Regional Operational Plan SF.3F.2019.03

Chinook Salmon Escapement in the Chena and Salcha Rivers and Coho Salmon Escapement in the Delta Clearwater River, 2019–2023

by

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and

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May 2019

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)

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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CHINOOK SALMON ESCAPEMENT IN THE CHENA AND SALCHA, RIVERS AND COHO SALMON ESCAPEMENT IN THE DELTA CLEARWATER RIVER, 2019–2023

by

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May 2019

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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, sonar

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 river stocks are among the largest spawning populations of Chinook salmon *Oncorhynchus tshawytscha* on 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 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 support some of 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. Long, unbroken data strings and continued annual Chinook salmon escapement assessments are important for examining the spawner-recruit relationships used to determine meaningful biological escapement goals (BEGs). Biological escapement goals 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). The current BEG is evaluated every 3 years during the BOF using additional years of data acquired since the previous meeting. A sustainable escapement goal (SEG) of 5,200–17,000 coho salmon in the DCR was established because the spawner-recruit information required to establish a BEG is not available (ADFG 2004). Boat survey counts of coho salmon in the DCR have been conducted annually by ADF&G since 1980 during the peak of the run.

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 sets in the Yukon River drainage. The annual monitoring programs provide inseason information on run magnitude and timing, which allows managers to modify fishing regulations through emergency order if necessary to achieve the established escapement goals. The information provided by the monitoring programs also allows for postseason updates to spawner-recruit relationships and assessments of biological escapement goals.

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 2019–2023 field seasons.

OBJECTIVES

The objectives for 2019–2023 are to:

1. estimate the total escapement of Chinook salmon in the Chena and Salcha rivers using tower-counting techniques (augmented by sonar counts as needed) 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; and,
3. count coho salmon in the Delta Clearwater River from a drifting river boat during peak spawning to estimate minimum escapement.

Concurrent to the objectives, there is 1 task for 2019–2023:

1. 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 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 4 km upstream of the Richardson Highway Bridge on the Salcha River, so final estimates will represent minimum estimates of total escapement in these 2 drainages.

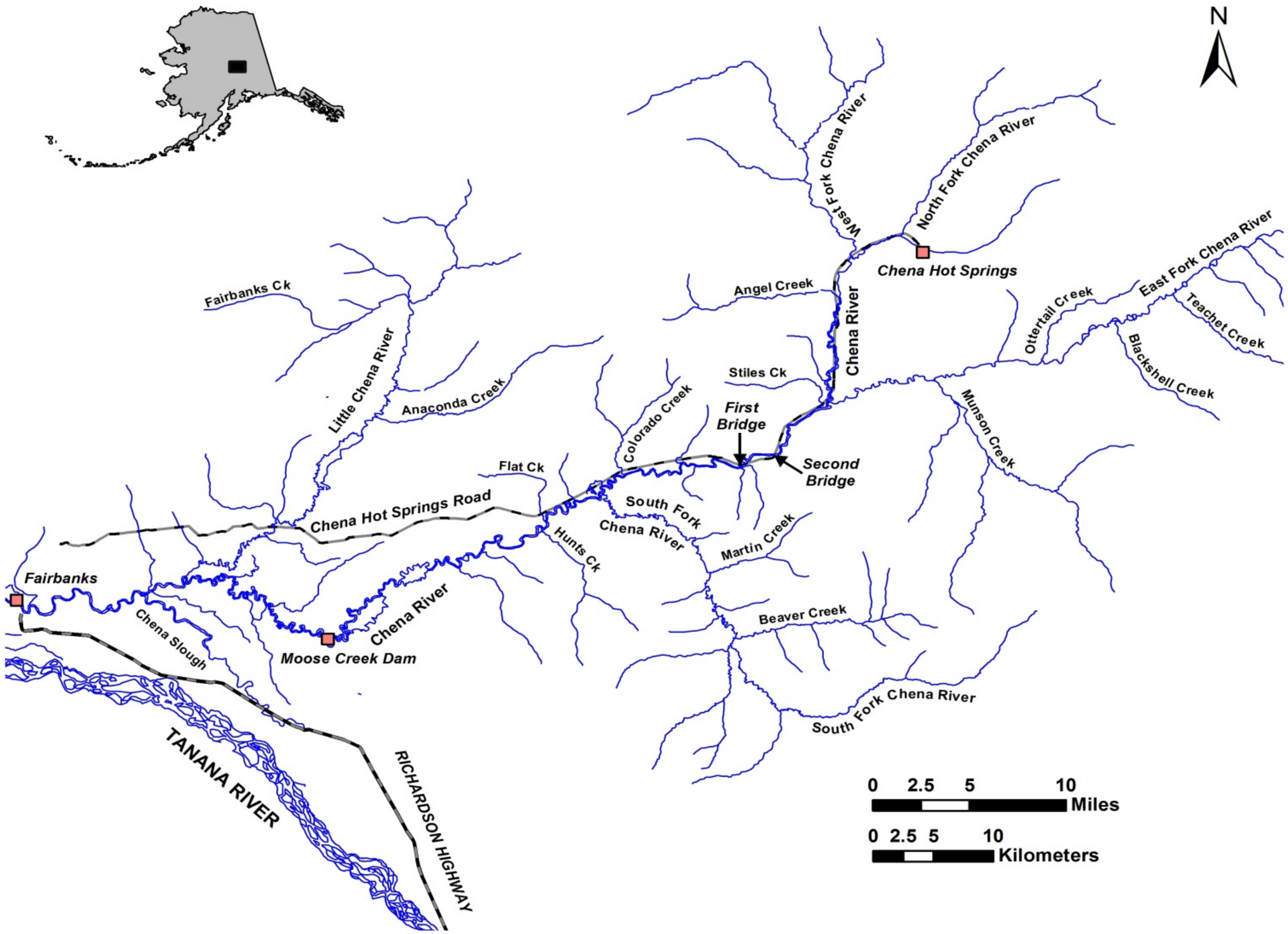

Figure 1.–Map of the Chena River demarcating the Moose Creek Dam (river km 72) and the first bridge on Chena Hot Springs Road (river km 161).

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, sonars will be deployed directly 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 visual tower counts cannot be completed. The 20-minute top-of-the-hour sonar files may be treated as visual counts and expanded for the whole hour. Post-season, visual counts will be compared to paired sonar counts to evaluate sonar effectiveness and accuracy. One dual-frequency identification sonar (DIDSON) and one adaptive resolution imaging sonar (ARIS) will be deployed on the Chena River and two ARIS sonar units will be deployed on either side of the river upstream of the Salcha River counting tower. Ranges of 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, while ARIS sonar units can precisely measure fish length up to 15 m away. For this reason, each sonar unit 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.

Sonar files will be processed daily to measure and count all fish >450 mm in length. Analysis of DIDSON sonar images will be performed using Echotastic (Pfisterer 2010) and ARIS sonar images will be processed using ARISFish (Sound Metrics Corp.). 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. Historical length distributions of chum and Chinook salmon from the Chena and Salcha rivers illustrate that few salmon are less than 450 mm in length. The same historical length distributions show that fish over 650 mm in length are almost exclusively Chinook salmon. In-season, daily salmon counts will be reported using 650 mm as a threshold with fish ≥ 650 mm being reported as Chinook salmon and fish ≤ 650 mm being reported as a mix of small Chinook and chum salmon.

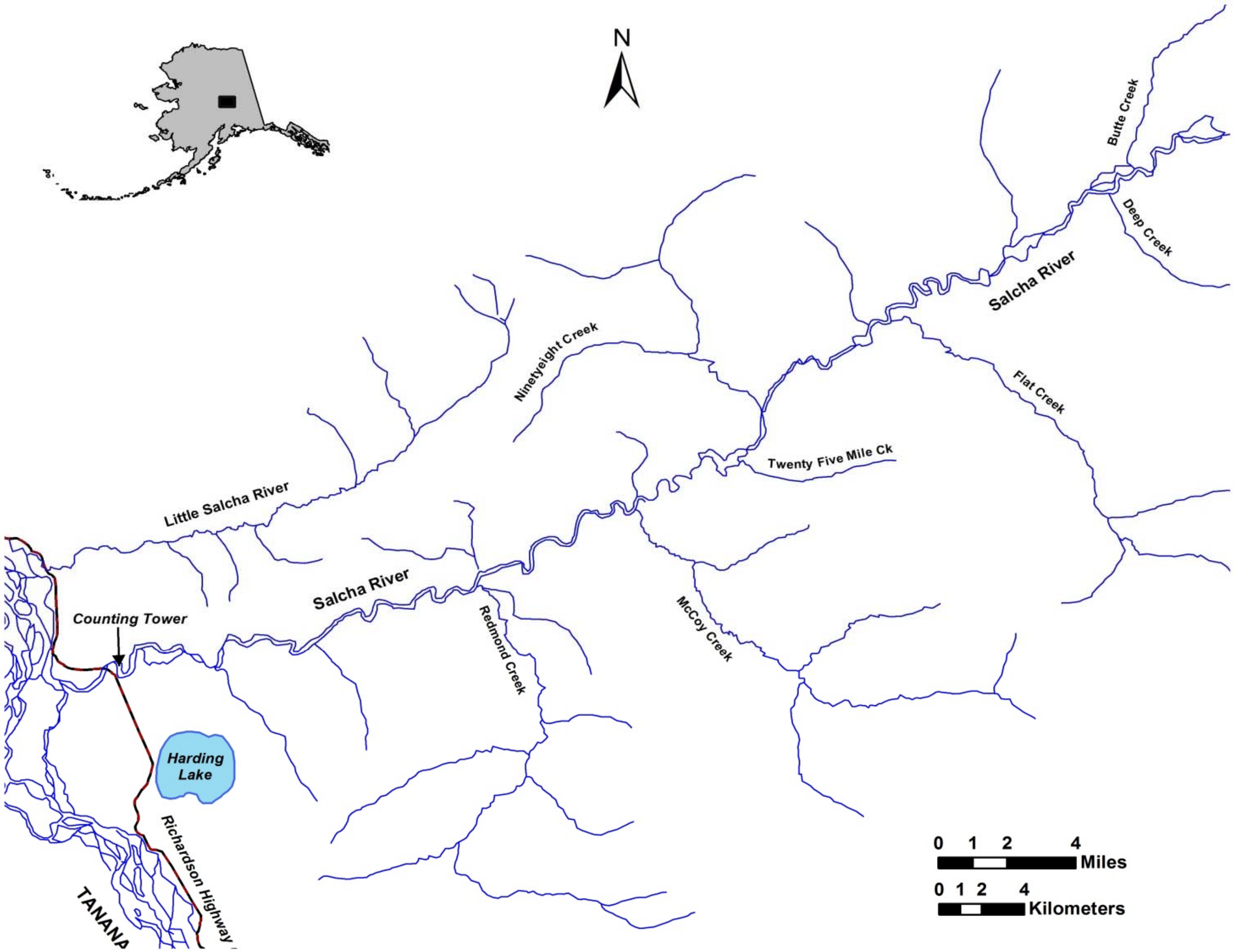

Figure 2.–Map of the Salcha River demarcating the counting tower.

In addition to the tower and sonar counts, carcasses of spawned-out Chinook salmon will be collected to estimate age, length, and sex composition of the escapement. Carcass sampling will occur between the last week of July and the first 2 weeks of August. The Chena River will be sampled from river km 72 to 161 (Figure 1) and the Salcha River will be sampled from the Richardson Highway Bridge (rkm 2) to Butte Creek (75 rkm). Ages will be determined from scale patterns as described by Mosher (1969). A minimum of 4 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 scales remain, 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 opportunistically for chum salmon.

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. During 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 (late October to early November) 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.

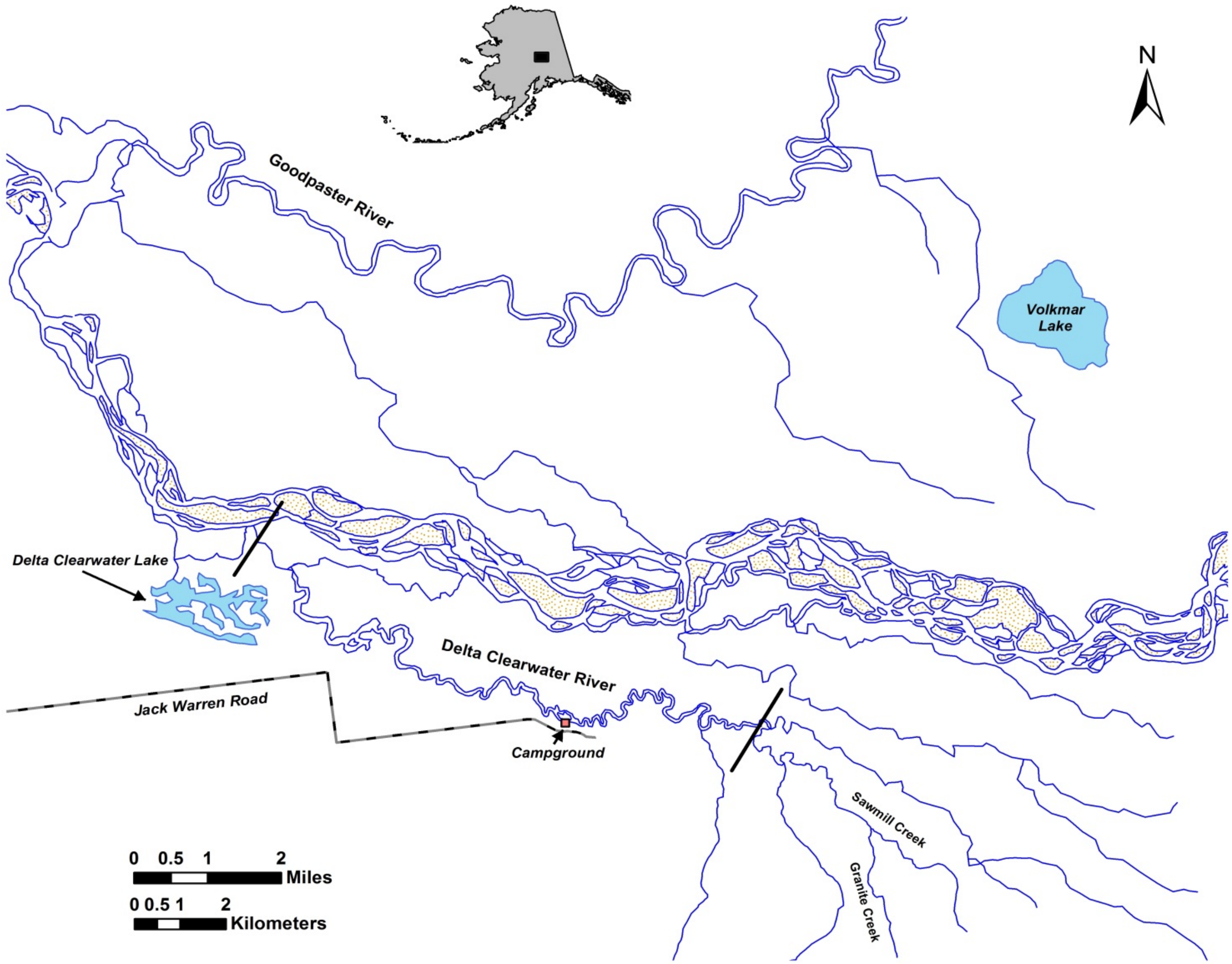

Figure 3.–Map of the Delta Clearwater River demarcating the survey area (bold lines).

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 to estimate escapement. A count with an associated water clarity rating of 4 or 5 is considered as no count. Each day, the data sheets will be returned to the project leader at the end of Shift 3.

All recorded images from the sonars will be stored on an external hard drive. 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 down the left side 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. 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 one-mile section of river 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 visual data will be entered into a Microsoft Excel spreadsheet for data analysis. The spreadsheet calculates daily estimates of Chinook and chum salmon escapement and the associated variance. Summary tables documenting the daily counts, number of counts conducted, expanded counts, and cumulative totals for Chinook and chum salmon passage are also generated.

Recorded data from the sonars will be stored on external hard drives. In previous years, all recorded sonar files were processed 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. For this operational plan, the top-of-the-hour sonar files will be processed in-season and text files will be copied and brought to the office for processing daily. Sonar data will be entered into 2 separate Microsoft Excel spreadsheets based on measured fish length.

Species, sex, and length data from carcass samples will be entered into a Microsoft Excel spreadsheet. Once scales are cleaned and mounted onto scale cards, scale cards and a copy of the spreadsheet will be sent to Division of Commercial Fisheries (DCF) in Anchorage. The scale samples will be imprinted on acetate cards and aged, and the ages will be entered into the spreadsheet for the corresponding fish. The completed file will be used by DCF for assessment and reporting purposes. A copy of the file will be returned to Fairbanks for final analysis and archiving.

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 annually in a memo to all state and federal agencies and stakeholders. A final FDS Report covering 3 years of the project will be available at the end of each period of grant funding.

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, sonar targets will be measured into two length categories using 650 mm as the cutoff value and reported inseason. Post-season, escapement for these dates will be estimated using the mixture model that apportions the sonar counts of salmon by species and compared to the inseason estimates (Huang 2012, Stuby and Tyers 2016);
4. when all 8-hr shifts on 3 or more but fewer than 10 consecutive days are considered incomplete, postseason daily escapement values will be assessed using a mixture model that apportions the sonar counts of salmon by species (Huang 2012, Stuby and Tyers 2016); 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 run-timing 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), none 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 are comprised of the 8-h shifts within a day and the second stage the 20 min counting periods within each 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:

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

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

$$\bar{Y}_{d} = \frac{\sum_{i=1}^{h_d} \hat{Y}_{di}}{h_d} \, . \qquad (2)$$

The expanded daily escapement will be:

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

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

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

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:

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

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

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

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 in a given day; and,

f_2 = fraction of 20 min counting periods sampled in a given 8-h shift.

Total escapement and variance estimates are calculated as 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 allow for 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 1 shift is worked, an average CV will be calculated as:

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

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). Sonar data will be used to fill gaps that exceed 3 days of lost visual counts.

Carcass Surveys

Past mark-recapture work on Chinook salmon in the Chena and Salcha rivers has demonstrated biased estimates of sex composition from carcass surveys and therefore a "correction factor" is used to derive unbiased estimates of sex composition. A comparison of sex composition estimates from past 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; Doxey 2004). To correct for this bias we compared the sex composition estimates from the mark-recapture data to that calculated from carcass sampling and used the average of that ratio as our correction factor. The values used for those corrections are based on mark-recapture data from 9 and 7 years from the Chena (1989–1992, 1995–1997, 2000, and 2002) and Salcha rivers (1987–1992, 1996), respectively (Doxey 2004).

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 including 1 year of egg development). 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 2004).

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

$$\tilde{p}_{fe} = \hat{p}_{fc}\hat{R}_p \tag{18}$$

with variance:

$$\hat{V}(\tilde{p}_{fe}) = \hat{p}_{fc}^2\hat{V}(\hat{R}_p) + \hat{R}_p^2\hat{V}(\hat{p}_{fc}) - \hat{V}(\hat{R}_p)\hat{V}(\hat{p}_{fc}). \tag{19}$$

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

$$\tilde{p}_{me} = 1 - \tilde{p}_{fe} \quad (20)$$

with variance:

$$\hat{V}(\tilde{p}_{me}) = \hat{V}(\tilde{p}_{fe}). \quad (21)$$

Escapement of each sex is then estimated by:

$$\hat{N}_s = \tilde{p}_{se}\hat{N} \quad (22)$$

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

$$\hat{V}(\hat{N}_s) = \hat{V}(\tilde{p}_{se})\hat{N}^2 + \hat{V}(\hat{N})\tilde{p}_{se}^2 - \hat{V}(\tilde{p}_{se})\hat{V}(\hat{N}). \quad (23)$$

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

$$\hat{p}_{sk} = \frac{n_{sk}}{n_s} \quad (24)$$

where $\hat{p}_{sk}$ = the estimated proportion of Chinook salmon that are age *k*; n_{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:

$$\hat{V}[\hat{p}_{sk}] = \frac{\hat{p}_{sk}(1 - \hat{p}_{sk})}{n_s - 1} \quad (25)$$

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

$$\bar{l}_{sk} = \frac{\sum_{j=1}^{n_{sk}} l_{skj}}{n_{sk}}\text{; and,} \quad (26)$$

$$V[\bar{l}_{sk}] = \frac{\sum_{j=1}^{n_{sk}} (l_{skj} - \bar{l}_{sk})^2}{n_{sk}(n_{sk} - 1)}. \quad (27)$$

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

$$\hat{N}_{sk} = \hat{p}_{sk}\hat{N}_s \quad (28)$$

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

$$\hat{V}(\hat{N}_{sk}) = \hat{V}(\hat{p}_{sk})\hat{N}_s^2 + \hat{V}(\hat{N}_s)\hat{p}_{sk}^2 - \hat{V}(\hat{p}_{sk})\hat{V}(\hat{N}_s). \quad (29)$$

Sonar Mixture Model

In addition to inseason estimation of Chinook salmon passage by counting sonar images of fish > 650 mm, we will also use a Bayesian mixture model to provide a more precise estimate of

Chinook and chum salmon passage by estimating the species composition (Chinook vs. chum salmon). 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 a (l_a) will be modeled using a weighted mixture model,

$$f(l_a) = \pi_{c,a} f_c(l_a) + \pi_{k,a} f_k(l_a), \tag{30}$$

where:

$$0 \leq \pi_{c,a}, \pi_{k,a} \leq 1, \text{ and } \pi_{c,a} + \pi_{k,a} = 1 \tag{31}$$

and where $f_c(l_a)$ is the length distribution of chum salmon and $f_k(l_a)$ is the length distribution of Chinook salmon; weights $\pi_{c,a}$ and $\pi_{k,a}$ 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,

$$f_c(l_a) = \psi_{cf} f_{cf}(l_a) + \psi_{cm} f_{cm}(l_a) \tag{32}$$

and

$$f_k(l_a) = \psi_{kf} f_{kf}(l_a) + \psi_{km} f_{km}(l_a) \tag{33}$$

where ψ_{cm} and ψ_{cf} are the proportions of male and female chum salmon, respectively; and ψ_{km} and ψ_{kf} 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 sex *s* and species *g*, within year *t*.

$$l_a \sim N(\mu_{gst}, \sigma^2_{gs}) \tag{34}$$

Prior distributions of the length means (μ) and variances (σ^2) in equation (34) will be modeled hierarchically using data from each year's carcass surveys and from data found in other fishery research publications. For this study, additional 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). In order to account for yearly variation in length composition, a hierarchical normal distribution is assumed for carcass *c* lengths associated with each year's run:

$$\mu_{gst} \sim N\left(\mu_{gs}, \sigma^2_{\mu gs}\right) \quad for\ t = 1, \dots, T \tag{35}$$

$$l_c \sim N\left(\mu_{gst}, \sigma^2_{gs}\right) \quad for\ c = 1, \dots, N_{gst} \tag{36}$$

This relationship will be modeled separately, and model code is provided in Appendix D. The respective posterior means and variances associated with the analysis year's mean length and global error variance will be used as parameters for the associated mixture model priors. True individual fish length (*l*) is not measured directly from individual fish and therefore is considered an unobserved variable. Instead, fish length will be measured from sonar images. A linear relationship is assumed between sonar length ($l_{obs,a}$) and the true fish length (l_a) for fish a. The sonar fish length ($l_{obs,a}$) is modeled as a normal variable whose mean is a linear function of actual fish length (l_a; Equation 37).

$$l_{obs,a} = \beta_0 + \beta_1 l_a + \varepsilon_a \quad (37)$$

where $l_{obs,a}$ refers to observed sonar length, which are the fish length measurements obtained from the sonar images; l_a refers to the actual fish length; the intercept β_0 and slope β_1 are unknown parameters of the linear relationship between $l_{obs,a}$ and l_a. Paired data used to inform the relationship between $l_{obs,a}$ and l_a were obtained from a tethered-fish experiment (conducted by D. Burwen and S. Fleischman, ADF&G, personal communication).

The mixture model (equations 30–34) contains unknown parameters including species probability parameters $\pi_{g,a}$, sex proportion parameters ψ_s, intercept parameter β_0, and slope parameter β_1. In order to estimate these unknown parameters, the mixture model will be 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 jagsUI (Kellner 2017) or equivalent.

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 30). The prior distributions of the sex ratio parameters ψ_s were assigned a Dirichlet (5, 5) 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 probability parameters $\pi_{gr,a}$ for run day x_a on river r are assigned diffuse Dirichlet priors ($\eta_{r,a}$, $\zeta_{r,a}$) calculated by run date according to:

$$log\left(\frac{\eta_{dr}}{1-\eta_{dr}}\right) = \alpha_{0r,t} + \alpha_{1r,t} x_d \quad (38)$$

and

$$\zeta_{dr} = 1 - \eta_{dr}. \quad (39)$$

Hyperparameters $\alpha_{0r,t}$ and $\alpha_{1r,t}$ are estimated for each river r and year t using a hierarchical multivariate logistic regression model to model the relationship between run-timing and species in historical data. Logistic hyperparameters are modeled as multivariate normal to account for correlation between rivers. Parameter $\varphi_{dr,t}$ is used to denote the probability of a visually observed salmon on day d and river r being a Chinook salmon.

$$y_{kdr,t} \sim Binom\left(\phi_{dr,t}, (y_{kdr,t} + y_{cdr,t})\right) \quad (40)$$

where

$$\log\left(\frac{\phi_{dr,t}}{1-\phi_{dr,t}}\right) = \alpha_{0r,t} + \alpha_{1r,t} x_{dr,t} \quad (41)$$

$$\alpha_{0t} \sim MVN(\mu_{\alpha 0}, \Sigma_{\alpha 0}) \quad (42)$$

where

$$\Sigma_{\alpha 0} = \begin{bmatrix} \sigma^2_{\alpha 0,Chena} & \rho_{\alpha 0}\sigma_{\alpha 0,Chena}\sigma_{\alpha 0,Salcha} \\ \rho_{\alpha 0}\sigma_{\alpha 0,Chena}\sigma_{\alpha 0,Salcha} & \sigma^2_{\alpha 0,Salcha} \end{bmatrix} \quad (43)$$

$$\alpha_{1t} \sim MVN(\mu_{\alpha 1}, \Sigma_{\alpha 1}) \quad (44)$$

where:

$$\Sigma_{\alpha 1} = \begin{bmatrix} \sigma^2_{\alpha 1,Chena} & \rho_{\alpha 1}\sigma_{\alpha 1,Chena}\sigma_{\alpha 1,Salcha} \\ \rho_{\alpha 1}\sigma_{\alpha 1,Chena}\sigma_{\alpha 1,Salcha} & \sigma^2_{\alpha 1,Salcha} \end{bmatrix} \quad (45)$$

This relationship will be modeled separately from the species-apportionment mixture model, and posterior median values for α_{0r} and α_{1r} associated with the estimation year will be used as constants in the species-apportionment model to aid convergence. JAGS code for this model is included in Appendix E.

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

In the event of incomplete sonar data, posterior sonar totals for each species and river may be expanded in the same manner as visual counts, using equations 1–3 and substituting the posterior median counts associated with each 20-minute period of available data.

The assumption can be made that the variances due to expansion and due to modeled species apportionment are independent, and therefore additive. Day-level variance can therefore be considered as a sum of the variance due to expansion and the expansion of the variance due to apportionment, as calculated in a modified form of Equation 6 with appropriate substitutions. In the third term, $V(y_{di})$ denotes the variance of the 20-minute period count in the sonar mixture model.

$$\hat{V}(\hat{N}_d) = \left[(1-f_{1d})H_d^2\frac{s_{1d}^2}{h_d}\right] + \left[\frac{1}{f_{1d}}\sum_{i=1}^{h_d}\left((1-f_{2di})M_{di}^2\frac{s_{2di}^2}{m_{di}}\right)\right] + \left(\frac{H_d}{h_d}\right)^2\sum_{i=1}^{h_d}\left(\frac{M_{di}}{m_{di}}\right)^2 V(y_{di}) \quad (46)$$

JAGS code for the mixture model can be found in Appendix B.

Bayesian hierarchical run-timing 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 run-timing 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 *t* are assumed to be normally distributed around either a lognormal, extreme-value, or log-logistic trends by date.

$$\hat{N}_{t[d]} \sim N(\theta_{t[d]}, {\sigma_\theta}^2) \quad (47)$$

The run-timing trends of year *t* are determined by 3 parameters: a_t describes the amplitude of the run peak, μ_t describes the location by date of the run peak, and b_t 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 $x_{t[d]}$.

$$\theta_{t[d]} = a_t e^{\left(-0.5\left(\frac{ln\left(\frac{x_{t[d]}}{\mu_t}\right)}{b_j}\right)^2\right)} \quad (48)$$

$$\theta_{t[d]} = a_t e^{\left(-e^{\left(-\frac{x_{t[d]}-\mu_t}{b_t}\right)}-\left(\frac{x_{t[d]}-\mu_t}{b_t}\right)+1\right)} \quad (49)$$

$$\theta_{t[d]} = a_t \left(\frac{\left(\frac{b_t}{\mu_t}\right)\left(\frac{x_{t[d]}}{\mu_t}\right)^{(b_t-1)}}{\left(1+\left(\frac{x_{t[d]}}{\mu_t}\right)^{b_t}\right)^2}\right) \quad (50)$$

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

$$\mu_t \sim N(\mu_0, {\sigma_\mu}^2) \quad (51)$$

and

$$b_t \sim N(b_0, {\sigma_b}^2) \quad (52)$$

with uninformative priors placed on parameters μ_0, σ_μ^2, b_0, and σ_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, mean timing parameters μ_t for each river are not modeled independently; rather, the difference δ between the two will be modeled as Normal. This will allow the model to have greater predictive power, particularly if counts are available for one river while a data gap exists for the other.

$$\mu_{t,Salcha} = \mu_{t,Chena} + \delta_t \quad (53)$$

where:

$$\delta_t \sim N(\mu_\delta, \sigma_\delta) \quad (54)$$

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:

$$E_{\min} = \sum_{i=1}^{s} C_i \quad (55)$$

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 memorandum for which a draft will be submitted to the Research Supervisor by 1 March each year; a final FDS report will be submitted at the end of each river's 3 year AKSSF contract. The FDS report will be uploaded to the AKSSF website as project deliverables. Semiannual reports will also be submitted online each year to satisfy the AKSSF 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

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

Phil Joy, Fisheries *Biologist III*. General project support and editing of annual report.

Pete Nyren, *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.

Matt Stoller, *Fish & Wildlife Technician III*. 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.

Vacant, *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.

Brit Hayes, *Fish & Wildlife Technician II*. Salcha River and Chena River Crew Member. Oversees sonar operations for both rivers, mobilization, day-to-day project tasks, all aspects of field work, demobilization.

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

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

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

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

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

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

Vacant, *Fish & Wildlife Technician II (Non Perm*). Salcha 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 III*. Assist with project design and data analysis.

James Savereide, *Fishery Biologist IV*. Final report editing and project support.

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

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APPENDIX A:
CHENA RIVER DAILY COUNT FORMS AND CARCASS SAMPLE FORM

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

VISUAL TOWER COUNTS

RIVER: ______________________

DATE: ________________________

Total Salmon= Number up minus number down

OBSERVER:

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

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

OBSERVER:

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

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

OBSERVER:

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

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

Appendix A2.–Field Forms used to record daily 20-min sonar counts for the Salcha and Chena rivers.

SONAR COUNTS

RIVER: ______________________

DATE: ________________________

Total Salmon= Number up minus number down

OBSERVER: ____

Time	TOWER-SIDE				GRAVELBAR-SIDE			Comments
	Up	Down	Total		Up	Down	Total	
0000								
0100								
0200								
0300								
0400								
0500								
0600								
0700								
TOTAL								

OBSERVER: ____

Time	TOWER-SIDE				GRAVELBAR-SIDE			Comments
	Up	Down	Total		Up	Down	Total	
0800								
0900								
1000								
1100								
1200								
1300								
1400								
1500								
TOTAL								

OBSERVER: ____

	TOWER-SIDE				GRAVELBAR-SIDE			Comments
Time	Up	Down	Total		Up	Down	Total	
1600								
1700								
1800								
1900								
2000								
2100								
2200								
2300								
TOTAL								

Appendix A3.–Salmon carcass survey field form for the Salcha and Chena rivers.

DATE:__________________________ RIVER:______________________

START LOCATION:________________________ END LOCATION:_______________________

CHINOOK				**CHUM**		
Fish#	**Sex**	**Length (mm)**		**Sex**	**Length (mm)**	**Comments**

APPENDIX B:
JAGS CODE OF MIXTURE MODEL

Appendix B1.–JAGS code of mixture model[ab].

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

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

      logit(pi[i]) <- b0[river[i]]+b1[river[i]]*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])
   }

   prec[1,1,1] <- pow(chena_chin_m_sd,-2)
   prec[1,2,1] <- pow(chena_chin_f_sd,-2)
   prec[2,1,1] <- pow(chena_chum_m_sd,-2)
   prec[2,2,1] <- pow(chena_chum_f_sd,-2)
   prec[1,1,2] <- pow(salcha_chin_m_sd,-2)
   prec[1,2,2] <- pow(salcha_chin_f_sd,-2)
   prec[2,1,2] <- pow(salcha_chum_m_sd,-2)
   prec[2,2,2] <- pow(salcha_chum_f_sd,-2)

   chena_chin_m_sd ~ dnorm(chena_chin_m_sd_mn, chena_chin_m_sd_prec)
   chena_chin_f_sd ~ dnorm(chena_chin_f_sd_mn, chena_chin_f_sd_prec)
   chena_chum_m_sd ~ dnorm(chena_chum_m_sd_mn, chena_chum_m_sd_prec)
   chena_chum_f_sd ~ dnorm(chena_chum_f_sd_mn, chena_chum_f_sd_prec)
   salcha_chin_m_sd ~ dnorm(salcha_chin_m_sd_mn, salcha_chin_m_sd_prec)
   salcha_chin_f_sd ~ dnorm(salcha_chin_f_sd_mn, salcha_chin_f_sd_prec)
   salcha_chum_m_sd ~ dnorm(salcha_chum_m_sd_mn, salcha_chum_m_sd_prec)
   salcha_chum_f_sd ~ dnorm(salcha_chum_f_sd_mn, salcha_chum_f_sd_prec)
```

```
chena_chin_m_sd_prec <- pow(chena_chin_m_sd_sd,-2)
chena_chin_f_sd_prec <- pow(chena_chin_f_sd_sd,-2)
chena_chum_m_sd_prec <- pow(chena_chum_m_sd_sd,-2)
chena_chum_f_sd_prec <- pow(chena_chum_f_sd_sd,-2)
salcha_chin_m_sd_prec <- pow(salcha_chin_m_sd_sd,-2)
salcha_chin_f_sd_prec <- pow(salcha_chin_f_sd_sd,-2)
salcha_chum_m_sd_prec <- pow(salcha_chum_m_sd_sd,-2)
salcha_chum_f_sd_prec <- pow(salcha_chum_f_sd_sd,-2)

precL <- 1/(54.59*54.59)

betaD0[1] ~ dnorm(betaD0_mn,betaD0_prec)
betaD1[1] ~ dnorm(betaD1_mn,betaD1_prec)
betaD0[2] ~ dnorm(betaD0_mn,betaD0_prec)
betaD1[2] ~ dnorm(betaD1_mn,betaD1_prec)

b0 <- mu.b0 # ~ dnorm(mu.b0,prec.b0)
b1 <- mu.b1 # ~ dnorm(mu.b1,prec.b1)

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

lambda[1,1,1] ~ dnorm(chena_chin_m_mn,t1)
lambda[1,2,1] ~ dnorm(chena_chin_f_mn,t2)
lambda[2,1,1] ~ dnorm(chena_chum_m_mn,t3)
lambda[2,2,1] ~ dnorm(chena_chum_f_mn,t4)
lambda[1,1,2] ~ dnorm(salcha_chin_m_mn,t5)
lambda[1,2,2] ~ dnorm(salcha_chin_f_mn,t6)
lambda[2,1,2] ~ dnorm(salcha_chum_m_mn,t7)
lambda[2,2,2] ~ dnorm(salcha_chum_f_mn,t8)

t1 <- pow(chena_chin_m_se,-2)
t2 <- pow(chena_chin_f_se,-2)
t3 <- pow(chena_chum_m_se,-2)
t4 <- pow(chena_chum_f_se,-2)
```

```
t5 <- pow(salcha_chin_m_se,-2)
t6 <- pow(salcha_chin_f_se,-2)
t7 <- pow(salcha_chum_m_se,-2)
t8 <- pow(salcha_chum_f_se,-2)



}
```

[a]The species proportions π_c and π_k were coded as *ps* and the sex proportions ψ's were coded as *psex*. Parameters *lambda*'s refer to the means of the length distribution of Chinook and chum salmon for each river, and the ζ and η parameters were expressed by the two-element vector *alpha.inf*. By JAGS coding convention, all Normal standard deviation parameters were expressed in terms of precision (the reciprocal of variance), and were coded as either *prec* or *t*.

[b]To speed convergence, the paired sonar and actual length data were modeled in a separate regression, with results used as prior distributions for β_0/*BetaD0* and β_1/*BetaD1*. The constant value for *precL* also comes from this relationship.

APPENDIX C:
JAGS CODE OF BAYESIAN HIERARCHICAL RUN-TIMING 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]
 }
}
}
```

APPENDIX D:
JAGS CODE OF BAYESIAN HIERARCHICAL MEANS MODEL

Appendix D1.–JAGS code of Bayesian Hierarchical Means Model

```
model {
  for (i in 1:N) {
    y[i] ~ dnorm(mu[cat[i],year[i]], tau[cat[i]])
  }
  for(j in 1:Ncat) {
    for(k in 1:Nyear) {
      mu[j,k] ~ dnorm(mumu[j], taumu[j])
    }
    mumu[j] ~ dnorm(500,0.0001)
    sigmu[j] ~ dunif(0,100)
    taumu[j] <- pow(sigmu[j], -2)
    tau[j] <- pow(sigma[j], -2)
    sigma[j] ~ dunif(0,500)
  }
  catmean[1:Ncat] <- mu[1:Ncat,Nyear]

}
```

APPENDIX E:
JAGS CODE OF BAYESIAN HIERARCHICAL LOGISTIC MODEL

Appendix E1.–JAGS code of Bayesian Hierarchical Logistic Model

```
model {
 for(i in 1:Cn) {
  logit(Cpi[i]) <- a0[Cyear[i],1] + a1[Cyear[i],1]*Cday[i]
  Cchin[i] ~ dbin(Cpi[i],Ctot[i])
 }
 for(i in 1:Sn) {
  logit(Spi[i]) <- a0[Syear[i],2] + a1[Syear[i],2]*Sday[i]
  Schin[i] ~ dbin(Spi[i],Stot[i])
 }
 for(i in 1:nyear) {
  a0[i,1:2] ~ dmnorm(b0[],tau0[,])
  a1[i,1:2] ~ dmnorm(b1[],tau1[,])
 }
 tau0[1:2,1:2] <- inverse(Sigma0[,])
 tau1[1:2,1:2] <- inverse(Sigma1[,])
 Sigma0[1,1] <- pow(sig01,2)
 Sigma0[2,2] <- pow(sig02,2)
 Sigma0[1,2] <- rho0*sig01*sig02
 Sigma0[2,1] <- Sigma0[1,2]
 sig01 ~ dunif(0,10)   # was 1000
 sig02 ~ dunif(0,10)   # was 1000
 rho0 ~ dunif(-1,1)
 Sigma1[1,1] <- pow(sig11,2)
 Sigma1[2,2] <- pow(sig12,2)
 Sigma1[1,2] <- rho1*sig11*sig12
 Sigma1[2,1] <- Sigma1[1,2]
 sig11 ~ dunif(0,10)
 sig12 ~ dunif(0,10)
 rho1 ~ dunif(-1,1)
 b0[1] ~ dnorm(0,0.001)
 b1[1] ~ dnorm(0,0.001)
 b0[2] ~ dnorm(0,0.001)
 b1[2] ~ dnorm(0,0.001)  }
```