clear--Partly Cloudy--Mostly Cloudy--Rain:

DIDSON SONAR COUNTS

RIVER: ____________________________
DATE: ____________________________
OBSERVER: ____________________________

TOTAL SALMON

Time	North Up		South Up	Comments
0000				
0100				
0200				
0300				
0400				
0500				
0600				
0700				
TOTAL				

OBSERVER______________________________

TOTAL SALMON

Time	North Up		South Up	Comments
0800				
0900				
1000				
1100				
1200				
1300				
1400				
1500				
TOTAL				

OBSERVER______________________________

TOTAL SALMON

Time	North Up		South Up	Comments
1600				
1700				
1800				
1900				
2000				
2100				
2200				
2300				
TOTAL				

Appendix A2.–Salmon carcass survey field form for the Salcha and Chena rivers.

DATE:__________________________ SAMPLE KIT #:______________________

START LOCATION:________________________ END LOCATION:_______________________

CHINOOK				**CHUM**		
Fish#	**Sex**	**Length (mm)**	**Eggs Collected (Y/N)**	**Sex**	**Length (mm)**	**Comments**

APPENDIX B:
JAGS CODE OF MIXTURE MODEL

Appendix B1.–JAGS code of mixture model[a,b].

```
model {
  for(i in 1:n.fish) {
    L.mm.D[i] ~ dnorm(muL[i],precL)
    muL[i] <- betaD0 + betaD1*L.mm.act[i]
    L.mm.act[i]~dnorm(mu[i],tau[i])
    mu[i]<-lambda[species[i],sex[i]]
    tau[i]<-prec[species[i],sex[i]]

    species[i]~dcat(ps[i,1:2])
    sex[i]~dcat(psex[species[i],1:2])

    logit(pi[i]) <- b0+b1*day[i]
    alpha.inf[i,1] <- pi[i]
    alpha.inf[i,2] <- (1-pi[i])
    ps[i,1:2]~ddirch(alpha.inf[i,1:2])
  }

  sig[1,1]<-133.9025
  sig[2,1]<-34.03293
  sig[1,2]<-68.59446
  sig[2,2]<-30.45913

  prec[1,1]<-1/(sig[1,1]*sig[1,1])
  prec[1,2]<-1/(sig[1,2]*sig[1,2])
  prec[2,1]<-1/(sig[2,1]*sig[2,1])
  prec[2,2]<-1/(sig[2,2]*sig[2,2])

  for(j in 1:m) {
    DL.star[j] ~ dnorm(mu.star[j],prec.star)
    mu.star[j] <- betaD0 + betaD1*AL.star[j]
  }
  precL <- 1/(54.59*54.59)
  betaD0 ~ dnorm(0,0.01)
  betaD1 ~ dnorm(1,0.01)
  prec.star ~ dunif(0.0001,1000)
  sig.star <- 1/sqrt(prec.star)

  b1 <- -0.2902526
  b0 <- -0.4378678

  psex[1,1:2]~ddirch(alpha.sex.chin[])
  psex[2,1:2]~ddirch(alpha.sex.chum[])

  lambda[1,1]~dnorm(704.6867,t1)
  lambda[1,2]~dnorm(853.1523,t2)
  lambda[2,1]~dnorm(585.3996,t4)
  lambda[2,2]~dnorm(555.6491,t5)

  t1<-1/(1.301375*1.301375)
  t2<-1/(0.7703839*0.7703839)
  t4<-1/(1.502591*1.502591)
  t5<-1/(1.198398*1.198398)

  N.chum <- sum(species[]) - n.fish # posterior distributions of the totals of each species
  N.chin <- (2*n.fish) - sum(species[])


  }
```

[a] The species proportions p_c and p_k were coded as *ps* and the sex proportions θ's were coded as *psex*. Parameters *sig*'s refer to the standard deviations in the length distribution for Chinook and chum salmon.

[b] The numerical values of the *sig*, *lambda*, *t*, and *b* priors will be updated as needed to reflect each year's additional data.

APPENDIX C:
JAGS CODE OF BAYESIAN HIERARCHICAL MODEL

Appendix C1.–JAGS code of Bayesian Hierarchical Model

```
model {
    for(j in 1:nyrs) {
    for(i in 1:ndays){
      y1[i,j] ~ dnorm(theta1[i,j], tausq1[j])
    #    y1[i,j] ~ dpois(theta1[i,j])
    # Assume that run timing distribution takes log normal distribution
    theta1[i,j] <- a1[j]*exp(-0.5*pow(log(x[i]/mu1[j])/b1[j],2))
    # Assume that run timing distribution takes Extreme value distribution
    #   theta1[i,j] <- a1[j]*exp(-exp(-(x[i]-mu1[j])/b1[j])-(x[i]-mu1[j])/b1[j]+1)
    # Assume that run timing distribution takes log-logistic distribution
    #   theta1[i,j] <- (a1[j]*(b1[j]/mu1[j])*pow((x[i]/mu1[j]),b1[j]-1))/pow(1+pow((x[i]/mu1[j]),b1[j]),2)

      y2[i,j] ~ dnorm(theta2[i,j], tausq2[j])
      #    y2[i,j] ~ dpois(theta2[i,j])
      # Assume that run timing distribution takes log normal distribution
      theta2[i,j] <- a2[j]*exp(-0.5*pow(log(x[i]/mu2[j])/b2[j],2))
      # Assume that run timing distribution takes Extreme value distribution
      #   theta2[i,j] <- a2[j]*exp(-exp(-(x[i]-mu2[j])/b2[j])-(x[i]-mu2[j])/b2[j]+1)
      # Assume that run timing distribution takes log-logistic distribution
      #   theta2[i,j] <- (a2[j]*(b2[j]/mu2[j])*pow((x[i]/mu2[j]),b2[j]-1))/pow(1+pow((x[i]/mu2[j]),b2[j]),2)
    }
  }
  # a[] indicates the maximum height (amplitude) of the function a>0
  # mu[] indicates the function peaks when x = mu mu>0 : Peak timing
  # b[] indicates peak width of the function b>0 standard deviation

  # Priors
  for(i in 1:nyrs) {
    # Normal distribution Positive only
    #  a: is independent not hierarchical
    a1[i] ~ dnorm(0,0.00001)T(0,)
    b1[i] ~ dnorm(b01,b01.prec)T(0.16,)
```

```
  mu1[i] <- mu2[i] + eps

  a2[i] ~ dnorm(0,0.00001)T(0,)
  b2[i] ~ dnorm(b02,b02.prec)T(0.16,)
  mu2[i] ~ dnorm(mu02,mu02.prec)T(0,)
}
eps ~ dnorm(0,0.01)
prec.mu <- pow(sig.mu,-2)
sig.mu ~ dunif(0,2)

b01 ~ dnorm(0.5,0.001)T(0.16,)
mu01 ~ dnorm(25,0.001)T(0,)
b01.prec <-1/b01.ssq
b01.ssq <- b01.sigma*b01.sigma
b01.sigma ~ dunif(0,100)
mu01.prec <-1/mu01.ssq
mu01.ssq <- mu01.sigma*mu01.sigma
mu01.sigma ~ dunif(0,100)

b02 ~ dnorm(0.5,0.001)T(0.16,)
mu02 ~ dnorm(25,0.001)T(0,)
b02.prec <-1/b02.ssq
b02.ssq <- b02.sigma*b02.sigma
b02.sigma ~ dunif(0,100)
mu02.prec <-1/mu02.ssq
mu02.ssq <- mu02.sigma*mu02.sigma
mu02.sigma ~ dunif(0,100)

## This assumes that variance of each year is independent.
for(i in 1:nyrs) {
  tausq1[i] <- pow(sigma1[i],-2)
  sigma1[i] ~ dunif(0,100)

  tausq2[i] <- pow(sigma2[i],-2)
```

```
  sigma2[i] ~ dunif(0,100)
}

# Backestimate escapement
for(j in 1:nyrs){
  for(i in 1:ndays){
    y1est[i,j] <- y1[i,j]
    y2est[i,j] <- y2[i,j]
  }
}
missing <- sum(y1est[1:20,12])    }
```