Fishery Data Series No. 12-39

Sonar-based Chena River Salmon Assessment 2008

by

Jiaqi Huang

August 2012

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

Symbols and Abbreviations

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Weights and measures (metric)

centimeter	cm
deciliter	dL
gram	g
hectare	ha
kilogram	kg
kilometer	km
liter	L
meter	m
milliliter	mL
millimeter	mm

Weights and measures (English)

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

Time and temperature

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

Physics and chemistry

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

General

Alaska 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

FISHERY DATA SERIES NO. 12-39

SONAR-BASED CHENA RIVER SALMON ASSESSMENT 2008

By
Jiaqi Huang

Division of Sport Fish, Fairbanks

Alaska Department of Fish and Game
Division of Sport Fish, Research and Technical Services
333 Raspberry Road, Anchorage, Alaska, 99518-1599

August 2012

Development and publication of this manuscript were partially financed by the Federal Aid in Sport fish Restoration Act (16 U.S.C.777-777K) under Project F-10-17 and 18, Job No. S-3-1(a).

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Jiaqi Huang,
Alaska Department of Fish and Game, Division of Sport Fish
1300 College Road, Fairbanks, AK 99701-1599, USA

This document should be cited as:

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

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ABSTRACT

Dual-frequency Identification Sonar (DIDSON) was deployed in the Chena River, Alaska, during the Chinook salmon run of 2008. The sonar was tested alongside the existing Chena River counting tower project to count the salmon escapement in the river. The sonar was in operation from 9 July to 25 July, 2008. The acoustic data recovered from the sonar equipment were processed and the images of fish generated from the data were examined. Fish length measurements based on the sonar images were collected using preprogrammed DIDSON software. The total fish escapement including Chinook (*Oncorhynchus tshawytscha*) and chum (*Oncorhynchus keta*) salmon was estimated to be 3,814 (SE = 182) during this period. A statistical mixture model was applied to distinguish the two species based on their different length distributions. The estimated proportion of Chinook salmon was 88.1% (SE = 2.3%) and the estimated proportion of chum salmon was 11.9% (SE = 2.3%). Accordingly, the estimated Chinook salmon escapement was 3,362 (SE = 183) and the estimated chum salmon escapement was 452 (SE = 90). In comparison, during the same period, the counting tower project reported a total of 2,761 (SE = 181) Chinook and 617 (SE = 88) chum salmon. The difference between DIDSON and counting tower techniques are discussed in the report.

Key words: Chinook salmon, *Oncorhynchus tshawytscha*, chum salmon, *Oncorhynchus keta*, Chena River, DIDSON, sonar, escapement, mixture model.

INTRODUCTION

CHENA RIVER MANAGEMENT

The Chena River flows west from the White Mountains approximately 257 km to the Tanana River through the city of Fairbanks. Both the Chena and Tanana rivers are tributaries of the Yukon River. The Chena River supports one of the largest spawning Chinook salmon (*Oncorhynchus tshawytscha*) populations in the Alaska portion of the Tanana River drainage. Adult Chinook salmon migrate into the Tanana River and appear in the Lower Chena River between late June and the second week of July. The Chinook salmon run typically ends near the end of July or the beginning of August (Brase 2008). Chum salmon (*Oncorhynchus keta*) and Arctic grayling (*Thymallus arcticus*) are also present in the Chena River. Chena River Chinook and chum salmon are harvested in commercial, subsistence, and sport fisheries throughout the Yukon and Tanana rivers. The fisheries may be restricted or closed when the projected run size falls below the biological escapement goal (BEG) adopted by the Alaska Board of Fisheries (BOF). In 2000, the BEG range for Chinook salmon was set to be 2,800–5,700 in the Chena River.

Annual assessment of the Chinook salmon escapement in the Chena River has been conducted since 1986 by Alaska Department of Fish and Game (ADF&G). Mark-recapture and counting tower techniques were used to gather the information of the salmon return. Counting tower techniques were heavily relied on to count the day-to-day Chinook salmon run in the Chena River. The counting tower operation was conducted annually on the Moose Creek dam (Figure 1) at river km 72 during the Chinook salmon run. All Chinook salmon spawning occurs upstream of this site. Monitoring of this counting tower provides important run information in terms of run size and timing so that the area manager can issue timely changes in the regulations in order to achieve the BEG while attempting to meet the needs of the subsistence, commercial, and sport fisheries. The recent 5-year (2003–2007) average annual escapement of Chinook salmon in the Chena River was 6,282, the recent 5-year (2003–2007) average sport catch of Chinook salmon was reported to be 2,024, and the average harvest was 428 fish (Brase 2009).

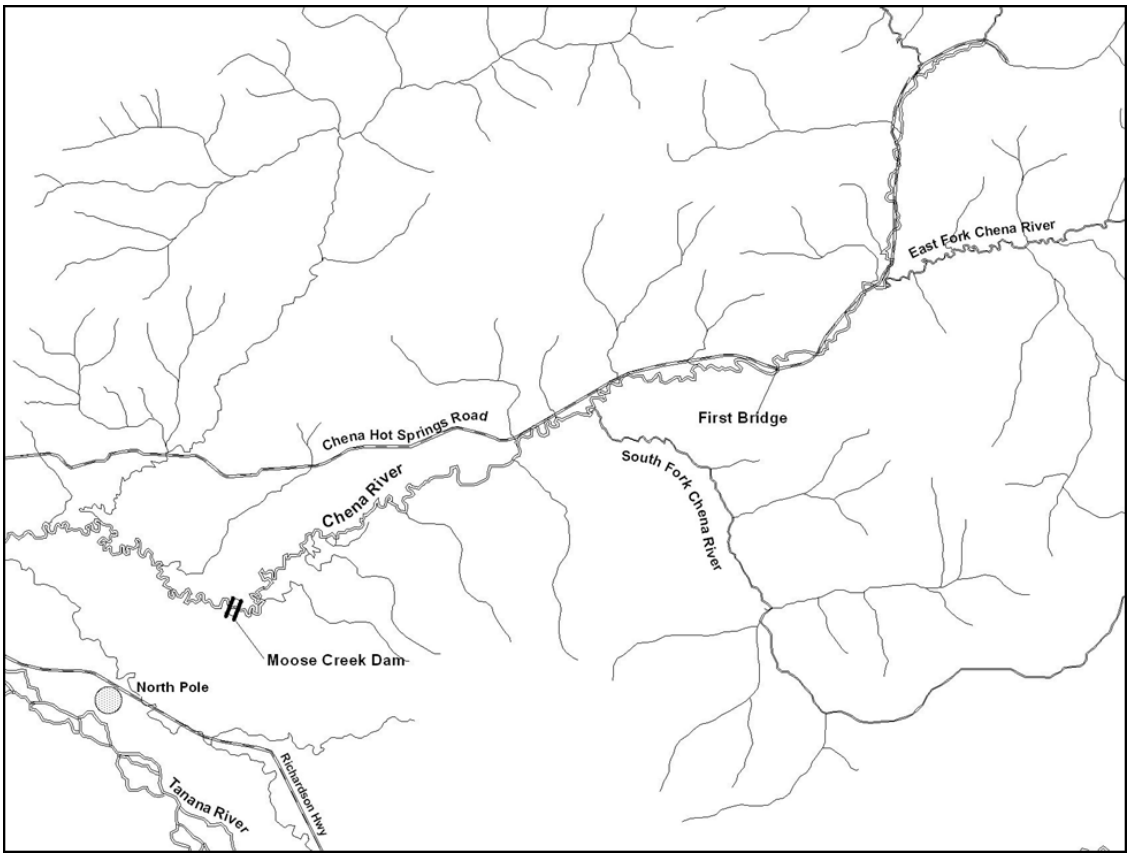


Figure 1.–Map of the Chena River and the Moose Creek Dam.

Enumerating salmon passage using counting tower techniques is affected by water turbidity and ambient light conditions. During periods of low ambient light (at night and during inclement weather) additional lighting is required to observe migrating salmon. When the water level is high and/or the river is turbulent, the observation of passing fish is not possible and no data are recorded. In 2005, the counting tower did not produce an estimate of Chinook salmon escapement because the water was high and turbid for most of the counting period. Information on run magnitude and timing is needed by the manager to modify fishing regulations to achieve the established escapement goal. When the water conditions are not suitable for a counting tower, a more reliable and accurate technique is needed to estimate escapement. In 2008, a dual frequency identification sonar (DIDSON) was deployed in the Chena River to determine if this methodology is an appropriate means to estimate salmon passage when conditions prohibit tower counts.

SONAR OVERVIEW

Side-scan, fixed-location, underwater sonar technology for detecting and estimating inriver salmon abundance was introduced to salmon fishery management in Alaska in the early 1970s. Since that time, several generations of sonar technology have been studied and adapted for fisheries management in Alaskan rivers. The first model of sonar adopted for counting fish was designed by the Electrodynamics Division of the Bendix Corporation[1]. The feasibility test of using this type of single-beam Bendix sonar to count fish was carried out in a field experiment on the Kvichak River, Alaska, in 1970 (Paulus and McCurdy 1972). Also, in 1978, two single-beam sonar devices were

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

deployed on both banks of the Copper River to count the sockeye salmon escapement to the spawning tributaries of the Upper Copper River drainage; as described in Brady (1986). At the time, there was no species apportionment by sonar and all counts were classified as salmon passage. The single-beam sonar technology was studied along with the existing mark and recapture techniques of estimating fish passage using fish wheels, fish traps, electrofishing, and/or drift gillnets. Although the mark and recapture technique was proved to be more accurate, the sonar can provide daily fish counts. Such information is beneficial for fishery management during the fishing season.

Dual-beam sonar technology replaced the single-beam in the 1980s and was used for the Kenai River Chinook salmon escapement project. It was reported that the acoustic size (target strength) measured by the dual-beam sonar could be used to classify the species in the Kenai River, primarily Chinook and sockeye salmon. Management-level operation of this technology on the Kenai River began in early July 1987 (Eggers et al. 1995). Target strength thresholds were set up in order to distinguish the large fish (mainly Chinook salmon) from the smaller fish. However, the acoustic signals generated by the dual-beam sonar were mixed with other acoustic noises, which induced errors into the population estimates. The classification and counts were thus not accurate and were recommended to serve as indices of abundance instead of real counts (Burwen et al. 1998).

In the 1990s, split-beam sonar replaced dual-beam sonar. Research by Fleischman and Burwen (2003) reported that echo-envelope length derived from the sonar signal served as a better discriminatory variable to identify and count large Chinook salmon than target strength.

In 2003, a new dual frequency identification sonar (DIDSON) was introduced into fisheries management in Alaska. DIDSON generates high frequency, narrowband hydroacoustic data that can give high resolution video-like images of the fish detected. The advantage of DIDSON sonar over counting tower techniques is that the water level and turbidity has little impact on the quality of the hydroaccoustic data. The data produced by DIDSON can be stored and re-studied as needed whereas counting fish from a counting tower relies heavily on an individual's one-time judgment. In addition, with pre-programmed software, the lengths of fish can be measured manually on a computer. Although the fish lengths measured from DIDSON images did not represent the actual fish length, a tethered-fish experiment shows that the DIDSON fish length is a good predictor of the actual fish length (Burwen et al. 2007).

SPECIES PROPORTION

The two major species of interest present in the Chena River during this study were Chinook and chum salmon. The DIDSON sonar collected hydroacoustic data for both species in the river. The species cannot be distinguished by just examining the sonar footage. However, it is essential to distinguish between the two species so managers can have accurate information on the populations of both species and set regulations accordingly. Although Chinook salmon are generally larger in size than chum salmon, it is difficult to distinguish the two species because they may differ only modestly in size. Simply setting up a threshold to distinguish the two species can cause unreasonable bias especially when the discriminating criterion is unknown and the length distributions of two species overlap. Therefore, in this study, a statistical mixture model was established to estimate the proportions of the two species in the river. Mixture models are widely used to model heterogeneous data. It provides a framework for statistical modeling when the data are categorized into one of many classes, and whose individual class memberships

are unavailable (Gelman et al. 2004). Using a mixture model to estimate species composition based on length information can help avoid the problems that would have been caused by a threshold-based approach. In this study, sex and length compositions of the two species reported from recent literature were acquired and incorporated in the mixture model. Statistical software WinBUGS (Bayesian inference Using Gibbs Sampling; Lunn et al. 2000) and the statistical software program R[2] were used to establish the model and estimate the proportion parameters.

OBJECTIVES

The primary objectives in 2008 were:

1. Test the DIDSON's ability to enumerate the migrating fish in the Chena River and estimate the total number of fish migrating upstream of the sonar site;
2. Estimate the proportions of Chinook and chum salmon migrating upstream of the sonar site based on their length information using a mixture model; and,
3. Estimate the number of Chinook and chum salmon migrating upstream of the sonar site separately.

METHODS

SONAR INSTALLATION

A sonar site was installed in the Chena River, Alaska, from July 9 to July 25, 2008, to monitor the passage of returning Chinook and chum salmon. The sonar (DIDSON Model 300 Sonar Metric Corp., Lake Forest Park, WA) was located downstream of the ADF&G counting tower located on the Moose Creek Dam (river km 72; Figure 1) on the north bank of the Chena River. The sonar was positioned to capture images of the river profile tilted slightly towards the bottom of the river. The river is approximately 42 m wide at the sonar site but the majority of fish observed at the counting tower site are closer to the north bank than the middle or south bank. A DIDSON transducer was fixed onto an aluminum tripod, which was then deployed offshore into the river. The angle and the depth of the transducer were adjusted so that the insonified area would cover the majority (40 m) of the river at low frequency (1.1 MHz). Weir structures were used upstream and downstream of the sonar site to ensure migrating fish would swim in front of the sonar transducer and to prevent debris from colliding into the transducer. The sonar was operated 24 hours a day, and 7 days a week. The transducer was programmed to shift from low frequency to high frequency every 30 minutes on a systematic sampling scheme. The low frequency operation of the sonar covered the insonified area from 15 to 40 m from the north bank. The high frequency (1.8 MHz) operation covered the first 15 m from the north bank. The sonar power was provided by the nearby dam facility. The crew members of the counting tower project were responsible for the sonar's continuous operation, keeping the transducer clear of any debris in the river, and adjusting the depth and angle of the transducer when necessary. Each day the hydroacoustic data recorded were downloaded to a portable hard drive and later sent to the ADF&G office in Fairbanks for further analysis.

DATA COLLECTION

The sonar data were processed using pre-programmed software, DIDSON Control and Display (Version 5.20.09; Sonar Metric Corp., Lake Forest Park, WA). This software was used to display the hydroacoustic data in both an echogram and a video-like footage, as well as to identify the fish by its location and time, and measure the lengths of fish. The software interface

[2] The R Project for statistical computing. Available for download from http://www.r-project.org/

and the length measuring procedure are illustrated in Appendix A (Appendix A1 illustrates a frame of the sonar image that identifies objects within the detecting range of the sonar device).

Usually the sonar data were first transformed into an echogram, which displayed the hydroacoustic-echoes by its occurring location and time (Appendix A2). A fish could be quickly and easily spotted by identifying a shadow area on the echogram (Appendix A2). Once the fish was identified, video-like footage was then easily retrieved by right clicking the computer's mouse on the spot on the echogram. The footage was zoomed and adjusted to its best angle and clearest frame before the fish's length was measured. Appendix A3 illustrates a zoomed fish image. A line was drawn manually from its head to tail by two segments using the measuring tool provided by the software. Length and location information are displayed at the right and left lower corners of the frame, respectively. The length and location information was recorded and saved for further study. All the potential objects within the DIDSON detecting range were examined. Because Arctic grayling were also present in the Chena River, fish less than 400mm were not included in the data analysis because they were not likely to be salmon. To study the relationship between the DIDSON measured fish lengths and the actual fish lengths, a tethered-fish experiment was performed by Steve Fleischman and Debby Burwen of ADF&G in the Kenai River, Alaska, in 2007 (personal communication). In this experiment, 17 fish (9 Chinook salmon and 8 sockeye salmon) were tethered by their tails and were allowed to swim in front of the DIDSON sonar device at various distances. Actual fish lengths were measured before the experiment and DIDSON lengths were recorded using DIDSON Control and Display software. This data set of 17 pared lengths was provided by Fleischman and Burwen to be incorporated in the analysis of this study. A strong linear correlation was seen between the actual length and the DIDSON length (Figure 2).

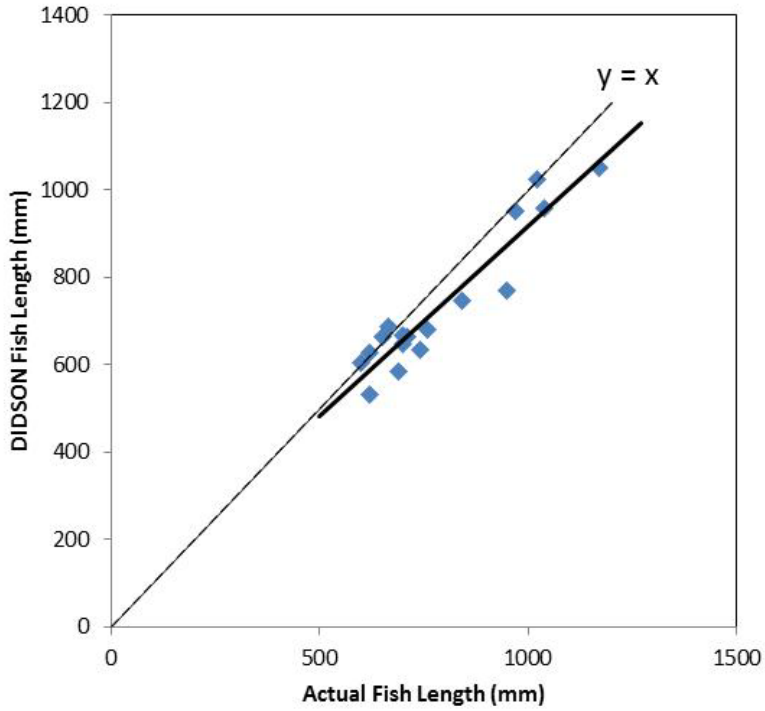


Figure 2.–Plot of DIDSON length against actual length with data from tethered-fish experiment. The bold line is a simple linear regression between DIDSON fish lengths and the actual fish lengths. The R-square value is 0.8919. The dashed line is y = x for comparison with the linear regression.

DATA ANALYSIS

Abundance Estimation

Acoustic data generated by low frequency DIDSON operation did not result in footage clear enough for the purpose of identifying fish and measuring the length, only the high frequency operation data were used in the analysis. This resulted in a 30 minute fish count every hour, 24 hours a day, covering less than half of the river width. The 30-min count was considered as a systematic sample with the abundance estimate being stratified by time (day) and location (less than half of the river). The hourly counts were first expanded into a 24-hour estimate for the half of the river. Then the counts were expanded into daily abundance estimate for the whole river based on the assumption that the rest half of the river had the same run magnitude.

The daily passage in half of the river was estimated as:

$$\hat{N}_{dh} = \frac{M_d}{m_d} \sum_{j=1}^{m_d} c_{dj} \tag{1}$$

The variance associated with periods was estimated using the successive difference model (Wolter 1985):

$$s_{dh}^2 = \frac{1}{2(m_d - 1)} \sum_{j=2}^{m_d} (c_{dj} - c_{d(j-1)})^2 \tag{2}$$

The variance of the daily passage in half of the river was then estimated as:

$$\hat{V}(\hat{N}_{dh}) = (1 - \frac{m_d}{M_d}) M_d^2 \frac{s_d^2}{m_d} \tag{3}$$

The total daily passage for the whole Chena River, its variance, and standard error were estimated using the following equations:

$$\hat{N}_d = 2\hat{N}_{dh} \tag{4}$$

$$\hat{V}(\hat{N}_d) = 4\hat{V}(\hat{N}_{dh}) \tag{5}$$

$$\hat{s}(\hat{N}_d) = \sqrt{\hat{V}(\hat{N}_d)} \tag{6}$$

where *d* is the index of the day; *j* is the index of 30-min operation periods; *dh* indicates that the counts estimate is for the whole day and half of the river; *c* is the counts; *m* is the number of the 30-min operation periods in one day; *M* is the total number of possible 30-min operation periods in one day; *N* is counts; *V* is variance, and *s* is the standard error. The above procedure was according to or modified from that provided by Cochran (1977).

If incidents such as power loss or configuration failure prevented the sonar device from functioning for 1 to 2 days then the moving average procedure was used to estimate the counts on the missing day(s). The count and its associated variance were estimated using the following equations:

$$\hat{N}_i = \frac{\sum_{j=i-k}^{i+k} I(\text{counting was successful on day } j)\hat{N}_j}{\sum_{j=i-k}^{i+k} I(\text{counting was successful on day } j)} \tag{7}$$

$$\hat{V}(\hat{N}_i) = \max[\hat{V}(\hat{N}_{i-k}) : \hat{V}(\hat{N}_{i-1}), \hat{V}(\hat{N}_{i+1}) : \hat{V}(\hat{N}_{i+k})] \tag{8}$$

where $I(\cdot) = \begin{cases} 1 & \text{when the condition is true} \\ 0 & \text{otherwise} \end{cases}$ is an indicator function, and k is the number of consecutive days of no successful counts.

The total escapement of the fish during sonar operation was calculated as:

$$\hat{N} = \sum_{d=1}^{D} \hat{N}_d \tag{9}$$

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

where D is the total number of possible operation days.

Proportion Estimation Using Mixture Model

The proportions of Chinook salmon and chum salmon in the total counts were estimated using a mixture model with the fish length being the discriminating information. The probability density function (pdf) of actual fish length (y) was modeled using a weighted mixture model:

$$f(y) = p_c f_c(y) + p_k f_k(y), \quad 0 \le p_c, p_k \le 1, \tag{11}$$

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 and p_k are the proportions parameters of the chum and Chinook salmon, respectively, so that the equation $p_c + p_k = 1$.

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

$$\begin{aligned} f_c(y) &= \theta_{c1} f_{c1}(y) + \theta_{c2} f_{c2}(y) \\ f_k(y) &= \theta_{k1} f_{k1}(y) + \theta_{k2} f_{k2}(y) \end{aligned}, \tag{12}$$

where θ_{c1} and θ_{c2} are the proportions of male and female chum salmon, respectively; θ_{k1} and θ_{k2} are the proportions of male and female Chinook salmon, respectively. The proportions of male and female add up to one for each species. Length distributions $f_{cs}(y)$ and $f_{ks}(y)$ are assumed to be normal in either sex component s,

$$f_{cs}(y) \sim N(\mu_{cs}, \sigma_{cs}^2)$$
$$f_{ks}(y) \sim N(\mu_{ks}, \sigma_{ks}^2), \quad (13)$$

Length distribution information about the length means (μ) and variances (σ^2) in equation (13) could be found in previous fishery research publications. For this study, prior information for Chinook salmon length distribution was taken from the report of Brase and Doxey (2006). Information about 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. Because there was a strong correlation between the two variables (Figure 2), a linear relationship was assumed between DIDSON length (y_{obs}) and the actual fish length (y). The DIDSON fish length (y_{obs}) was modeled as a normal variable whose mean was a linear function of actual fish length (y) (Equation 14)

$$y_{obs,i} = \beta_1 + \beta_2 y_i + \varepsilon_i \quad (14)$$

where y_{obs} refers to observed DIDSON length, which are the fish length measurements observed using the DIDSON sonar; y refers to the actual fish length; the intercept β_1 and slope β_2 are unknown parameters of the linear relationship between y_{obs} and y. Data y_{obs} and y were obtained from the tethered-fish experiment conducted by Burwen and Fleischman (personal communication).

Once the proportions were estimated, the corresponding escapement of each species was then estimated by:

$$\hat{N}_k = \hat{p}_k \hat{N}$$
$$\hat{N}_c = \hat{p}_c \hat{N} \quad (15)$$

And their variances were estimated as (Goodman 1960):

$$\hat{V}(\hat{N}_k) = \hat{V}(\hat{p}_k)\hat{N}^2 + \hat{V}(\hat{N})\hat{p}_k{}^2 - \hat{V}(\hat{p}_k)\hat{V}(\hat{N})$$
$$\hat{V}(\hat{N}_c) = \hat{V}(\hat{p}_c)\hat{N}^2 + \hat{V}(\hat{N})\hat{p}_c{}^2 - \hat{V}(\hat{p}_c)\hat{V}(\hat{N}) \quad (16)$$

Bayesian Analysis and the Prior Information

The mixture model (equations 11–14) contains unknown parameters of interest including species proportion parameters p_c and p_k, sex proportion parameters θ's, intercept parameter β_1, and slope parameter β_2. In order to estimate these unknown parameters, the mixture model was fitted using a Bayesian approach, implemented by Markov Chain Monte Carlo (MCMC) using the statistical software package WinBUGS (Lunn et al. 2000).

According to Bayes' Theorem, the posterior distribution of the unknown parameters is proportional to the likelihood of the data multiplied by the prior distribution of the parameters. The likelihood of the data collected follows the mixture model density function (Equation 11). As are often used as priors for proportions in Bayesian analysis, uninformative Dirichlet distributions were used in this study as priors for species (p) and sex proportions (θ). The distributions of the sex-length compositions for either species are listed in Table 1 (Brase and Doxey 2006; Clark 1993) and are summarized and plotted in Figure 3. The plot suggests that

male and female chum salmon lengths are similar. Female chum salmon have a mean length of 550 mm (SE = 2 mm), and male chum salmon have a mean length of 585 mm (SE = 2 mm). Chinook salmon have a moderate difference in their sex-length composition between female and male. Female Chinook salmon have a mean length of 870 mm (SE = 4 mm), and male Chinook salmon are smaller in size with a mean length of 730 mm (SE = 12 mm). The prior distributions of β_1 and β_2 were set to uninformative normal distributions.

Table 1.–Sex-length composition for Chinook and chum salmon in the Chena River.

Species	Sample Size	Mean (mm)	S.E. (mm)
Chinook (Male)	98	730	12
Chinook (Female)	160	870	4
Chum(Male)	202	585	2
Chum (Female)	235	550	2

Note: Sex–length information for Chinook salmon is from Brase and Doxey (2006). Sex–length information for chum salmon is from Clark (1993).

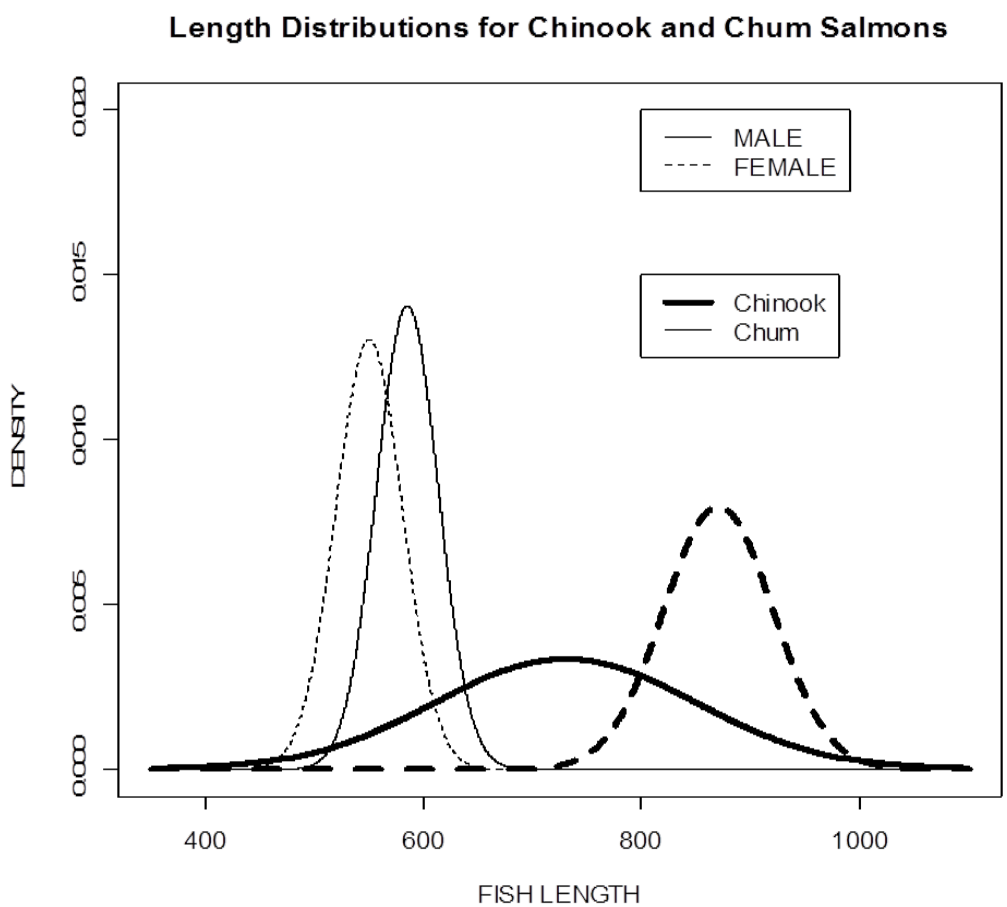


Figure 3.–Prior length distributions of Chinook and chum salmon length used in the Bayesian analysis.

The Bayesian MCMC was conducted using WinBUGS with 3 chains and 50,000 iterations in each chain. The first 10,000 iterations in each chain were considered as burn-in and discarded. After model fitting, the posterior distributions of species proportion, p_c and p_k, together with the sex proportions, θ_{cs} and θ_{ks}, were examined and their means and standard deviations were reported. WinBUGS code for model fitting can be found in Appendix B.

RESULTS

CHENA RIVER SONAR COUNTS AND LENGTH DISTRIBUTION

In 2008, a total of 723 fish measuring greater than 400 mm were recorded by the DIDSON from the north bank of the Chena River using a systematic sampling method from 9 July to 25 July. Fish lengths measured using DIDSON software ranged from 402 mm to 1,172 mm (Figure 4). Two main distributions with an overlap between them can be identified by the two separate peaks in the figure. The major peak was around 750 mm with another smaller peak around 550 mm. Judging from the prior information and the density plot of DIDSON length, the major peak (~ 750mm) is most likely to be categorized as Chinook salmon and the smaller peak is likely to be categorized as chum salmon (Figures 3 and 4).

During 9 July through 25 July, 2008, the total estimated salmon escapement (including both Chinook salmon and chum salmon) was 3,814 fish (SE = 182; Table 2).

Table 2.–Daily DIDSON estimates of Chena River salmon escapement (Chinook and chum salmon), 2008.

Date	Number of 30-min counts	Number of fish observed	Daily Passage Estimate	Daily SE
9-Jul	10	7	67	31
10-Jul	24	19	76	12
11-Jul	24	27	108	23
12-Jul	24	50	200	39
13-Jul	24	126	504	101
14-Jul	24	63	252	46
15-Jul	24	36	144	27
16-Jul	24	35	140	25
17-Jul	15	62	397	89
18-Jul	24	61	244	36
19-Jul	24	51	204	34
20-Jul	14	36	247	30
21-Jul	0	0	196	34
22-Jul	0	0	205	30
23-Jul	14	20	137	25
24-Jul	24	58	232	27
25-Jul	15	72	461	44
Total	-	723	3,814	-

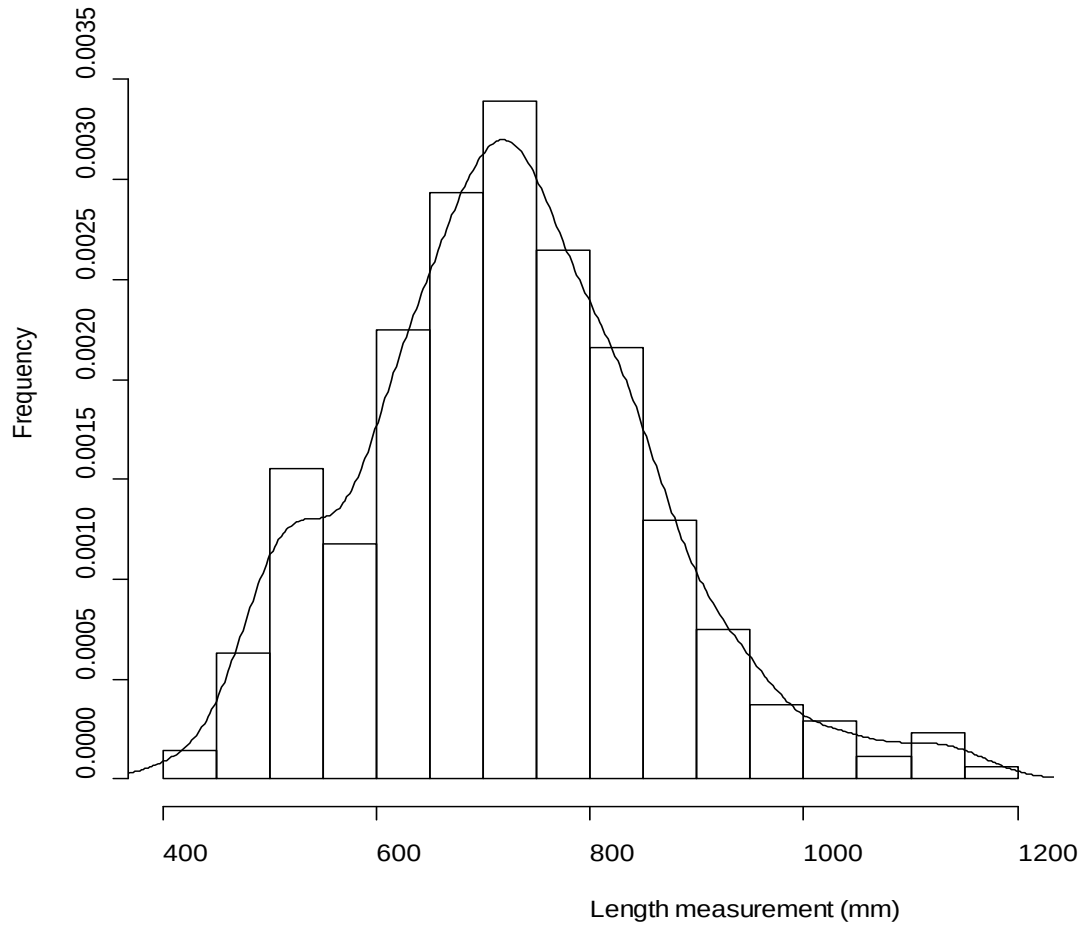


Figure 4.–Histogram and density plot of the length measurements by DIDSON Sonar on Chena River 2008.

SPECIES PROPORTION ESTIMATES AND ESCAPEMENT

The proportion for Chinook salmon (p_k) was estimated to be 88.1% (SE= 2.3%; Table 3). The 95% credible set of Bayesian analysis for the Chinook salmon proportion estimate ranges from 83.5% to 92.5%. The proportion for chum salmon (p_c) was estimated to be 11.9% (SE=2.3%). The 95% credible set for the chum salmon proportion estimate ranges from 7.5% to 16.5%. These estimates indicate that during the period of July 9, 2008 to July 25, 2008, the majority of fish passing the sonar in the Chena River were Chinook salmon. Accordingly, the estimated Chinook salmon escapement was 3,362 (SE = 183). The estimated chum salmon passage was 452 (SE = 90).

For Chinook salmon, the proportion of male Chinook salmon was estimated to be 90.3% (SE= 3.7%) and the female proportion was estimated to be 9.7% (SE = 3.7%). For chum salmon, the proportion male chum salmon was estimated to be 41.8% (SE= 14.0%) and the female proportion was estimated to be 58.2% (SE = 14.0%).

Table 3.–Summary of species and sex proportions and the corresponding escapements.

	Mean	S.E.	95% C.I.	
Chinook (fish)	3,362	183	3,004	3,720
Chum (fish)	452	90	276	628
Chinook (%)	88.1	2.3	83.5	92.5
Chum (%)	11.9	2.3	7.5	16.5
Male Chinook (%)	90.3	3.7	83.0	97.6
Female Chinook (%)	9.7	3.7	2.4	17.0
Male Chum (%)	41.8	14.0	14.4	69.2
Female Chum (%)	58.2	14.0	30.8	85.6

DISCUSSION

This was a preliminary study of application of DIDSON to count salmon escapement in the Chena River, Alaska. Several advantages of DIDSON were encountered during the study. DIDSON was able to identify fish in the conditions where the water level was high, the current was turbulent, and regardless of the ambient light level. Counting tower techniques require personnel to wait and observe migrating salmon, whereas sonar can be configured to record images automatically and the data can be processed in the office. The pre-programmed software allows fish to be counted faster. Fish were more easily and quickly identified on the echogram (Appendix A2) rather than inspecting the lengthy video-like image. Additionally, DIDSON data can be stored for future re-evaluation and may also provide valuable data for further biological research, whereas counting tower techniques rely on an individual's one-time judgment and has little future research value. Then again, DIDSON still requires human monitoring to keep the sonar operating normally (cleaning the lens, maintaining an appropriate viewing angle) and to keep river debris off the device. Continuous power supply is also required near the sonar site to operate the device. A large digital data storage device is needed to store the vast amount of hydroacoustic data produced by DIDSON. The cost of device is not only expensive to procure but precautions should be used to prevent theft and vandalism. Also further study is needed to develop a more efficient and accurate way to collect and process the DIDSON data.

The 2008 sonar operation was carried out alongside the counting tower project. In 2008, the counting tower project reported that the estimated escapement of Chinook salmon was 3,208 (SE = 198) during the operation period from June 30 through July 28, 2008 (Savereide 2012). During the same period, the chum salmon escapement was reported to be 1,300 (SE = 106). To compare results derived by counting tower and DIDSON, the fish counts during the same operation periods were calculated. During the period of July 9 through July 25, 2008, the estimated daily Chinook salmon escapement derived from the counting tower was 2,761 (SE = 181) with a 95% confidence interval ranging from 2,407 to 3,116 (Savereide, personal communication), whereas the DIDSON reported an estimate of 3,362 (SE = 183) with a 95% confidence interval ranging from 3,004 to 3,720. During the same period, the counting tower project produced an estimate of chum salmon escapement of 617 (SE = 88) with a 95% confidence interval ranging from 445 to 789, whereas the DIDSON reported an estimate of chum escapement of 452 (SE = 90) with a 95% confidence interval of 276 to 628. Estimates derived from both methods showed that the majority of the passing fish in the Chena River during the designated timeframe were Chinook salmon. Although there was a noticeable difference

between the two point estimates for Chinook salmon escapement using the two counting techniques, their confidence intervals overlap. The possible reasons for differences in Chinook salmon estimate are discussed in the following paragraphs. The sizable difference of the length distributions between Chinook and chum salmon (Figure 3 and Table 1) makes it possible for the mixture model to distinguish the species based on their length information from DIDSON images. However, it should be advised that the length information of the two species should be updated as more data on salmon length in the Chena River become available. The alternative method is to sample the salmon for length information along with the DIDSON operation.

For sex proportions, the DIDSON operation reported 90.3% (SE = 3.7%) male Chinook salmon and 9.7% (SE = 3.7%) female, whereas carcass surveys 2008 reported 68.8% (SE = 6.7%) male Chinook salmon and 31.2% (SE = 6.7%) female. For chum salmon, DIDSON mixture model reported the male proportion to be 41.8% (SE = 14.0%) and female proportion to be 58.2% (SE = 14.0%). The DIDSON sex proportion estimates only reflect partial estimates of the salmon run in 2008. The difference between the length distributions of the genders among each species may not be sizable enough to derive unbiased point estimates and may result in large standard errors (Figure 3). It is advised that the gender estimation might serve as index or reference at this point.

A limitation of the DIDSON operation in 2008 was that the DIDSON only successfully sampled less than half width of the river because the low-frequency sampling did not yield clear enough sonar images to obtain counts and lengths for the other portion of the river. With no further data or information about the other portion of the river, the DIDSON estimate was derived based on the assumption that the conditions of both portions of the river were identical and thus the final DIDSON estimates for the whole river had to be based on and expanded from the results from the one-side sampling of the river. This assumption about the unknown condition of the other portion of the river might bring bias into the final estimate for the whole river. This assumption also increased the uncertainty of the final estimates, in that the standard errors of the DIDSON estimates were increased by such an expansion. In future operation, it is advised that such a situation could be avoided by setting up another DIDSON on the other side of the river or by replacing the current DIDSON with a sonar device that has longer detecting range and higher resolution. In 2008, there were 2 days when DIDSON operation was interrupted due to configuration problems after power loss, which resulted in no data recorded on either July 21 or July 22, 2008. The moving average estimator was used for those 2 days.

ACKNOWLEDGMENTS

The author would like to thank Steve Fleischman and Debby Burwen for their data and advice on the data analysis. Thanks also go to James Savereide and Allen Bingham for their review and edits. Rachael Kvapil provided the editorial assistance for publication. Thanks to the Chena River counting tower crew and to the Division of Commercial Fisheries for providing the sonar device.

REFERENCES CITED

Brady, J. 1986. Copper River hydroacoustical salmon enumeration studies, 1984 and 1985. Alaska Department of Fish and Game, Division of Commercial Fisheries, Technical Data Report No. 183, Juneau.

Brase, A. L. J. 2008. Fishery management report for recreational fisheries in the lower Tanana River management area, 2006. Alaska Department of Fish and Game, Fishery Management Report No. 08-27, Anchorage.

Brase, A. L. J. 2009. Fishery management report for recreational fisheries in the lower Tanana River management area, 2007. Alaska Department of Fish and Game, Fishery Management Report, No. 09-23, Anchorage.

Brase, A. L .J., and M. Doxey. 2006. Salmon studies in the Chena, Chatanika Delta Clearwater, and Salcha Rivers, 2004 and 2005. Alaska Department of Fish and Game, Fishery Data Series, No. 06-61, 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. 07-44, Anchorage.

Burwen, D. L., D. E. Bosch, and S. J. Fleischman. 1998. Evaluation of hydroacoustic assessment techniques for Chinook salmon on the Kenai River, 1995. Alaska Department of Fish and Game, Fishery Data Series No. 98-3, 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.

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

Eggers, D. M., P. A. Skvorc II, and D. L. Burwen. 1995. Abundance estimates of Chinook salmon in the Kenai River using dual-beam sonar. Alaska Department of Fish and Game, Fishery Research Bulletin 2(1):1-22.

Fleischman, S. J., and D. L. Burwen. 2003. Mixture models for the species apportionment of hydroacoustic data with echo-envelop length as the discriminatory variable. ICES Journal of Marine Science 60: 592-598.

Gelman, A., J. B. Carlin, H. S. Stern, and D. B. Rubin. 2004. Bayesian data analysis. 3rd edition. Chapman and Hall, Boca Raton, Florida.

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

Lunn, D. J., A. Thomas, N. Best, and D. Spiegelhalter. 2000. WinBUGS – a Bayesian modeling framework: concepts, structure, and extensibility. Statistics and Computing 10: 235-337.

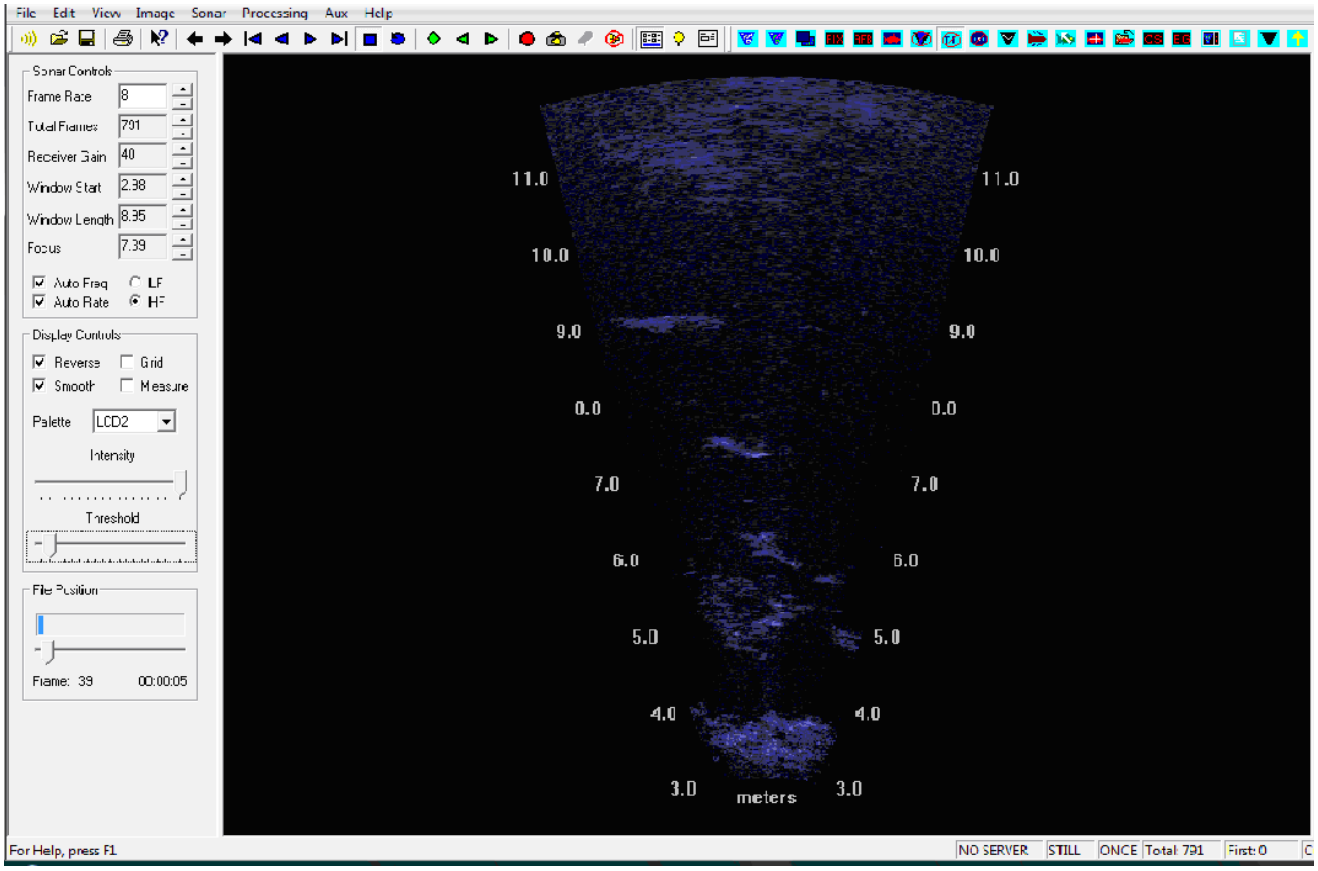
Paulus, R. D., and M. L. McCurdy. 1972. 1970 Kvichak River sockeye salmon smolt studies. Pages 1-13 [*In*] Russell, P. A., *editor*. 1972. 1970 Bristol Bay sockeye salmon smolt studies. Alaska Department of Fish and Game, Division of Commercial Fisheries, Technical Data Report No. 4, Juneau.

Savereide, J. W. 2012. Salmon Studies in the Chena , Delta Clearwater, Goodpaster and Salcha Rivers, 2007-2009. Alaska Department of Fish and Game, Fishery Data Series No. 12-03, Anchorage.

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

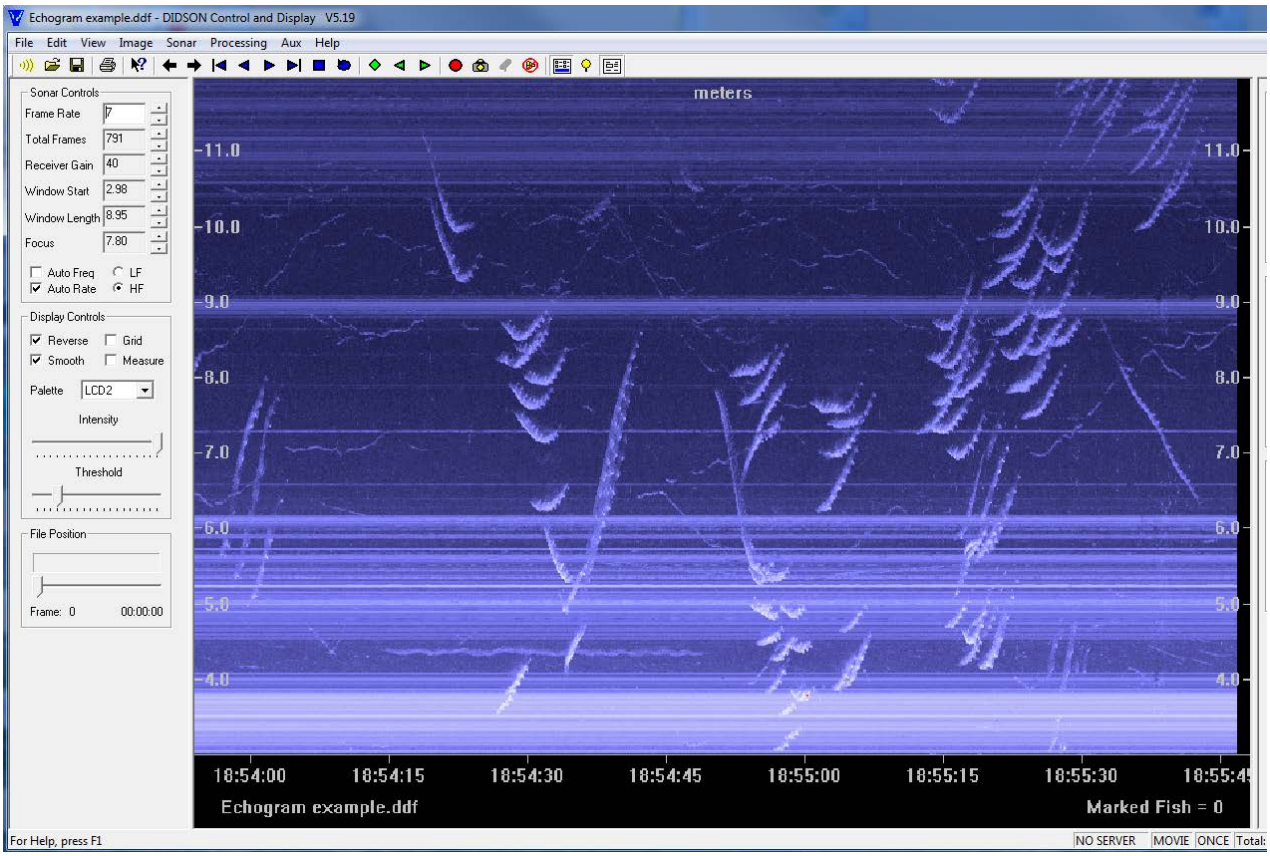
APPENDIX A:
DIDSON CONTROL AND DISPLAY ILLUSTRATION

Appendix A1.–DIDSON Control and Display (Version 5.20.09) interface and sonar image.



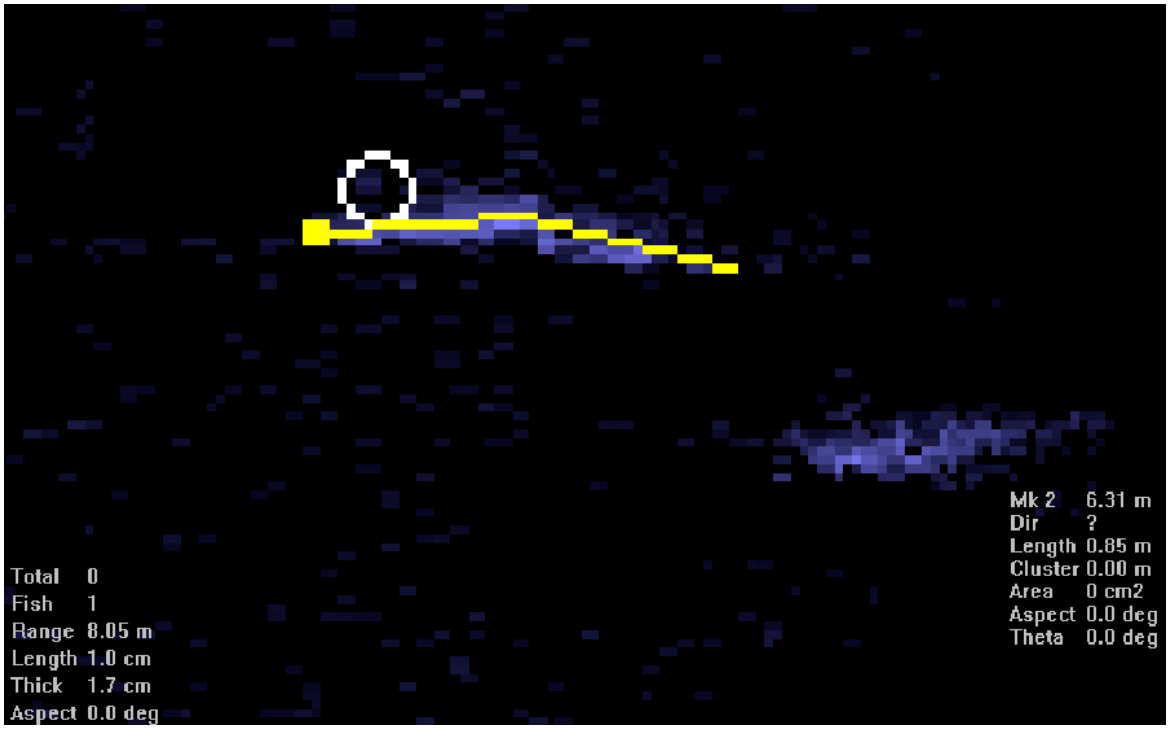
Appendix A2.–Illustration of an echogram of DIDSON data.

Below is an example of an echogram, which is generated from the original DIDSON data. Each shadow in this echogram represents the trace of a potential fish or an obeject passing in front of the sonar. A video-like footage of this fish or object can be retrieved by right clicking on the shadow spot. The fish passing in front of the sonar can be identified quickly by locating its trace on the echogram. The occuring location and time of this object can be recorded by the software.



Appendix A3.–Illustration of length measurement on DIDSON image.

Below is an image that illustrates the procedure of measuring a fish length on DIDSON image. Once the video-like footage was retrieved, it was zoomed and adjusted to its best angle and clearest frame. The measuring tool included in the software was used to measure the fish length. In the image below, the yellow line was drawn manually from its head to tail by two segments. The first segment is from head to the middle of the body and the second segment is from the middle of the body to the tail. As is shown in the right lower corner of the image, the fish measured in this illustration is 0.85 meters in length.



APPENDIX B:
WINBUGS CODE OF MIXTURE MODEL

Appendix B1.–WinBUGS code of mixture model[a].

```
model{
    for(i in 1:n.fish) {
            L.mm.D[i]<-L[i]*10
            L.mm.D[i]~dnorm(muL[i],precL)
            muL[i]<-beta[1]+beta[2]*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[])
            sex[i]~dcat(psex[species[i],1:2])
                }
     sig[1,1]~dunif(110,126)
     sig[2,1]~dunif(20,36)
     sig[1,2]~dunif(42,58)
     sig[2,2]~dunif(22,38)
     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) {  # Tethered-fish data
                DL.star[j]~dnorm(mu.star[j],prec.star)
                mu.star[j]<-beta[1]+beta[2]*AL.star[j]
                 }
       beta[1]~dnorm(1,0.01)
       beta[2]~dnorm(0,0.01)
       prec.star~dunif(0.0001,1000)

     precL<-1/tauL
     tauL~dunif(2800,3160)

     ps[1:2]~ddirch(alpha.s[])
     psex[1,1:2]~ddirch(alpha.sex.chin[])
```

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

    lambda[1,1]~dnorm(730,t1)
    lambda[1,2]~dnorm(870,t2)
    lambda[2,1]~dnorm(585,t4)
    lambda[2,2]~dnorm(550,t5)

    t1<-1/(12*12)
    t2<-1/(4*4)
    t4<-1/(2*2)
    t5<-1/(2*2)
      }
list(n.fish=695,m=17,alpha.s=c(5,5),alpha.sex.chin=c(5,5),alpha.sex.chum=c(5,5),
DL.star=c(632,602,1049,664,768,663,1025,685,681,957,953,747,646,666,627,531,584),
AL.star=c(740,600,1170,710,950,650,1020,665,760,1040,970,840,700,700,620,620,690))
list(species=c(2,1,1,…1))  #initial values

L[]
#list of length data
.
.
.
END
```

[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.