Fishery Data Series No. 11-08

Sonar Estimation of Chinook and Fall Chum Salmon Passage in the Yukon River near Eagle, Alaska, 2009

by

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and

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April 2011

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

Dual-Frequency Identification Sonar 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 July 5 to October 6, 2009. A total of 69,957 Chinook were estimated to have passed the sonar site between July 5 and August 20, and an estimated 95,462 chum salmon passed between August 21 and October 6. The sonar-estimated passage of chum salmon was subsequently expanded to a total passage estimate of 101,734 to include fish that may have passed after operations ceased. The estimated border passage of 69,575 Chinook and 94,739 chum salmon was achieved by subtracting the preliminary subsistence catch above the sonar site. A drift gillnet sample fishery was conducted to collect age, sex, length, and genetic information. Species composition was also recorded to determine when the Chinook run ended and the fall chum run began. Both sonar systems functioned well with minimal interruptions to operation. Range of ensonification was considered adequate for most fish that migrated upstream. A continued long-term hydroacoustic enumeration project for Chinook and chum salmon near the United States/Canada border will help fishery managers meet conservation and management commitments made by both countries under the Yukon River Salmon Agreement.

Key words: Alaska, DIDSON, Eagle, hydroacoustics, *Oncorhynchus*, salmon, Chinook, chum, split-beam sonar, Yukon River.

INTRODUCTION

The Yukon River is the largest river in Alaska, spanning 3,700 km. 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 salmon *Oncorhynchus* spp. 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 this 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 is 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 Yukon River 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 of Chinook *O. tshawytscha* and chum *O. keta* salmon stocks is to meet negotiated escapement goals and also 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.

Because of the highly turbid water of the Yukon River, and the width of the mainstem (roughly 400 m across at the study site), daily passage estimation methods such as counting towers and weirs are not feasible. Split-beam sonar technology has been 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 (Pfisterer 2002) and the Kenai River (Miller and Burwen 2002). Dual-Frequency Identification Sonar (DIDSON) has been used at several sites, including the Aniak River (McEwen 2005) and the Sheenjek River (Dunbar and

Pfisterer 2009) to give daily passage estimates where bottom profile 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 resulting in 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: linear bottom profiles on both sides of the river without large obstructions; a single channel; available beach above water level 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 bottom profiling transects led to a narrowing of potential project locations to an area between 9 and 19 km downriver from the town of Eagle. The 2003 study identified the two most promising sonar deployment locations at Calico Bluff and Shade Creek. Though sonar was not deployed in 2003, the bottom profiles at the preferred sites indicated that it should be possible to estimate fish passage with 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 two 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, DIDSON was deployed on the right bank and split-beam sonar was deployed on the left bank. The project duration was extended in 2006 to also provide an estimate of fall chum salmon passage. Split-beam and DIDSON technology have been used in all subsequent years to estimate border passage for both Chinook and fall chum salmon.

STUDY AREA

The study area is a 2 km section of the mainstem Yukon River at Six Mile Bend, 11.5 km downriver from Eagle, Alaska (Figure 2). Some additional drift gillnet fishing occurs about 5 km downriver near Calico Bluff.

Average monthly discharge for the Yukon River ranges from 110,500 to 223,600 ft^3/s. Flows are highest in June, with greatest variability in flow occurring in May, after which discharge and the variability in discharge decline. The upper Yukon River is turbid and silty in the summer and fall with an estimated annual suspended sediment load at Eagle of 33,000,000 tons (Brabets et al. 2000).

Hungwitchin Native Corporation owns the majority of land in the study area above the ordinary mean high water mark. Permission was granted to operate a sonar project on Hungwitchin land at Six Mile Bend. A semi-permanent field camp consisting of 6 canvas tents on plywood platforms was constructed in 2005 on the left bank (64° 51’55.70” N 141° 04’43.62” W). An additional tent platform was constructed on the left bank 1.3 km downriver from the camp (64°52’30.84” N 141°04’52.77” W) to house computer and sonar related equipment. This tent was replaced with a 12 ft. x 15 ft. Weatherport portable building in 2009. A portable wooden shelter was used on the right bank to house topside sonar equipment, a wireless router, and a solar-powered battery system.

In early May, before the 2009 field season, the ice in the Yukon River began to break up. Soon after, an ice dam developed about 16 km downriver of Eagle and about 7 km downriver of the sonar site. The Yukon River valley quickly began to fill with water and ice. A few days later the ice dam broke, leaving the Village of Eagle completely destroyed, Eagle City partly destroyed and many kilometers of forest along the riverbank flattened. The Fish and Game sonar field camp was destroyed as well as the location of the sonar itself. The crew initially visited the site on June 9 to assess damage. Damage above the normal waterline was in fact extensive. Fortunately however, profiling transects showed that the river bottom remained unchanged and an ideal location for sonar. Sonar operations were not affected by the flood although the downed trees had to be moved or removed, and all of the camp facilities had to be replaced.

OBJECTIVES

The primary goals of this project in 2009 were to:

1. Estimate the daily and seasonal passage of Chinook and fall chum salmon using fixed-location split-beam and DIDSON sonar.
2. Use drift gillnets to estimate run timing of Chinook and fall chum salmon past the sonar site.
3. Collect a minimum of 160 Chinook salmon samples during each of 3 stratum 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 (α=0.05 and d=0.10).
4. Collect a minimum of 160 fall chum salmon samples during each of 4 stratum 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 (α=0.05 and d=0.10).
5. Collect Chinook and chum salmon tissue samples for genetic stock identification.
6. Collect daily climate and hydrologic measurements representative of the study area.

METHODS

HYDROACOUSTIC EQUIPMENT

A fixed-location, split-beam sonar developed by Kongsberg Simrad[1] 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. ER60 data acquisition software installed on a laptop computer connected to the echosounder collected raw data for processing. Digital files created by the ER60 software were examined with an echogram viewer program created in *Java* computer language to produce an estimate of fish passage.

The transducer was attached to 2 Hydroacoustic Technology Incorporated (HTI) model 662H single-axis rotators. Aiming was performed remotely using a HTI model 660 remote control unit that provides horizontal and vertical position readings.

A DIDSON long-range unit, manufactured by Sound Metrics Corporation, was deployed on the right bank. This sonar was operated at 1.2 MHz (high frequency option) for the 0 to 20 m range, and at 0.70 MHz (low frequency option) for the 20 to 40 m range, using 48 beams. Both the low and high frequency modes have a viewing angle of 29° x 14°. A 60 m cable carried power and data between the DIDSON unit in the water and a topside breakout box. A wireless router transferred data between the breakout box and a laptop computer on the opposite bank. Sampling was controlled by DIDSON software loaded on the laptop computer. All surface electronics were housed on shore in a small wood frame shelter.

Right bank power was supplied by a 12 V solar powered system consisting of a four 85 W solar panel array, ten 6 V batteries, a charge controller, and inverter. The solar power system was supplemented with a portable 2000 W generator and a power converter/charger. Left bank hydroacoustic equipment and computers were powered with a portable 2000 W generator running continuously.

SONAR DEPLOYMENT AND OPERATION

Many bottom profiling transects were made in 2005 to find a suitable specific location for sonar deployment on both banks. Specific sites were selected based on a profile consisting of a steady downward sloping gradient without large dips or obstructions that can hinder full acoustic beam coverage or detection of targets, sufficient current containing no eddies, and sufficient beach above water line to house topside sonar equipment. To ensure the original sites remain acceptable for ensonification, bottom profiles are obtained prior to transducer placement each season. Data this season was collected from four 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 and plotted with Microsoft® Excel (Figure 3).

The split-beam sonar was deployed July 5 on the left bank. The transducer and rotators were mounted on a frame constructed of aluminum pipe and deployed approximately 15 m from shore. The frame was secured with sandbags and the 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 1.0 to 1.5 m in depth and aimed perpendicular to the current along the

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

natural substrate. The transducer was deployed at a location with consistent flow and no eddy or slack water.

An artificial acoustic target was used at various distances from the transducer during deployment to verify that the transducer aim was low enough to prevent salmon from passing undetected beneath the acoustic beam and to test target detection at different ranges. The target, an airtight 250 ml weighted plastic bottle tied with monofilament line, was drifted downstream along the river bottom and through the acoustic beam. Several drifts were made with the target in an attempt to pass it through as much of the counting range as possible. Proper aim for the split-beam system was verified with visual interpretation of an echogram on a computer screen, i.e. with visible, but not overpowering return of bottom signal appearing over the majority of the ensonified range.

The split-beam system was aimed to ensonify a range of approximately 2 to 150 m when counting Chinook salmon, and 2 to 75 m when counting chum salmon. Settings for data acquisition included: 256 µs transmit pulse lengths, 500 W power output, 5 pings per second at 150 m range, and 10 pings per second at 75 m range.

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. Sixteen freestanding lead sections constructed of 5 cm diameter steel pipes connected with adjustable fittings to form tripods were used. Aluminum stringers, approximately 2.5 m long, were then attached horizontally to the upstream side of the tripods. The sections were finished with vertical lengths of aluminum conduit 381 mm apart. Lead sections were placed side by side in the water from shore to an initial distance of 7 m beyond the transducer. The portability of this style of 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 summer, the transducer and lead require frequent relocation to shallower or deeper water.

The DIDSON was deployed July 5 on the right bank. It was mounted on an aluminum frame and aimed using a manual crank-style rotator. Operators adjusted the aim by viewing the video image and relaying aiming instructions to a technician on the remote bank via handheld VHF radio. Proper aim was achieved when adequate bottom features appeared over the majority of the ensonified range (0 to 40 m).

A fish lead was constructed with 2 m steel "T" stakes and 1.2 m high galvanized chain link fencing. 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 short lead was appropriate for this bank because of the steep slope and short nearfield distance (0.83 m) of the DIDSON. The right bank was ensonified to a range of 40 m from the transducer, with two sampling zones, ranging from approximately 1 to 20 m and 20 to 40 m. Sonar control parameters included:

1) Nearshore zone - 0.83 m window start, 20.01 m window length, high frequency mode, and 7 frames per second; and
2) Offshore zone - 20.84 m window start, 20.01 m window length, low frequency mode, and 4 frames per second.

SONAR DATA PROCESSING AND PASSAGE ESTIMATION

Split-beam data was collected continuously in 60 min increments and saved as .raw files to an external hard drive for tracking and counting. The operator opened each .raw data file in the split-beam echogram viewer program and marked each upstream fish track by clicking a computer mouse (Figure 4). The number of marks for each hour was saved as a text file and recorded on a count form.

DIDSON data was collected in two 30 min samples each hour of the day. For the first 30 min of every hour, the DIDSON sampled the ensonified range from 1 to 20 m (zone 1) and the second half of each hour sampled from 20 to 40 m (zone 2). Upstream migrating fish were counted by marking each fish track on a DIDSON echogram (Figure 5). Upstream direction of travel was verified using the DIDSON video feature. These counts were saved as text files and recorded on a count form.

The actual count for each 30 min sample was expanded for the full hour, and the estimated counts from zone 1 and zone 2 were summed for a total hourly count. The daily passage $\hat{y}$ for zone z on day d was calculated by summing the hourly passage rates for each hour as follows:

$$\hat{y}_{dz} = \sum_{p=1}^{24} \frac{y_{dzp}}{h_{dzp}} \tag{1}$$

where h_{dzp} is the fraction of the hour sampled on day d, zone z, period p and y_{dzp} is the count for the same sample.

Treating the systematically sampled sonar counts as a simple random sample would yield an over-estimate of the variance of the total, since sonar counts are highly auto-correlated. To accommodate these data characteristics, a variance estimator based on the squared differences of successive observations was employed. The variance for the passage estimate for zone z on day d is estimated as:

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

Where n_{dz} is the number of samples in the day (24), f_{dz} is the fraction of the day sampled (12/24=0.5), and y_{dzp} is the hourly count for day d in zone z for sample p. Since the passage estimates are assumed independent between zones and among days, the total variance was estimated as the sum of the variances:

$$\hat{V}ar(\hat{y}) = \sum_d \sum_z \hat{V}ar(\hat{y}_{dz}) \tag{3}$$

The reported variance reflects the sampling done on the right bank. The sampling variance for the left bank is inconsequential since the split-beam sonar sampled the entire range continuously.

The counts from each split-beam and DIDSON sample were entered into a Microsoft® *Excel* spreadsheet where counts were adjusted for missing samples when data collection was interrupted. Brief interruptions intermittently occurred when routine maintenance (i.e. silt removal) or relocation of a transducer was required.

Whenever a portion of a sample was missing, on either bank, passage was estimated by expansion based on the known portion of the sample. The number of minutes in a complete sample period m_s was divided by the number of minutes counted m_i, and then multiplied by the number of fish counted x in that period i. Passage y_i was estimated as:

$$\hat{y}_i = \left(m_s / m_i \right) x_i \tag{4}$$

If data from one or more complete sample periods was missing, passage for that portion of the day y_m was estimated by averaging passage from the sample periods immediately before (y_b) and after (y_a) the missing sample period(s), and then multiplying by the number of sample periods missed n:

$$\hat{y}_m = \left(\frac{y_b + y_a}{2} \right) n \tag{5}$$

If data from one or more complete days d was missing, passage for each missing day y_d was estimated using simple linear interpolation, based on the known passage y for the day immediately before (x_b) and the day immediately after (x_a) the missing day(s) x_d:

$$\hat{y}_d = y_b + \left(x_d - x_b \right) \left(\frac{y_a - y_b}{x_a - x_b} \right) \tag{6}$$

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

If a large number of chum salmon was passing on the last day of sonar operation, the estimate was expanded using a second order polynomial equation, where y_i is the i^{th} 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):

$$y_i = \frac{L}{d^2} \left(x_i - d \right)^2 \tag{7}$$

Postseason, the Chinook and 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 chum salmon were examined postseason by importing text files containing all fish track information into *R* statistical software package (R Development Core Team 2009) where the individual fish were binned by range. Microsoft® Excel was used to plot the binned data and investigate the spatial distribution of fish passing the sonar site. Histograms of passage by hour were created in Microsoft® Excel to investigate diel patterns of migration. Run timing of Chinook and 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 AND SAMPLING

To monitor species composition and collect age, sex, length, and genetic samples, gillnets of mesh sizes 7.5 in and 5.25 in were drifted through three zones; left bank inshore (LBI), left bank nearshore (LBN) and left bank offshore (LBF) (Figure 2). Nets were 25 fathoms long, approximately 25 ft deep, constructed of Momoi MTC or MT, shade 11, double knot multifilament nylon twine and hung "even" at a 2:1 ratio of web to corkline. In 2007, it was determined that the nets being used were too deep to effectively fish the inshore zone. Consequently, more appropriate nets of shorter depth, approximately 8 ft deep were used for the inshore drifts only, with all other specifications remaining the same as the original nets.

Fishing for species composition was conducted once daily from August 2 to October 4 between approximately 0800 and 1200 hours (period 1) on the left bank. During the sampling period, both the 5.25 in and the 7.5 in nets were drifted twice within each of three zones (inshore, nearshore and offshore), for a total of 12 drifts. Drifts were targeted to be 6 minutes in duration, but were occasionally shortened as necessary to avoid snags or to limit catches and thus prevent mortalities during times of high fish passage. The inshore drifts were referred to as "beach walks" (Fleischman et al. 1995), where one 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 was approximately one net length offshore of the inshore zone and the offshore zone was approximately one net length offshore of the nearshore zone. The order of drifts was 1) LBI, 2) LBN, and 3) LBF, with a minimum of 15 minutes between drifts in the same zone (Table 1). All drifts with one mesh size were completed before switching to another mesh size. Starting mesh sizes were alternated each day.

In an effort to collect more Chinook salmon genetic samples, an additional fishing period was conducted that targeted Chinook salmon (period 2). Between July 11 and August 1, period 2 fishing occurred twice per day; from approximately 0800 to 1200 hours and again from approximately 1300 to 1700 hours. Between August 2 and August 15, period 2 fishing was conducted once per day after period 1 fishing was completed. Chinook salmon genetic and ASL samples were collected to estimate specific Canadian stock proportions and ASL composition of Chinook salmon entering Canada. Four different mesh sizes (5.25 in, 6.5 in, 7.5 in, and 8.5 in) were drifted in a rotating schedule over the course of the Chinook salmon run to effectively capture all size classes present (Table 2). Nets were 25 fathoms long, approximately 25 ft deep and hung "even" at a 2:1 ratio of web to corkline. Three net sizes 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 5 km downriver from the sonar site where river conditions were suitable for drift gillnetting on that bank (Figure 2). This resulted in a total of 9 drifts for period 2.

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

$$t = SI - FO + \frac{FO - SO}{2} + \frac{FI - SI}{2} \tag{8}$$

Total effort e, in fathom-hours, of drift j with mesh size m during fishing period f in zone z on day d was calculated as:

$$e_{dzfmj} = \frac{25 t_{dzfmj}}{60} \tag{9}$$

Captured salmon were sampled in the following ways:

For standard ASL samples, length (METF to nearest 5 mm), and sex (determined by external characteristics) were recorded. Three scales from Chinook salmon and one scale from 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. These scale data were used to estimate the age composition of salmon that pass the Eagle sonar site.

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 chum salmon samples were stored in bulk collections started weekly. All samples were sent to ADF&G genetics laboratory and from there forwarded to the Fisheries and Oceans Canada genetics laboratory in Nanaimo, BC 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. Most captured fish were quickly sampled and returned to the river. Mortalities were distributed to local residents after sampling.

SPECIES DETERMINATION

Although the Chinook and fall chum salmon runs are considered discrete in time, some temporal overlap does occur. In season tentative dates are chosen based on sonar counts, gillnet catches, and local harvest to represent the last day of the Chinook salmon run and the first day of the chum salmon run. After thorough examination of the sample fishery data postseason, the tentative dates used may be changed to more accurately represent the runs. Sample fishery information was used to determine the specific date after which sonar counts were classified as chum salmon. This was ascertained using reverse-cumulative Chinook catches and cumulative chum catches. Chinook catch was summed in reverse from the date when the last Chinook was caught by calculating the total Chinook catch to date subtracted from the Chinook catch for the entire season. The date at which the chum catch surpassed the succeeding Chinook catch became the species changeover date.

CLIMATE AND HYDROLOGIC OBSERVATIONS

Climate and hydrologic data were collected daily at approximately 1800 hours. Air temperatures and subjective measures of wind speed and direction, cloud cover and precipitation were also recorded. Water temperature was recorded every 4 hours with a HOBO U22 water temperature data logger suspended approximately 30 cm below the surface from a float tied to a stake about 10 m from the left bank shore. Data was transferred from the temperature logger to a computer postseason to produce an average daily water temperature. Reported stream levels are taken from the U.S. Geological Survey’s gauging station at Eagle, although water levels at the sonar site were carefully monitored.

RESULTS

SONAR DEPLOYMENT

On July 4 the left bank sonar was deployed approximately 800 m downriver from the camp and the right bank sonar was deployed across the river approximately 700 m downriver from the camp (Figure 2). Figure 3 shows zones of ensonification and bottom profile of the Yukon River at the sonar site. The left bank profile is approximately linear, extending 300 m to the thalweg at a -2.3° slope. The right bank profile is less linear, shorter and steeper, extending 100 m to the thalweg at a -6.3° slope. The substrate at Six Mile Bend is large cobble to small boulder on the right bank, and small to medium sized cobble and silt on the left bank.

CHINOOK AND CHUM SALMON PASSAGE ESTIMATION

In season, August 17 was tentatively deemed the last day of the Chinook salmon run based on relatively low sonar counts, gillnet catches and harvest information gathered from local subsistence fishermen. Fish range distribution from the sonar also was a primary indicator that the salmon run was changing from Chinook to chum salmon. The inseason species changeover date was adjusted postseason after thorough examination of sample fishery information. Analysis of reverse-cumulative Chinook catches and cumulative chum catches showed that August 20 was the last date when the overall Chinook catch was more than the overall chum catch (Figure 6) shows reverse-cumulative Chinook catch and cumulative chum catch plotted by day from just prior to the date of the first chum capture. The two lines cross at the point when the number of chum caught equals the number of Chinook caught subsequent to that point.

The total passage estimate at the Eagle sonar site for Chinook salmon was 69,957 for the dates July 5 to August 20, 2009 (Table 3 and Figure 7). A peak daily passage estimate of 4,887 Chinook salmon occurred on July 20 and 95 fish passed on August 20, the last day of estimating Chinook salmon passage. A total of 1,138 min on the left bank and 2,347 min on the right bank of sampling time were missed because of routine maintenance, system diagnostic test, system malfunction, or moving and aiming the transducer (Table 4). Postseason, the subsistence harvest from the Eagle area upstream of the sonar site was subtracted from the sonar estimate to produce a border passage estimate of 69,575 (Table 5). The preliminary subsistence harvest from the Eagle area upstream of the sonar was 382 (Dayna Norris, Commercial Fisheries Biologist, ADF&G, Fairbanks, Alaska; personal communication).

The total fall chum salmon passage estimate was 95,462 for the dates August 21 to October 6, 2009 (Table 6 and Figure 7). Fall chum salmon passage peaked on September 24 with a daily estimate of 5,487 fish. A total of 2,330 min on the left bank and 760 min on the right bank of sampling time were missed because of routine maintenance, system diagnostic test, system malfunction, moving and aiming the transducer, or flooding (Table 7). Although chum salmon passage was decreasing, 1,785 fish (almost 2% of total) passed on October 6, the last day of operation. Continuing chum salmon passage when the project was terminated prompted expansion of the sonar estimate which was subsequently adjusted to 101,734 chum salmon (Table 5 Figure 7). The expansion was calculated using a second order polynomial equation extended to October 18 (Bonnie Borba, Commercial Fisheries Biologist, ADF&G, Fairbanks, Alaska; personal communication). Postseason, the subsistence harvest from the Eagle area upstream of the sonar was subtracted from the sonar estimate to produce a border passage estimate of 94,739 (Table 5). The preliminary subsistence harvest from the Eagle area was 6,995 (Dayna Norris, Fisheries Biologist, ADF&G, Fairbanks, Alaska; personal communication).

SPATIAL AND TEMPORAL DISTRIBUTION

Fish were shore oriented on both banks (Figures 8 and 9). On the left bank during the Chinook salmon run, 96% of the fish were detected within 75 m of the transducer, and 99% within 95 m. On the right bank, 87% of the fish were detected within 20 m of the transducer and 98% within 28 m. During the fall chum salmon run on the left bank, 93% of the fish were detected within 15 m of the transducer, and 98% within 25 m. On the right bank, 93% of the fish were detected within 8 m of the transducer and 98% within 12 m. The percentage of fish passage estimated by bank for the Chinook salmon season was 80% on the left bank and 20% on the right bank. During the fall chum salmon run, 83% migrated on the left bank and 17% on the right bank.

Fewer Chinook salmon passed along the left bank during daylight hours compared to periods of darkness while the right bank remained more consistent (Figure 10). Conversely, more chum salmon passed along the right bank during daylight hours compared to periods of darkness while the left bank remained more consistent (Figure 11). Overall, when both banks are combined, there was a small diel fluctuation at the project site. During the Chinook salmon run fewer fish migrated during daylight hours, while during the chum salmon run more fish passed during daylight hours (Figure 10 and 11).

SAMPLE FISHING AND SAMPLING

A total of 711 Chinook salmon and 367 chum salmon were captured in drift gillnets between July 11 and October 4 (Table 8). Period 1 fishing occurred from August 2 to October 4, and period 2 fishing occurred from July 11 to August 15. Drifts during period 1 caught 17 Chinook salmon and 367 chum salmon, and 694 Chinook salmon were caught during period 2. Additionally, 10 sheefish *Stenodus leucichthys*, 4 whitefish *Coregoninae* spp. and 1 burbot *Lota lota* were captured during period 1. The number of Chinook and chum salmon captured in drift gillnets by period, zone and mesh size are contained in Tables 9 and 10. Capture mortalities consisted of 11 Chinook salmon and 4 chum salmon. An additional 5 Chinook salmon were observed to have clipped adipose fins indicating they held coded wire tags from the hatchery in Whitehorse, YT. These fish were killed and the heads sent to the ADF&G Mark, Tag and Age Lab in Juneau, AK. Mortalities were distributed to local area residents and added to the total subsistence harvest.

Chinook salmon samples collected from driftnets were composed of 421 (59.2%) males and 290 (40.8%) females. Chum salmon samples from driftnets were composed of 211 (57.5%) males and 156 (42.5%) females. Readable scale samples from 647 Chinook and 334 chum salmon collected in the drift nets were used to determine age compositions (Larry Dubois, Commercial Fisheries Biologist, ADF&G, Anchorage, Alaska; personal communication). From these samples it was determined that Chinook salmon age-1.4 fish predominated (59.0%) followed by age-1.3 (33.2%), and age-1.2, were 7.7%. No other age class of Chinook salmon was present in the catch. From the chum salmon samples it was determined that age-0.3 fish predominated (77.5%) followed by age-0.4 (13.5%); and age-0.2 were 9.0%. No age-0.5 or age-0.6 chum salmon were present in the catch. Genetic samples from 648 Chinook salmon and 367 chum salmon were collected and sent to the Fisheries and Oceans Canada genetics laboratory in Nanaimo, BC for processing.

Climate and Hydrologic Observations

Details of weather and water observations recorded at the sonar site are shown in Appendix A1. Water temperature decreased over the course of the season with a maximum daily average of 18.6°C and a minimum of 3.7°C. Water level decreased over the duration of the season, with occasional temporary increases following substantial rain events (Figure 12). Overall, between July 1 and October 6 the water level decreased 6.6 ft from 19.2 ft to 12.6 ft. The lowest water level recorded during the season was 12.3 ft on August 16.

DISCUSSION

Sonar Deployment and Operation

Pre-season, there was concern that severe spring ice and flood events may have caused the river bottom to change drastically, rendering the study site inappropriate for sonar technology. The crew initially visited the site on June 9 to assess damage. Damage above the normal waterline was extensive. Fortunately however, profiling transects showed that the river bottom remained unchanged and an ideal location for sonar.

The split-beam and DIDSON systems performed well over the entire season with no major technical difficulties or failures. Rapid water level fluctuations were minimal, contributing greatly to the ease of operation this season when compared to other years, especially 2008, which was characterized by heavy rains and substantial debris. Changes in water level at the sonar site usually necessitated moving the transducer(s) and fish lead(s) to deeper or shallower water, particularly on the left bank. The left bank fish lead collapsed during one brief high water event in September, but overall weather conditions were very favorable for sonar operation. Only when silt level was extremely high were sonar detection ranges diminished. Detection ranges for both sonars were reduced to approximately half of the normal counting range for two periods during the Chinook salmon run when silt load was exceptionally high. The DIDSON, with its wide vertical beam angle (14°), is well suited for the right bank, where the profile is steep and slightly less linear than the left bank. The split-beam system worked without malfunction, and appeared to have satisfactory detection nearshore, while still detecting targets adequately at 150 m.

Processing procedures for both DIDSON and split-beam files worked well for estimating salmon passage at the site. All data files were easily processed in a reasonable amount of time. An improved background removal feature to the echogram viewing program used for counting fish from the split-beam data files made distinguishing fish tracks, particularly for chum passing near the transducer, easier. The updated version allowed users to simply adjust the level of background removed, depending on counting conditions.

Chinook and Chum Salmon Passage Estimation

The main purpose of this study was to estimate the passage of Chinook and fall chum salmon to Canada in the mainstem of the Yukon River using hydroacoustics. The Chinook salmon border passage estimate of 69,575 is 22% above the average sonar border passage estimate of 56,833 Chinook salmon from 2005 to 2008. The fall chum salmon border passage estimate of 94,739 is 57% below the average sonar border passage estimate of 221,411 chum salmon from 2006 to 2008.

Subsistence catches upstream of the sonar project and below the US/Canada border were below average. The community of Eagle and vicinity suffered great losses of infrastructure during ice breakup in May, 2009. Unprecedented flooding and damage from ice floes destroyed homes and equipment, including fish wheels and boats used for subsistence fishing. In addition, the subsistence fishery schedule was restricted by ADF&G because of poor run projections, further contributing to lower harvest.

SPATIAL AND TEMPORAL DISTRIBUTIONS

Based on sample fishing results and range distributions observed with the sonar, very few fish migrate upstream in the unensonified portion of the river. The majority of fish migrate within 40 m of shore on both banks. The right bank DIDSON was aimed to ensonify to a range of 40 m, and the left bank split-beam system was aimed to ensonify to a range of 150 m. Because chum salmon tend to swim closer to shore, the range for the left bank split-beam system was reduced to 75 m on August 19 to allow faster ping rates and improved detection near shore. Diel migration patterns observed in 2009 were similar to past years. Upstream migration was greatest in periods of darkness or suppressed light on the left bank and greatest during daylight hours on the right bank.

SAMPLE FISHING AND SPECIES DETERMINATION

Sample fishing was conducted with drift gillnets to capture a representative sample of fish migrating past the sonar site. If fishing effort for both species is approximately the same, this method should recognize a particular date when chum salmon compose more of the sonar count than Chinook salmon, with a minimum error due to species misclassification. However, misclassification rates are relatively insensitive to species changeover date selection because of the typically low passage rates observed around this time (Withler 2006).

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TABLES AND FIGURES

Table 1.–Period 1 sample fishing schedule and drift gillnet mesh sizes (inches), 2009.

Zone	Day 1	Day 2
Left Bank	5.25	7.50
Inshore	7.50	5.25
Left Bank	5.25	7.50
Nearshore	7.50	5.25
Left Bank	5.25	7.50
Offshore	7.50	5.25

Table 2.–Period 2 sample fishing schedule and drift gillnet mesh sizes (inches), 2009.

Zone	Day 1	Day 2	Day 3	Day 4
Left Bank	5.25	7.50	6.50	8.50
Nearshore	6.50	8.50	5.25	7.50
	7.50	6.50	8.50	5.25
Right Bank	5.25	7.50	6.50	8.50
Nearshore	6.50	8.50	5.25	7.50
	7.50	6.50	8.50	5.25
Left Bank	5.25	7.50	6.50	8.50
Offshore	6.50	8.50	5.25	7.50
	7.50	6.50	8.50	5.25

Table 3.–Estimated daily and cumulative Chinook salmon passage by bank, Eagle Sonar, 2009.

	Daily			Cumulative			
Date	Left Bank	Right Bank	Total	Left Bank	Right Bank	Total	% of Total Passage
7/05 [a]	34	32	66	34	32	66	0.00
7/06	60	67	127	94	99	193	0.00
7/07	95	86	181	189	185	374	0.01
7/08	178	142	320	367	327	694	0.01
7/09	326	136	462	693	463	1,156	0.02
7/10	455	126	581	1,148	589	1,737	0.02
7/11	591	228	819	1,739	817	2,556	0.04
7/12	846	326	1,172	2,585	1,143	3,728	0.05
7/13 [b]	928	282	1,210	3,513	1,425	4,938	0.07
7/14 [b]	1,238	328	1,566	4,751	1,753	6,504	0.09
7/15 [b]	1,574	456	2,030	6,325	2,209	8,534	0.12
7/16 [b]	2,044	838	2,882	8,369	3,047	11,416	0.16
7/17 [b]	2,488	1,012	3,500	10,857	4,059	14,916	0.21
7/18 [b]	2,932	1,126	4,058	13,789	5,185	18,974	0.27 [c]
7/19 [b]	3,197	1,322	4,519	16,986	6,507	23,493	0.34
7/20	3,663	1,224	4,887	20,649	7,731	28,380	0.41
7/21	3,404	1,086	4,490	24,053	8,817	32,870	0.47
7/22	3,532	815	4,347	27,585	9,632	37,217	0.53 [d]
7/23	3,282	534	3,816	30,867	10,166	41,033	0.59
7/24	3,090	450	3,540	33,957	10,616	44,573	0.64
7/25	2,847	506	3,353	36,804	11,122	47,926	0.69
7/26	2,552	469	3,021	39,356	11,591	50,947	0.73
7/27	2,072	386	2,458	41,428	11,977	53,405	0.76
7/28	1,740	448	2,188	43,168	12,425	55,593	0.79
7/29	1,837	426	2,263	45,005	12,851	57,856	0.83
7/30	1,871	346	2,217	46,876	13,197	60,073	0.86
7/31	1,696	120	1,816	48,572	13,317	61,889	0.88
8/01 [b]	1,247	82	1,329	49,819	13,399	63,218	0.90
8/02 [b]	1,078	30	1,108	50,897	13,429	64,326	0.92
8/03 [b]	854	22	876	51,751	13,451	65,202	0.93
8/04	730	56	786	52,481	13,507	65,988	0.94
8/05	625	54	679	53,106	13,561	66,667	0.95
8/06	517	56	573	53,623	13,617	67,240	0.96
8/07	420	58	478	54,043	13,675	67,718	0.97
8/08	323	54	377	54,366	13,729	68,095	0.97
8/09	270	40	310	54,636	13,769	68,405	0.98
8/10	177	24	201	54,813	13,793	68,606	0.98

-continued-

Table 3.–Page 2 of 2.

	Daily			Cumulative			
Date	Left Bank	Right Bank	Total	Left Bank	Right Bank	Total	% of Total Passage
8/11	160	14	174	54,973	13,807	68,780	0.98
8/12	129	30	159	55,102	13,837	68,939	0.99
8/13	126	22	148	55,228	13,859	69,087	0.99
8/14	119	34	153	55,347	13,893	69,240	0.99
8/15	95	26	121	55,442	13,919	69,361	0.99
8/16	94	40	134	55,536	13,959	69,495	0.99
8/17	109	43	152	55,645	14,002	69,647	1.00
8/18	98	16	114	55,743	14,018	69,761	1.00
8/19	83	18	101	55,826	14,036	69,862	1.00
8/20	79	16	95	55,905	14,052	69,957	1.00
SE [e]		172				172	

[a] Right and left bank sonar operational.

[b] High silt load affected offshore counts.

[c] Boxed area identifies 2nd and 3rd quartile of run.

[d] Bold box identifies median day of passage.

[e] Sampling error associated with the left bank was treated as insignificant since data was collected 24 hours per day over the sampling range.

Table 4.–Number of minutes by bank and day that were adjusted, because of missed sampling time, to calculate the hourly or daily Chinook salmon passage, and the resulting number of fish either added or subtracted from estimate.

	Left Bank (0-150m)		Right Bank (0-20m)		Right Bank (20-40m)	
Date	Minutes	Fish	Minutes	Fish	Minutes	Fish
7/05	100.0	1	150.0	10	150.0	0
7/06	0.0	0	30.0	3	0.0	0
7/07	0.0	0	0.0	0	0.0	0
7/08	0.0	0	0.0	0	0.0	0
7/09	0.0	0	0.0	0	0.0	0
7/10	0.0	0	0.0	0	0.0	0
7/11	0.0	0	150.0	20	120.0	0
7/12	0.0	0	150.0	55	150.0	15
7/13	0.0	0	0.0	0	0.0	0
7/14	0.0	0	0.0	0	0.0	0
7/15	0.0	0	60.0	4	60.0	4
7/16	0.0	0	0.0	0	0.0	0
7/17	0.0	0	0.0	0	0.0	0
7/18	0.0	0	120.0	144	120.0	32
7/19	8.5	20	0.0	0	0.0	0
7/20	8.4	22	0.0	0	0.0	0
7/21	8.7	21	0.0	0	0.0	0
7/22	8.2	20	120.0	118	90.0	9
7/23	4.8	12	0.0	0	0.0	0
7/24	7.9	20	0.0	0	0.0	0
7/25	54.6	122	7.0	2	0.0	0
7/26	8.8	19	70.0	50	90.0	15
7/27	9.1	15	10.0	2	5.0	0
7/28	53.1	59	0.0	0	0.0	0
7/29	9.4	13	6.0	2	0.0	0
7/30	10.1	15	0.0	0	0.0	0
7/31	17.9	21	0.0	0	10.0	0
8/01	44.5	35	0.0	0	0.0	0
8/02	10.3	0	0.0	0	0.0	0
8/03	10.3	0	0.0	0	0.0	0
8/04	10.3	0	0.0	0	0.0	0
8/05	10.3	0	0.0	0	0.0	0
8/06	10.3	0	0.0	0	0.0	0
8/07	10.3	0	0.0	0	0.0	0
8/08	10.3	0	0.0	0	0.0	0
8/09	24.9	1	0.0	0	0.0	0
8/10	10.3	0	0.0	0	0.0	0
8/11	427.0	56	240.0	0	240.0	0
8/12	9.4	0	0.0	0	0.0	0
8/13	9.0	0	0.0	0	0.0	0
8/14	8.7	0	0.0	0	0.0	0
8/15	8.9	0	0.0	0	0.0	0
8/16	9.2	0	0.0	0	0.0	0
8/17	157.9	12	90.0	9	90.0	0
8/18	9.0	0	0.0	0	0.0	0
8/19	30.3	3	9.0	0	0.0	0
8/20	7.7	0	1.0	0	9.0	0
Total	1,138.4	487	1,213.0	419	1,134.0	75

Table 5.–Eagle sonar estimate, Eagle area subsistence harvest, and U.S. and Canadian border passage estimates, 2005–2009.

	Sonar Estimate		Eagle Area Subsistence Harvest [a]		U.S. Sonar Mainstem Border Passage Estimate		Canadian Mainstem Border Passage Estimate [b]	
Date	Chinook	chum	Chinook	chum	Chinook	chum	Chinook	chum
2005	81,528	ND	2,566	ND	78,962	ND	42,245	451,477
2006	73,691	236,386	2,303	17,775	71,388	218,611	36,748	217,810
2007	41,697	282,670 [c]	1,999	18,691	39,698	263,979	22,120	235,956
2008	38,097	193,397 [c]	815	11,755	37,282	181,642	14,666	132,048
2009	69,957	101,734 [c]	382	6,995	69,575	94,739	Project did not operate.	

Note: 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 most likely in the hundreds for Chinook salmon, and a few thousand for 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] Except for 2005 and 2008, subsistence estimates are preliminary.

[b] Canadian mainstem border passage estimates from JTC 2008, except 2008 estimate from (Patrick Milligan, Stock Assessment Biologist, DFO, Whitehorse, Yukon, Canada, personal communication).

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

Table 6.–Estimated daily and cumulative chum salmon passage by bank, Eagle Sonar, 2009.

	Daily			Cumulative			
Date	Left Bank	Right Bank	Total	Left Bank	Right Bank	Total	% of Total Passage
8/21	97	28	125	97	28	125	0.00
8/22	73	18	91	170	46	216	0.00
8/23	97	24	121	267	70	337	0.00
8/24	109	26	135	376	96	472	0.00
8/25	88	24	112	464	120	584	0.01
8/26	103	38	141	567	158	725	0.01
8/27	85	26	111	652	184	836	0.01
8/28	95	20	115	747	204	951	0.01
8/29	143	60	203	890	264	1,154	0.01
8/30	146	52	198	1,036	316	1,352	0.01
8/31	155	26	181	1,191	342	1,533	0.02
9/01	182	28	210	1,373	370	1,743	0.02
9/02	247	24	271	1,620	394	2,014	0.02
9/03	310	50	360	1,930	444	2,374	0.02
9/04	353	38	391	2,283	482	2,765	0.03
9/05	433	42	475	2,716	524	3,240	0.03
9/06	520	44	564	3,236	568	3,804	0.04
9/07	649	72	721	3,885	640	4,525	0.05
9/08	687	68	755	4,572	708	5,280	0.06
9/09	739	101	840	5,311	809	6,120	0.06
9/10	1,069	130	1,199	6,380	939	7,319	0.08
9/11	1,575	230	1,805	7,955	1,169	9,124	0.10
9/12	2,243	134	2,377	10,198	1,303	11,501	0.12
9/13	2,811	216	3,027	13,009	1,519	14,528	0.15
9/14	3,366	372	3,738	16,375	1,891	18,266	0.19
9/15	3,596	465	4,061	19,971	2,356	22,327	0.23
9/16	3,623	606	4,229	23,594	2,962	26,556	0.28 [a]
9/17	3,323	382	3,705	26,917	3,344	30,261	0.32
9/18	2,424	312	2,736	29,341	3,656	32,997	0.35
9/19	2,422	[b] 223	2,645	31,763	3,879	35,642	0.37
9/20	2,420	1,188	3,608	34,183	5,067	39,250	0.41
9/21	2,532	1,048	3,580	36,715	6,115	42,830	0.45
9/22	3,213	1,344	4,557	39,928	7,459	47,387	0.50 [c]
9/23	3,549	1,514	5,063	43,477	8,973	52,450	0.55
9/24	3,951	1,536	5,487	47,428	10,509	57,937	0.61
9/25	3,424	1,098	4,522	50,852	11,607	62,459	0.65
9/26	3,398	612	4,010	54,250	12,219	66,469	0.70
9/27	3,296	406	3,702	57,546	12,625	70,171	0.74
9/28	3,344	484	3,828	60,890	13,109	73,999	0.78
9/29	3,360	322	3,682	64,250	13,431	77,681	0.81
9/30	2,997	362	3,359	67,247	13,793	81,040	0.85

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Table 6.–Page 2 of 2.

	Daily			Cumulative			
Date	Left Bank	Right Bank	Total	Left Bank	Right Bank	Total	% of Total Passage
10/01	2,597	244	2,841	69,844	14,037	83,881	0.88
10/02	2,472	330	2,802	72,316	14,367	86,683	0.91
10/03	2,264	232	2,496	74,580	14,599	89,179	0.93
10/04	1,914	336	2,250	76,494	14,935	91,429	0.96
10/05	1,714	534	2,248	78,208	15,469	93,677	0.98
10/06	1,231	554	1,785	79,439	16,023	95,462	1.00
SE [d]		225				225	

[a] Boxed area identifies 2nd and 3rd quartile of run.

[b] Left bank daily total calculated using linear interpolation for day when sonar was adversely affected by flood conditions.

[c] Bold box identifies median day of passage.

[d] Sampling error associated with the left bank was treated as insignificant since data was collected 24 hours per day over the sampling range.

Table 7.–Number of minutes by bank and day that were adjusted, because of missed sampling time, to calculate the hourly or daily chum salmon passage, and the resulting number of fish either added or subtracted from estimate.

	Left Bank (0-75m)		Right Bank (0-20m)		Right Bank (20-40m)	
Date	Minutes	Fish	Minutes	Fish	Minutes	Fish
8/21	0.7	1	0.0	0	0.0	0
8/22	3.2	0	0.0	0	0.0	0
8/23	24.3	2	0.0	0	0.0	0
8/24	66.5	5	0.0	0	0.0	0
8/25	14.7	0	3.0	0	21.0	0
8/26	7.5	1	0.0	0	0.0	0
8/27	27.5	0	0.0	0	0.0	0
8/28	-4.5	0	0.0	0	0.0	0
8/29	3.2	2	0.0	0	0.0	0
8/30	4.2	1	0.0	0	0.0	0
8/31	5.1	1	0.0	0	0.0	0
9/01	18.5	1	0.0	0	0.0	0
9/02	4.1	3	0.0	0	0.0	0
9/03	10.7	5	0.0	0	0.0	0
9/04	12.4	6	0.0	0	0.0	0
9/05	28.2	12	0.0	0	0.0	0
9/06	50.3	21	0.0	0	0.0	0
9/07	59.3	26	0.0	0	0.0	0
9/08	25.3	8	0.0	0	0.0	0
9/09	11.7	3	67.0	11	90.0	0
9/10	9.6	6	0.0	0	0.0	0
9/11	12.9	13	0.0	0	0.0	0
9/12	16	22	0.0	0	0.0	0
9/13	98.5	212	0.0	0	0.0	0
9/14	20.4	48	0.0	0	0.0	0
9/15	36.7	90	10.0	7	0.0	0
9/16	10.9	28	14.0	30	30.0	0
9/17	4.9	10	0.0	0	0.0	0
9/18	24.6	25	60.0	26	90.0	0
9/19	1,440.0	2,422	30.0	7	45.0	0
9/20	74.0	132	0.0	0	0.0	0
9/21	24.6	36	0.0	0	0.0	0
9/22	16.4	29	0.0	0	0.0	0
9/23	65.9	140	0.0	0	0.0	0
9/24	4.8	18	0.0	0	0.0	0
9/25	4.8	8	0.0	0	0.0	0
9/26	4.8	8	0.0	0	0.0	0
9/27	4.8	8	60.0	52	30.0	0
9/28	4.8	8	0.0	0	0.0	0
9/29	4.8	8	0.0	0	0.0	0
9/30	4.8	3	90.0	84	90.0	0
10/1	4.8	1	0.0	0	0.0	0
10/2	3.8	-1	0.0	0	0.0	0
10/3	4.8	0	0.0	0	0.0	0
10/4	4.8	0	0.0	0	0.0	0
10/5	4.8	0	0.0	0	0.0	0
10/6	45.2	16	0.0	0	30.0	0
Total	2,330.1	3,388	334.0	217	426.0	0

Table 8.–Fish caught with gillnets at the Eagle sonar project site, 2009.

Species	Period 1	Period 2	Total
Chinook	17	694	711
chum	367	0	367
sheefish	10	0	10
whitefish	4	0	4
burbot	1	0	1
Total	399	694	1,093

Table 9.–Period 1, effort, salmon catch, and percentage of Chinook and chum catch, by zone and mesh size, Eagle sonar project site, 2009.

	Mesh Size	Effort	Catch (Period 1)		Percent of	
Zone	(inches)	(fathom hours)	Chinook	Chum	Chinook Catch	Chum Catch
LBI	5.25	332.07	1	265	5.9	72.2
	7.50	329.92	1	70	5.9	19.1
Total		661.99	2	335	11.8	91.3
LBN	5.25	348.42	8	24	47.1	6.5
	7.50	344.03	6	6	35.3	1.6
Total		692.45	14	30	82.4	8.2
LBF	5.25	344.78	1	2	5.9	0.5
	7.50	342.46	0	0	0.0	0.0
Total		687.24	1	2	5.9	0.5
Grand Total		2,041.68	17	367	100	100

Table 10.–Period 2, effort, salmon catch, and percentage of Chinook and chum catch, by zone and mesh size, Eagle sonar project site, 2009.

	Mesh Size	Effort	Catch (Period 2)		Percent of	
Zone	(inches)	(fathom hours)	Chinook	Chum	Chinook Catch	Chum Catch
LBN	5.25	91.05	44	0	6.3	0.0
	6.50	93.01	69	0	9.9	0.0
	7.50	86.97	48	0	6.9	0.0
	8.50	87.74	64	0	9.2	0.0
Total		358.78	225	0	32.4	0.0
RBN	5.25	90.67	101	0	14.6	0.0
	6.50	88.28	87	0	12.5	0.0
	7.50	83.35	99	0	14.3	0.0
	8.50	85.57	78	0	11.2	0.0
Total		347.86	365	0	52.6	0.0
LBF	5.25	87.26	20	0	2.9	0.0
	6.50	89.02	25	0	3.6	0.0
	7.50	83.66	35	0	5.0	0.0
	8.50	87.11	24	0	3.5	0.0
Total		347.05	104	0	15.0	0.0
Grand Total		1053.69	694	0	100	0.0

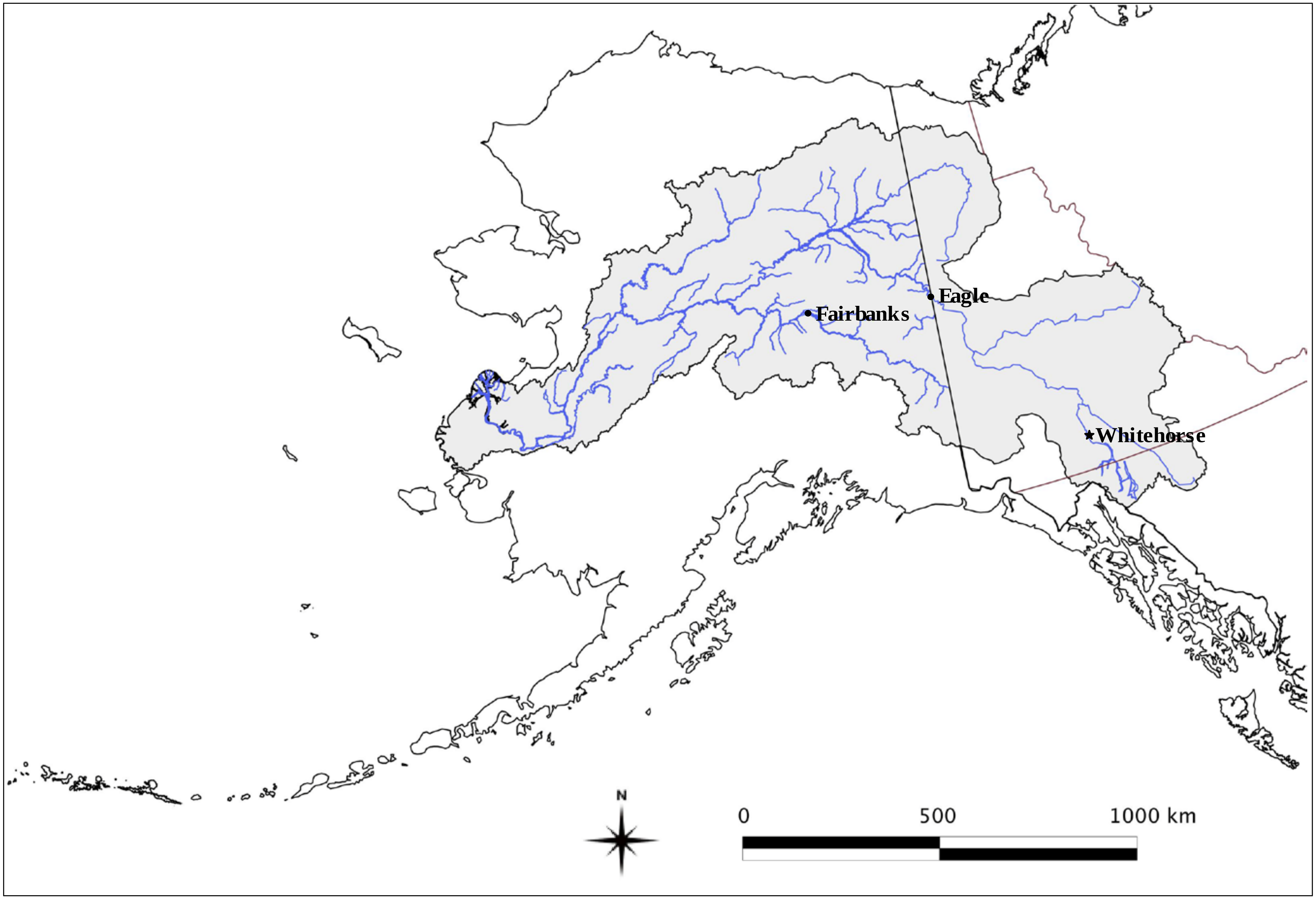


Figure 1.–Yukon River drainage.

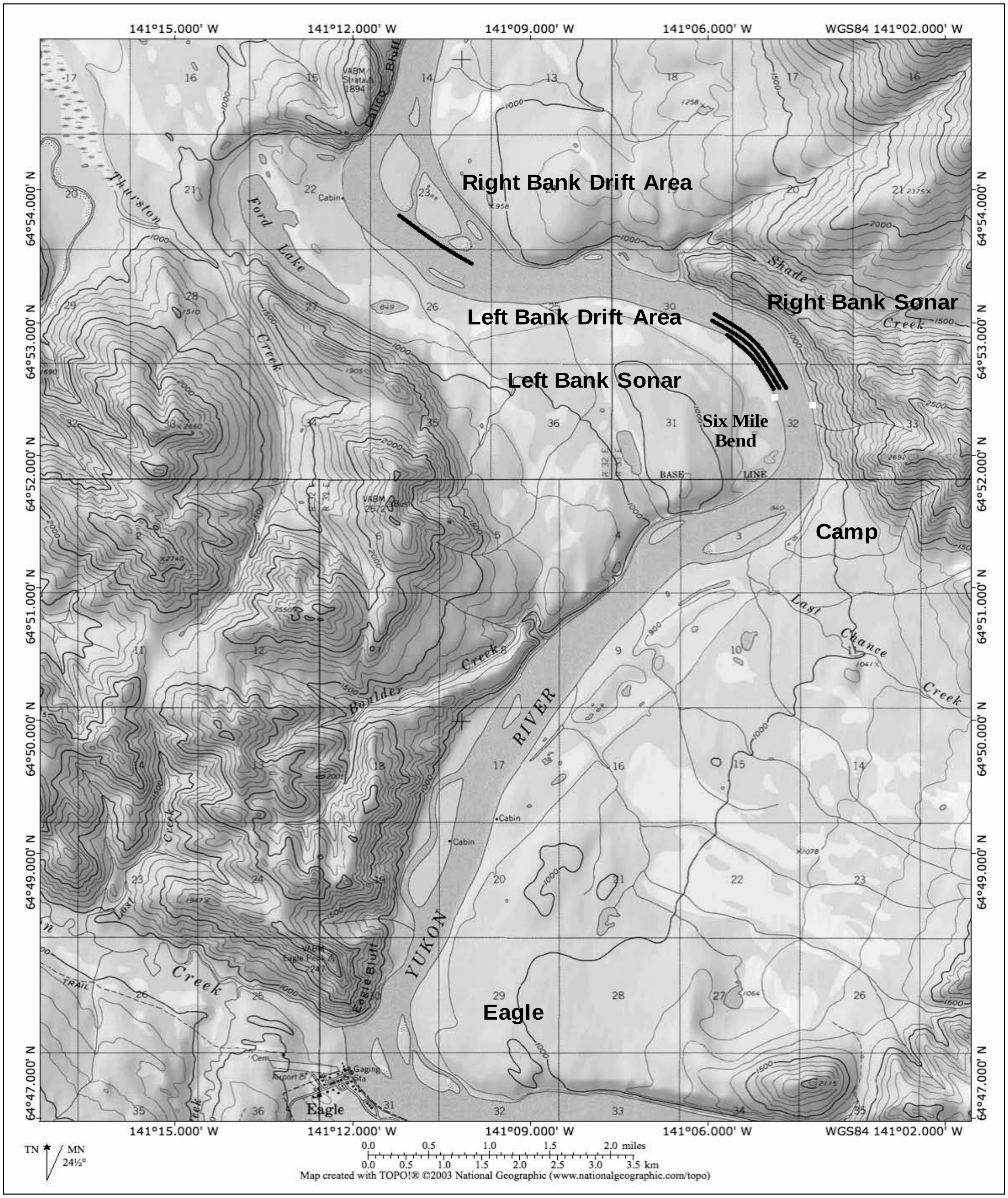


Figure 2.–Eagle sonar project site at Six Mile Bend, showing sonar and sample fishing locations.

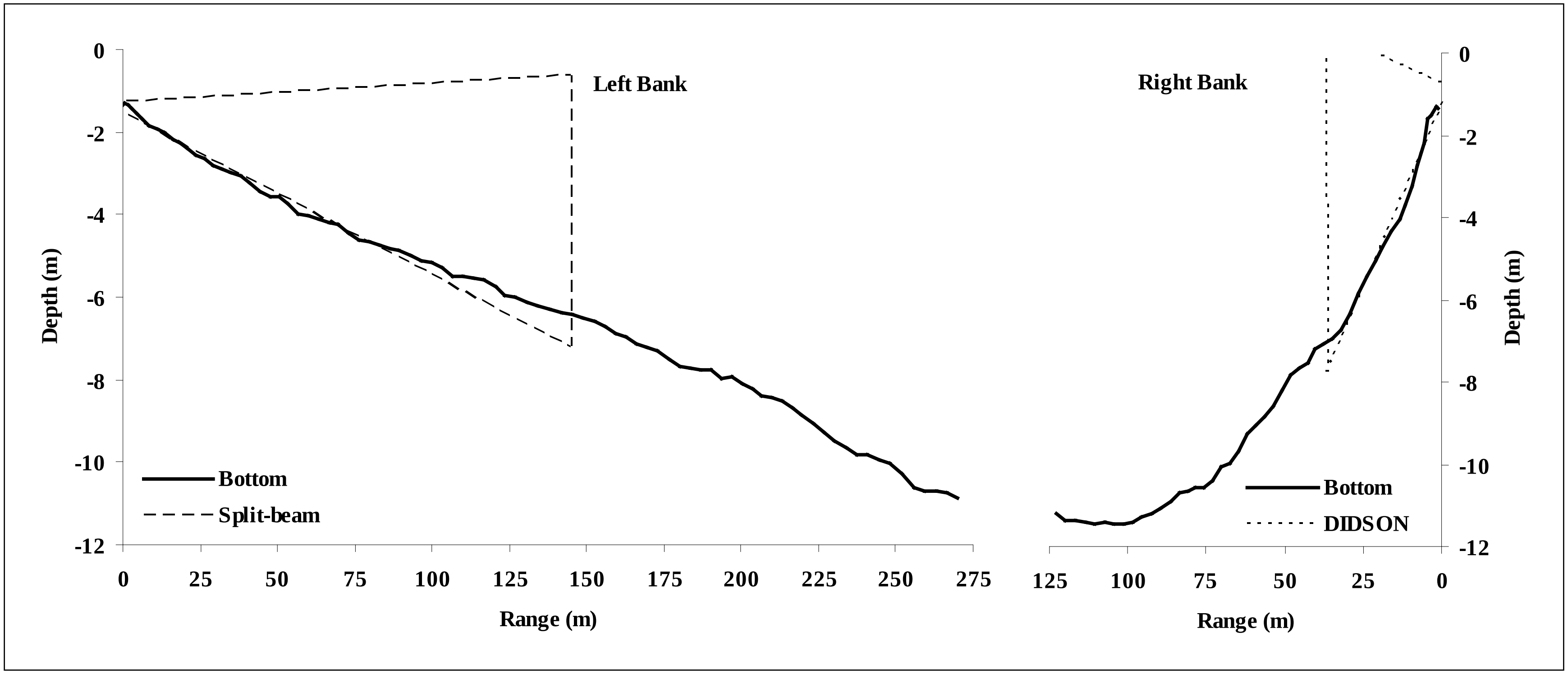


Figure 3.–Depth profile (downstream view), and ensonified zones of Yukon River at Eagle sonar project site, 2009.

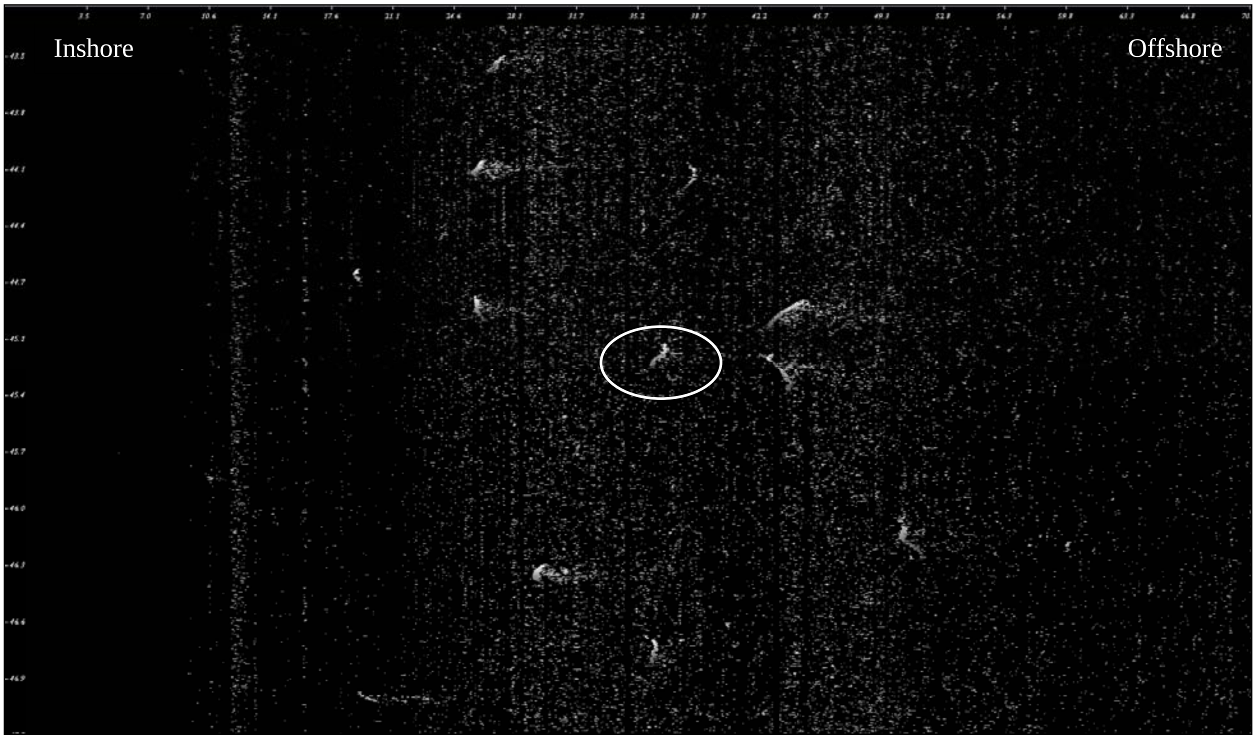


Figure 4.–Screenshot of echogram used to count fish from split-beam sonar data files. Ellipse encompasses typical upstream migrating salmon.

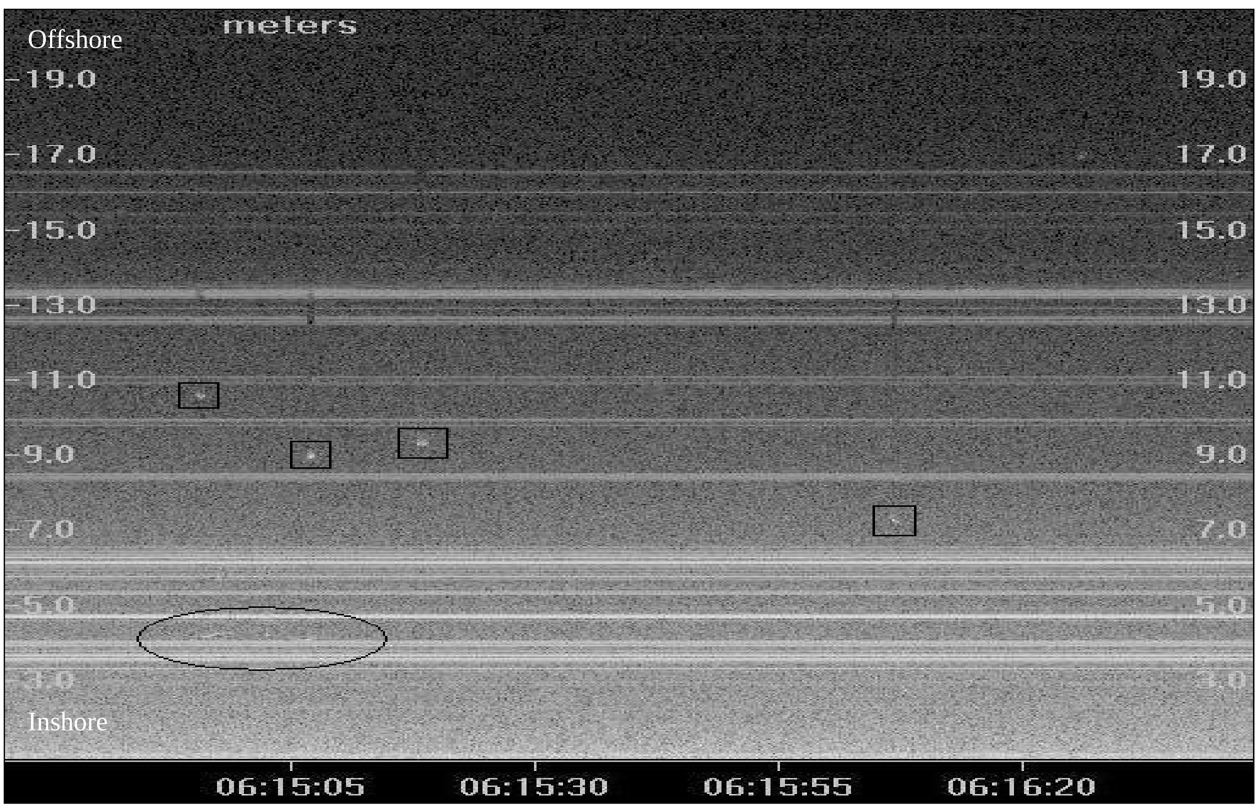


Figure 5.–Screenshot of echogram used to count fish from DIDSON data files. Rectangles encompass typical migrating salmon traces and ellipse encompasses small, slow moving non-salmon.

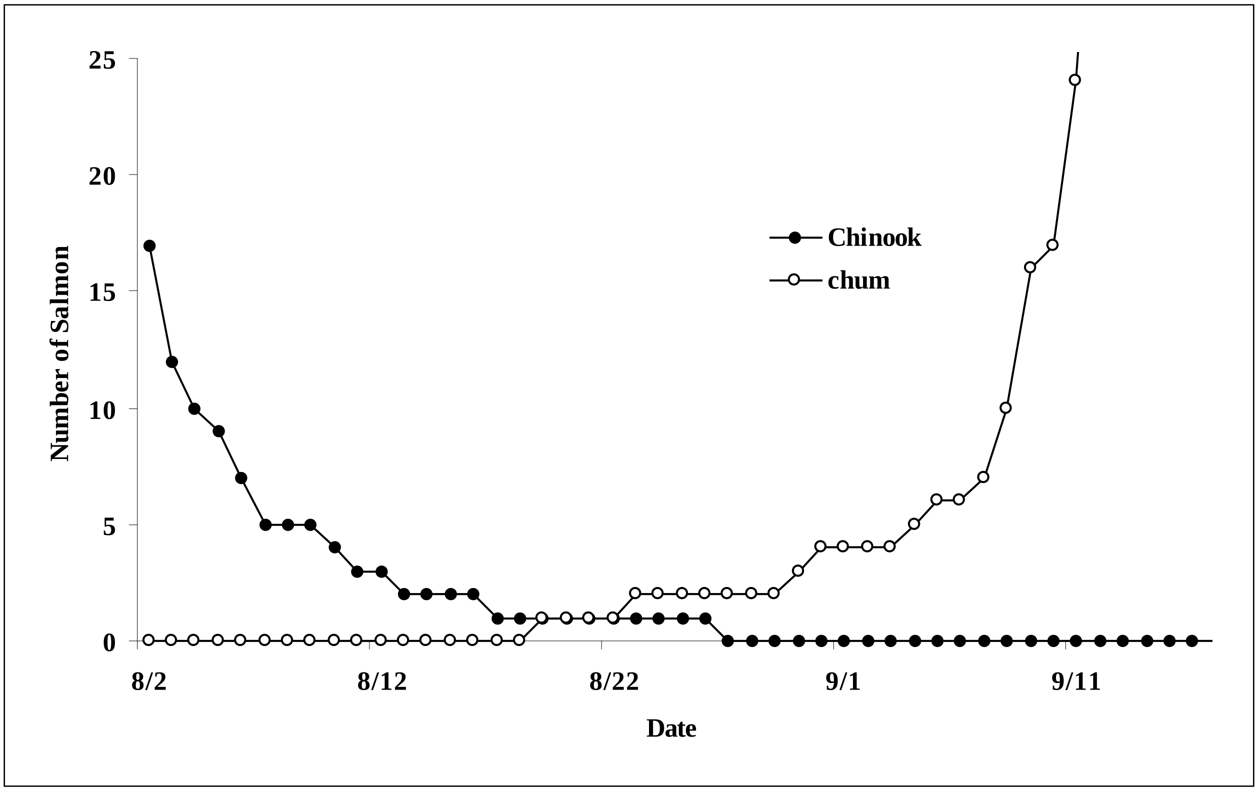


Figure 6.–Species changeover date determined from reverse cumulative Chinook and cumulative chum salmon catches at the Eagle sonar project site, 2009.

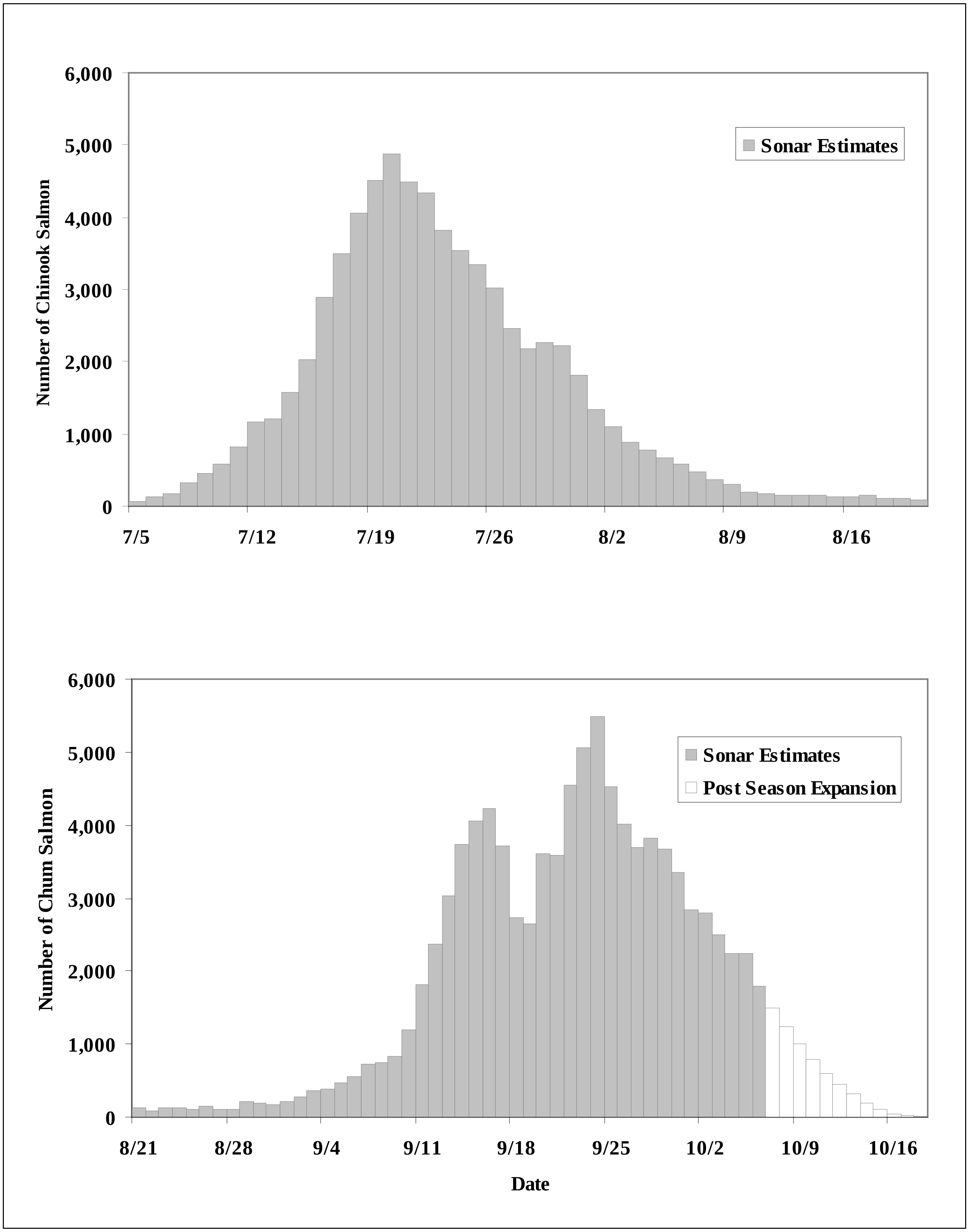


Figure 7.–Daily sonar estimates for Chinook Salmon, July 5 through August 20, 2009 (top), and daily sonar estimates for chum salmon, August 21 through October 6, 2009 (bottom). Also, postseason chum salmon expansion estimates, October 7 through October 18 (bottom).

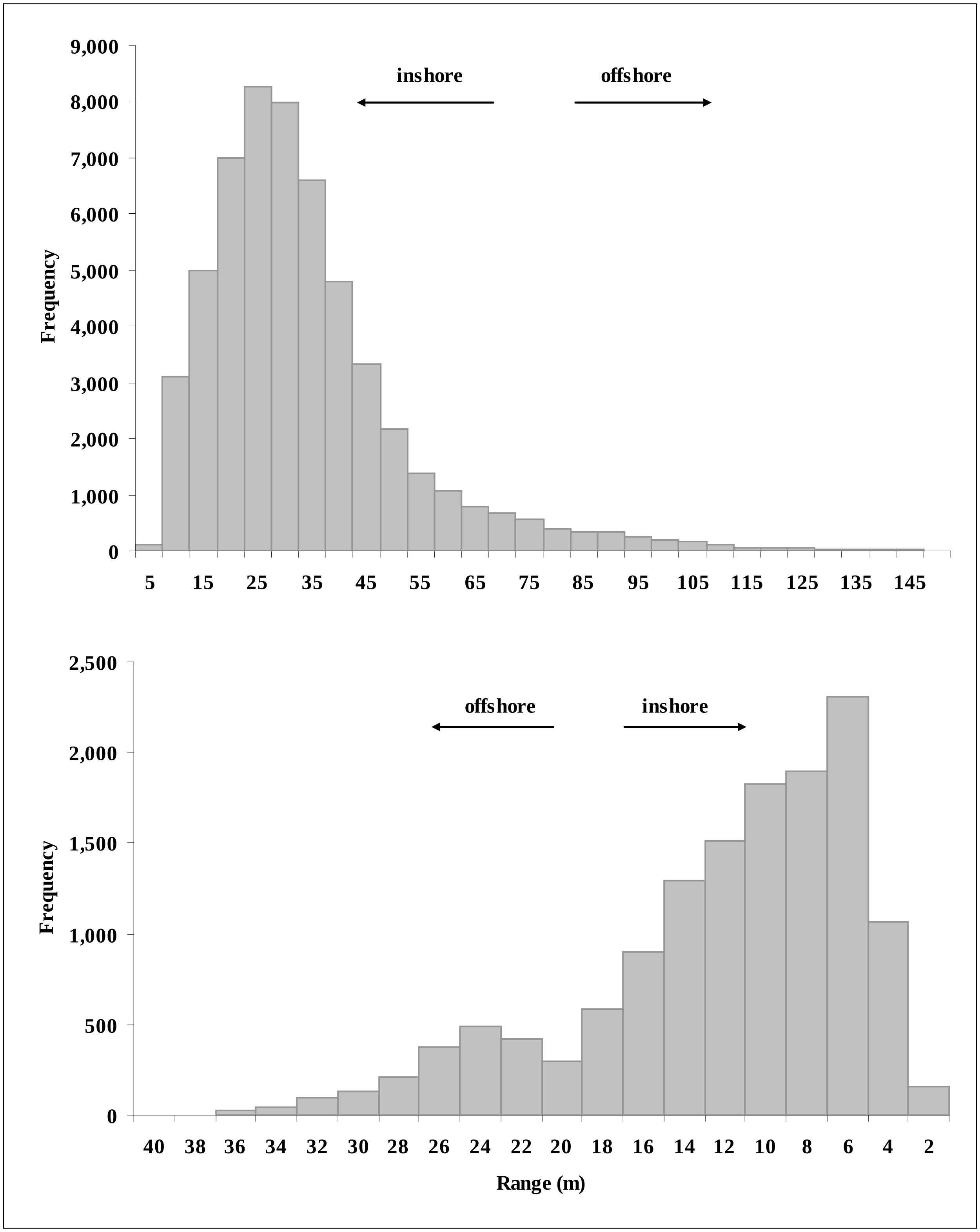


Figure 8.–Left bank (top) and right bank (bottom) horizontal distribution of upstream Chinook salmon passage in the Yukon River at Eagle sonar project site, July 5 through August 20, 2009.

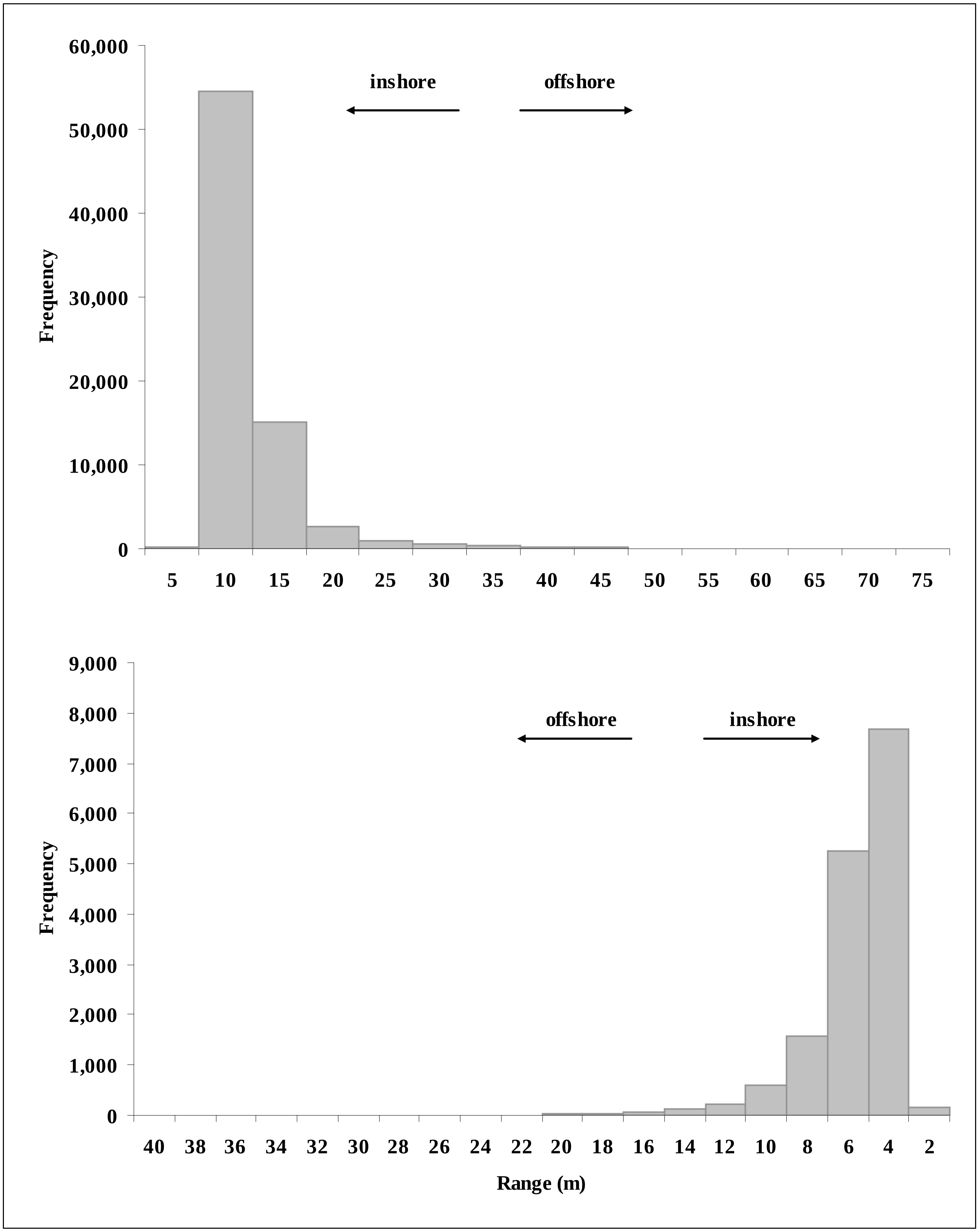


Figure 9.–Left bank (top) and right bank (bottom) horizontal distribution of upstream chum salmon passage in the Yukon River at Eagle sonar project site, August 21 through October 6, 2009. Left bank data for the time period September 18 at 1900 hours through September 20 at 0900 hours is excluded because the fish lead collapsed and was not functional for adequate offshore diversion of fish.

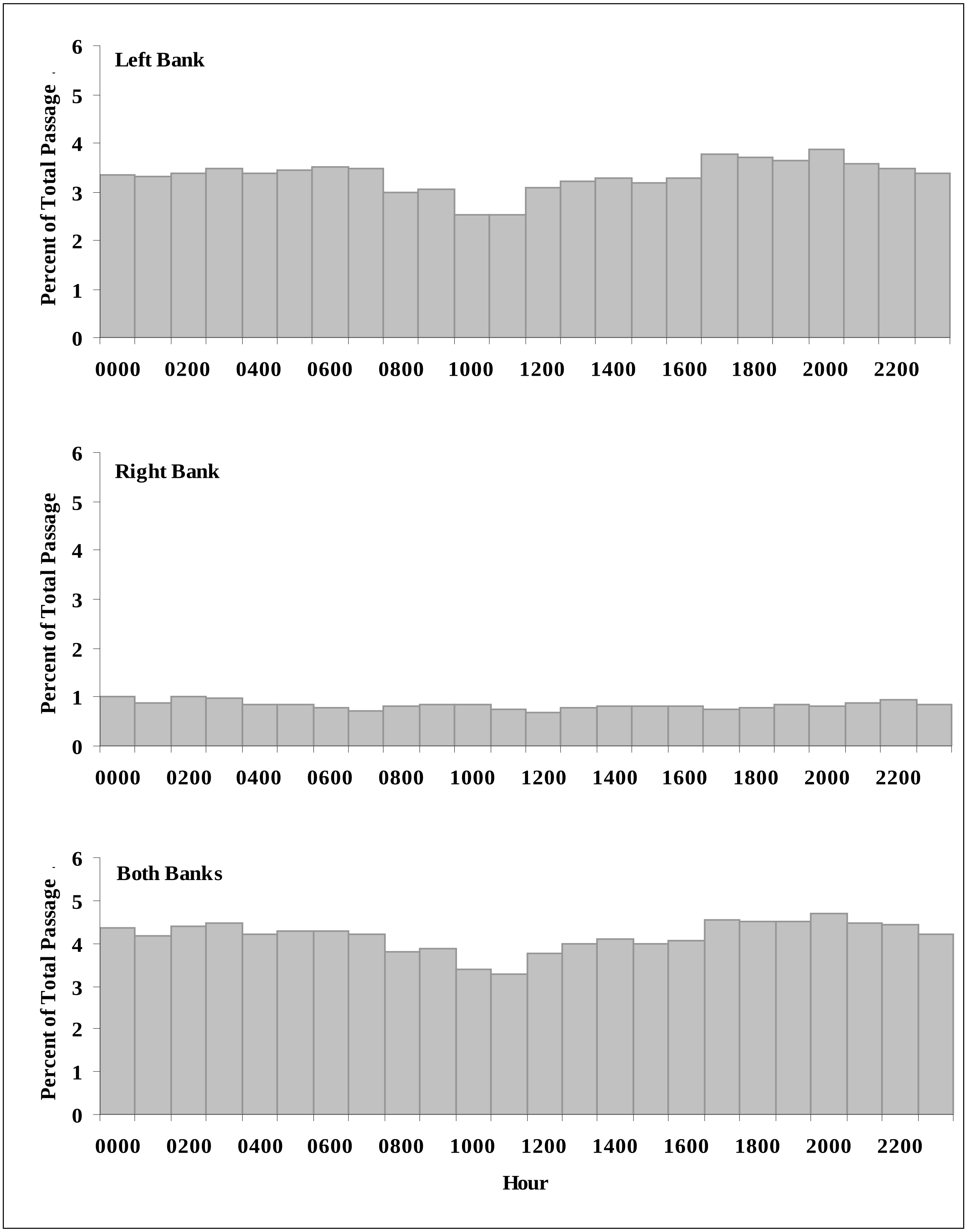


Figure 10.–Diel Chinook salmon migration pattern observed on the left bank (top), right bank (middle), and both banks combined (bottom) of the Yukon River at the Eagle sonar project site from July 5 through August 20, 2009.

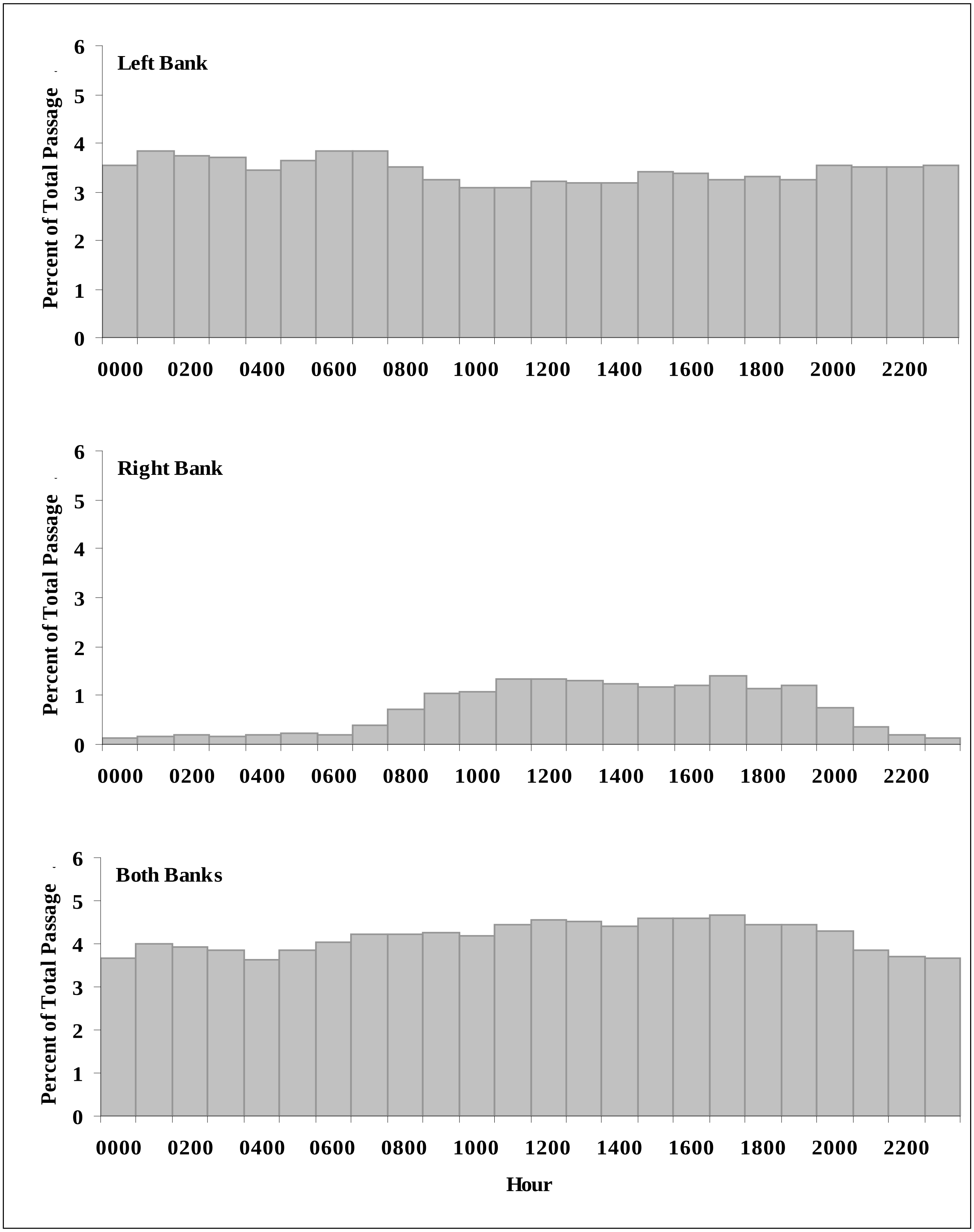
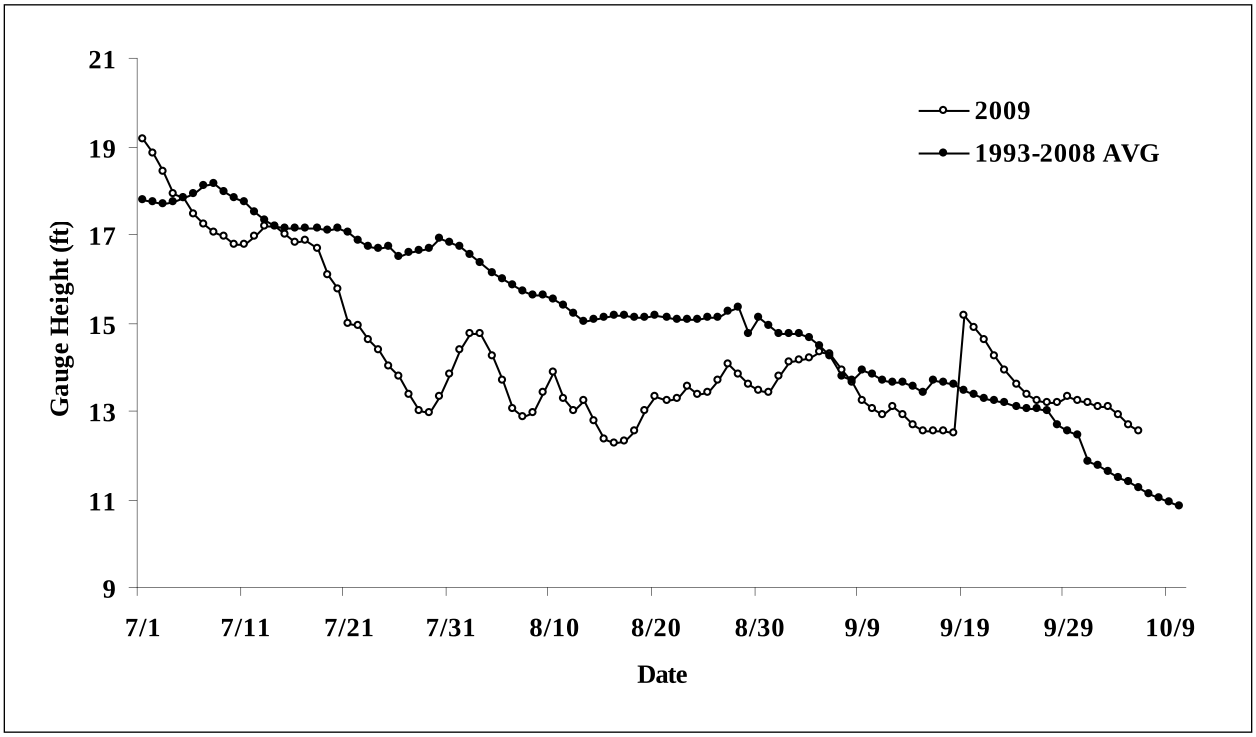


Figure 11.–Diel chum salmon migration pattern observed on the left bank (top), right bank (middle), and both banks combined (bottom) of the Yukon River at the Eagle sonar project site from August 21 through October 6, 2009.



Source: United States Geological Survey

Figure 12.–Daily water elevation measured at Eagle, July 1 through October 6, 2009, and average water level from 1993 through 2008. All measurements from United States Geological Survey except for July 6–July 20, September 5–September 10 and September 25–October 6 when data was taken at the sonar site because USGS measurements were unavailable.

APPENDIX A. CLIMATE AND HYDROLOGIC OBSERVATIONS

Appendix A1.–Climate and hydrologic observations recorded daily at 1800 hours at the Eagle sonar project site, 2009.

	Precipitation	Wind		Sky	Temperature (C°)	
Date	(code)[a]	Direction	Speed (mph)	(code)[b]	Air	Water[c]
7/05	A	S	5	B	29.8	16.6
7/06	A	calm	calm	C	29.1	16.3
7/07	A	calm	calm	C	35.1	16.5
7/08	A	calm	calm	C	30.2	17.0
7/09	A	calm	calm	B	25.1	17.0
7/10	A	SW	5	S	25.0	16.9
7/11	A	SW	5	O	18.8	16.6
7/12	A	SW	5	S	26.4	16.8
7/13	A	calm	calm	C	29.0	17.2
7/14	A	NW	2	C	29.3	17.7
7/15	A	NW	5	C	25.0	17.7
7/16	A	calm	calm	C	24.5	17.2
7/17	A	calm	calm	C	27.1	17.0
7/18	A	SE	calm	B	16.2	16.4
7/19	A	NW	5	S	25.3	16.2
7/20	A	S	5-7gusty	C	24.1	16.3
7/21	A	S	5-10gusty	C	24.5	16.7
7/22	A	S	5	B	21.1	16.8
7/23	A	S	5	O	17.6	16.3
7/24	B	SE	5-7gusty	B	15.1	15.7
7/25	A	S	5	S	22.9	15.9
7/26	A	S	5-10gusty	S	24.6	15.9
7/27	A	S	calm	B	29.6	16.6
7/28	A	S	calm	B	33.5	16.6
7/29	A	S	3	S	30.4	17.3
7/30	A	calm	calm	F	28.2	17.9
7/31	A	NW	3	B	29.4	18.6
8/01	A	NW	calm	F	14.0	18.5
8/02	A	NW	calm	F	22.9	17.5
8/03	A	NW	calm	F	27.6	16.6
8/04	A	E	5	F	27.7	16.2
8/05	A	S	3	F	32.4	16.0
8/06	A	NW	3	F	19.2	15.7
8/07	A	NW	3	F	20.3	15.9
8/08	A	NW	3	F	27.7	15.9
8/09	B	N	5	O	9.4	15.2
8/10	C	NW	5	B	14.0	14.2
8/11	A	W	5	B	14.0	13.3
8/12	A	calm	0	S	18.3	13.1
8/13	A	NW	5	O	16.3	13.1
8/14	B	calm	0	B	14.1	13.4
8/15	B	S	2	O	13.4	13.5
8/16	C	NW	8	O	13.3	13.5
8/17	A	N	5	S	15.6	13.9
8/18	A	calm	calm	B	14.2	14.1

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Date	Precipitation (code)[a]	Wind Direction	Wind Speed (mph)	Sky (code)[b]	Temperature (C°) Air	Temperature (C°) Water[c]
8/19	C	N	5	O	10.2	13.9
8/20	A	N	<5	C	22.9	13.5
8/21	B	calm	calm	S	15.6	13.2
8/22	A	calm	calm	C	20.3	13.3
8/23	A	calm	calm	B	20.3	13.8
8/24	B	calm	calm	O	11.9	14.1
8/25	A	calm	calm	S	13.3	13.7
8/26	A	calm	calm	S	16.3	13.2
8/27	A	SW	<5	S	19.7	13.2
8/28	B	calm	calm	B	15.7	13.1
8/29	A	NNW	<5	B	15.9	12.9
8/30	B	S	<5	O	11.4	12.3
8/31	B	S	<5	O	12.9	12.1
9/01	A	N	<5	B	16.1	12.1
9/02	A	E	<5	O	19.3	12.2
9/03	A	W	10	B	26.2	12.0
9/04	A	W	5	S	21.2	12.0
9/05	A	calm	0	C	27.3	11.9
9/06	A	E	5	S	23.6	11.9
9/07	B	E	<5	B	17.8	11.9
9/08	A	E	<5	B	19.7	11.8
9/09	A	NE	5	B	15.4	11.5
9/10	A	S	<5	O	14.4	11.4
9/11	A	S	<5	B	12.4	11.4
9/12	A	calm	calm	S	14.8	11.2
9/13	B	calm	calm	O	12.6	10.7
9/14	A	N	<5	C	16.3	10.5
9/15	A	calm	calm	C	19.3	10.4
9/16	A	calm	calm	O	11.5	10.0
9/17	C	S	<5	O	7.6	9.9
9/18	C	calm	calm	O	9.4	9.6
9/19	B	calm	calm	O	5.1	8.7
9/20	A	N	<5	O	4.5	7.9
9/21	A	NE	5	O	9.0	8.2
9/22	A	E	<5	O	13.2	8.4
9/23	B	N	<5	O	2.9	7.9
9/24	A	calm	calm	B	6.0	7.4
9/25	D	calm	calm	O	4.3	6.8
9/26	A	calm	calm	O	2.8	6.5
9/27	A	calm	calm	O	2.5	6.3

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Appendix A1.–Page 3 of 3.

Date	Precipitation (code)[a]	Wind Direction	Wind Speed (mph)	Sky (code)[b]	Temperature (C°) Air	Temperature (C°) Water[c]
9/28	A	NW	<5	O	1.0	5.9
9/29	A	NE	8	B	2.8	5.5
9/30	A	E	10	S	3.0	5.0
10/1	A	N	8	S	1.0	4.3
10/2	A	calm	calm	C	0.9	4.0
10/3	A	SE	<5	O	2.0	3.7
10/4	A	calm	calm	S	4.4	3.8
10/5	B	W	10	O	3.2	4.0
10/6	A	calm	0	C	2.4	ND
Average					17.2	12.9

[a] Precipitation code for the preceding 24h 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 30cm below surface with HOBO U22 data logger every 4 hours. Reported values are daily averages.