Fishery Data Series No. 16-27

Sonar Estimation of Chinook and Fall Chum Salmon Passage in the Yukon River near Eagle, Alaska, 2015

by

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and

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July 2016

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

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ABSTRACT

Adaptive resolution imaging sonar (ARIS) and split-beam sonar equipment were used to estimate Chinook salmon *Oncorhynchus tshawytscha* and fall chum salmon *Oncorhynchus keta* passage in the Yukon River near Eagle, Alaska from June 30 to October 6, 2015. A total of 84,015 Chinook salmon were estimated to have passed the sonar site between June 30 and August 15. The midpoint of the Chinook salmon run occurred on July 23, which was 2 days early relative to the historical mean date of July 25. An estimated 112,095 fall chum salmon passed between August 16 and October 6. The sonar-estimated passage of fall chum salmon was subsequently expanded to a total passage estimate of 125,095 to include fish that may have passed after operations ceased. The midpoint of the expanded fall chum salmon estimate occurred on September 25, which is 3 days later than the historical mean date. Subtracting the preliminary subsistence catch upstream of the sonar site resulted in an estimated border passage of 83,674 Chinook salmon and 112,555 fall chum salmon. Drift gillnetting was conducted to collect age, sex, and length samples and tissue samples for genetic information. Species composition was also recorded to determine when the Chinook salmon run ended and the fall chum salmon run began.

Key words: Chinook *Oncorhynchus* t*shawytscha,* fall chum salmon *Oncorhynchus keta*, adaptive resolution imaging sonar ARIS, dual-frequency identification sonar DIDSON, split-beam sonar, hydroacoustic, Eagle, Yukon River, Alaska.

INTRODUCTION

The Yukon River is the longest river in Yukon and Alaska, spanning 3,185 km.[1] It flows northwesterly from its origin in northwestern British Columbia through the Yukon Territory and Central Alaska to its mouth at the Bering Sea. Commercial and subsistence fisheries harvest Chinook salmon *Oncorhynchus tshawytscha*, chum salmon *O. keta*, and coho salmon *O. kisutch* throughout most of the drainage. These fisheries are critical to the way of life and economy of people in dozens of communities along the river, in many instances providing the largest single source of food or income.

Fisheries management on the Yukon River is complex and difficult because of the number, diversity, and geographic range of fish stocks and user groups. Information upon which to base management decisions comes from several sources, each of which has unique strengths and weaknesses. Gillnet test fisheries provide inseason indices of run strength, but interpretation of these data are confounded by gillnet selectivity. In addition, the functional relationship between test fishery catches and abundance is poorly defined. Mark–recapture projects provide estimates of total abundance, but the information is typically not timely enough to make day-to-day management decisions. Sonar provides timely estimates of abundance, but is limited in its ability to identify fish to species level.

Alaska is obligated to manage Canadian-origin Yukon River Chinook and fall chum salmon stocks according to precautionary, abundance-based harvest-sharing principles set by the Yukon River Salmon Agreement (Yukon River Panel 2004). The goal of bilateral, coordinated management is to meet negotiated escapement goals and provide for subsistence and commercial harvests of surplus, in both the United States and Canada. Timely estimates of abundance not only help managers adjust harvest inseason, they are crucial for postseason analysis to determine whether treaty obligations were met. The Canadian Department of Fisheries and Oceans (DFO) provided estimates of mainstem salmon passage through the U.S./Canada border using mark–recapture techniques from 1980 to 2008 (JTC 2014). Because of the highly turbid water of the Yukon River, and the width of the mainstem (approximately 400 m across at the study site),

[1] Yukoninfo. 2015. Yukon River. http://www.yukoninfo.com/yukon-river/ (accessed December 2015).

daily passage estimation methods that rely on visual observation, such as counting towers and weirs, are not feasible. Split-beam sonar technology is used successfully by the Alaska Department of Fish and Game (ADF&G) to produce daily inseason estimates of salmon passage in turbid rivers, including the lower Yukon River at Pilot Station (Lozori and McIntosh 2013). Multi-beam imagining sonar (dual-frequency identification sonar DIDSON and adaptive resolution imaging sonar ARIS[2]) have been used at several sites, including the Anvik (Lozori 2015) and the Teslin rivers (Mercer 2015) to give daily passage estimates where bottom profiles and river width are appropriate for the wider beam angle and shorter-range capabilities of this technology.

In 1992, ADF&G initiated a project near Eagle, Alaska (Figure 1) to examine the feasibility of using split-beam sonar to estimate the number of salmon migrating across the U.S./Canada border (Johnston et al. 1993; Huttunen and Skvorc 1994). This project was the first documented use of split-beam sonar in a riverine environment, and over the 3-year duration of the study, a number of problems were identified. Phase corruption was observed and was probably exacerbated by the highly reflective river bottom (Konte et al. 1996). The errors in the phase measurement were believed to have resulted in overly restrictive echo angle thresholds causing the removal of echoes from fish that were physically within accepted detection regions. These and other equipment issues reflected the early state of split-beam development, most of which have since been addressed. A recommendation that came out of these studies was to find a more appropriate site with smaller rocks and a uniform bottom profile (Johnston et al. 1993). Too many large rocks or obstructions in the profile can compromise fish detection by limiting how close to the bottom the hydroacoustic beam can be aimed. Similarly, an uneven bottom profile permits fish to pass undetected by the sonar.

In 2003, ADF&G carried out a study to identify a more suitable location to deploy hydroacoustic equipment to estimate salmon passage into Canada. A 45 km section of river from the DFO mark–recapture fish wheel project at White Rock, Yukon Territory to 19 km downriver from Eagle, Alaska was explored (Pfisterer and Huttunen 2004). This area was investigated because of its proximity to the DFO project and the U.S./Canada border. Desirable characteristics included the following: consistent, downward-sloping linear bottom profiles on both sides of the river without large obstructions; a single channel; available beach above the ordinary high water mark (OHW) for topside equipment; and sufficient current (i.e., areas without eddies or slack water where fish milling behavior can occur). A total of 21 river transects led to a narrowing of potential project locations to an area between 9 km and 19 km downriver from the town of Eagle. The 2003 study identified the 2 most promising sonar deployment locations at Calico Bluff and Shade Creek. Although sonar was not deployed in 2003, the bottom profiles at the preferred sites indicated that it should be possible to estimate fish passage using a combination of split-beam sonar on the longer, linear left bank and DIDSON on the shorter, steeper right bank. ADF&G carried out a 2-week study in 2004 to test sonar at the preferred sites. The 2 types of sonar were tested at Calico Bluff and the Shade Creek area, and it was found that Six Mile Bend (11.5 km downriver from the town of Eagle and immediately upstream of Shade Creek) was the most ideal site (Carroll et al. 2007a).

In 2005, a full-scale sonar project was conducted from July 1 to August 13 to estimate Chinook salmon passage in the Yukon River at Six Mile Bend (Carroll et al. 2007b). As suggested,

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

DIDSON was deployed on the right bank, split-beam sonar was deployed on the left bank, and this equipment has been used in subsequent years to estimate border passage for both Chinook and fall chum salmon.

The project duration was extended in 2006 to provide an estimate of chum salmon passage. However, 2 genetically distinct runs of chum salmon enter the Yukon River, an early summer component and a later fall component (Estensen et al. 2013). Summer chum salmon spawn primarily in run-off streams in the lower 700 miles of the Yukon River drainage and in the Tanana River drainage. Fall chum salmon, which migrate past the Eagle sonar project, primarily spawn in the upper portion of the drainage in streams that are spring fed or have major upwelling features. Major fall chum salmon spawning areas include the Tanana, Porcupine, and Chandalar river drainages as well as various streams in the Yukon Territory, Canada, including the mainstem Yukon River.

In 2015, the project deployed split-beam and ARIS sonar to estimate Chinook and fall chum salmon passage migrating across the U.S./Canada border. Sample fisheries were conducted to determine the transition between Chinook and fall chum salmon runs as well as collect age, sex, and length (ASL) and tissue samples for stock identification. This report will describe the methodologies used to collect sonar and test fishery data, as well as provide passage estimates, species distributions, run timing, in addition to climate and hydrologic observations.

OBJECTIVES

The goal of this project in 2015 was to provide daily inseason estimates of Chinook and fall chum salmon migrating across the U.S./Canada border to fishery managers. Primary objectives included the following:

1. Begin field operations prior to the arrival of Chinook salmon, then operate continuously throughout the season until approximately October 6, when, historically, environmental conditions become unfavorable for field operations.
2. Operate side-looking split-beam and imaging sonar such that 95% of the migrating salmon detected are within three-quarters of the ensonified range.
3. Use drift gillnets to collect species composition and catch per unit effort (CPUE) data to estimate the transition period between the Chinook and fall chum salmon migration past the sonar site.

Secondary objectives included the following:

4. Collect a minimum of 160 Chinook salmon scale samples during each of 3 strata throughout the season to characterize the age, sex, and length (ASL) composition of Yukon River Chinook salmon passage, such that simultaneous 95% confidence intervals of age composition are no wider than 0.20 ($\alpha = 0.05$ and $d = 0.10$). Strata dates are determined by ADF&G fishery managers based on run timing, sample size, and fish pulses.
5. Collect a minimum of 160 fall chum salmon scale samples during each of 4 strata throughout the season to characterize the age, sex, and length (ASL) composition of Yukon River fall chum salmon passage, such that simultaneous 95% confidence intervals of age composition are no wider than 0.20 ($\alpha = 0.05$ and $d = 0.10$).
6. Collect Chinook and fall chum salmon tissue samples for genetic stock identification.
7. Collect daily climatic and hydrologic measurements representative of the study area.

METHODS

Study Area

The study area is located on the mainstem of the Yukon River at Six Mile Bend (64°52′30.8″N, 141°04′52.8″W), approximately 11.5 km downriver from Eagle, Alaska (Figure 2). The Yukon River Basin is the fourth largest basin in North America, has a drainage area of 857,300 km^2 and an average annual discharge of 6,400 m3/s. Flows are highest in June, but the greatest flow variability occurs in May, after which discharge (and the variability in discharge) decline. The upper Yukon River is turbid and silty throughout the summer and fall, and the estimated annual suspended sediment load at Eagle is 33,000,000 tons (Brabets et al. 2000).

Hydroacoustic Equipment

A fixed-location, split-beam sonar developed by Kongsberg Simrad was used to estimate salmon passage on the left bank. Fish passage was monitored with a model EK60 digital echosounder, which included a general-purpose transceiver and a 2.5° x 10° 120 kHz transducer (Table 1). ER60 data acquisition software was controlled with a Simrad Controller program (Carl Pfisterer, Commercial Fisheries Biologist, ADF&G, Fairbanks; personal communication), which was installed on a laptop computer and connected to the echosounder to collect raw data for processing.

An ARIS imaging sonar, manufactured by Sound Metrics Corporation, was deployed on the right bank. The sonar was operated at 1.2 MHz (high frequency) for the nearshore strata and at 0.70 MHz (low frequency) for the offshore strata. Forty-eight beams were used for both strata. Both the low and high frequency modes have a field of view of 28° (Table 2).

Digital files created by the ER60 software and the ARIS were examined with the echogram viewer program Echotastic (Version 3) to produce an estimate of fish passage (Carl Pfisterer, Commercial Fisheries Biologist, ADF&G, Fairbanks; personal communication).

Sonar Deployment and Operation

Each season, prior to transducer deployment, bottom profiles are checked to ensure the original sites remain acceptable for ensonification. Data were collected from transects made from bank-to-bank using a boat-mounted Lowrance LCX-15 dual-frequency transducer (down-looking sonar) with a built-in Global Positioning System (GPS). A bottom profile was then generated using data files uploaded to a computer (Figure 3).

The split-beam transducer was attached to 2 Hydroacoustic Technology Incorporated (HTI) model 662H single-axis rotators, configured perpendicularly to provide dual-axis rotation. Aiming was performed remotely using an HTI model 660 remote control unit that provided horizontal and vertical positioning.

The split-beam sonar was deployed from June 30 through October 6 on the left bank, approximately 800 m downriver from the camp (Figure 2). The transducer and rotators were mounted on a freestanding frame constructed of aluminum pipe and deployed approximately 15 m from shore (Figure 4). Transducer height was adjusted by sliding a mounting bar up or down along riser pipes that extended above the water. The transducer was deployed at approximately 1.5 m depth and aimed perpendicular to the current, at a location with consistent flow and no slack water.

When counting Chinook salmon, the split-beam system was aimed to ensonify a range of approximately 150 m from the transducer and sampled 2 strata (S1: approximately 0–50 m and S2: approximately 50–150 m). When counting fall chum salmon, the split-beam system was aimed to ensonify a range of 75 m and sampled 2 strata (S3: approximately 0–25 m and S4: approximately 25–75 m) (Figure 5).

A portable tripod-style fish lead was constructed approximately 1.5 m downstream from the transducer to prevent fish passage inshore of the transducer and provide sufficient offshore distance for fish swimming upstream to be detected in the sonar beam. Freestanding lead sections were constructed of 2 in diameter steel pipes connected with adjustable fittings to form tripods. Aluminum stringers, approximately 2.5 m long, were attached horizontally to the upstream side of the tripods. Vertical lengths of aluminum conduit spaced 3.8 cm apart finished the sections. Depending upon water level, flow, and debris load, lead sections were placed side-by-side in the water from shore to a distance of 5 m to 12 m beyond the transducer (Figure 6). The portability of this style of fish lead was important because of the gradual slope found on the left bank. As the water level rises and falls over the duration of the season, the transducer and lead require frequent relocation to maintain their depth in the water column.

The ARIS sonar was attached to a Sound Metrics ARIS Rotator AR2, and controlled by ARIScope software interface, which provided horizontal and vertical positioning. Aiming was performed remotely using a laptop computer.

The ARIS was deployed from June 30 through October 6 on the right bank, approximately 700 m downriver from the camp, and was aimed to ensonify approximately 40 m beginning at 0.7 m from the face of the transducer for 2 sampling strata (S5: 0.7–20 m and S6: 20–40 m) (Figure 5). The transducer and rotator where mounted on a freestanding aluminum frame similar to the split-beam sonar (Figure 7). Operators were able to remotely adjust the aim by viewing the video image for each stratum. Proper aim was achieved when adequate bottom features appeared over a majority of the ensonified range.

A fish lead was constructed using 2 m steel "T" stakes. A lead line strung through the bottom of the 1.22 m plastic snow fencing for weight (Figure 6). The fish lead was less than 1 m downstream from the transducer and extended 3 m offshore, beyond the transducer. This distance provided sufficient offshore diversion for fish swimming upstream to be detected in the sonar beam. A shorter lead was appropriate for this bank because of the steep slope and the shorter near field view of the ARIS.

Sonar Data Processing and Passage Estimation

Operators opened each data file in an echogram viewer program (Echotastic) and marked each upstream fish track with a computer mouse (Figures 8 and 9). The counts were saved as text files and recorded on a count form. Upstream migrating fish were counted using the Echotastic software. Upstream direction of travel was verified using the Echotastic video feature (Figure 8). The counts were saved as text files and also recorded on a paper count form.

The daily passage ($\hat{y}$) for stratum (s) on day (d) was estimated by averaging the hourly passage rates for the hours sampled and then multiplying by the number of hours in in day as follows:

$$\hat{y}_{ds} = 24 \bullet \frac{\sum_{p=1}^{n} \frac{y_{dsp}}{f_{dsp}}}{n_{ds}}, \tag{1}$$

where f_{dsp} is the fraction of the hour sampled on day (d), stratum (s), and period (p) and y_{dsp} is the count for the same sample.

Treating the systematically-sampled sonar counts as a simple random sample would yield an overestimate of the variance of the total since sonar counts are highly autocorrelated. To accommodate these data characteristics, a variance estimator based on the squared differences of successive observations was employed (Wolter 1985). The variance for the passage estimate for stratum (s) on day (d) is estimated as

$$\hat{V}_{y_{ds}} = 24^2 \frac{1-f_{ds}}{n_{ds}} \frac{\sum_{p=2}^{n_{ds}} \left(\frac{y_{dsp}}{h_{dsp}} - \frac{y_{ds,p-1}}{h_{ds,p-1}} \right)^2}{2(n_{ds}-1)}, \tag{2}$$

where n_{ds} is the number of samples in the day (typically 24), f_{ds} is the fraction of the day sampled (12/24 = 0.5), and y_{dsp} is the hourly count for day (d) in stratum (s) for sample (p). Since the passage estimates are assumed independent between strata and among days, the total variance was estimated as the sum of the variances:

$$\hat{V}ar(\hat{y}) = \sum_{d} \sum_{s} \hat{V}ar(\hat{y}_{ds}) \,. \tag{3}$$

MISSING DATA

Estimating daily passage by multiplying the average hourly passage rates by 24 (Equation 1) compensates for missing data (either shortened or missing periods within a day) and is reflected in the variance (Equation 2) by reducing the number of samples and the fraction of the day sampled. If 1 or multiple days were missed, the relationship of daily passage between banks was assessed. An XY scatterplot with a regression line was plotted using the observed passage from the previous days for each bank. If the regression was significant ($p < 0.05$), the linear regression equation of the line was then used to calculate missing passage for each missing day (d):

$$\hat{y}_d = a + bx_d, \tag{4}$$

where a and b are the regression coefficients, x equals the passage for day (d) on the opposite bank, and $\hat{y}_d$ is the estimated passage for missing day (d).

If the regression of daily passage by bank was not significant, daily passage was interpolated by averaging passage estimates from days before and after the missing day(s) as follows:

$$\hat{y}_d = \left(1/n\sum_{i=1}^{n} x_i\right)\begin{Bmatrix} d=1, n=4 \\ d=2, n=6 \\ d=3, n=8 \end{Bmatrix}, \qquad (5)$$

where d is the number of missed days, n is the number of days used for interpolation (half before and half after the missing day(s)), and x_i is the passage for each day i.

After editing was complete, an estimate of hourly, daily, and cumulative fish passage was produced and forwarded to the Fairbanks ADF&G office via email each day. The estimates produced during the field season were further reviewed postseason and adjusted as necessary.

Since project operations ceased prior to the end of the fall chum salmon run, the estimate was expanded using a second order polynomial equation extended to October 18, where y_i is the daily passage estimate, L is the count on the last day of sonar operation, d is the total number of days expanding for, and x_i is the day number being estimated (where i = 1 through total number of days expanding for):

$$y_i = \frac{L}{d^2}(x_i - d)^2 \qquad (6)$$

October 18 was chosen based on what is considered the most likely run timing scenario derived from 1982 to 2008 historical data collected at the DFO mark–recapture fish wheel project near the U.S./Canada border (Bonnie Borba, Commercial Fisheries Biologist, ADF&G, Fairbanks; personal communication)

Postseason, the U.S. portion of the Chinook and fall chum salmon subsistence harvest from the Eagle area, upstream of the sonar site, was subtracted from the adjusted sonar estimate to give a border passage estimate for each species.

Spatial and Temporal Distributions

Fish range distributions for Chinook and fall chum salmon were examined by importing text files containing all fish track information into *R* (*R* Development Core Team 2015)[3] where the fish counts were binned by range. The binned data was plotted to investigate the spatial distribution of fish passing the sonar site. Histograms of passage by hour were also created to investigate diel patterns of migration. Run timing of Chinook and fall chum salmon was examined inseason and postseason using information from the sonar estimate, fish range distribution, sample fishery catches, and local subsistence harvest.

Sample Fishing

Two specific test fisheries were implemented to monitor species composition and collect ASL, and genetic samples: 1) a Chinook salmon sample fishery (July 2 to August 15) collected data to estimate specific Canadian stock proportions and the ASL composition of Chinook salmon entering Canada, and 2) a species composition fishery (August 1 to September 30) to determine the transition date between the Chinook and fall chum salmon runs, as well as collect fall chum salmon ASL data.

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[3] R Development Core Team. 2015. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Available for download: http://www.R-project.org.

The Chinook salmon sample fishery occurred twice daily from July 2 through August 1, from approximately 0800 to 1200 hours and again at approximately 1300 to 1700 hours. The fishery specifically targeted Chinook salmon, which are the predominant species during the months of June and July. Between August 1 and August 15, Chinook salmon sample fishing was conducted once per day between 1300 and 1700 hours.

Genetic and ASL samples were collected using 4 different mesh sizes (5.25 in, 6.5 in, 7.5 in, and 8.5 in), which were drifted in a rotating schedule (Table 3) over the course of the Chinook salmon run to effectively capture all size classes present. Nets were 25 fathoms long, approximately 25 ft deep, and hung "even" at a 2:1 ratio of web to corkline (Table 4). Nets were drifted for approximately 6 minutes each within the left bank nearshore (LBN), left bank offshore (LBF), and right bank nearshore (RBN). The right bank zone was located approximately 2.5 km upriver from the sonar site where river conditions were suitable for drift gillnetting on that bank (Figure 2). This resulted in 9 drifts during the Chinook salmon sample fishing period.

For each drift, 4 times were recorded to the nearest second onto field data sheets: net start out (SO), net full out (FO), net start in (SI), and net full in (FI). Fishing time (t), in minutes, was approximated as

$$t = SI - FO + \frac{FO - SO}{2} + \frac{FI - SI}{2} \quad (7)$$

Total effort (f), in fathom-hours, of drift (j) and mesh size (m) during fishing Period l in zone (z) on day (d) was calculated as

$$F_{dzlm} = \frac{25t_{dzlmj}}{60} \quad (8)$$

Fishing for species composition and ASL collection was conducted once daily from August 1 to September 30 between approximately 0800 and 1200 hours on the left bank. During the sampling period, both 5.25 in and 7.5 in nets were drifted twice within each of the 3 left bank zones—left bank inshore (LBI), left bank nearshore (LBN), and left bank offshore (LBF) (Figure 2)—for a total of 12 drifts. Nets were hung the same as for the Chinook salmon sample fishery with the exception that the LBI nets, which were approximately 3 ft. deep (Table 4). Drifts were targeted to be 6 minutes in duration but were occasionally shortened as necessary to avoid snags or to limit catches and prevent mortalities during times of high fish passage. LBI drifts were referred to as "beach walks" (Fleischman et al. 1995) where 1 person held onto the shore end of the net and led it downstream along the beach while a boat drifted with the offshore end. The nearshore zone started approximately 1 net length from shore and the offshore zone started approximately 2 net lengths from shore. The order of drifts was 1) LBI, 2) LBN, and 3) LBF, and a minimum of 15 min between drifts in the same zone. All drifts using 1 mesh size were completed before switching to another mesh size. Starting mesh sizes were alternated each day (Table 3).

For standard ASL samples, length was measured mideye to tail fork (METF) to the nearest 1 mm. Sex was determined by visually examining features such as development of the kype, roundness of the belly, presence or absence of an ovipositor, and overall size. This is similar to the sampling routine used on the Kuskokwim River (Molyneaux et al. 2010). Four scales from

Chinook salmon and 1 scale from fall chum salmon were removed from the preferred area of the fish on the left side approximately 2 rows above the lateral line in an area transected by a diagonal line from the posterior insertion of the dorsal fin to the anterior insertion of the anal fin (Clutter and Whitesel 1956). All scale samples were cleaned and mounted on gum cards to be aged by ADF&G ASL lab in Anchorage.

For genetic stock identification (GSI), an axillary process was clipped from each salmon. Chinook salmon samples were stored individually in a vial of ethanol, while fall chum salmon samples were stored in bulk collections of up to 200 samples. All samples were sent to ADF&G genetics laboratory and, from there, forwarded to the Fisheries and Oceans Canada genetics laboratory in Nanaimo, British Columbia for processing. Non-salmon species were measured from nose to tail fork but were not sampled for other data. Captured fish were handled in a manner that minimized mortalities.

SPECIES DETERMINATION

Although Chinook and fall chum salmon migrations are considered discrete in time, some temporal overlap does occur. Inseason, a tentative date is chosen based on sonar counts, gillnet catches, and local harvest to represent the last day of the Chinook salmon migration. The remainder of the sonar estimates are classified as fall chum salmon. After thorough examination of the project's fishery data after the season, this date may be adjusted to more accurately represent the observed run timing.

Daily catch data and catch per unit effort (CPUE) from the species composition fishery were used to assess proportional abundance and as an indicator as to when the crossover date occurred. CPUE was calculated for each day (*d*) on the left bank (*b*) during species composition fishing using 2 specific sizes of gillnet mesh (*g*) regardless of catch size. Chinook salmon CPUE was calculated on the catch (*c*) and effort (*e*) (calculated in Equation 8) of the large mesh gillnet (7.5 in); fall chum salmon CPUE was calculated on the catch and effort of the small mesh gillnet (5.25 in). Since all nets were 25 fathoms (45.7 m) in length, CPUE estimates (in catch per fathom hour) for each species (*i*) were made daily for the left bank species composition test fishery:

$$CPUE_{dbi} = \frac{\sum_{g} c_{dbig}}{e_{dbg}} \quad . \tag{9}$$

CPUE data for Chinook and fall chum salmon were imported into *R* and a scatter plot from the data was smoothed using Friedman's supersmoother algorithm (Friedman 1984). The algorithm, which computes 3 separate smooth curves from the input data with symmetric spans of 0.05**n*, 0.2**n* and 0.5**n*, where *n* was the number of data points, selects the best of the 3 smooth curves for each predicted point using leave-one-out cross validation. The best spans are then smoothed by a fixed-span smoother (span = 0.2**n*) and the prediction is computed by linearly interpolating among the 3 smooth curves. This final smooth curve is then smoothed again with a fixed-span smoother (span = 0.05**n*). The crossover date is determined at the point where the 2 lines on the curve cross at the point where the CPUE for fall chum salmon equals the CPUE for Chinook salmon subsequent to that point.

CLIMATE AND HYDROLOGIC OBSERVATIONS

Climatic and hydrologic observations were collected at approximately 1800 hours daily. Reported stream levels are taken from the U.S. Geological Survey's gaging station at Eagle[4], although water levels were monitored at the sonar site as well. Surface water temperature was measured approximately 30 cm below the surface with a HOBO U22™ water temperature data logger. Data loggers were attached to the sonar transducer stands on each bank and set to record every hour. Air temperature, wind velocity, and wind direction were measured daily with a handheld weather meter. Other daily observations included occurrence of precipitation and percent cloud cover.

RESULTS

SONAR DEPLOYMENT

In 2015, both the right and left bank transducers were deployed in approximately the same locations that have been used in recent years (Figure 2). The left bank profile was approximately linear, extending approximately 300 m to the thalweg at a 2.9° slope. The right bank profile was less linear, shorter, and steeper, extending approximately 100 m to the thalweg at a 9.1° slope (Figure 3). The substrate at Six Mile Bend was large cobble to small boulder on the right bank and small to medium sized cobble and silt on the left bank.

CHINOOK AND FALL CHUM SALMON PASSAGE ESTIMATION

In season, August 12 was tentatively determined to be the last day of the Chinook salmon run based on relatively low sonar counts and catches from the species composition test fishery (Figure 10). The inseason species changeover date was adjusted postseason after thorough examination of species composition drift data. Analysis of CPUE and catch data for both the large and small mesh nets (7.50 in and 5.25 in) from the species composition test fishery were plotted by day, and the relationship between the variables summarized using the Friedman's supersmoother algorithm (Figures 11; Appendix A). Both plots suggest the first day of the fall chum salmon run was August 16.

The total passage estimate at the Eagle sonar site for Chinook salmon was 84,015 from June 30 through August 15, which is the highest passage estimate since the project began in 2005. The first quarter point was on July 16, the midpoint on July 23, and three-quarter point on July 29 (Table 5). Peak daily passage estimate of 3,716 Chinook salmon occurred on July 26 and 196 fish passed on August 15, which was the last day of the Chinook season (Figure 12). Compared to historical mean run timing from 2005 to 2014, the midpoint of the Chinook salmon run occurred 2 days early (Figure 13)[5]. Sampling time missed during this period varied by strata, and strata totals ranged from 20.8 h to 37.6 h (Table 6). Time missed was generally due to wireless connection failures, as well as down time while adjusting weir panels and re-aiming or cleaning the sonars. There were no full days of sampling missed this season.

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4 USGS (U.S. Geological Survey). 2014. National Water Information System: Web Interface. USGS 15356000 Yukon River at Eagle Alaska. http://waterdata.usgs.gov/ak/nwis/inventory/?site_no=15356000&agency_cd=USGS& (Accessed January 2016).

5 Differences in the transition dates for species crossover confounds computation of the historical daily cumulative and mean. As a convenience, the historical daily cumulative percent and mean were computed by assuming that 100 percent of the run was completed on the date the Chinook salmon run transitioned to fall chum salmon.

The preliminary subsistence harvest from the Eagle area upstream of the sonar was 341 Chinook salmon (Bonnie Borba, Commercial Fisheries Biologist, ADF&G, Fairbanks; personal communication). Postseason, adjusting for subsistence Chinook salmon harvest produced a border passage estimate of 83,674 Chinook salmon (Table 7). This estimate was above the preseason projection and the Interim Management Escapement Goal (IMEG)[6] [7] of 42,500 to 55,000, as well as approximately 57% above the 2006 to 2014 mean border passage estimate of 47,997.

The total fall chum salmon sonar passage estimate was 112,136 fish from August 16 through October 6. Approximately 3.3% (3,688 fish) of the total fall chum salmon passage occurred on October 6, the last day of operation (Table 8). Because fall chum salmon passage continued after the project was terminated, the sonar estimate was expanded and adjusted to 125,095 (Figure 12). The first quarter point of the run fell on September 18, the midpoint on September 25, and three-quarter point on October 2. These quartiles were calculated using the expanded passage estimate after the sonar project was terminated (Table 8). Fall chum salmon passage peaked on September 25 and the daily estimate was 4,844 fish. Compared to historical mean run timing from 2006 through 2014, the midpoint of the fall chum salmon run occurred 3 days later than the historic mean date (Figure 13). Sampling time missed during the fall chum migration varied by strata, and totals ranged from 21.3 h to 82.1 h (Table 9).

The preliminary subsistence harvest from the Eagle area was 12,540 fish (Bonnie Borba, Commercial Fisheries Biologist, ADF&G, Fairbanks; personal communication). Postseason, adjusting for subsistence fall chum salmon harvest produced a border passage estimate of 112,555 fish (Table 7). This estimate is approximately 64% below the 2006 to 2014 mean border passage estimate of 174,672. After accounting for preliminary Canadian harvest from both the First Nation (1,000) and Canadian Commercial/Domestic (2,897) fisheries[8], total fall chum salmon escapement was estimated to be 108,658 fish[9] for the mainstem Yukon River in Canada. This exceeded the interim management escapement goal range of 70,000 to 104,000 fish[10] and provided for harvest under the sharing agreement.

The objectives of operating continuously throughout the season until approximately October 6, as well as operating side-looking split-beam and imaging sonar such that 95% of the migrating salmon are detected within three-quarters of the ensonified range, were achieved. Although sonar operations began approximately 5 days early (2007–2013 average), the Chinook salmon migration started to pass the site before passage estimation began. The earlier start date accounted for 331 fish (0.4%) of the entire Chinook salmon run. This contribution was significantly less than in 2014, when an a early project start was conducted because of a unusual

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6 The U.S./Canada Yukon River Panel agreed to a 1-year Canadian Interim Management Escapement Goal (IMEG) of 42,500–55,000 Chinook salmon based on the Eagle sonar program. In order to meet this goal, the passage at Eagle sonar must include a minimum of 42,500 fish for escapement, provide for a subsistence harvest in the community of Eagle upstream of the sonar (approximately 1,000–2,000 fish), and incorporate Canadian harvest sharing as dictated in the U.S./Canada Yukon River Treaty (20%–26% of the total allowable catch).

7 Schmidt, S. and S. Garcia.2015. 2015 Preliminary Yukon River Summer Season Summary, Alaska Department of Fish and Game, Division of Commercial Fisheries, News Release, Juneau Alaska. [issued 2015 October 1; cited January 6, 2016] Available from: http://www.adfg.alaska.gov/static/applications/dcfnewsrelease/623677826.pdf (Accessed January 2016).

8 Canadian chum salmon assessment 2015 presented at: Yukon Joint Technical Meeting, November 17-19, 2015, Seattle Washington; Power Point Presentation.

9 Estimated mainstem Yukon River Canadian escapement is derived from Eagle sonar estimate (expanded through October 18; 2008 to present) minus harvest from Eagle community upstream including Canadian harvests.

10 Estensen, J. and B. Borba. 2014. 2014 Yukon River Fall Season Summary. Alaska Department of Fish and Game, Division of Commercial Fisheries, News Release, Juneau Alaska. [issued 2014 December 5; cited January 5, 2015] Available from: http://www.adfg.alaska.gov/static/applications/dcfnewsrelease/505439194.pdf (Accessed January 2015).

early run of Chinook salmon which accounted for approximately 7% of the total Chinook salmon passage (Lozori and Borden 2015).

SPATIAL AND TEMPORAL DISTRIBUTION

Fish were shore oriented on both banks (Figures 14 and 15). On the left bank, during the Chinook salmon migration, approximately 95% of the fish were detected within 60 m of the transducer and 99% within 90 m. On the right bank, 95% of the fish were detected within 20 m of the transducer and 99% within 30 m. During the fall chum salmon migration on the left bank, approximately 95% of the fish were detected within 20 m of the transducer and 99% within 30 m. On the right bank, approximately 95% of the fish were detected within 6 m of the transducer and 99% within 8 m. Approximately 72% of both Chinook and fall chum salmon passed on the left bank.

Although overall Chinook salmon migration past the sonar does not suggest a distinct diel migration pattern, a slight decrease in passage on the left bank and an increase on the right bank was evident between 0900 and 1600 (Figure 16). This period corresponds with the test fishery schedule and suggests there may be a relationship between the fishing schedule and daily Chinook salmon passage. Because the right bank test fishery occurs far upstream from the sonar (Figure 2), effectively only the left bank salmon passage would be impacted.

Similarly, but more distinctive, the fall chum salmon passage increased on the right bank during the morning test fishery (Figure 17). It is noteworthy to mention that test fishing is not conducted on the right bank during the majority of the fall chum salmon migration.

SAMPLE FISHING

A total of 1,058 Chinook and 831 fall chum salmon were captured in drift gillnets between July 2 and October 1 (Table 10). Fishing for species composition and sample collection occurred from August 1 to October 1, and additional Chinook salmon sample fishing occurred from July 2 to August 15. Four sheefish *Stenodus leucichthys*; 2 Arctic grayling *Thymallus arcticus*; 1 Humpback whitefish *Coregonus pidschian*; 1 burbot *Lota lota*; and 1 longnose sucker *Catostomus catostomus* were captured. The number of Chinook and fall chum salmon captured in drift gillnets by sampling purpose (species composition sampling or Chinook salmon sampling) (Tables 11 and 12). The cumulative Chinook salmon CPUE was higher than has been observed historically at the project, and fall chum salmon cumulative CPUE was near average (Figure 18). There were no known Chinook or fall chum salmon capture mortalities. Nineteen Chinook salmon had clipped adipose fins, indicating they held coded wire tags from the hatchery in Whitehorse, Yukon Territory. These fish were retained and the heads sent to the ADF&G Mark, Tag, and Age Lab in Juneau, Alaska.

Chinook salmon samples collected from driftnets were composed of 625 (59%) males and 433 females. Fall chum salmon samples from driftnets were composed of 477 (61%) males and 304 females (Tables 11 and 12). ASL samples from all Chinook and fall chum salmon (unless recaptured) were collected and sent to the ADF&G age determination laboratory in Anchorage for processing. Genetic samples from Chinook and fall chum salmon were collected and sent to the ADF&G Genetics Laboratory in Anchorage, Alaska and, from there, forwarded to the Fisheries and Oceans Canada genetics laboratory in Nanaimo, British Columbia for processing.

The objective to collect a minimum of 160 Chinook salmon ASL samples was met in 2 of the 3 strata, and the objective to collect 160 fall chum salmon ASL samples was met in 2 of the 4 strata (Table 13). Goals to collect Chinook and fall chum tissue samples for genetic stock identification were achieved.

CLIMATE AND HYDROLOGIC OBSERVATIONS

Weather and water observations were recorded at the sonar site daily (Appendix B). Water temperature on the left bank decreased over the course of the season; the highest was 16.9ºC on July 26, and the lowest was 3.1ºC on October 5 (Figure 19). The water level was near the historic mean (1995–2014) on June 30 when sonar operations began. Water levels remained near the mean until August 21, when an increase began after which it remained above the mean for the remainder of the season. The water level exceeded the historical maximum on September 4 and remained at or above the maximum until September 10 (Figure 20). All goals to collect climatic and hydrologic measurements were achieved this season.

DISCUSSION

This was the first season an ARIS was deployed at the project. The transition from DIDSON to ARIS was smooth and required very little additional preparation besides fabricating a new mount for the AR2 rotator (Figure 7). Remote aiming worked well, and unlike previous seasons using the DIDSON, we were able to specifically define aim for both strata rather than aiming to ensonify the full 40 m on the right bank.

Overall there were no significant problems with project operations. Both sonars performed well the entire season and there were no major technical difficulties or failures. There were minimal interruptions or problems with detection caused by heavy silt or high water, except when both sonars were pulled from the water on September 4–5 because of a high water event. This resulted in a total loss (both banks combined) of 45.3 h (Table 9). Rapid water level fluctuations and substantial debris made it necessary to frequently move the transducers and fish leads to deeper or shallower water.

The sonar sampling range on the left bank was stratified during the fall chum salmon migration. Stratifying the range enabled us to increase the ping rate and improve visual detection on echograms specifically in the nearshore where a majority of passage occurs.

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TABLES AND FIGURES

Table 1.–Split-beam sonar system settings at the Eagle sonar site on the Yukon River 2015.

Component	Setting	Stratum [a]	Value
Transducer	Beam size (h x w)	All	2.5º x 10.0º
Echosounder	Power output (W)	All	500
	Pulse width (μ)	All	256
	Ping rate (pps)	S1	8.33
		S2	4.16
		S3	16.66
		S4	8.33
	Range (m)	S1	50
		S2	150
		S3	25
		S4	75
	Duration (min)	S1	30
		S2	30
		S3	30
		S4	30

[a] When counting Chinook salmon, the split-beam system was aimed to ensonify a range of approximately 150 m from the transducer, and sampled 2 strata, (S1: approximately 0–50 m and S2: approximately 50–150 m). When counting fall chum salmon, the split-beam system was aimed to ensonify 2 strata (S3, approximately 0–25, and S4 approximately 25–75 m).

Table 2.–Technical specifications and settings for the adaptive resolution imaging sonar (ARIS) at the Eagle sonar site on the Yukon River, 2015.

Setting	Stratum[a]	Value
Mode	S5	Identification
	S6	Detection
Frequency (MHz)	S5	1.20
	S6	0.70
Number of beams	S5	48
	S6	48
Start range (m)	S5	0.7
	S6	20.7
End range (m)	S5	20.0
	S6	40.0
Frame rate	S5	7 frames/s
	S6	4 frames/s
Duration in minutes	S5, S6	30
Field of view	S5, S6	28°

[a] The 2 ARIS sampling strata (S5: 0.7–20 m and S6: 20–40 m) were independently aimed using a Sound Metrics AR2 Rotator and ARIScope software.

Table 3.–Net schedule of mesh sizes (inches) for species composition and additional Chinook salmon samples, all zones, at the Eagle sonar project on the Yukon River, 2015.

		Drift		
Sampling purpose	Day	1	2	3
Species composition	1	5.25	7.50	NA
	2	7.50	5.25	NA
Additional Chinook salmon samples	1	5.25	6.50	7.50
	2	7.50	8.50	6.50
	3	6.50	5.25	8.50
	4	8.50	7.50	5.25

Table 4.–Specifications for drift gillnets used for test fishing at the Eagle sonar project on the Yukon River, 2015.

	Stretch mesh size		Mesh diameter	Meshes deep	Depth
Method	(inch)	(mm)	(mm)	(MD)	(m)
Drift	5.25	133	85	69	8.0
	6.50	165	105	55	7.9
	7.50	191	121	48	8.0
	8.50	216	137	43	8.1
Beach walk	5.25	133	85	26	3.0
	7.50	191	121	18	3.0

Note: Gillnet webbing consisted of Momoi MTC or MT, shade 11 or equivalent, double knot multifilament nylon twine.

Table 5.–Estimated daily and cumulative Chinook salmon passage by bank at the Eagle sonar project on the Yukon River, 2015.

	Daily			Cumulative			
Date	Left bank	Right bank	Total	Left bank	Right bank	Total	Proportion of total passage
30 Jun [a]	19	111	130	19	111	130	0.002
1 Jul	76	43	119	95	154	249	0.003
2 Jul	122	50	172	217	204	421	0.005
3 Jul	158	30	188	375	234	609	0.007
4 Jul	253	97	350	628	331	959	0.011
5 Jul	307	157	464	935	488	1,423	0.017
6 Jul	380	123	503	1,315	611	1,926	0.023
7 Jul	397	200	597	1,712	811	2,523	0.03
8 Jul	578	276	854	2,290	1,087	3,377	0.04
9 Jul	842	306	1,148	3,132	1,393	4,525	0.054
10 Jul	1,250	220	1,470	4,382	1,613	5,995	0.071
11 Jul	1,420	379	1,799	5,802	1,992	7,794	0.093
12 Jul	1,838	537	2,375	7,640	2,529	10,169	0.121
13 Jul	2,036	700	2,736	9,676	3,229	12,905	0.154
14 Jul	1,750	1,044	2,794	11,426	4,273	15,699	0.187
15 Jul	1,870	1,339	3,209	13,296	5,612	18,908	0.225
16 Jul	2,722	912	3,634	16,018	6,524	22,542	0.268
17 Jul	2,012	1,371	3,383	18,030	7,895	25,925	0.309
18 Jul	2,042	1,400	3,442	20,072	9,295	29,367	0.35
19 Jul	2,054	1,190	3,244	22,126	10,485	32,611	0.388
20 Jul	2,266	952	3,218	24,392	11,437	35,829	0.426
21 Jul	2,118	820	2,938	26,510	12,257	38,767	0.461
22 Jul	1,872	754	2,626	28,382	13,011	41,393	0.493
23 Jul	2,000	968	2,968	30,382	13,979	44,361	0.528
24 Jul	2,145	850	2,995	32,527	14,829	47,356	0.564
25 Jul	2,412	958	3,370	34,939	15,787	50,726	0.604
26 Jul	2,766	950	3,716	37,705	16,737	54,442	0.648
27 Jul	2,560	978	3,538	40,265	17,715	57,980	0.69
28 Jul	2,312	968	3,280	42,577	18,683	61,260	0.729
29 Jul	2,696	744	3,440	45,273	19,427	64,700	0.77
30 Jul	2,284	720	3,004	47,557	20,147	67,704	0.806
31 Jul	2,462	531	2,993	50,019	20,678	70,697	0.841
1 Aug	1,908	574	2,482	51,927	21,252	73,179	0.871
2 Aug	1,684	390	2,074	53,611	21,642	75,253	0.896
3 Aug	1,510	281	1,791	55,121	21,923	77,044	0.917
4 Aug	1,210	234	1,444	56,331	22,923	78,,\488	0.934

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Table 5.–Page 2 of 2.

	Daily			Cumulative			
Date	Left bank	Right bank	Total	Left bank	Right bank	Total	Proportion of total passage
5 Aug	862	325	1,187	57,193	22,482	79,675	0.948
6 Aug	672	356	1,028	57,865	22,838	80,703	0.961
7 Aug	676	123	799	58,541	22,961	81,502	0.97
8 Aug	460	136	596	59,001	23,097	82,098	0.977
9 Aug	282	150	432	59,283	23,247	82,530	0.982
10 Aug	220	78	298	59,503	23,325	82,828	0.986
11 Aug	216	78	294	59,719	23,403	83,122	0.989
12 Aug	176	78	254	59,895	23,481	83,376	0.992
13 Aug	166	62	228	60,061	23,543	83,604	0.995
14 Aug	144	71	215	60,205	23,614	83,819	0.998
15 Aug [b]	150	46	196	60,355	23,660	84,015	1
Var				189,936	48,359	238,295	
SE				436	220	488	

Note: The outside box identifies the second and third quartile of run, the inside box identifies median day of passage.

[a] Sonar operational on both banks.

[b] Last day of Chinook salmon estimation.

Table 6.–Sampling time, in minutes, missed by bank, zone, and date during Chinook salmon sampling at the Eagle sonar project on the Yukon River, 2015.

	Left bank		Right bank	
Date	0–50 m	50–150 m	0–20 m	20–40 m
30 Jun	570	540	540	510
1 Jul	0	0	60	12
2 Jul	0	0	0	0
3 Jul	18	6	156	150
4 Jul	120	108	24	90
5 Jul	102	96	48	120
6 Jul	0	0	258	264
7 Jul	6	12	0	0
8 Jul	0	0	0	0
9 Jul	0	0	0	0
10 Jul	0	0	6	12
11 Jul	0	0	84	78
12 Jul	0	0	6	6
13 Jul	0	0	30	6
14 Jul	0	0	0	0
15 Jul	0	0	12	12
16 Jul	0	0	0	0
17 Jul	0	0	66	66
18 Jul	48	60	0	0
19 Jul	0	0	30	6
20 Jul	0	0	42	30
21 Jul	0	0	42	48
22 Jul	0	0	0	0
23 Jul	0	0	0	0
24 Jul	0	0	12	0
25 Jul	0	0	0	0
26 Jul	0	0	0	0
27 Jul	150	96	0	0
28 Jul	0	0	0	0
29 Jul	0	0	0	0
30 Jul	0	0	0	0
31 Jul	48	60	36	90
1 Aug	228	270	90	90
2 Aug	0	0	0	0
3 Aug	0	0	42	126
4 Aug	0	0	12	102
5 Aug	0	0	12	84
6 Aug	0	0	198	234
7 Aug	0	0	6	42
8 Aug	0	0	0	0
9 Aug	0	0	0	0
10 Aug	0	0	0	0
11 Aug	0	0	0	0
12 Aug	0	0	54	72
13 Aug	0	0	0	0
14 Aug	0	0	6	6
15 Aug	0	0	0	0
Total min	1,290	1,248	1,872	2,256
Total hours	21.5	20.8	31.2	37.6

Table 7.–Eagle sonar estimate, Eagle area subsistence harvest, and border passage estimates, 2005–2015.

	Sonar estimate		Subsistence harvest		Border passage estimate	
Date	Chinook	Fall chum	Chinook	Fall chum	Chinook	Fall chum
2005	81,528	ND	2,566	ND	78,962	ND
2006	73,691	236,386	2,303	17,775	71,388	218,611
2007	41,697	265,008 [a]	1,999	18,691	39,698	246,317
2008	38,097	185,409 [a]	815	11,381	37,282	174,028
2009	69,957	101,734 [a]	382	6,995	69,575	94,739
2010	35,074	133,413 [a]	604	11,432	34,470	121,498
2011	51,271	224,355 [a]	370	12,477	50,901	211,878
2012	34,747	153,248 [a]	91	11,681	34,656	141,567
2013	30,725	216,794 [a]	152	12,692	30,573	204,102
2014	63,482	172,887 [a]	55 [b]	13,575 [b]	63,427	159,312
2015	84,015	125,095 [a]	341 [b]	12,540 [b]	83,674	112,555

Note: ND indicates that data was not collected. Estimates for subsistence caught salmon between the sonar site and border (Eagle area) prior to 2008 include an unknown portion caught below the sonar site. This number is probably in the hundreds for Chinook salmon, and a few thousand for fall chum salmon. Starting in 2008, the estimates for subsistence caught salmon only include salmon harvested between the sonar site and the U.S./Canada border.

[a] Expanded sonar estimate includes expansion for fish that may have passed after sonar operations ceased.

[b] Subsistence estimates are preliminary.

Table 8.–Estimated daily and cumulative fall chum salmon passage by bank at the Eagle sonar project, on the Yukon River, 2015.

	Daily			Cumulative			
Date	Left bank	Right bank	Total	Left bank	Right bank	Total	Proportion of total passage
8/16 [a]	84	30	114	84	30	114	0.001
8/17	99	60	159	183	90	273	0.002
8/18	72	48	120	255	138	393	0.003
8/19	90	36	126	345	174	519	0.004
8/20	160	26	186	505	200	705	0.006
8/21	180	36	216	685	236	921	0.007
8/22	206	28	234	891	264	1,155	0.009
8/23	252	22	274	1,143	286	1,429	0.011
8/24	298	26	324	1,441	312	1,753	0.014
8/25	318	14	332	1,759	326	2,085	0.017
8/26	328	29	357	2,087	355	2,442	0.02
8/27	362	32	394	2,449	387	2,836	0.023
8/28	406	10	416	2,855	397	3,252	0.026
8/29	448	30	478	3,303	427	3,730	0.03
8/30	408	20	428	3,711	447	4,158	0.033
8/31	260	14	274	3,971	461	4,432	0.035
9/01	505	33	538	4,476	494	4,970	0.04
9/02	644	37	681	5,120	531	5,651	0.045
9/03	635	32	667	5,755	563	6,318	0.051
9/04	487	40	527	6,242	603	6,845	0.055
9/05	684	22	706	6,926	625	7,551	0.06
9/06	740	44	784	7,666	669	8,335	0.067
9/07	796	70	866	8,462	739	9,201	0.074
9/08	1,120	104	1,224	9,582	843	10,425	0.083
9/09	1,384	238	1,622	10,966	1,081	12,047	0.096
9/10	1,456	240	1,696	12,422	1,321	13,743	0.11
9/11	1,512	315	1,827	13,934	1,636	15,570	0.124
9/12	1,568	422	1,990	15,502	2,058	17,560	0.14
9/13	1,500	551	2,051	17,002	2,609	19,611	0.157
9/14	1,652	481	2,133	18,654	3,090	21,744	0.174
9/15	1,760	593	2,353	20,414	3,683	24,097	0.193
9/16	2,112	789	2,901	22,526	4,472	26,998	0.216
9/17	2,255	1,060	3,315	24,781	5,532	30,313	0.242
9/18	2,806	914	3,720	27,587	6,446	34,033	0.272
9/19	2,842	1,252	4,094	30,429	7,698	38,127	0.305
9/20	3,084	1,435	4,519	33,513	9,133	42,646	0.341
9/21	3,326	1,150	4,476	36,839	10,283	47,122	0.377
9/22	3,688	975	4,663	40,527	11,258	51,785	0.414
9/23	3,512	853	4,365	44,039	12,111	56,150	0.449
9/24	3,428	1,345	4,773	47,467	13,456	60,923	0.487
9/25	3,366	1,478	4,844	50,833	14,934	65,767	0.526
9/26	2,806	1,979	4,785	53,639	16,913	70,552	0.564

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Table 8.–Page 2 of 2.

Date		Daily			Cumulative			
		Left bank	Right bank	Total	Left bank	Right bank	Total	Proportion of total passage
9/27		2,956	1,831	4,787	56,595	18,744	75,339	0.602
9/28		3,004	1,572	4,576	59,599	20,316	79,915	0.639
9/29		3,139	1,484	4,623	62,738	21,800	84,538	0.676
9/30		2,598	1,504	4,102	65,336	23,304	88,640	0.709
10/1		2,444	1,638	4,082	67,780	24,942	92,722	0.741
10/2		2,684	1,435	4,119	70,464	26,377	96,841	0.774
10/3		2,600	1,338	3,938	73,064	27,715	100,779	0.806
10/4		2,418	1,385	3,803	75,482	29,100	104,582	0.836
10/5		2,376	1,490	3,866	77,858	30,590	108,448	0.867
10/6	b	2,692	996	3,688	80,550	31,586	112,136	0.896
10/7	c	2262	837	3,099	82,812	32,423	115,235	0.921
10/8	c	1869	692	2,561	84,681	33,115	117,796	0.942
10/9	c	1514	560	2,075	86,196	33,675	119,871	0.958
10/10	c	1196	443	1,639	87,392	34,118	121,510	0.971
10/11	c	916	339	1,255	88,308	34,456	122,765	0.981
10/12	c	673	249	922	88,981	34,705	123,687	0.989
10/13	c	467	173	640	89,449	34,878	124,327	0.994
10/14	c	299	111	410	89,748	34,989	124,737	0.997
10/15	c	168	62	231	89,916	35,051	124,967	0.999
10/16	c	75	28	102	89,991	35,079	125,070	1
10/17	c	19	7	26	90,009	35,086	125,095	1
10/18	c	0	0	0	90,009	35,086	125,095	1
Var	d	177,628	180,043	112,136				
SE	d	421	424	598				

Note: Median is based on inseason sonar estimates and does not include postseason expansion. The outside box identifies the second and third quartile of run, including the expanded estimate. The inside box identifies median day of passage, including the expanded estimate.

[a] First day of fall chum salmon counts.

[b] Last day of sonar operation.

[c] Expanded passage estimate.

[d] Variance and standard error are only calculated to October 6, which was the last day of sonar operation.

Table 9.–Sampling time, in minutes, missed by bank, zone, and date during fall chum salmon sampling at the Eagle sonar project on the Yukon River, 2015.

	Left bank		Right bank	
Date	0–25m	25–75m	0–20 m	20–40 m
8/16	0	0	0	0
8/17	222	150	0	0
8/18	0	0	0	0
8/19	0	0	0	0
8/20	0	0	0	0
8/21	12	0	0	0
8/22	0	0	0	0
8/23	0	0	54	108
8/24	0	0	24	90
8/25	0	0	108	156
8/26	0	0	180	180
8/27	0	0	0	0
8/28	0	0	0	0
8/29	6	0	96	156
8/30	0	0	12	12
8/31	0	0	0	0
9/01	90	102	120	144
9/02	0	0	90	96
9/03	36	60	102	126
9/04	300	312	354	342
9/05	288	270	432	420
9/06	6	0	114	102
9/07	0	0	126	60
9/08	0	0	216	132
9/09	0	0	42	36
9/10	0	0	180	150
9/11	0	0	54	108
9/12	0	0	102	66
9/13	0	0	132	78
9/14	0	0	312	216
9/15	0	0	60	66
9/16	0	0	162	144
9/17	0	0	0	0
9/18	0	0	48	60
9/19	0	0	60	30
9/20	0	0	156	120
9/21	0	0	0	0
9/22	0	0	6	0
9/23	0	0	0	0
9/24	0	0	186	156
9/25	0	0	0	0

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Table 9.–Page 2 of 2.

Date	Left Bank 0–75 m		Right Bank 0–20 m	Right Bank 20–40 m
9/26	0	0	6	0
9/27	0	0	60	48
9/28	0	0	54	6
9/29	0	0	222	150
9/31	0	0	192	156
10/1	0	0	90	48
10/2	0	0	24	6
10/3	0	0	174	168
10/4	0	0	96	90
10/5	0	0	0	12
10/6	6	384	480	528
Total min	1,320	1,278	4,926	4,566
Total hours	22	21.3	82.1	76.1

Table 10.–Fish caught with gillnets at the Eagle sonar project, on the Yukon River, 2015.

Species	Species composition	Chinook sample	Total
Chinook salmon	89	969	1,058
Fall chum salmon	827	4	831
sheefish	4	0	4
whitefish	1	0	1
burbot	1	0	1
grayling	2	0	2
sucker	1	0	1
Total	925	973	1,898

Table 11.–Species composition fishing effort, catch, and percentage by zone and mesh for Chinook and fall chum salmon, at the Eagle sonar project, on the Yukon River 2015.

	Mesh size	Effort	Chinook salmon		Fall chum salmon	
Zone[a]	(inches)	(fathom hours)	Catch	Proportion	Catch	Proportion
LBI	5.25	374.3	14	0.16	536	0.65
	7.50	348	11	0.12	162	0.20
Total		722.3	25	0.28	698	0.84
LBN	5.25	354.4	30	0.34	63	0.08
	7.50	350.9	26	0.29	60	0.07
Total		705.3	56	0.63	123	0.15
LBF	5.25	337.7	2	0.02	1	0
	7.50	340.9	6	0.07	5	0.01
Total		678.6	8	0.09	6	0.01
	Grand total	2,106.10	89	1	827	1

[a] Gillnets were drifted through 3 zones on the left bank; left bank inshore (LBI) which was held from shore and led downstream while a boat drifted with the offshore end; left bank nearshore (LBN) which was drifted approximately 1 net length from shore; and left bank offshore (LBF) which was drifted approximately 2 net lengths from shore.

Table 12.–Chinook salmon sample fishing effort, catch, and percentage for Chinook and fall chum salmon, Eagle sonar project, on the Yukon River 2015.

	Mesh size	Effort	Chinook salmon		Fall chum salmon	
Zone[a]	(inches)	(fathom hours)	Catch	Proportion	Catch	Proportion
LBN	5.25	173.1	225	0.23	3	0.75
	6.50	177	188	0.19	1	0.25
	7.50	195.7	143	0.15	0	0
	8.50	172.1	128	0.13	0	0
Total		717.9	684	0.71	4	1
RBN	5.25	151.9	26	0.03	0	0
	6.50	156	32	0.03	0	0
	7.50	158.7	32	0.03	0	0
	8.50	151	29	0.03	0	0
Total		617.6	119	0.12		0
LBF	5.25	143.5	30	0.03	0	0
	6.50	156.5	41	0.04	0	0
	7.50	159.5	47	0.05	0	0
	8.50	172.1	48	0.05	0	0
Total		631.6	166	0.17	0	0
Grand total		1967.1	969	1	4	1

[a] Gillnets were drifted through 3 zones: left bank nearshore (LBN) which was drifted approximately 1 net length from shore; left bank offshore (LBF) which was drifted approximately 2 net lengths from shore; and right bank nearshore (RBN) which was drifted approximately 1 net length from shore.

Table 13.–Number of salmon scales sampled at the ADF&G age determination laboratory, by stratum dates, to characterize age, sex, and length (ASL) composition at the Eagle sonar project, on the Yukon River 2015.

Stratum dates [a]	Chinook salmon	Fall Chum salmon
7/02–7/16	219	NA
7/17–7/31	585	NA
8/01–8/15	120	NA
8/08–8/20	NA	19
8/21–9/02	NA	207
9/03–9/15	NA	181
9/16–9/30[b]	NA	613
Total		

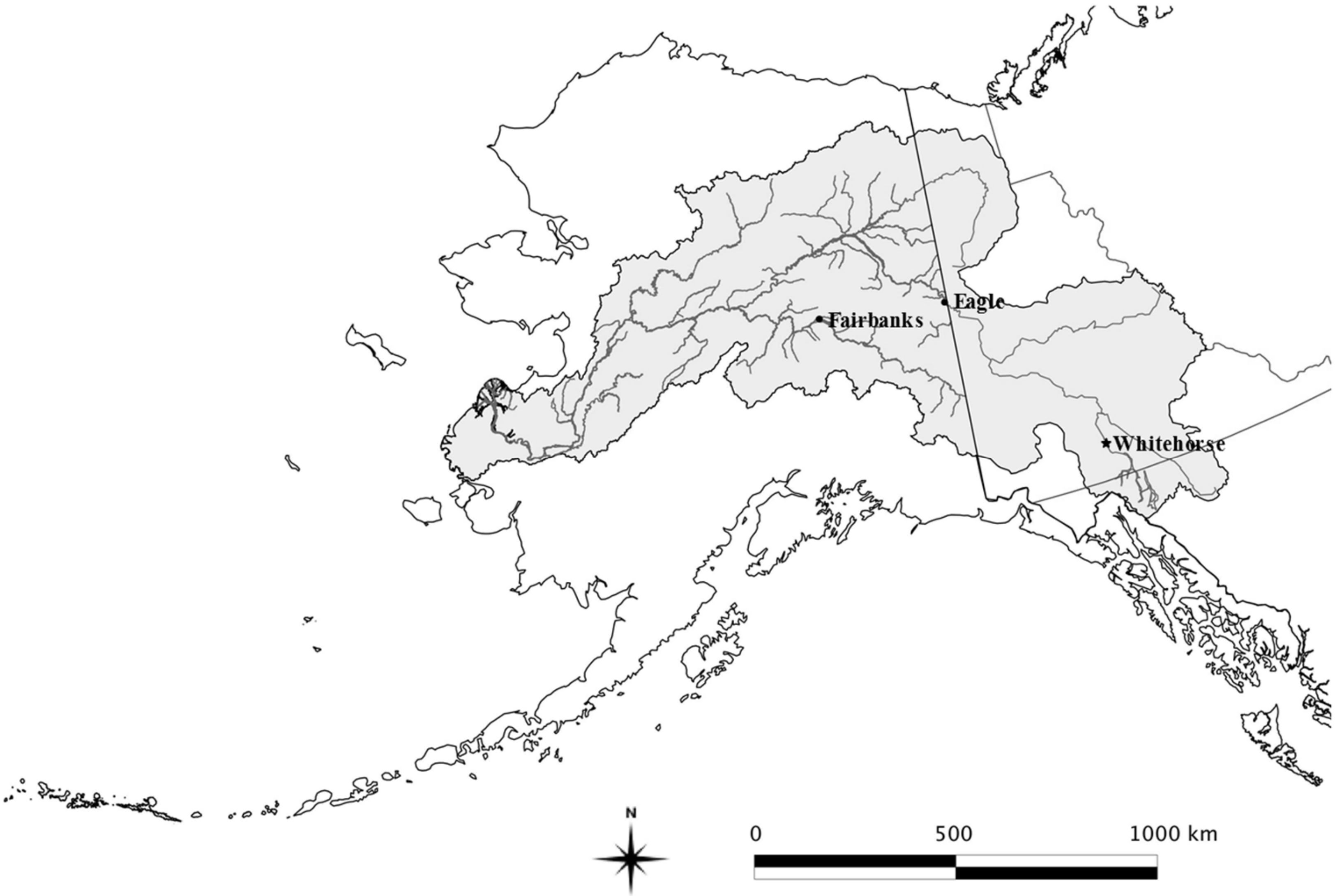


Figure 1.–Yukon River drainage.

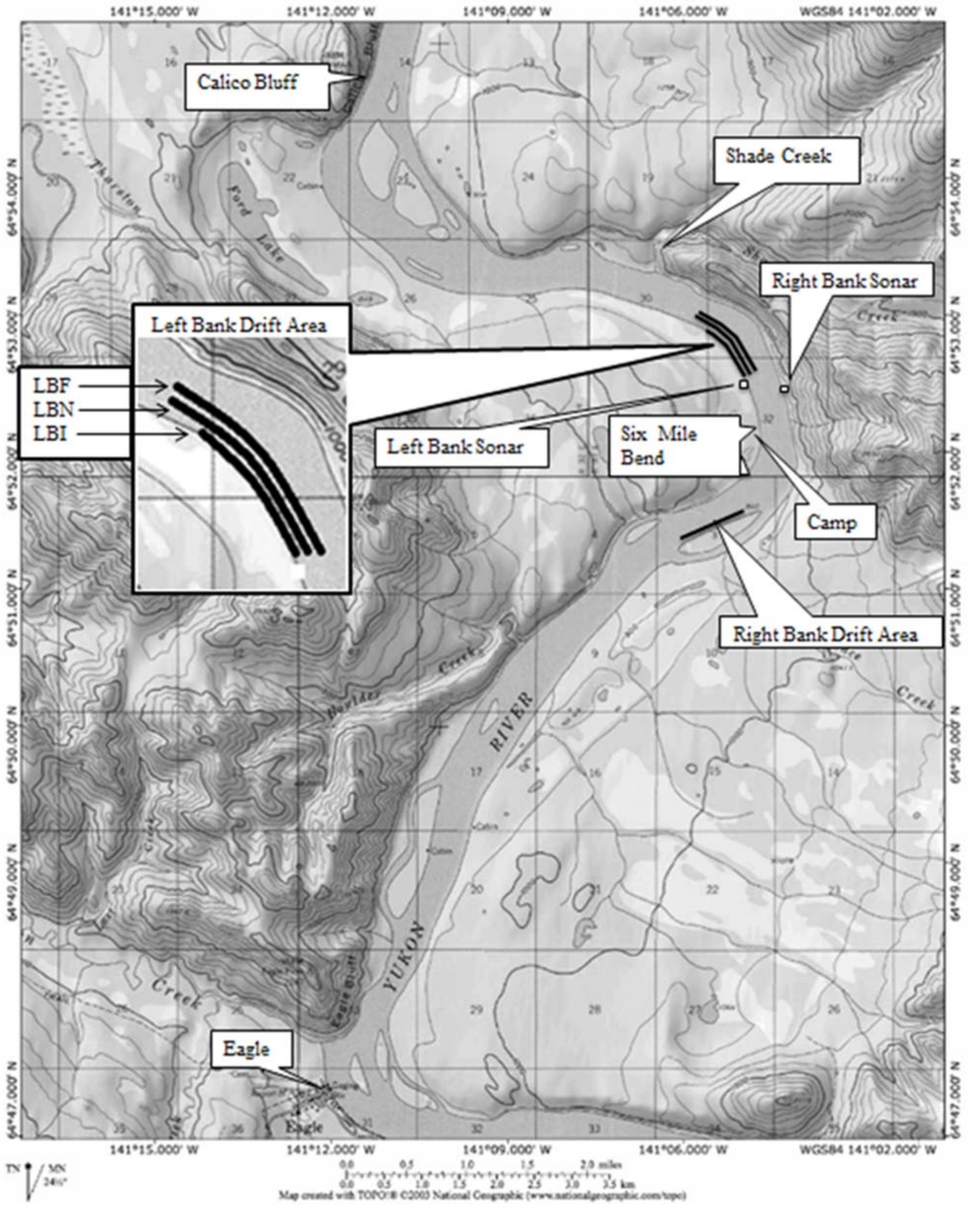


Figure 2.–Eagle sonar project site at Six Mile Bend on the Yukon River, showing sonar and drift gillnet fishing locations, 2015.

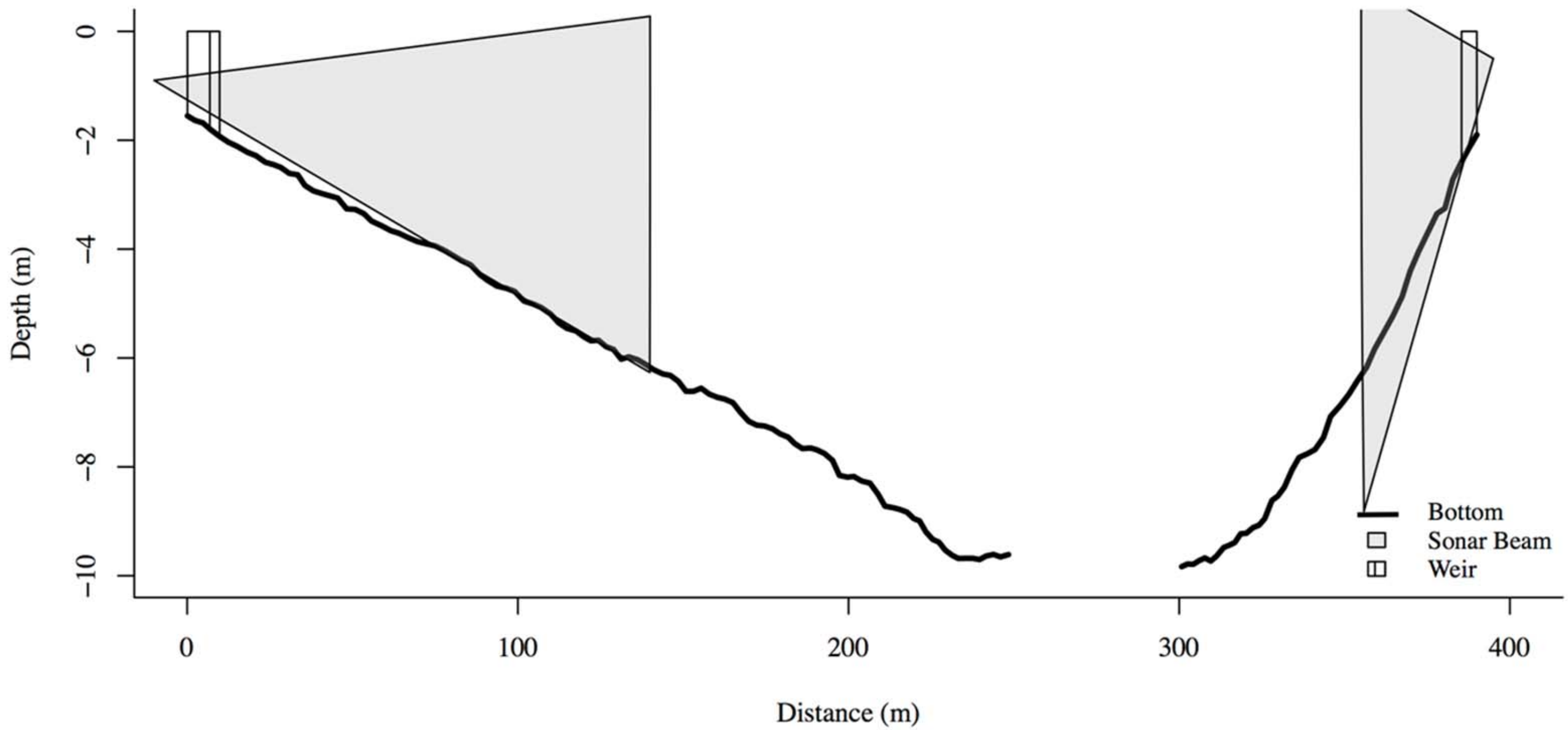


Figure 3.–Depth profile of Yukon River in front of transducers (downstream view), and approximate sonar coverage at the Eagle sonar project.

Note: To avoid damage to the outboard motor and transducer, bathymetric data collection began offshore at a depth of approximately 2 m.

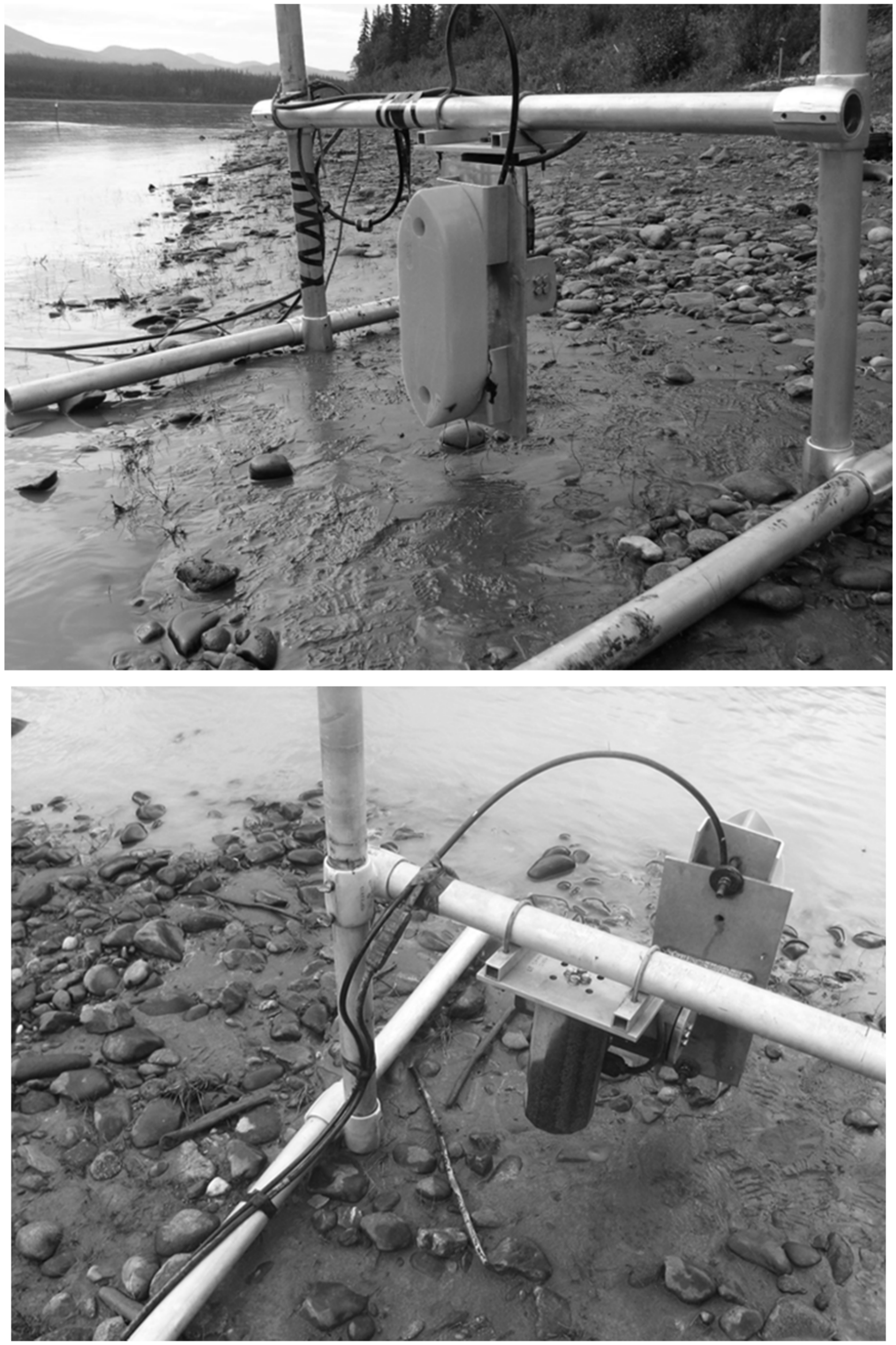


Figure 4.–Split-beam transducer mounted to an aluminum H-mount (top) and the same transducer mounted to 2 single-axis automated rotators (bottom), used on the left bank at the Eagle sonar project, on the Yukon River, 2015.

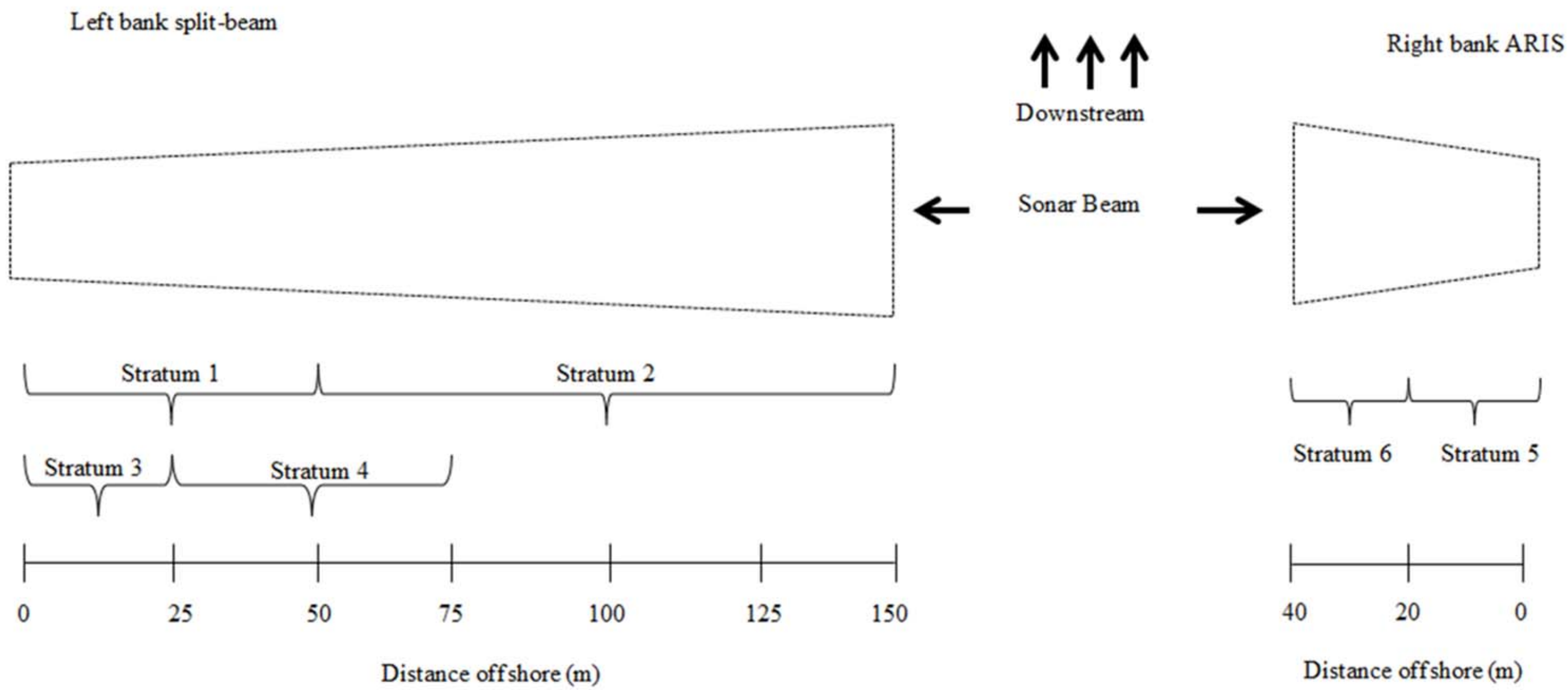


Figure 5.–Illustration of strata and approximate sonar ranges (not to scale) at the Eagle sonar project, on the Yukon River 2015.

Figure 6.–Portable tripod-style fish lead used on the left bank (top) and plastic snow fencing used on the right bank at the Eagle sonar project, on the Yukon River, 2015.

Figure 7.–View of ARIS imaging sonar and AR2 rotator mounted to an aluminum H mount (top), Close up view of mount for rotator (bottom), at the Eagle sonar project on the Yukon River, 2015.

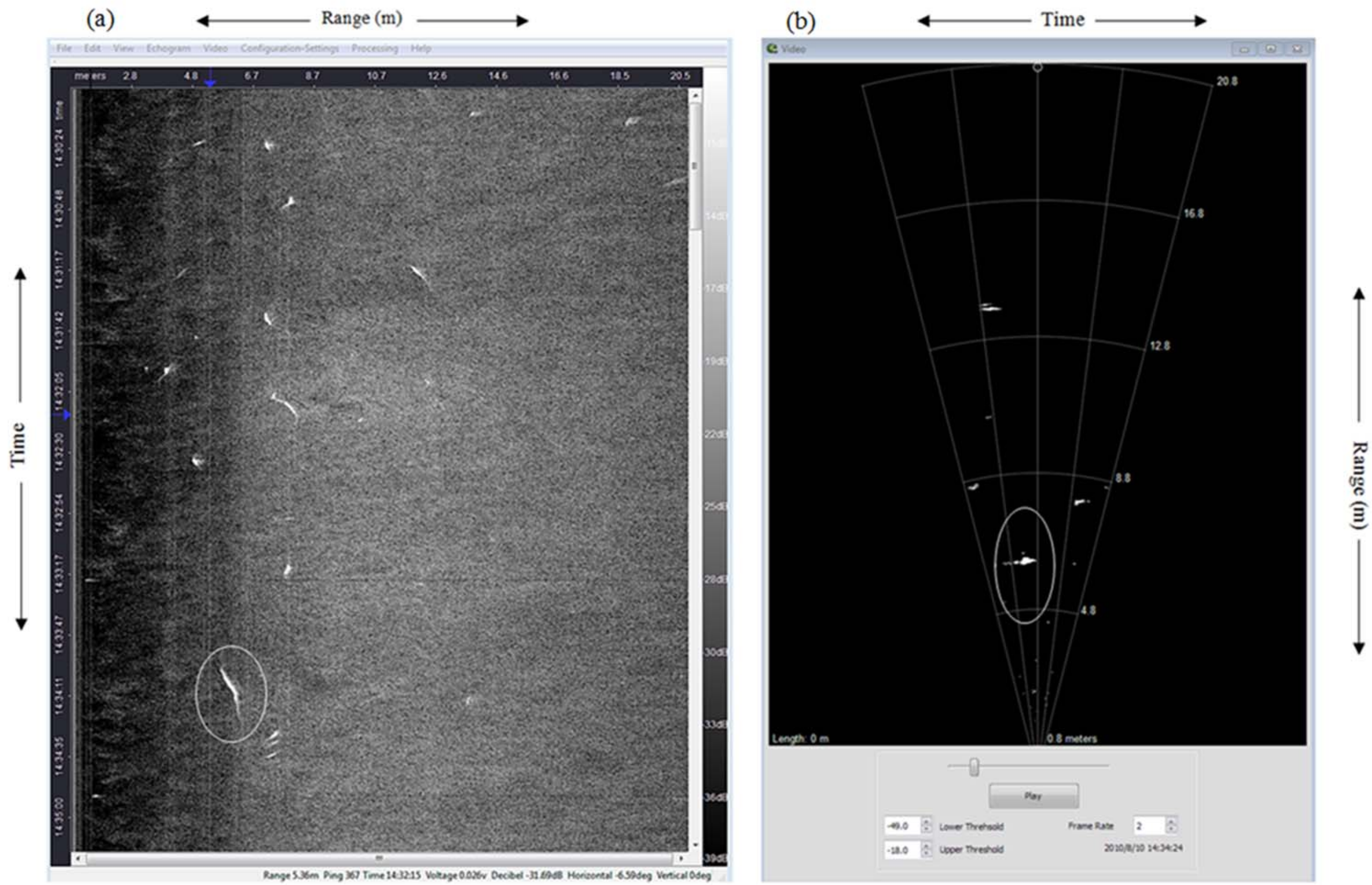


Figure 8.–Screenshots of echogram (a) and video (b) used to count and determine direction of travel from ARIS data files at the Eagle sonar project on the Yukon River, 2015.

Note: Ellipse encompasses typical upstream migrating salmon.

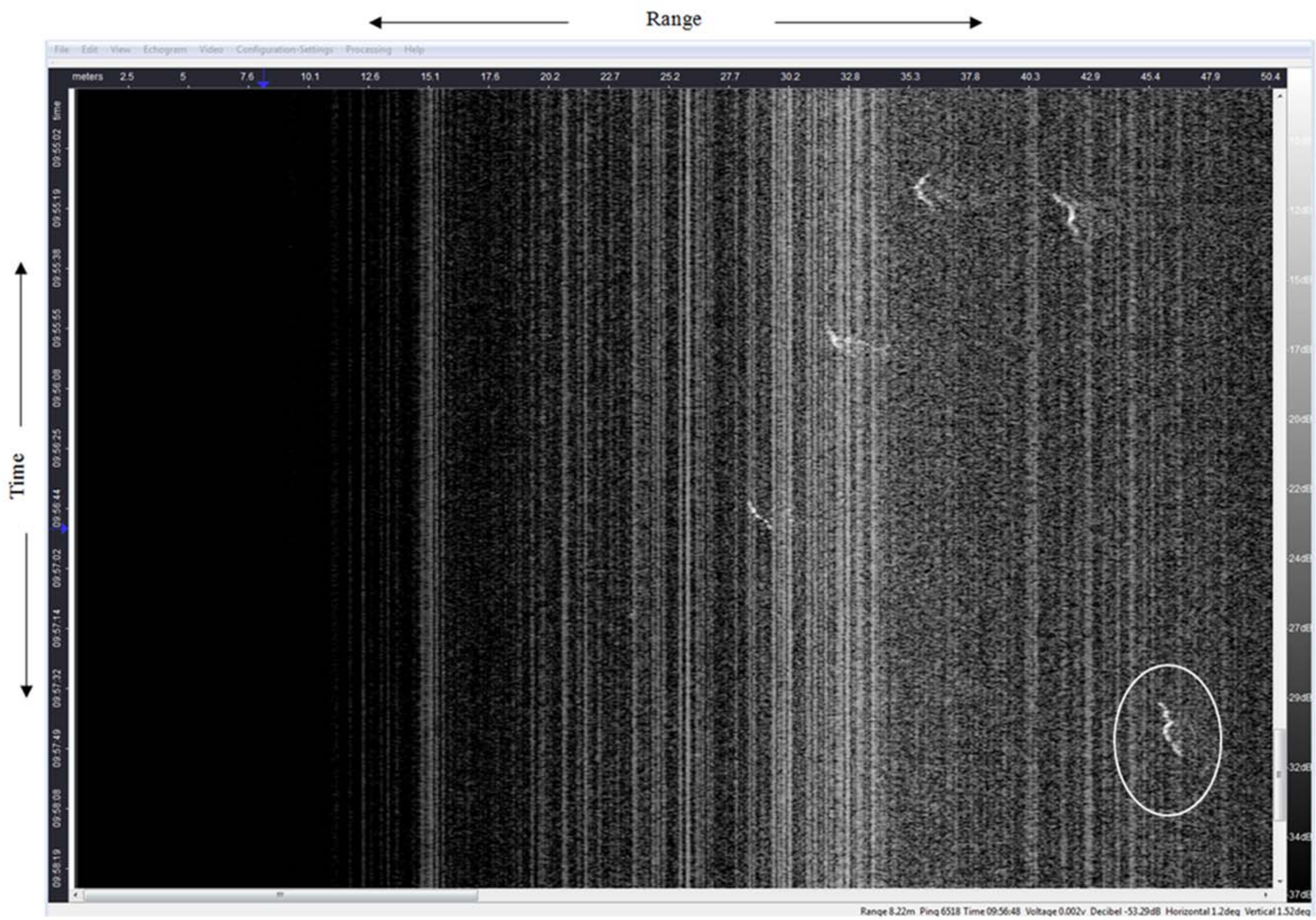


Figure 9.–Screenshot of echogram used to count and determine direction of travel from split-beam sonar data files at the Eagle sonar project on the Yukon River, 2015.

Note: Ellipse encompasses typical upstream migrating salmon.

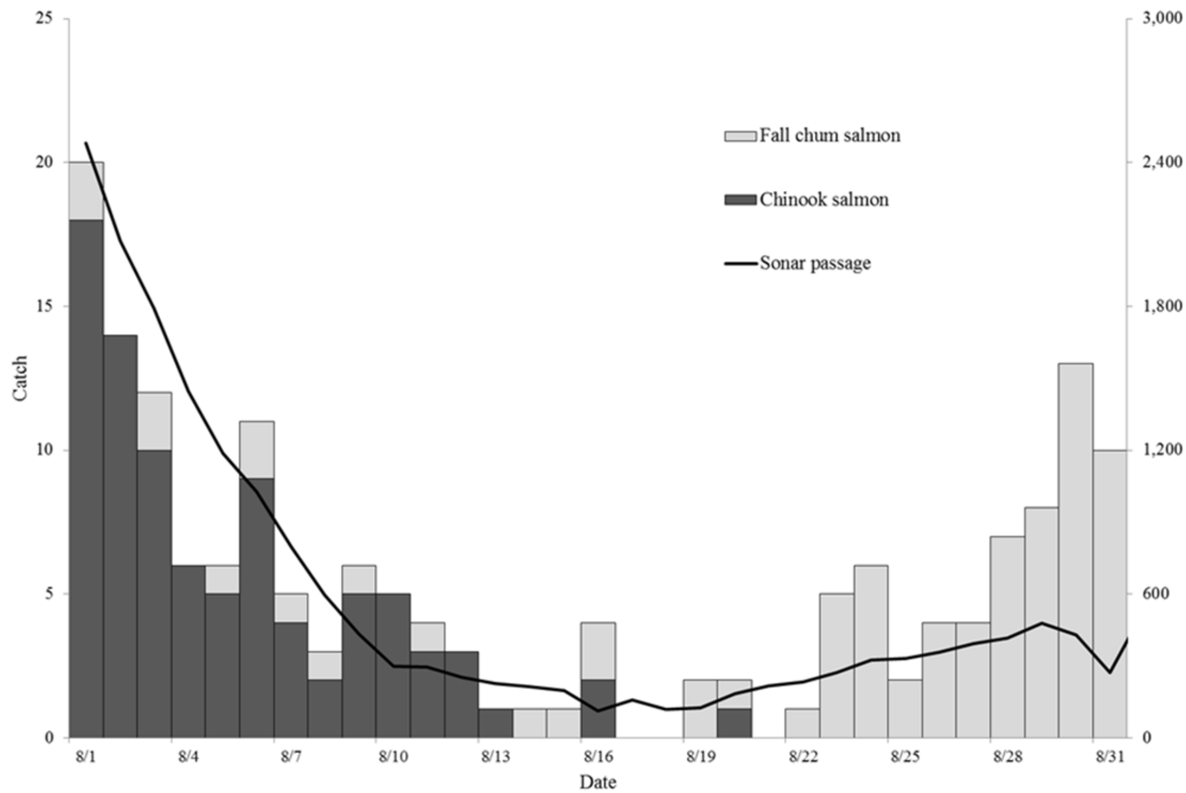


Figure 10.–Daily catch during species composition fishing and sonar passage estimates at the Eagle sonar project, on the Yukon River, 2015.

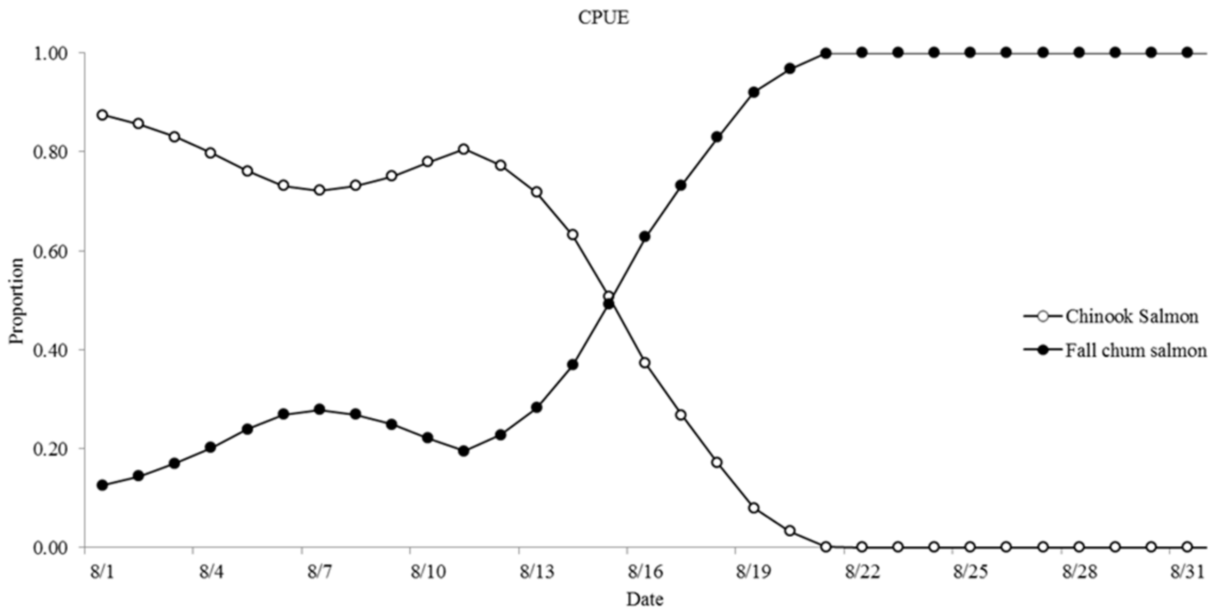
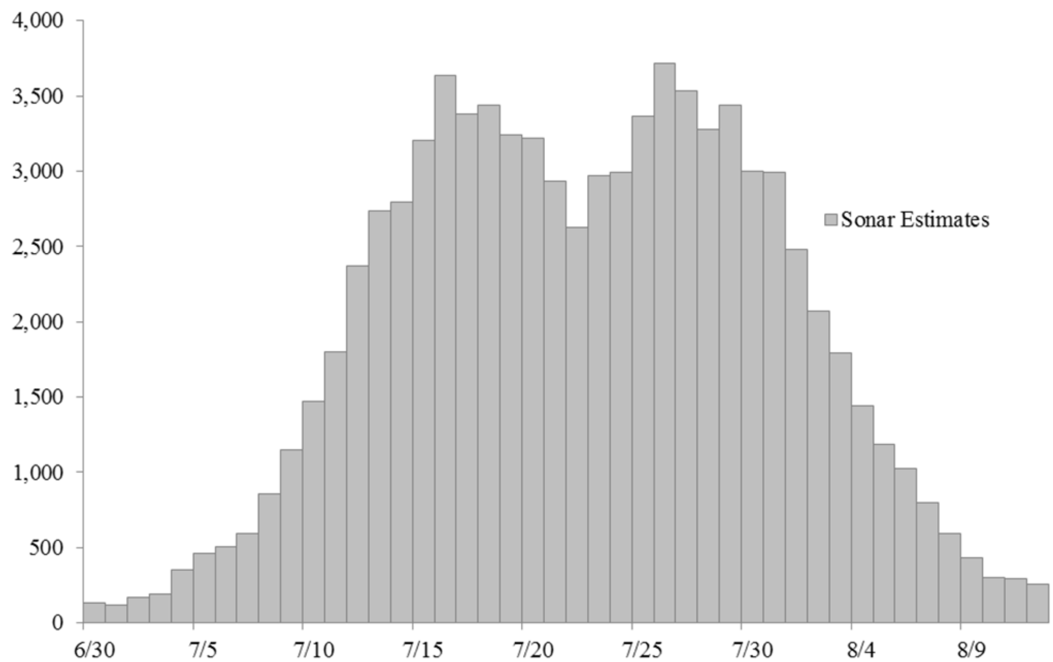


Figure 11.–Results of applying smoothing algorithm to Chinook and fall chum salmon species composition CPUE data at the Eagle sonar project, on the Yukon River, 2015.

Note: Species changeover date (August 15) determined at the point the curves intersect.



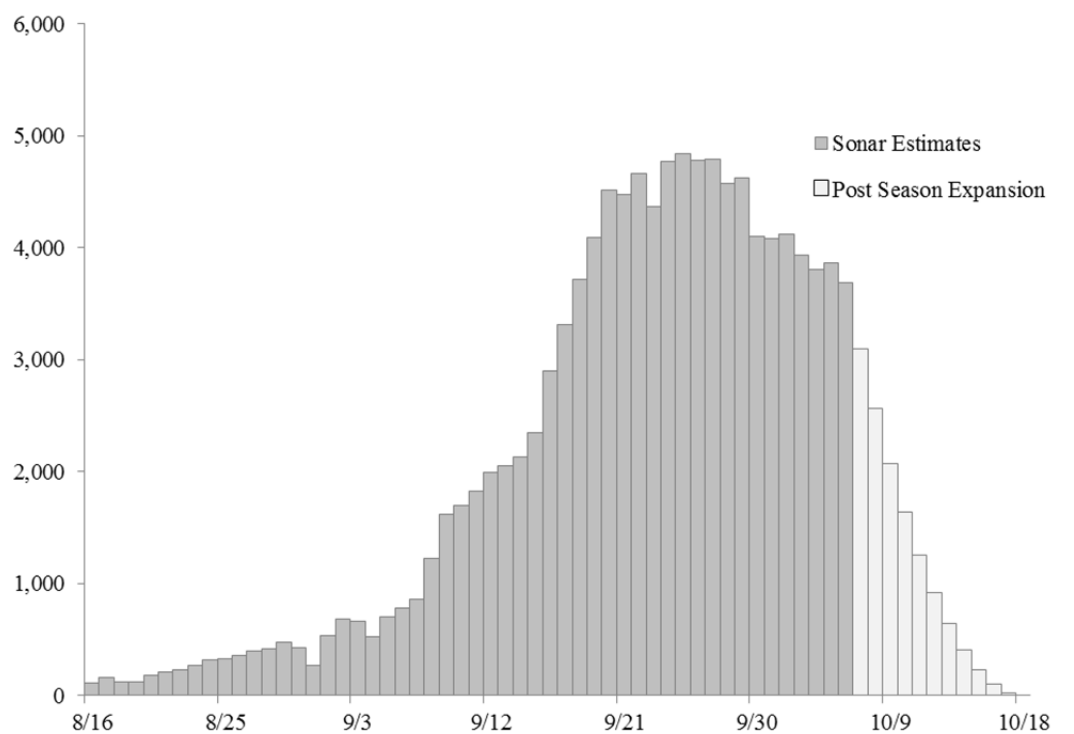


Figure 12.–Daily sonar estimates for Chinook salmon, June 30 through August 15, 2015 (top), daily sonar estimates, and postseason fall chum salmon expansion estimates for fall chum salmon, August 16 through October 18 (bottom).

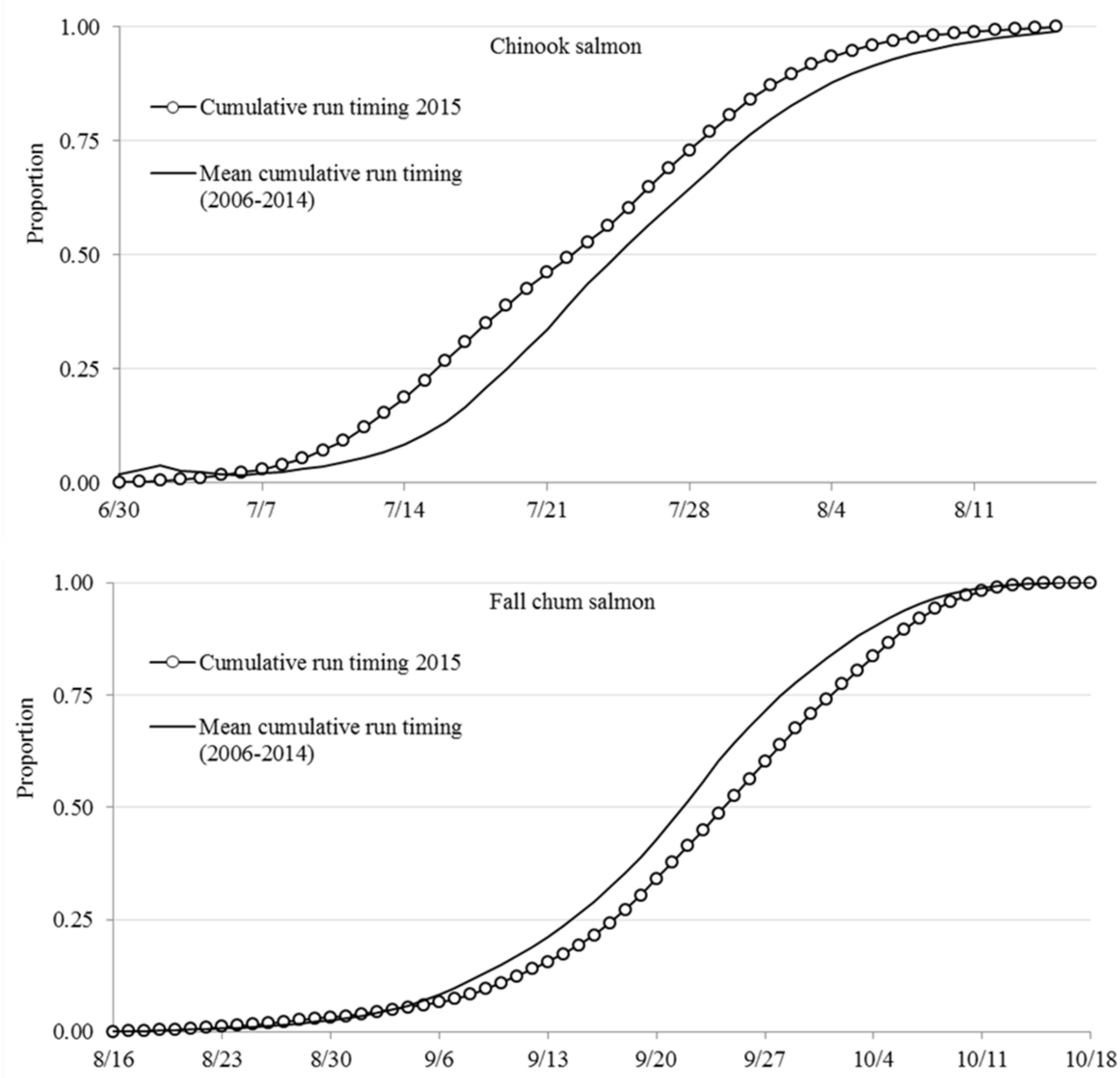


Figure 13.–2015 Chinook (top) and fall chum salmon (bottom) daily cumulative passage timing, compared to the 2005–2014 mean passage timing at the Eagle sonar project, on the Yukon River.

Note: Fall chum salmon cumulative passage timing includes postseason expansion estimates.

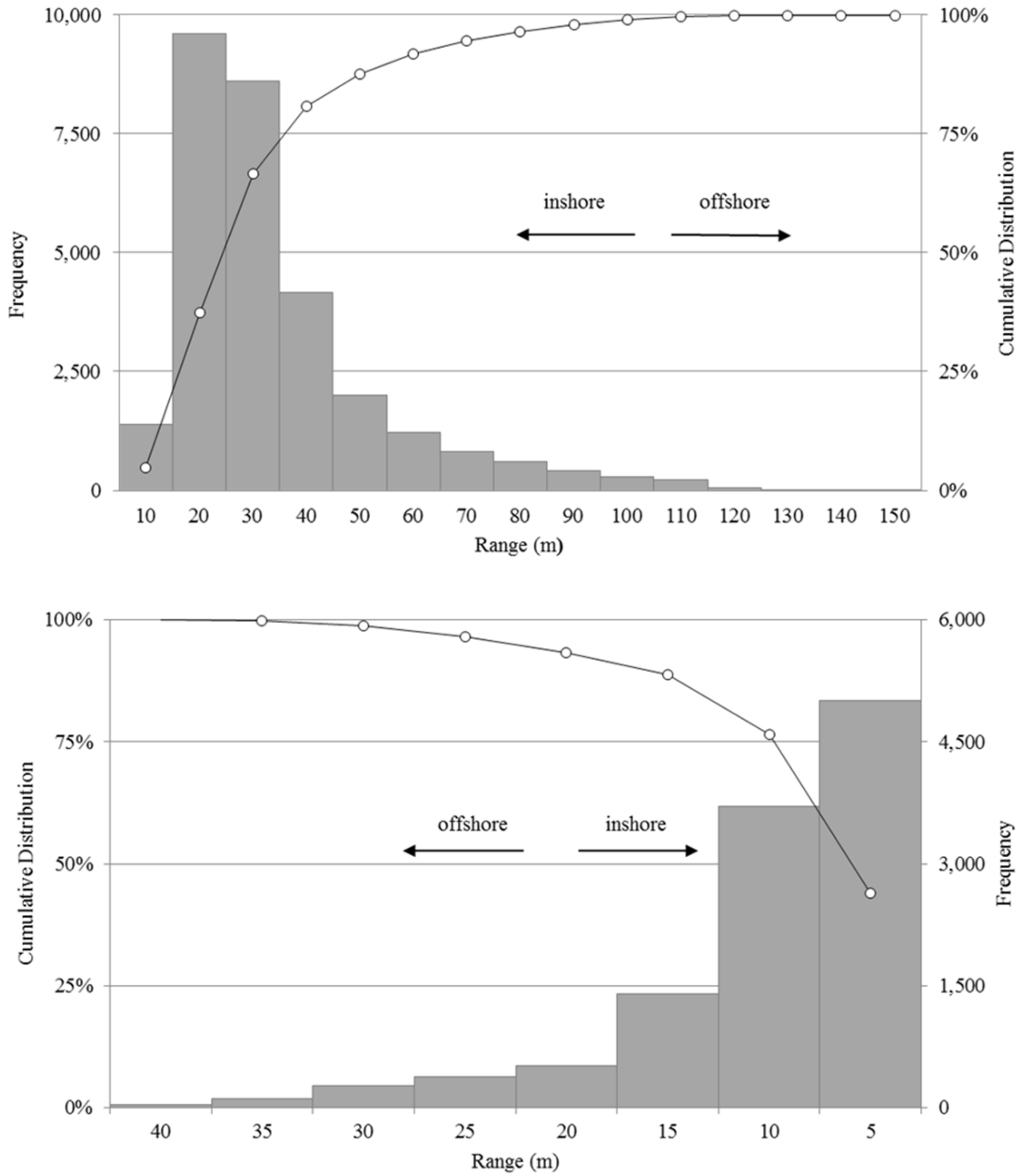


Figure 14.–Left bank (top) and right bank (bottom) horizontal distribution of upstream migrating Chinook salmon in the Yukon River at Eagle sonar project site, June 30 through August 15, 2015.

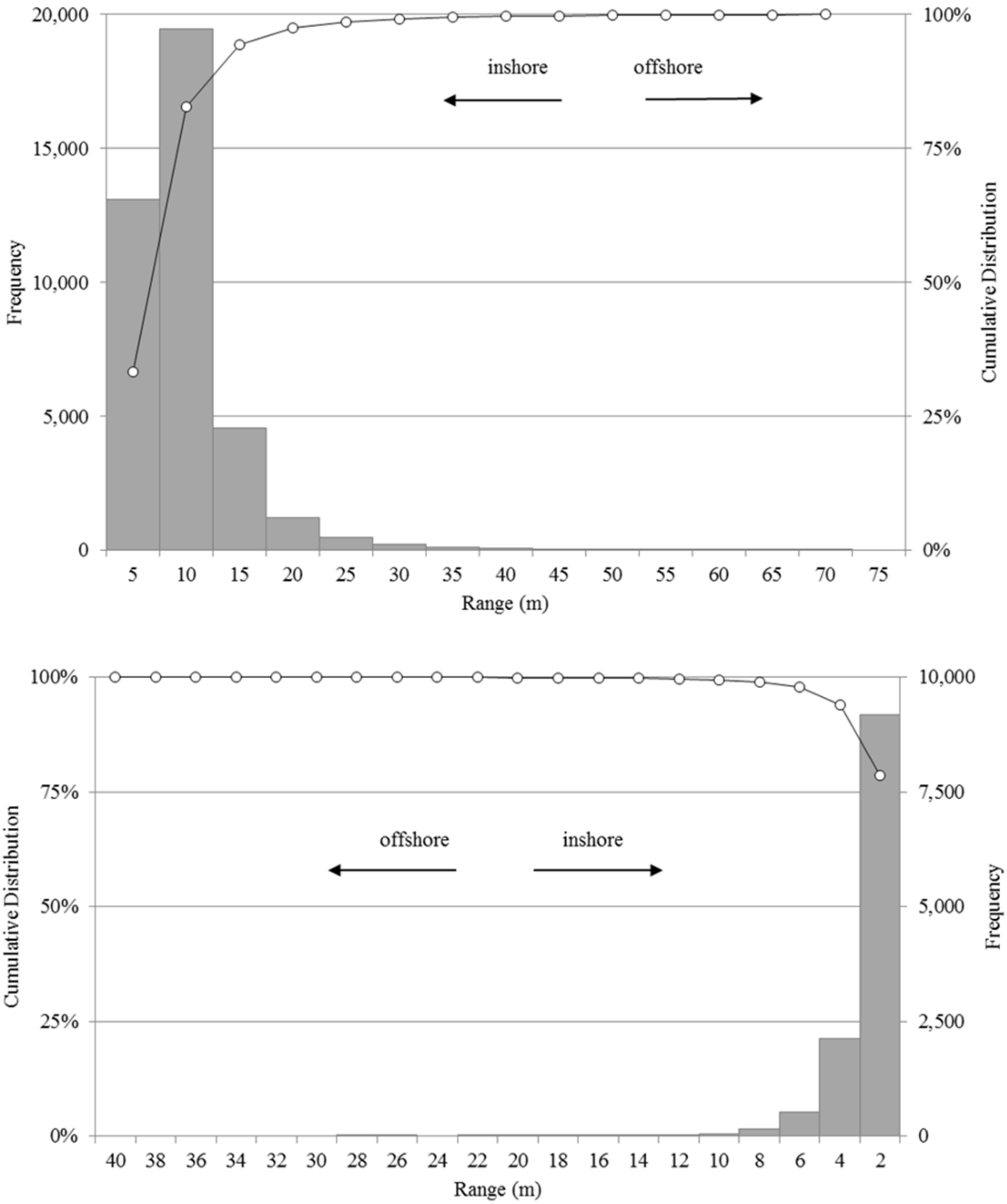


Figure 15.–Left bank (top) and right bank (bottom) horizontal distribution of upstream migrating fall chum salmon in the Yukon River at Eagle sonar project site, August 16 through October 6, 2015.

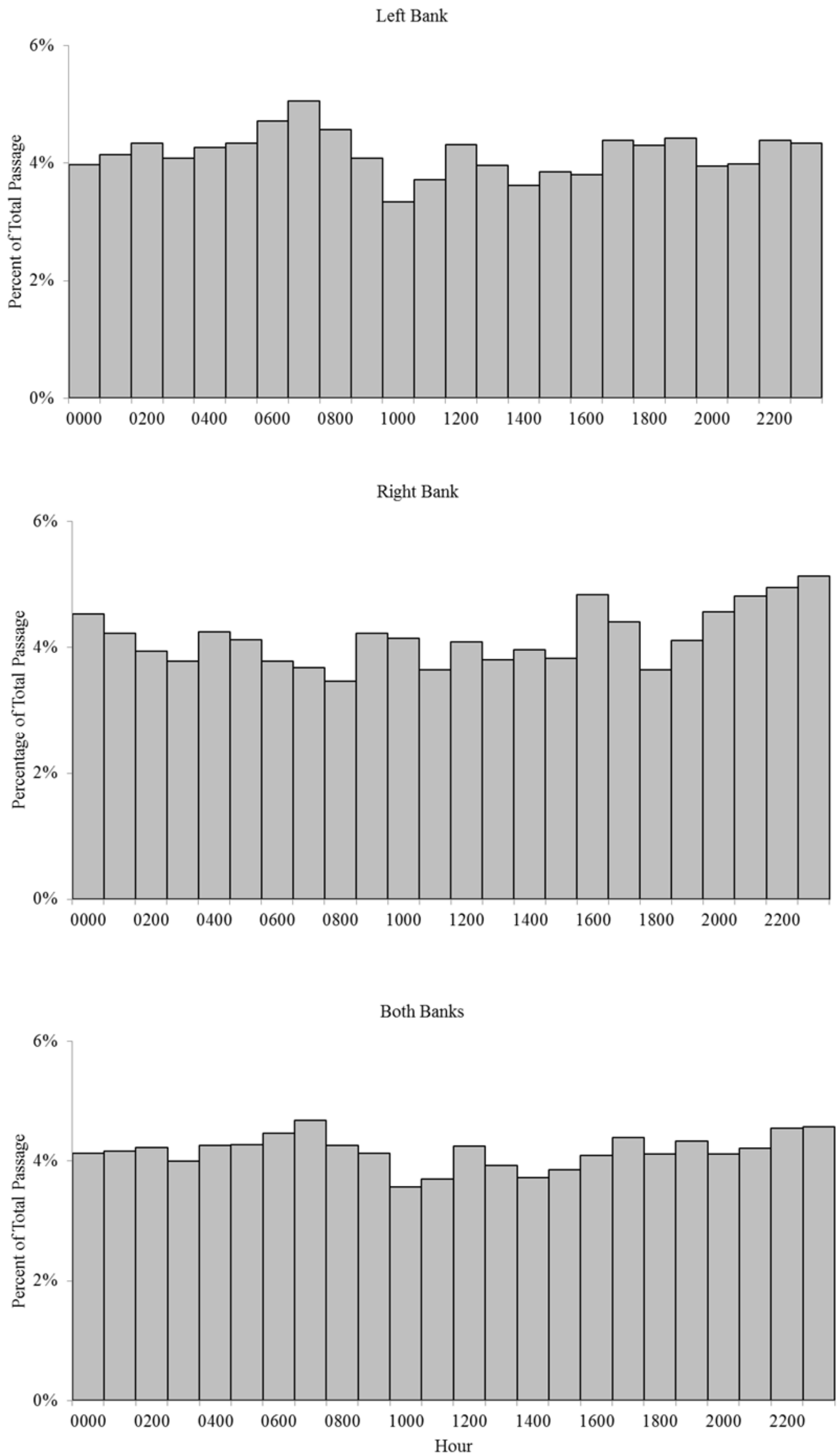


Figure 16.–Percentage of total Chinook salmon passage, by hour, observed on the left bank (top), right bank (middle), and both banks combined (bottom) of the Yukon River at the Eagle sonar project site from June 30 through August 15, 2015.

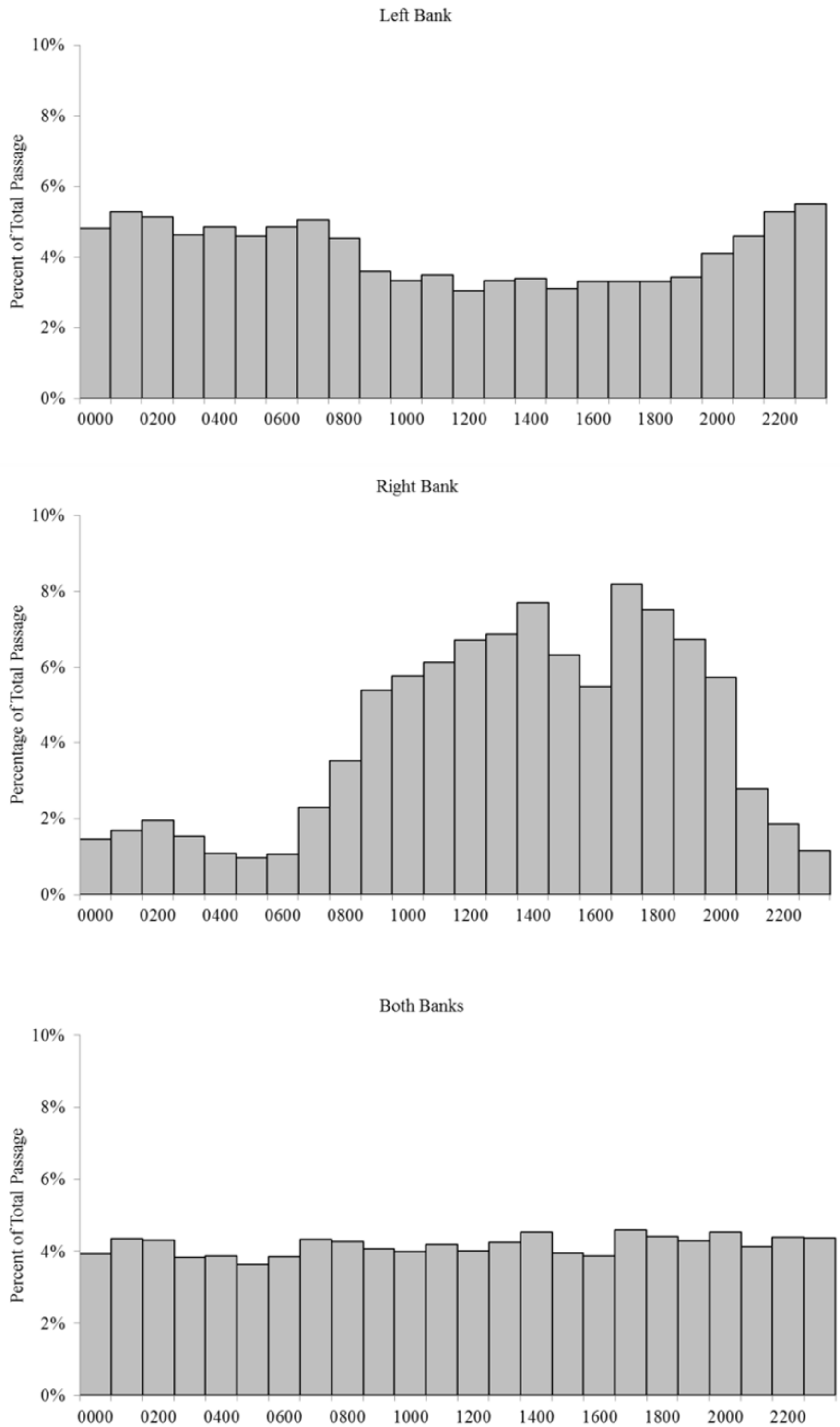


Figure 17.–Percentage of total fall chum salmon passage, by hour, observed on the left bank (top), right bank (middle), and both banks combined (bottom) of the Yukon River at the Eagle sonar project site from August 16 through October 6, 2015.

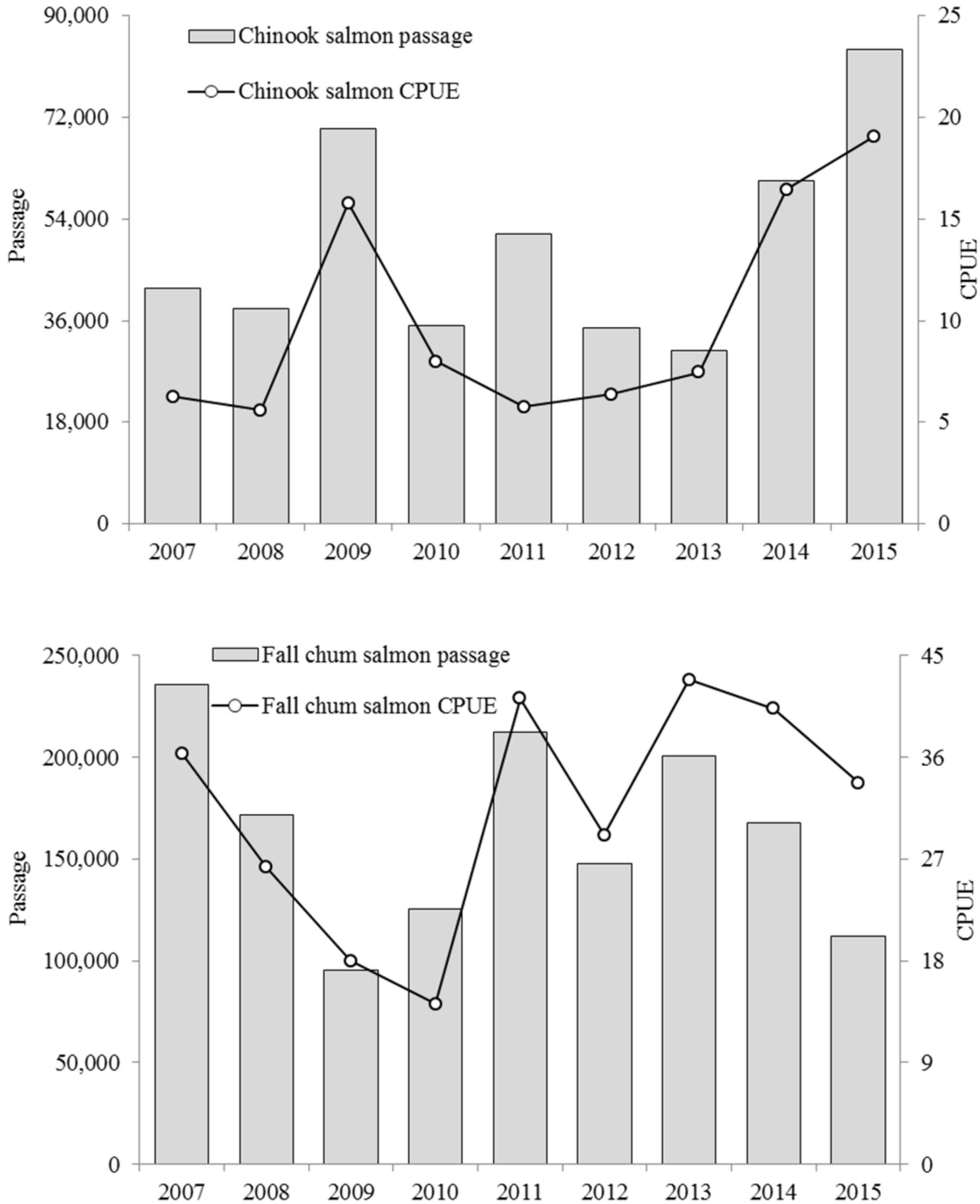


Figure 18.–Chinook (top) and fall chum salmon (bottom) passage and total cumulative catch per unit effort (CPUE) by year at the Eagle sonar project site, on the Yukon River, 2015.

Note: Because test fishing sites on the right bank have changed several times throughout the years, CPUE calculations are derived from the left bank fishery only. Prior to 2013, to avoid mortalities, there were occasions that fish were released without sampling, therefore for these years CPUE only represents fish sampled.

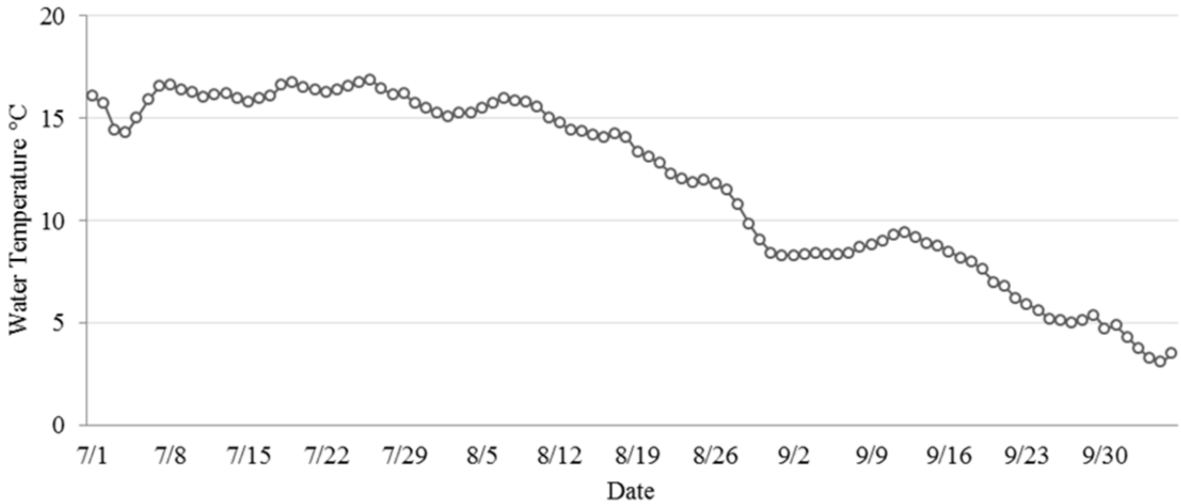


Figure 19.–Mean daily water temperatures recorded on the left bank at the Eagle sonar project on the Yukon River, 2015.

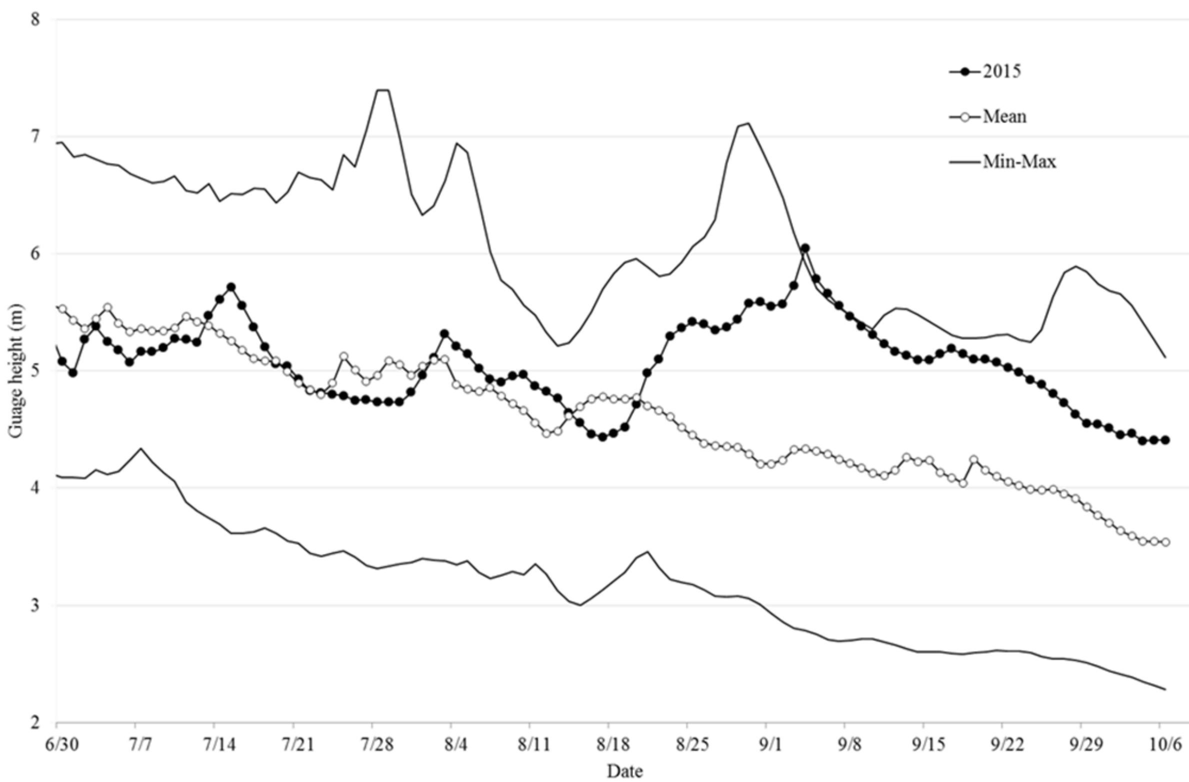


Figure 20.–Yukon River daily water level during the 2015 season at the Eagle water gage compared to minimum, maximum, and mean gage height 1995 to 2014.

Source: United States Geological Survey.

APPENDIX A: SPECIES COMPOSITION TEST FISHERY CATCH, CPUE, AND SMOOTHED DATA BY DAY AND SALMON SPECIES

Appendix A1.–Species composition test fishery catch, CPUE, and smoothed data by day and salmon species at the Eagle sonar project, on the Yukon River, 2015.

	Chinook salmon					Fall chum salmon				
Date	Large mesh fathom hours	Catch	CPUE	Catch smoothed	CPUE smoothed	Small mesh fathom hours	Catch	CPUE	Catch smoothed	CPUE smoothed
8/1	17.35	9	0.52	9.12	0.52	17.91	2	0.11	1.32	0.08
8/2	17.6	9	0.51	7.46	0.43	17.35	0	0	1.25	0.07
8/3	16.77	3	0.18	5.8	0.33	17.3	2	0.12	1.19	0.07
8/4	17.23	5	0.29	4.41	0.26	16.3	0	0	1.12	0.06
8/5	16.22	1	0.06	3.35	0.2	17.58	1	0.06	1.06	0.06
8/6	16.68	2	0.12	2.68	0.16	17.15	2	0.12	0.99	0.06
8/7	17.7	3	0.17	2.32	0.14	17.01	1	0.06	0.9	0.05
8/8	16.08	1	0.06	2.11	0.13	16.16	1	0.06	0.78	0.05
8/9	16.11	3	0.19	1.93	0.12	16.73	1	0.06	0.65	0.04
8/10	16.48	1	0.06	1.76	0.11	17.01	0	0	0.5	0.03
8/11	16.53	3	0.18	1.55	0.09	16.18	0	0	0.38	0.02
8/12	15.91	1	0.06	1.24	0.08	16.6	0	0	0.37	0.02
8/13	16	0	0	0.97	0.06	16.3	0	0	0.39	0.02
8/14	16.32	1	0.06	0.73	0.05	16.31	1	0.06	0.44	0.03
8/15	16.05	0	0	0.54	0.03	16.19	0	0	0.56	0.03
8/16	13.49	1	0.07	0.38	0.03	16.34	2	0.12	0.71	0.04
8/17	16.06	0	0	0.25	0.02	15.9	0	0	0.79	0.05
8/18	16.2	0	0	0.17	0.01	16.16	0	0	0.95	0.06
8/19	16.19	0	0	0.09	0.01	16.41	2	0.12	1.21	0.07
8/20	15.74	0	0	0.04	0	15.88	0	0	1.53	0.09
8/21	16.26	0	0	0	0	15.97	0	0	1.88	0.11
8/22	16.46	0	0	0	0	16.45	1	0.06	2.35	0.14
8/23	16.4	0	0	0	0	16.83	5	0.3	2.82	0.17
8/24	16.26	0	0	0	0	17.27	5	0.29	3.34	0.2
8/25	16.74	0	0	0	0	16.47	2	0.12	3.83	0.22
8/26	16.48	0	0	0	0	16.98	4	0.24	4.35	0.25
8/27	16.3	0	0	0	0	16.65	4	0.24	4.9	0.29
8/28	16.41	0	0	0	0	17.27	7	0.41	5.39	0.31
8/29	17.13	0	0	0	0	17.23	6	0.35	5.8	0.34
8/30	17.54	0	0	0	0	18.06	7	0.39	6.15	0.35
8/31	17.62	0	0	0	0	17.06	5	0.29	6.47	0.37

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Date	Chinook salmon: Large mesh fathom hours	Catch	CPUE	Catch smoothed	CPUE smoothed	Fall chum salmon: Small mesh fathom hours	Catch	CPUE	Catch smoothed	CPUE smoothed
9/1	17.28	0	0	0	0	17.28	12	0.69	6.68	0.38
9/2	16.79	0	0	0	0	17.26	6	0.35	6.83	0.39
9/3	16.76	0	0	0	0	16.99	6	0.35	6.93	0.4
9/4	16.89	0	0	0	0	17.05	10	0.59	7.07	0.41
9/5	17.31	0	0	0	0	17.14	3	0.18	7.14	0.41
9/6	17.56	0	0	0	0	17.69	10	0.57	7.29	0.42
9/7	14.18	0	0	0	0	17.01	4	0.24	7.93	0.45
9/8	16.68	0	0	0	0	16.22	6	0.37	8.83	0.5
9/9	16.84	0	0	0	0	17.07	8	0.47	9.89	0.55
9/10	17.06	0	0	0	0	16.9	6	0.36	11.31	0.63
9/11	16.69	0	0	0	0	18.04	17	0.94	12.85	0.72
9/12	16.44	0	0	0	0	17.58	17	0.97	14.09	0.79
9/13	16.76	0	0	0	0	17.61	14	0.8	15.21	0.85
9/14	17.03	0	0	0	0	17.56	18	1.03	16.26	0.91
9/15	16.43	0	0	0	0	18.53	28	1.51	17.12	0.96
9/16	16.61	0	0	0	0	16.77	10	0.6	17.87	1
9/17	16.5	0	0	0	0	17.92	22	1.23	18.69	1.05
9/18	17.46	0	0	0	0	21.6	26	1.2	19.5	1.09
9/19	17.39	0	0	0	0	15.91	27	1.7	20.25	1.13
9/20	17.15	0	0	0	0	17.4	13	0.75	20.96	1.17
9/21	19.31	0	0	0	0	17.86	20	1.12	21.73	1.21
9/22	17.64	0	0	0	0	17.7	22	1.24	22.46	1.25
9/23	17.89	0	0	0	0	17.31	17	0.98	23.1	1.28
9/24	17.46	0	0	0	0	17.83	27	1.51	23.74	1.32
9/25	18.31	0	0	0	0	19.83	44	2.22	24.34	1.36
9/26	17.14	0	0	0	0	19.16	34	1.78	24.83	1.38
9/27	16.64	0	0	0	0	18.65	23	1.23	25.22	1.41
9/28	16.89	0	0	0	0	18.44	18	0.98	25.58	1.43
9/29	18.12	0	0	0	0	17.67	22	1.25	25.86	1.44
9/30	17.21	0	0	0	0	15.76	30	1.9	26.1	1.45
10/1	17.07	0	0	0	0	17.66	19	1.08	26.34	1.46

APPENDIX B: CLIMATE AND HYDROLOGIC OBSERVATIONS

Appendix B1.–Climate and hydrologic observations recorded daily at 1800 hours, at the Eagle sonar project site on the Yukon River, 2015.

	Precipitation	Wind		Sky	Temperature (°C)	
Date	(code)[a]	Direction	Speed (mph)	(code)[b]	Air	Water[c]
1 Jul	B	Calm	0	O	19.2	16.2
2 Jul	C	N	1.7	O	17.8	16
3 Jul	A	NWW	1.9	F	22.1	14.6
4 Jul	A	NE	0	S	27.4	15
5 Jul	A	NWW	1.3	S	27.2	15.9
6 Jul	A	SEE	1	C	33	17
7 Jul	B	N	1.7	F	18.2	16.8
8 Jul	B	NWW	5.2	B	14.8	16.8
9 Jul	A	NWW	2	S	17.2	16.7
10 Jul	A	WNW	3.8	C	23.6	16.8
11 Jul	A	SEE	3.3	O	17.5	16.2
12 Jul	B	SW	4.2	B	19.8	16.7
13 Jul	B	SEE	3.2	B	17.7	16.6
14 Jul	B	SEE	3.6	B	19.5	15.9
15 Jul	A	NE	4.2	S	22	16.3
16 Jul	A	SW	4	C	25	16.5
17 Jul	B	N	3.6	B	18.4	16.9
18 Jul	B	Calm	0	S	20	17
19 Jul	B	Calm	0	S	23	17
20 Jul	B	Calm	0	S	19	16.7
21 Jul	B	NEE	3	B	17	16.8
22 Jul	A	WNW	4.1	C	22.4	17.2
23 Jul	A	N	4.7	B	22.7	17.2
24 Jul	A	NWW	5.5	C	23	17.4
25 Jul	B	SEE	5.3	B	16.4	16.9
26 Jul	B	NWW	3.6	B	16	17.2
27 Jul	B	N	2	O	16.2	16.7
28 Jul	B	NW	4.1	B	16.9	16.4
29 Jul	B	NW	3.7	B	20.2	16.4
30 Jul	A	NW	4.5	S	21.5	16.3
31 Jul	A	N	2.3	S	20.5	15.9
1 Aug	B	N	6.5	O	18.9	15.6
2 Aug	A	N	1.2	S	18.4	15.4
3 Aug	A	S	1.4	S	27.3	16
4 Aug	A	S	0.7	C	29.4	15.9
5 Aug	A	SE	2	B	25.8	15.6
6 Aug	A	NW	5	B	14	16.2
7 Aug	A	NW	2	C	14	16.7
8 Aug	A	NW	0.5	C	21.8	16.5
9 Aug	B	SE	7.9	B	22.3	16.2
10 Aug	B	N	1.5	O	13.2	15.6

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Date	Precipitation (code)[a]	Wind Direction	Wind Speed (mph)	Sky (code)[b]	Temperature (°C) Air	Temperature (°C) Water[c]
11 Aug	A	WNW	2.5	O	13.1	15.2
12 Aug	A	SE	3.7	S	13	15.2
13 Aug	B	SE	0.5	B	21	14.7
14 Aug	A	SE	3.2	S	19	14.9
15 Aug	A	S	5.1	S	22.1	14.6
16 Aug	A	SE	1.4	B	18.3	14.3
17 Aug	A	S	5.5	O	19.5	14.7
18 Aug	A	NW	0.7	O	14.9	13.9
19 Aug	A	NW	0.9	O	15.4	13.4
20 Aug	A	NW	2.1	S	18.6	13.6
21 Aug	A	S	0.2	S	19.6	13.3
22 Aug	B	NW	1	O	13	12.4
23 Aug	A	NNE	1	B	14	12.3
24 Aug	A	NW	4	B	13	12.1
25 Aug	A	S	4	O	15	12.2
26 Aug	B	Calm	0	B	14	11.9
27 Aug	B	N	4	O	10	11.7
28 Aug	A	N	3	O	8	10.8
29 Aug	A	N	0	S	8	9.9
30 Aug	A	NW	4	O	8	9
31 Aug	A	N	8	O	7	8.4
1 Sep	A	NW	3	B	8	8.7
2 Sep	A	Calm	0	C	12	8.7
3 Sep	A	Calm	0	S	12	8.7
4 Sep	B	Calm	0	O	9	9.3
5 Sep	A	N	2	B	11	8.5
6 Sep	A	Calm	0	C	10	8.9
7 Sep	A	S	2	S	14	8.8
8 Sep	A	N	1	B	13	8.9
9 Sep	A	S	2	B	15	9.2
10 Sep	A	S	6	S	16	9.5
11 Sep	A	Calm	0	B	13	9.7
12 Sep	B	W	3	O	11	9.8
13 Sep	A	Calm	0	O	9	9.3
14 Sep	A	Calm	0	O	8	9
15 Sep	A	Calm	0	B	10.7	9
16 Sep	A	SE	7	S	11	8.8
17 Sep	A	W	3.2	O	8.8	8.2
18 Sep	A	NW	1.8	B	12.7	8.2
19 Sep	A	NWW	2.6	O	7.2	7.6
20 Sep	A	E	6	O	3	7

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	Precipitation	Wind		Sky	Temperature (°C)	
Date	(code)[a]	Direction	Speed (mph)	(code)[b]	Air	Water[c]
21 Sep	A	NW	3	B	3	6.9
22 Sep	A	NW	6	O	1	6.2
23 Sep	A	N	4	O	0	5.9
24 Sep	A	W	3	S	3	5.7
25 Sep	A	Calm	0	B	3	5.2
26 Sep	A	Calm	0	C	2	5.4
27 Sep	B	SE	1.6	O	3	5.2
28 Sep	A	SE	0	B	11	5.3
29 Sep	A	N	4	O	2	5.4
30 Sep	A	Calm	0	B	3	4.8
1 Oct	A	Calm	0	C	0	5.1
2 Oct	A	S	8.9	B	2	4.3
3 Oct	A	S	5.1	O	2	3.6
4 Oct	B	E	0	O	2	3.3
5 Oct	A	SE	0	B	3	3.1

[a] Precipitation code for the preceding 24 hour period: A = none; B = intermittent rain; C = continuous rain; D = snow and rain mixed; E = light snowfall; F = continuous snowfall; G = thunderstorm w/ or w/o precipitation.

[b] Instantaneous cloud cover code: C = clear, cloud cover < 10% of sky; S = cloud cover < 60% of sky; B = cloud cover 60-90% of sky; O = overcast (100%); F = fog, thick haze or smoke.

[c] Water temperature collected approximately 30 cm below surface with Hobo U22™ Data logger.