Fishery Data Series No. 09-27

Sonar Estimation of Chinook and Fall Chum Salmon in the Yukon River Near Eagle, Alaska, 2007

by

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and

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June 2009

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)

Measures (fisheries)

fork length	FL
mideye to fork	MEF
mideye to tail fork	METF
standard length	SL
total length	TL

Mathematics, statistics

all standard mathematical signs, symbols and abbreviations	
alternate hypothesis	H_A
base of natural logarithm	*e*
catch per unit effort	CPUE
coefficient of variation	CV
common test statistics	(F, t, χ^2, etc.)
confidence interval	CI
correlation coefficient (multiple)	R
correlation coefficient (simple)	r
covariance	cov
degree (angular)	°
degrees of freedom	df
expected value	*E*
greater than	>
greater than or equal to	≥
harvest per unit effort	HPUE
less than	<
less than or equal to	≤
logarithm (natural)	ln
logarithm (base 10)	log
logarithm (specify base)	log_2, etc.
minute (angular)	'
not significant	NS
null hypothesis	H_O
percent	%
probability	P
probability of a type I error (rejection of the null hypothesis when true)	α
probability of a type II error (acceptance of the null hypothesis when false)	β
second (angular)	"
standard deviation	SD
standard error	SE
variance	
population	Var
sample	var

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TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

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 7 to October 6, 2007. A total of 41,697 Chinook were estimated to have passed the sonar site between July 7 and August 22, and an estimated 235,871 chum salmon passed between August 23 and October 6. The sonar-estimated passage of chum salmon was subsequently expanded to a total abundance estimate of 282,670 using run historic time data from the Department of Fisheries and Oceans border fish wheel. Border passage estimates were 39,725 Chinook salmon, and 263,997 chum salmon. A drift gillnet test 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.

From September 8 to October 4, 2006 and July 31 to August 9, 2007, a Dual-Frequency Identification Sonar was operated side-by-side with the split-beam sonar to collect data to determine whether technicians were counting non-salmon fish with the split-beam system. Analyses of data collected suggest that within 0–20 m, 0.6% of all fish counted using the split-beam echogram were small non-salmon fish.

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 throughout most of the drainage. These salmon 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. Management of the fisheries 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 bi-national, coordinated management of Chinook and chum salmon stocks 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 in season, they are crucial for postseason analysis to determine whether treaty obligations were met. The Canadian Department of Fisheries and Oceans (DFO) currently provides estimates of mainstem salmon passage through the U.S./Canada border using mark–recapture techniques.

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[1]) has been used in the Aniak River to give daily passage estimates where bottom profile and river width are appropriate for the wider beam angle and shorter-range capabilities of this sonar (McEwen 2005).

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 from the early sonar studies near the U.S./Canada border 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, uneven bottom may have allowed fish to pass undetected by the sonar, and a linear profile would alleviate this problem and allow detection of fish at longer ranges.

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. Criteria for suitable sites 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 narrowing of potential project locations to an area between 9 and 19 km downriver from the town of Eagle. The 2003 study found that the two most promising sonar deployment locations meeting the above criteria were 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 bank and DIDSON on the shorter, steeper bank.

After finding a suitable section of river for a potential sonar project in 2003, ADF&G carried out a 2-week study in 2004 to test sonar at the preferred sites. Two types of sonar were tested at Calico Bluff and the Shade Creek area. It was found that Six Mile Bend (9.7 km downriver from

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

the town of Eagle, and immediately upstream of Shade Creek) was the most ideal site, and that a DIDSON should be deployed on the shorter, steeper right bank, and a split-beam unit should be deployed on the longer, more linear left bank (Carroll et al. 2007a).

In 2005, a full-scale sonar project was conducted from July 1 to August 13 to estimate Chinook salmon *Oncorhynchus tshawytscha* 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 provide an estimate of fall chum salmon *Oncorhynchus keta* passage. Split-beam and DIDSON technology were again used in 2007 to estimate border passage for both Chinook and fall chum salmon.

STUDY AREA

The study area is a 1.6 km section of the mainstem Yukon River at Six Mile Bend, 9.7 km downriver from Eagle, Alaska (Figure 2).

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 flow slowly declines and varies only slightly. 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 and an outhouse was constructed in 2005 on the left bank (64° 51'55.70" N 141° 04'43.62" W). An additional platform and canvas tent was constructed on the left bank 1.3 km downriver from camp (64°52'30.84" N 141°04'52.77" W) to house computer and sonar related equipment. A portable wooden shelter was used on the right bank to house topside sonar equipment, a wireless router, and a solar powered battery system.

OBJECTIVES

The primary goals of this project in 2007 were to:

1. Estimate the daily and seasonal passage of Chinook and fall chum salmon using fixed-location, split-beam and DIDSON, side looking hydroacoustic techniques.
2. Use 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 estimate the age, sex and length (ASL) composition of the 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 estimate the age, sex and length (ASL) composition of the 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 hydrological measurements representative of the study area.
7. Determine if the split-beam sonar counts include significant numbers of non-salmon fish.

METHODS

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. 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 0.70 MHz (low frequency option) for the 20- to 40-m range and at 1.2 MHz (high frequency option) for the 0- to 20-m range, both 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 power system consisting of a four 85-W solar panel array, ten 6-V batteries, a charge controller, and an inverter. The solar power system was backed up with a portable 2000-W generator and a power converter/charger when sunlight was insufficient. Left bank hydroacoustic equipment and computers were powered with a portable 2000-W generator that ran continuously.

SONAR DEPLOYMENT AND OPERATION

Several 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. The sites chosen in 2005 were also used for deployment in 2006 and 2007. To ensure the original sites had remained acceptable for ensonification in 2007, a bottom profile was obtained after initial transducer placement. Data was collected from 5 transects which were 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*.

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 in water ranging from approximately 1.0 to 1.5 m in depth and was aimed perpendicular to the current along the 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. This process was repeated later in the season using a spherical plastic ball weighted with lead BB shot to verify target detection throughout the counting range. 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 system was calibrated in-situ using a 3.8-cm tungsten carbide sphere of nominal target strength -39.5 dB at 200 kHz. The sphere was attached to a pole with monofilament line and held in the acoustic beam to verify that the target was being detected by the split-beam system within acceptable limits. 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 weir 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 weir sections were built using 2-in (5.08 cm) diameter steel pipes connected with adjustable fittings to form tripods. Aluminum stringers, approximately 2.5 m long, were then attached horizontally to the upstream side of the tripods. The sections were then finished with vertical lengths of aluminum conduit 1.5 in (3.8 cm) apart. Weir sections were placed side by side in the water from shore to an initial distance of 7 m beyond the transducer. The ease of transport of this style of weir 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 weir require frequent relocation to shallower or deeper water.

The DIDSON unit was deployed July 5, on the right bank. The unit was mounted on an aluminum frame and was 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 (0–40 m).

A fish lead was constructed with 2-m metal "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 river was ensonified to a range of 40 m from the transducer, with 2 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 ABUNDANCE ESTIMATION

Split-beam data was collected continuously by the data acquisition software in 60 minute increments each hour of the day 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 3). 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-minute samples each hour of the day. For the first 30 minutes 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 4). 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 minute sample was expanded for the full hour, and the estimated counts from zone 1 and zone 2 were summed for a total hour estimated count for that bank. The daily passage ŷ 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 periods when data collection was interrupted. Brief interruptions intermittently occurred when routine maintenance (i.e. silt removal) or relocation of a transducer was required. When 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 was divided by the number of minutes counted and then multiplied by the number of fish counted in that period. Passage was estimated as follows:

$$P = (h_s / h_c)x \tag{4}$$

Where h_s is the number of minutes in a complete sample, and h_c is the number of minutes in sample that where actually counted. x is the number of fish counted.

If data from one or more complete samples was missing, counts were interpolated by averaging counts from samples before and after the missing sample(s) as follows:

$$P = \left(1/n\sum_{i=1}^{n} x_i\right)\begin{Bmatrix} s = 1, n = 4 \\ s = 2, n = 6 \\ s = 3, n = 8 \\ s \geq 4, n = 10 \end{Bmatrix} \tag{5}$$

Where n is the number of samples used for interpolation (half before and half after missing sample(s)), x_i is the count for each sample i, and s is the number of missed samples.

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. The estimates produced during the field season were further scrutinized post season, and adjusted as necessary. High chum salmon counts at the end of the season, and late run timing elsewhere in the Yukon drainage, prompted an expansion of the sonar estimate to include chum salmon that may have passed after operations ceased (JTC 2008). The expansion used run timing information from the DFO mark–recapture project near the border, and area under the curve calculations. Post season, the Chinook and chum salmon subsistence harvest from the Eagle area 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 the *R* statistical software package (R Development Core Team 2007) 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, test fishery catches, local subsistence harvest, and Canadian mark–recapture fish wheels.

TEST FISHING AND SAMPLING

To monitor species composition and collect age, sex, length, and genetic samples, gillnets of mesh sizes 7.5 in (191 mm) and 5.25 in (133 mm) were drifted through 3 zones; left bank inshore (LBI), left bank nearshore (LBN) and left bank offshore (LBO). Nets were 25 fathoms (45.7 m) long, approximately 25 ft (7.6 m) 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. Midway through the season 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 (2.4 m) deep with mesh sizes 7.5 in and 5.75 in (146 mm) (5.25-in net of shorter depth was unavailable), were used for the inshore drifts only, with all other specifications remaining the same as the original nets.

Test fishing for species composition was conducted once daily between 0800 and 1200 hours (Period 1) on the left bank. During the sampling period, both the 5.25 in (5.75 in for the inshore) and the 7.5-in nets were drifted twice within each of 3 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, 3) LBO, with a minimum of 20 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.

An additional fishing period was conducted once daily between July 9 and August 15 after the normal test fishing period, from approximately 1300 to 1700 hours (Period 2). Chinook salmon genetic and ASL samples were collected to estimate specific Canadian stock proportions and ASL composition of Chinook entering Canada. Three different mesh sizes (6.5 in, 7.5 in and 8.5 in) were fished daily over the course of the Chinook salmon run to effectively capture all size classes present (Table 2). Nets were 25 fathoms (45.7 m) long, approximately 25 ft (7.6 m) deep and hung "even" at a 2:1 ratio of web to corkline. Each net was drifted for approximately of 6 minutes twice daily within the left bank nearshore and offshore zones and once on the right bank (RB) approximately 2 km downriver from the sonar site where river conditions were suitable for drift gillnetting on that bank, for a total of 9 drifts.

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:

$$t = SI - FO + \frac{FO - SO}{2} + \frac{FI - SI}{2} \tag{6}$$

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

$$e_{dzfmj} = \frac{25\, t_{dzfmj}}{60} \tag{7}$$

Captured salmon were sampled in the following ways:

For standard ASL samples, length (METF to nearest 5 mm), and sex (determined by inspection of external characteristics) were recorded. Three scales from Chinook salmon and one scale from chum salmon were removed from the preferred area on the left side of the fish, 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 the ADF&G ASL lab in Anchorage, Alaska. These scale data are 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, stored in vials of ethanol, and sent to Fisheries and Oceans Canada genetics laboratory in Nanaimo, BC. 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 water and any 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. Test 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 HYDROLOGICAL SAMPLING

Climate and hydrologic data were collected daily at approximately 1800 hours at the sonar site. Air temperatures were measured, while subjective notes on wind speed and direction, cloud cover and precipitation were also recorded. Water temperatures were recorded every 4 hours with a HOBO U22 water temperature data logger suspended approximately 30 cm below the surface from a float tied to the water level gauge about 10 m from the left bank shore. Data was transferred to a computer postseason to produce an average daily water temperature. Although reported stream levels are taken from the U.S. Geological Survey's gauging station at Eagle, a water level gauge at the sonar site was used to track relative daily water level changes. Water levels were carefully monitored, because changes usually necessitated moving the transducer(s) and fish lead(s) to deeper or shallower water, particularly on the left bank.

NON-SALMON STUDY

From September 8 to October 4, 2006 and July 31 to August 9, 2007, a DIDSON long-range unit was operated side-by-side with the split-beam sonar on the left bank. The purpose was to collect data to examine whether small, non-salmon species were misclassified as salmon on the split-beam echogram. The DIDSON was deployed using the same type of pod as the split-beam sonar. The transducer was attached to a manual crank-style rotator to facilitate aiming. The electronic equipment was housed in a self-supporting tent and powered with the same 2000-W generator as the split-beam system. The DIDSON was operated as time allowed, and data was collected at different times of day during periods of high and low fish passage.

In 2006, DIDSON data was collected in two 30-minute range samples per hour. For the first 30 minutes of every hour, the DIDSON sampled the ensonified range from 1 to 20 m and the second half of each hour sampled from 20 to 40 m. For comparison, the 1-hour split-beam files were divided into corresponding half-hour files of corresponding range. In 2007, the DIDSON collected 1-hour data files and was set to ensonify from 1 to 20 m. The system operator manually counted fish using DIDSON editing software and a split-beam viewer program. Non-salmon fish were detected primarily by small size and shape of trace on the DIDSON echogram and swimming motion on the DIDSON video. They often produce a faint, lingering trace (Figure 4) and do not resemble the dense, bright trace of migrating salmon moving upstream at a deliberate, relatively rapid pace. If non-salmon fish were seen on the echogram or video, their range, direction of travel and time of passage was noted. Targets were then measured with the measuring tool on the DIDSON program to verify length. Non-salmon targets found in the DIDSON files were then located at the same time and range on the split-beam files to determine if the split-beam system was detecting the smaller fish, how the traces appeared on the split-beam echograms, and how the traces compared to that of a salmon.

RESULTS

SONAR DEPLOYMENT

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. On July 7, 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 camp (Figure 2). Figure 5 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 2.2° slope. The right bank profile is less linear, shorter and steeper, extending 100 m to the thalweg at a 5.8° slope.

CHINOOK AND CHUM SALMON ABUNDANCE ESTIMATION

In season, August 18 was tentatively deemed the last day of the Chinook salmon run based on relatively low sonar counts, gillnet catches, harvest information gathered from local subsistence fishers, and Canadian mark–recapture fish wheel data. Fish range distribution from the sonar also was an indication that the salmon run was changing from Chinook to chum salmon. The inseason species changeover date was adjusted postseason after thorough examination of test fishery information. Analysis of reverse-cumulative Chinook catches and cumulative chum catches showed that August 22/23 was the specific date when the overall Chinook catch was less 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 2 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 41,697 for the dates July 7 through August 22, 2007 (Table 3). Peak daily passage estimate of 2,776 Chinook salmon occurred on July 18 and 140 fish passed on August 22, the last day of estimating Chinook salmon passage. Postseason, the subsistence harvest from the Eagle area was subtracted from the sonar estimate to produce a border passage estimate of 39,725 (Table 4). The preliminary subsistence harvest from the Eagle area was 1,972 (William Busher, Fisheries Biologist, ADF&G, Fairbanks, Alaska; personal communication).

The total fall chum salmon passage estimate was 235,871 for the dates August 23 through October 6, 2007 (Table 5). Fall chum salmon passage peaked on September 18 with a daily estimate of 13,519 fish. Although chum salmon passage was decreasing, 8,292 fish passed on October 6, the last day of operation. Because of the high passage when the project was terminated, and late run timing at other projects in the Yukon drainage, the sonar estimate was subsequently adjusted to 282,670 chum salmon. The expansion was calculated using historic run timing data from the DFO mark–recapture project near the Canadian border, and area under the curve calculations (Bonnie Borba, Fisheries Biologist, ADF&G, Fairbanks, Alaska; personal communication). Post season, the subsistence harvest from the Eagle area was subtracted from the sonar estimate to produce a border passage estimate of 263,997 (Table 4). The preliminary subsistence harvest from the Eagle area was 18,673 (William Busher, Fisheries Biologist, ADF&G, Fairbanks, Alaska; personal communication).

SPATIAL AND TEMPORAL DISTRIBUTION

Fish were shore oriented on both banks (Figures 7 and 8). On the left bank during the Chinook salmon run, 89% of the fish were detected within 75 m of the transducer, and 98% within 120 m. On the right bank, 83% of the fish were detected within 26 m of the transducer and 98% within 36 m. During the fall chum salmon run on the left bank, 86% of the fish were detected within 15 m of the transducer, and 97% within 25 m. On the right bank, 88% of the fish were detected within 6 m of the transducer and 96% within 8 m. The percentage of fish passage estimated by bank for the Chinook salmon season was 72% on the left bank and 28% on the right bank. During the fall chum salmon run, 51% migrated on the left bank and 49% on the right bank. Overall, there does not appear to be any discernable diel fluctuation at the project site during the Chinook salmon run (Figure 9). During the fall chum salmon run more fish passed the sonar site in the late afternoon and early evening as compared to after midnight, especially on the right bank (Figure 10).

TEST FISHING AND SAMPLING

A total of 424 Chinook and 748 chum salmon were captured in test fish drift gillnets during the period July 9–October 4 (Table 6). Period 1 fishing occurred from July 18 through October 4, and Period 2 fishing occurred from July 9 through August 15. Test drifts during Period 1 caught 123 Chinook and 748 chum salmon, while an additional 301 Chinook were caught during Period 2. Additionally, 1 coho salmon *O. kisutch,* 1 longnose sucker *Catostomus catostomus*, 1 Arctic grayling *Thymallus arcticus*, 4 sheefish *Stenodus leucichthys*, and 1 whitefish *Coregoninae* (not keyed to species), 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 7 and 8.

Chinook salmon samples collected from driftnets were composed of 235 (55.4%) males and 189 (44.6%) females. Chum salmon samples from driftnets were composed of 508 (67.9%) males and 240 (32.1%) females. Readable scale samples from 389 Chinook and 644 chum salmon collected in the drift nets were used to determine age compositions (Horne-Brine et al. 2009). From these samples it was determined that Chinook salmon age-1.4 fish predominated (53.5%) followed by age-1.3 (40.1%), age-1.2, age-1.5, and age 2.3 were 5.7%, 0.5% and 0.3% respectively. No other age class of Chinook was sampled. From the chum salmon samples, it was determined that age-0.3 fish predominated (76.2%) followed by age-0.4 (20.5%), age-0.2 and age-0.5 were 1.9% and 1.4% respectively. No age-0.6 chum salmon were present in the catch. Genetic samples from 423 Chinook salmon and 300 chum salmon were collected and sent to the sent to Fisheries and Oceans Canada genetics laboratory in Nanaimo, BC.

The smallest salmon (Chinook) caught in all gear was 440 mm (METF). Of 366 fish caught in the LBO and LBN drift zones, one (0.3%) was species other than salmon (whitefish, not keyed to species). The beach walk (LBI) caught 746 fish, of which 6 (0.8%) were not salmon (4 sheefish, 1 Arctic grayling, 1 longnose sucker). The only species to show an overlap with the lengths of the Chinook or chum salmon (>440 mm) caught in these drifts was sheefish and the 1 coho salmon (Table 9). This is may be evidence that most of the fish we count with the sonar are likely salmon.

CLIMATE AND HYDROLOGICAL SAMPLING

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°C and a minimum of 2°C. The water level steadily decreased over the duration of the season, except for occasional temporary increases following substantial rain events. Overall, the water level decreased 158 cm from July 1 through October 10. Figure 11 shows USGS water levels measured at Eagle during the project as well as the average water levels for 1993 to 2006.

NON-SALMON STUDY

A total of 91 paired samples collected on the left bank in 2006 and 2007 were reviewed to determine if any small non-salmon fish were misclassified and counted as salmon on the split-beam counting echogram. Of 3,283 fish counted from 0–20 m with the split-beam sonar during 54 hours (75 files) of recorded data, 19 of the 97 non-salmon detected with the DIDSON, were misclassified and counted as salmon on the split-beam echogram (Table 10) – this represents a misclassification of 0.6% for 0 – 20 m. From 8 hrs (16 files) of DIDSON observations, no small non-salmon fish were observed from 20–40 m (Table 11).

DISCUSSION

Sonar Deployment and Operation

The split-beam and DIDSON systems performed well over the entire season with no major technical difficulties or failures. The DIDSON, with its wide beam angle (29°), was the ideal system 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 marking 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. The addition of background removal to the echogram viewing program used for counting fish from the split-beam data files was a new feature that made distinguishing fish tracks, particularly for chum passing near the transducer, much easier. Improvements in processing procedures are an ongoing endeavor.

Chinook and Chum Salmon Abundance 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 sonar estimate of 41,697 Chinook is almost double the preliminary Canadian mark–recapture border passage estimate of 22,120 (JTC 2008). When the 1,972 Chinook salmon harvested in the Eagle subsistence fishery in 2007 are removed from the sonar estimate, then the Canadian border passage estimate is 56% of the sonar border passage estimate. The Canadian border passage estimate was 51% of the sonar derived border passage estimate in 2005 and 53% of the sonar derived border passage estimate in 2006 (Table 4). The exact number of salmon harvested above and below the sonar location is not known. In the future, Eagle subsistence harvest numbers will be recorded as being above or below the sonar site, allowing us to get a better estimate of border passage.

The sonar estimate for fall chum salmon was 235,871, which is essentially the same as the preliminary Canadian mark–recapture border passage estimate of 235,956 (JTC 2008). Post season, the sonar estimate of chum salmon was expanded to 282,670 to account for chum salmon that may have passed after sonar operations ceased (Table 4) (Bonnie Borba, Fisheries Biologist, ADF&G, Fairbanks, Alaska; personal communication). The subsistence harvest from the Eagle area was 18,673 (William Busher, Fisheries Biologist, ADF&G, Fairbanks, Alaska; personal communication). When the Eagle area subsistence harvest was removed from the original sonar estimate (Canadian estimate was not expanded), the sonar estimated border passage was 8% lower than the Canadian border passage estimate. In 2006, the Canadian border passage estimate was less than 1% lower than the sonar border passage estimate. Operating both the DFO and ADF&G projects simultaneously for a few years will allow managers to examine the relationship between the 2 estimation methods, determine why the Chinook estimates for the 2 projects are so different, and whether the border passage goals should be revised.

Spatial and Temporal Distributions

Based on test 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. There does not appear to be much of a diel fluctuation at the project site during the Chinook or fall chum salmon runs.

TEST FISHING AND SPECIES DETERMINATION

Test fishing was conducted with drift gillnets to capture a representative sample of fish migrating past the sonar site. This method seemed to be a reliable way of determining the species changeover date. The overall test fish catch composition (Period 1 only) was 14% Chinook and 86% chum salmon. This compares with the total sonar passage estimate, which was composed of 15% Chinook and 85% chum salmon. The similarity between test fish catch and sonar estimate species compositions supports the assumption that test fishing with gillnets eliminated bias between species. 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).

The DFO border fish wheel project species changeover date occurred 8 days prior to the sonar changeover date (P. Milligan, Stock Assessment Biologist, Fisheries and Oceans Canada, Whitehorse, Yukon; personal communication). This discrepancy may be explained by the common belief that fish wheels are biased toward chum salmon because of the close proximity to shore, thus catching a disproportionately high number of chums to Chinook. We believe driftnetting different mesh sizes in multiple zones (ranges), as done at the sonar site, more accurately describes the relative abundance of each salmon species.

NON-SALMON STUDY

The wide beam angle of the DIDSON allows for detection of small fish at close range. With the DIDSON, it is possible to separate smaller non-salmon species from salmon by using video images and the sizing tool. As such, it is possible to exclude smaller non-salmon species when counting salmon passage with the DIDSON. This is not possible with the split-beam. However, the split-beam echogram viewing program is configured to minimize counting fish other than salmon. Most of the non-salmon observed on the DIDSON did not appear on the split-beam. Some of the non-salmon observed on the DIDSON are visible on the split-beam, but classified correctly because they do not appear as salmon. The purpose of this investigation was to determine if other species are being counted as salmon on the split-beam. Results show 3% of the small non-salmon fish detected by the DIDSON were also visible with the split-beam from 0 to 20 m. Approximately 0.6% of all fish counted with the split-beam from 0 to 20 m were misclassified and counted as salmon. Small non-salmon fish were not detected beyond 20 m, which compares with the very low catch of non-salmon at that range by drift gillnetting operations. Although there are some non-salmon species that can be the same size or larger than Chinook or chum salmon, these are an exception and considered insignificant based on past and current drift gillnetting in the area of the sonar. Data collected using the same method in 2005 also suggest that less than 4% of the split-beam sonar estimate is from non-salmon species (Carroll et al, 2007b). Considering that the split-beam system only operates on one side of the river, and that most of the non-salmon species are within the first 20 m, the actual percentage of non-salmon fish misclassified as salmon, is likely very small.

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TABLES AND FIGURES

Table 1.–Period 1 (0800–1200 hrs) test fishing schedule and drift gillnet mesh sizes (inches), 2007.

Zone	Day 1	Day 2
Left Bank	5.75	7.50
Inshore	7.50	5.75
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 (1300–1700 hrs) test fishing schedule and drift gillnet mesh sizes (inches), 2007.

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

Table 3.–Estimated daily and cumulative Chinook salmon passage by bank, Eagle Sonar, 2007.

	Daily			Cumulative			
Date	Left Bank	Right Bank	Total	Left Bank	Right Bank	Total	% of Total Passage
7/07	2	32	34	2	32	34	0.00
7/08	9	48	57	11	80	91	0.00
7/09	34	75	109	45	155	200	0.00
7/10	48	128	176	93	283	376	0.01
7/11	117	218	335	210	501	711	0.02
7/12	280	302	582	490	803	1,293	0.03
7/13	530	422	952	1,020	1,225	2,245	0.05
7/14	886	501	1,387	1,906	1,726	3,632	0.09
7/15	1,197	752	1,949	3,103	2,478	5,581	0.13
7/16	1,392	1,000	2,392	4,495	3,478	7,973	0.19
7/17	1,837	915	2,752	6,332	4,393	10,725	0.26 [a]
7/18	1,768	1,008	2,776	8,100	5,401	13,501	0.32
7/19	2,006	562	2,568	10,106	5,963	16,069	0.39
7/20	1,640	564	2,204	11,746	6,527	18,273	0.44
7/21	1,327	375	1,702	13,073	6,902	19,975	0.48
7/22	1,186	540	1,726	14,259	7,442	21,701	0.52 [b]
7/23	900	578	1,478	15,159	8,020	23,179	0.56
7/24	818	387	1,205	15,977	8,407	24,384	0.58
7/25	748	310	1,058	16,725	8,717	25,442	0.61
7/26	853	234	1,087	17,578	8,951	26,529	0.64
7/27	734	200	934	18,312	9,151	27,463	0.66
7/28	927	276	1,203	19,239	9,427	28,666	0.69
7/29	1,159	258	1,417	20,398	9,685	30,083	0.72
7/30	1,015	236	1,251	21,413	9,921	31,334	0.75
7/31	1,102	194	1,296	22,515	10,115	32,630	0.78
8/01	904	194	1,098	23,419	10,309	33,728	0.81
8/02	746	206	952	24,165	10,515	34,680	0.83
8/03	783	200	983	24,948	10,715	35,663	0.86
8/04	645	235	880	25,593	10,950	36,543	0.88
8/05	572	226	798	26,165	11,176	37,341	0.90
8/06	410	130	540	26,575	11,306	37,881	0.91
8/07	373	117	490	26,948	11,423	38,371	0.92
8/08	379	72	451	27,327	11,495	38,822	0.93
8/09	310	80	390	27,637	11,575	39,212	0.94
8/10	213	38	251	27,850	11,613	39,463	0.95
8/11	224	40	264	28,074	11,653	39,727	0.95
8/12	245	42	287	28,319	11,695	40,014	0.96
8/13	200	20	220	28,519	11,715	40,234	0.96
8/14	194	16	210	28,713	11,731	40,444	0.97
8/15	123	16	139	28,836	11,747	40,583	0.97
8/16	208	29	237	29,044	11,776	40,820	0.98
8/17	187	20	207	29,231	11,796	41,027	0.98
8/18	138	20	158	29,369	11,816	41,185	0.99
8/19	88	12	100	29,457	11,828	41,285	0.99
8/20	106	15	121	29,563	11,843	41,406	0.99
8/21	139	12	151	29,702	11,855	41,557	1.00
8/22	124	16	140	29,826	11,871	41,697	1.00
Total	29,826	11,871	41,697	29,826	11,871	41,697	
SE[c]		143			143	143	

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

[b] Bold box identifies median day of passage.

[c] No sampling error is associated with left bank since data were collected 24 hrs per day over the sampling range.

Table 4.–Eagle sonar estimate, Eagle area subsistence harvest, and U.S. and Canadian border passage estimates, 2005–2007.

	Sonar Estimate		Eagle Area Subsistence Harvest		U.S. Sonar Mainstem Border Passage Estimate		Canadian Mainstem Border Passage Estimate [a]	
Date	Chinook	chum	Chinook	chum	Chinook	chum	Chinook	chum
2005	81,528	NA	2,387	NA	79,141	NA	42,245	451,477
2006 [b]	73,691	236,386	2,283	17,760	71,408	218,626	36,748	217,810
2007 [b]	41,697	282,670 [c]	1,972	18,673	39,725	263,997	22,120	235,956

Note: Estimates for subsistence caught salmon from the Eagle area include a small but unknown number caught downriver of the sonar site. Starting in 2008 the number of salmon caught between the sonar site and the border will be documented on subsistence permits.

[a] Canadian estimate from JTC 2008.

[b] Subsistence estimates are preliminary.

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

Table 5.–Estimated daily and cumulative chum salmon passage by bank, Eagle Sonar, 2007.

	Daily			Cumulative			
Date	Left Bank	Right Bank	Total	Left Bank	Right Bank	Total	% of Total Passage
8/23	104	6	110	104	6	110	0.00
8/24	117	21	138	221	27	248	0.00
8/25	110	20	130	331	47	378	0.00
8/26	128	14	142	459	61	520	0.00
8/27	112	14	126	571	75	646	0.00
8/28	132	22	154	703	97	800	0.00
8/29	118	6	124	821	103	924	0.00
8/30	132	16	148	953	119	1,072	0.00
8/31	150	13	163	1,103	132	1,235	0.01
9/01	176	18	194	1,279	150	1,429	0.01
9/02	182	22	204	1,461	172	1,633	0.01
9/03	182	16	198	1,643	188	1,831	0.01
9/04	223	8	231	1,866	196	2,062	0.01
9/05	187	18	205	2,053	214	2,267	0.01
9/06	141	38	179	2,194	252	2,446	0.01
9/07	255	46	301	2,449	298	2,747	0.01
9/08	722	112	834	3,171	410	3,581	0.02
9/09	1,446	272	1,718	4,617	682	5,299	0.02
9/10	1,949	670	2,619	6,566	1,352	7,918	0.03
9/11	3,290	740	4,030	9,856	2,092	11,948	0.05
9/12	4,940	780	5,720	14,796	2,872	17,668	0.07
9/13	6,582	774	7,356	21,378	3,646	25,024	0.11
9/14	6,237	282	6,519	27,615	3,928	31,543	0.13
9/15	6,926	290	7,216	34,541	4,218	38,759	0.16
9/16	7,953	633	8,586	42,494	4,851	47,345	0.20
9/17	9,677	566	10,243	52,171	5,417	57,588	0.24
9/18	12,939	580	13,519	65,110	5,997	71,107	0.30 [a]
9/19	11,510	560	12,070	76,620	6,557	83,177	0.35
9/20	9,334	786	10,120	85,954	7,343	93,297	0.40
9/21	8,771	1,484	10,255	94,725	8,827	103,552	0.44
9/22	6,930	3,322	10,252	101,655	12,149	113,804	0.48
9/23	5,970	3,230	9,200	107,625	15,379	123,004	0.52 [b]
9/24	4,904	2,880	7,784	112,529	18,259	130,788	0.55
9/25	3,935	3,657	7,592	116,464	21,916	138,380	0.59
9/26	3,377	3,932	7,309	119,841	25,848	145,689	0.62
9/27	3,607	3,988	7,595	123,448	29,836	153,284	0.65
9/28	3,981	4,336	8,317	127,429	34,172	161,601	0.69
9/29	3,528	4,778	8,306	130,957	38,950	169,907	0.72
9/30	4,084	5,656	9,740	135,041	44,606	179,647	0.76
10/01	4,198	5,444	9,642	139,239	50,050	189,289	0.80
10/02	4,115	5,872	9,987	143,354	55,922	199,276	0.84
10/03	4,280	5,894	10,174	147,634	61,816	209,450	0.89
10/04	4,918	4,352	9,270	152,552	66,168	218,720	0.93
10/05	4,545	4,314	8,859	157,097	70,482	227,579	0.96
10/06	3,764	4,528	8,292	160,861	75,010	235,871	1.00
Total	160,861	75,010	235,871	160,861	75,010	235,871	
SE[c]		590			590	590	

[a] Boxed area identifies 2nd and 3rd quartile of run.
[b] Bold box identifies median day of passage.
[c] No sampling error is associated with left bank since data was collected 24 hrs per day over the sampling range.

Table 6.–Fish caught with gillnets at the Eagle sonar project site, 2007.

Species	Period 1	Period 2	Total
Chinook	123	301	424
chum	748	0	748
sheefish	4	0	4
coho	1	0	1
Arctic grayling	1	0	1
longnose sucker	1	0	1
whitefish	1	0	1
Total	879	301	1180

Table 7.–Period 1, effort, salmon catch, and percentage of Chinook and chum catch, by zone and mesh size, Eagle sonar project site, 2007.

Zone	Mesh Size (inches)	Effort (fathom hours)	Catch (Period 1) Chinook	Catch (Period 1) Chum	% of Chinook Catch	% of Chum Catch
LBI	5.25	225.98	12	4	9.8	0.5
	5.75	170.85	0	536	0.0	71.7
	7.50	399.04	6	181	4.9	24.2
Total		795.87	18	721	14.6	96.4
LBN	5.25	426.66	33	18	26.8	2.4
	7.50	421.73	48	4	39.0	0.5
Total		848.39	81	22	65.9	2.9
LBO	5.25	427.19	9	5	7.3	0.7
	7.50	425.53	15	0	12.2	0.0
Total		852.72	24	5	19.5	0.7
Grand Total		2496.98	123	748	100	100

Table 8.–Period 2, effort, salmon catch, and percentage of Chinook and chum catch, by zone and mesh size, Eagle sonar project site, 2007.

	Mesh Size	Effort	Catch (Period 2)			
Zone	(inches)	(fathom hours)	Chinook	Chum	% of Chinook Catch	% of Chum Catch
RB	6.50	75.76	26	0	8.6	0.0
	7.50	74.22	27	0	9.0	0.0
	8.50	73.20	15	0	5.0	0.0
Total		223.18	68	0	22.6	0.0
LBN	6.50	203.91	80	0	26.6	0.0
	7.50	199.58	59	0	19.6	0.0
	8.50	193.22	45	0	15.0	0.0
Total		596.71	184	0	61.1	0.0
LBO	6.50	178.04	18	0	6.0	0.0
	7.50	180.51	23	0	7.6	0.0
	8.50	174.43	8	0	2.7	0.0
Total		532.97	49	0	16.3	0.0
Grand Total		1352.85	301	0	100	0.0

Table 9.–Lengths of fish caught by zone and fishing method, Eagle sonar project site, 2007.

	Driftnet (LBN, LBO, RB)				Beachwalk (LBI)			
		Length (mm)				Length (mm)		
Species	Catch	Minimum	Maximum	Mean	Catch	Minimum	Maximum	Mean
Chinook	406	440	1055	788	18	450	900	699
chum	27	515	690	594	721	510	705	594
sheefish	0				4	630	675	653
coho	0				1	595	595	595
grayling	0				1	250	250	250
sucker	0				1	295	295	295
whitefish	1	375	375	375	0			

Table 10.–Results from 0–20 m side-by-side evaluation, left bank Eagle sonar, 2006 and 2007.

	DIDSON		Split-Beam	
File	Non-salmon observed [a]	Total Fish observed [b]	Non-salmon misidentified [c]	Total fish counted [d]
9/8/06 19:00	4	122	0	81
9/8/06 22:00	0	104	0	103
9/10/06 5:00	1	95	0	93
9/10/06 11:00	2	69	0	63
9/11/06 2:00	1	74	0	66
9/11/06 20:00	2	102	2	104
9/12/06 13:00	7	90	0	72
9/12/06 18:00	1	71	1	55
9/13/06 7:00	12	51	3	61
9/13/06 8:00	10	79	2	78
9/13/06 10:00	1	78	0	77
9/13/06 14:00	2	73	0	65
9/15/06 17:00	4	113	0	99
9/15/06 19:30	6	99	2	94
9/16/06 12:00	0	98	0	105
9/16/06 18:00	2	123	1	122
9/16/06 23:30	1	150	0	148
9/17/06 14:00	1	126	1	136
9/17/06 19:30	1	79	1	82
9/18/06 3:00	1	129	1	129
9/18/06 23:00	0	205	0	204
9/19/06 6:00	1	161	0	129
9/19/06 20:00	0	87	0	69
9/20/06 8:00	2	79	1	65
9/20/06 23:00	0	148	0	144
9/21/06 9:00	0	86	0	76
9/21/06 11:00	2	62	1	56
9/24/06 17:00	2	101	0	64
9/24/06 21:00	1	80	1	66
9/25/06 18:00	1	47	0	37
9/26/06 8:00	2	42	0	49
9/26/06 11:00	2	57	0	54
9/28/06 17:00	2	58	0	53
9/29/06 15:00	2	31	0	36
9/30/06 3:00	0	30	0	35
9/30/06 10:00	4	25	0	20
10/2/06 19:00	0	19	0	19
10/2/06 21:00	0	50	0	48
10/3/06 1:00	0	16	0	20
10/3/06 18:00	2	25	0	25
10/4/06 0:00	0	34	0	32
10/4/06 9:00	3	20	2	24
8/1/07 13:00	0	2	0	0
8/1/07 15:00	2	4	0	0

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Table 10.–Page 2 of 2.

	DIDSON		Split-Beam	
File	Non-salmon observed [a]	Total Fish observed [b]	Non-salmon misidentified [c]	Total fish counted [d]
8/1/07 23:00	0	14	0	1
8/2/07 7:00	0	11	0	4
8/2/07 9:00	0	0	0	0
8/2/07 14:00	1	2	0	0
8/2/07 17:00	1	0	0	2
8/3/07 4:00	0	13	0	13
8/3/07 6:00	0	6	0	8
8/4/07 16:00	1	5	0	3
8/4/07 19:00	0	6	0	4
8/4/07 20:00	1	9	0	7
8/4/07 22:00	0	5	0	8
8/5/07 0:00	0	14	0	11
8/5/07 6:00	0	5	0	6
8/5/07 11:00	1	4	0	2
8/5/07 20:00	0	9	0	7
8/6/07 3:00	0	4	0	2
8/6/07 12:00	0	5	0	4
8/6/07 19:00	0	1	0	0
8/6/07 22:00	1	9	0	6
8/7/07 1:00	0	14	0	7
8/7/07 4:00	0	3	0	2
8/7/07 10:00	0	1	0	0
8/7/07 20:00	1	3	0	2
8/8/07 6:00	2	6	0	5
8/8/07 9:00	0	3	0	1
8/8/07 11:00	1	2	0	0
8/8/07 23:00	0	3	0	3
8/9/07 2:00	0	3	0	1
8/9/07 4:00	0	5	0	6
8/9/07 5:00	0	7	0	6
8/9/07 8:00	0	2	0	4
75 files (54hrs)	97	3,568	19	3,283

[a] Fish trace observed on DIDSON file as a non-salmon species determined by smaller size and swimming behavior.

[b] Total number of fish observed on DIDSON file, including salmon and non-salmon.

[c] Fish determined to be non-salmon on DIDSON file, which were misidentified as salmon on split-beam file.

[d] Total fish counted on split-beam file that were originally assumed to be salmon, including non-salmon that were misidentified.

Table 11.–Results from 20–40 m side-by-side evaluation, left bank Eagle sonar, 2006.

	DIDSON		Split-Beam	
File	Non-salmon observed[a]	Total fish observed[b]	Non-salmon misidentified[c]	Total fish counted[d]
9/8/06 23:30	0	9	0	6
9/10/06 10:30	0	2	0	2
9/11/06 12:30	0	1	0	1
9/12/06 4:30	0	1	0	0
9/13/06 2:30	0	0	0	0
9/18/06 14:30	0	0	0	0
9/19/06 14:30	0	0	0	0
9/20/06 16:30	0	0	0	0
9/24/06 12:30	0	0	0	0
9/25/06 23:30	0	3	0	2
9/28/06 13:30	0	1	0	0
9/29/06 4:30	0	4	0	4
9/30/06 6:30	0	2	0	2
10/2/06 11:30	0	0	0	0
10/3/06 14:30	0	0	0	0
10/4/06 5:30	0	0	0	0
16 files (8 hrs)	0	23	0	17

[a] Fish trace observed on DIDSON file as a non-salmon species determined by smaller size and swimming behavior.

[b] Total number of fish observed on DIDSON file, including salmon and non-salmon.

[c] Fish determined to be non-salmon on DIDSON file, which were misidentified as salmon on split-beam file.

[d] Total fish counted on split-beam file that were originally assumed to be salmon, including non-salmon that were misidentified.

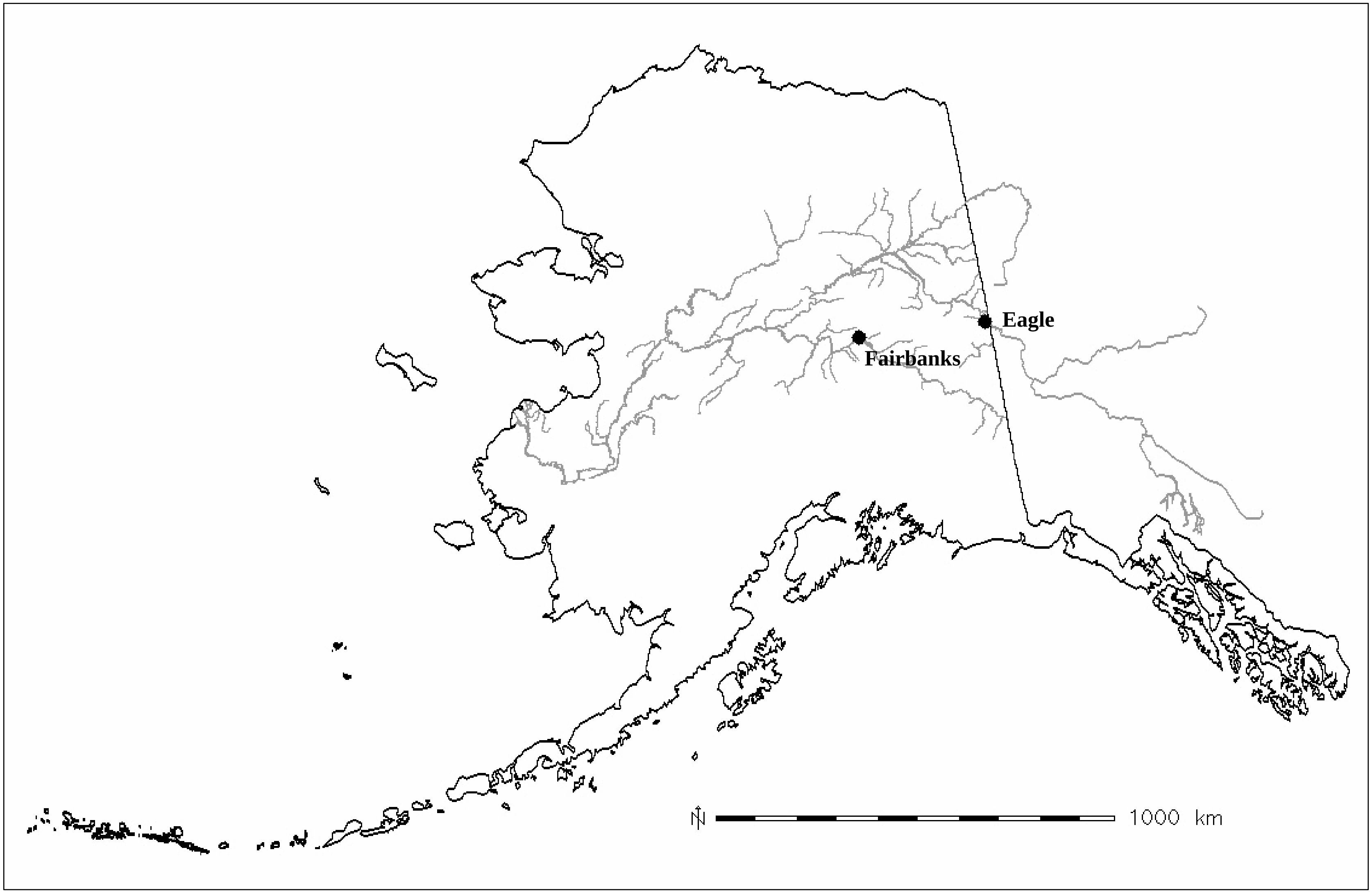


Figure 1.–Yukon River drainage.

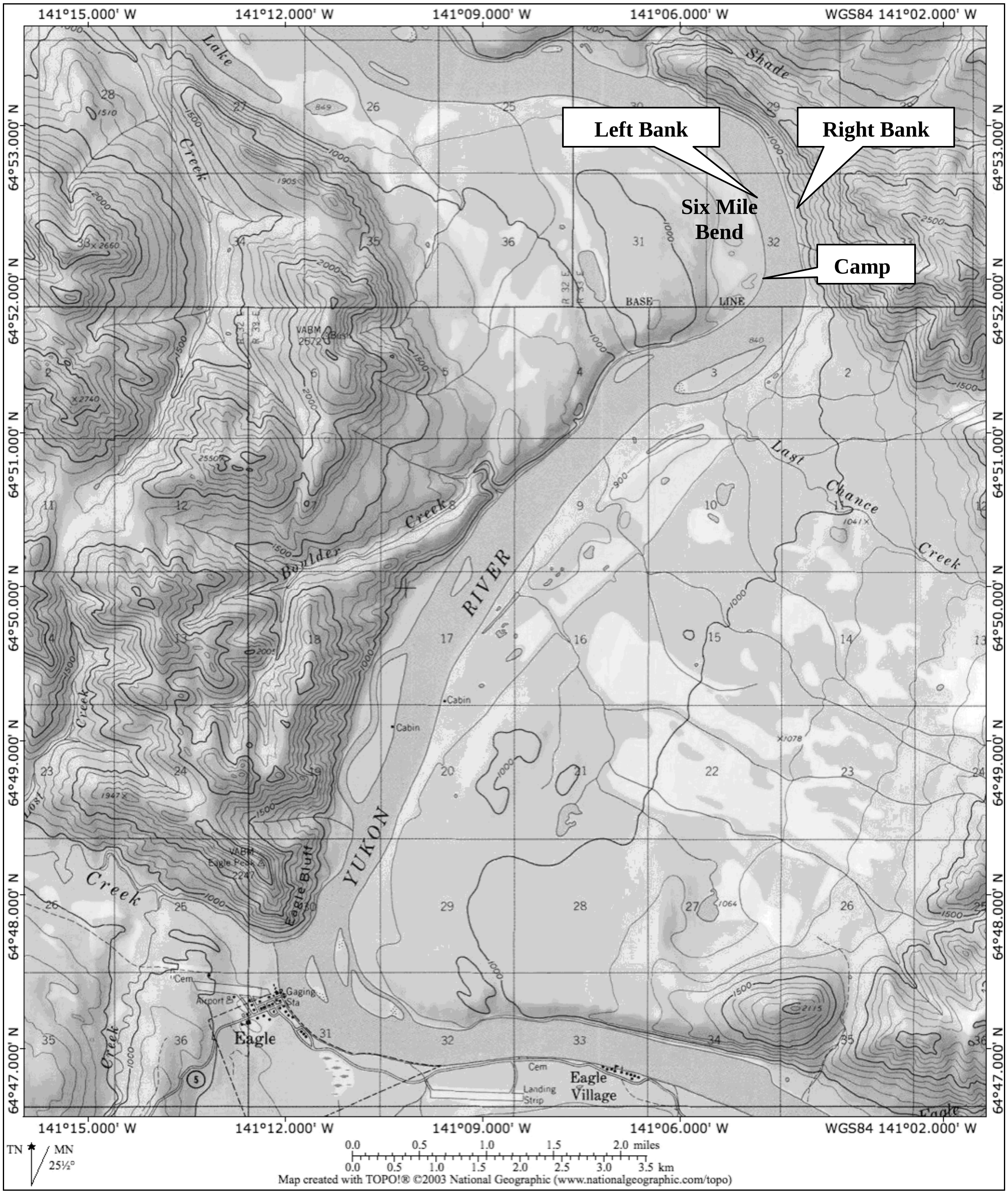


Figure 2.–Eagle sonar project site at Six Mile Bend.

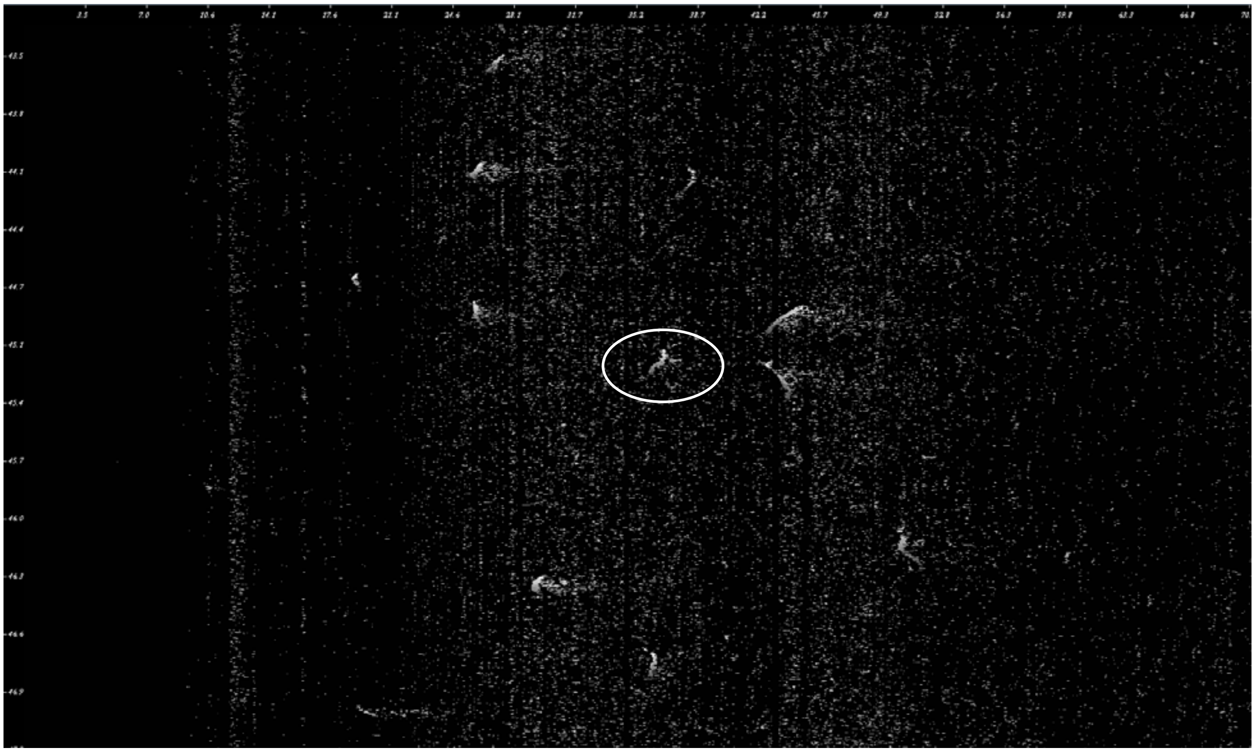


Figure 3.–Screenshot of echogram used to count fish from split-beam sonar data files. Ellipse encompasses typical upstream migrating salmon.

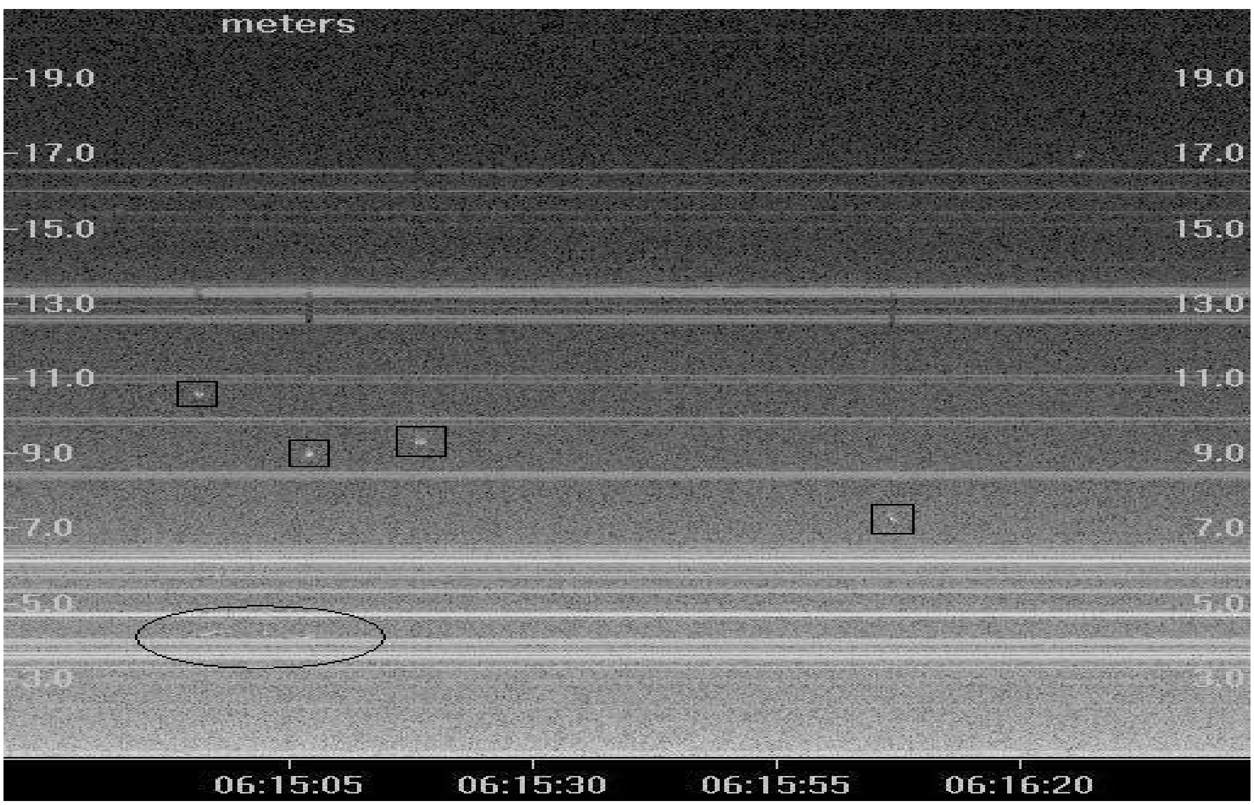


Figure 4.–Screenshot of echogram used to count fish from DIDSON data files. Rectangles encompass typical migrating salmon traces and ellipse encompasses small, slow non-salmon.

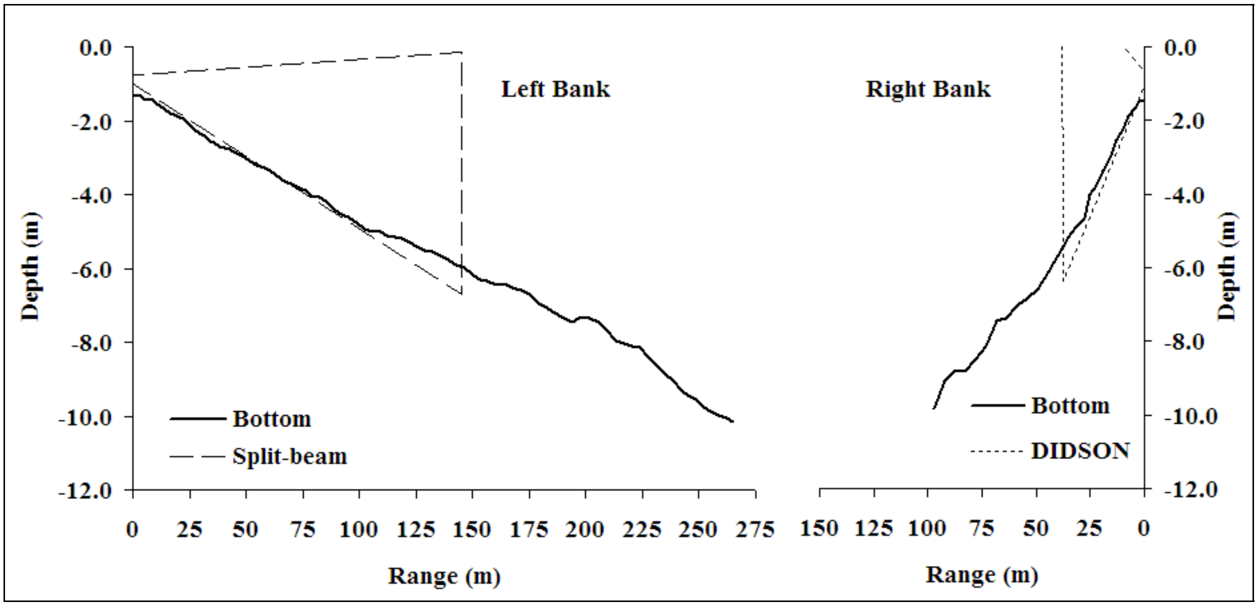


Figure 5.–Depth profile (downstream view), and ensonified zones of Yukon River at Eagle sonar project site, 2007 (parallel bars represent missing data).

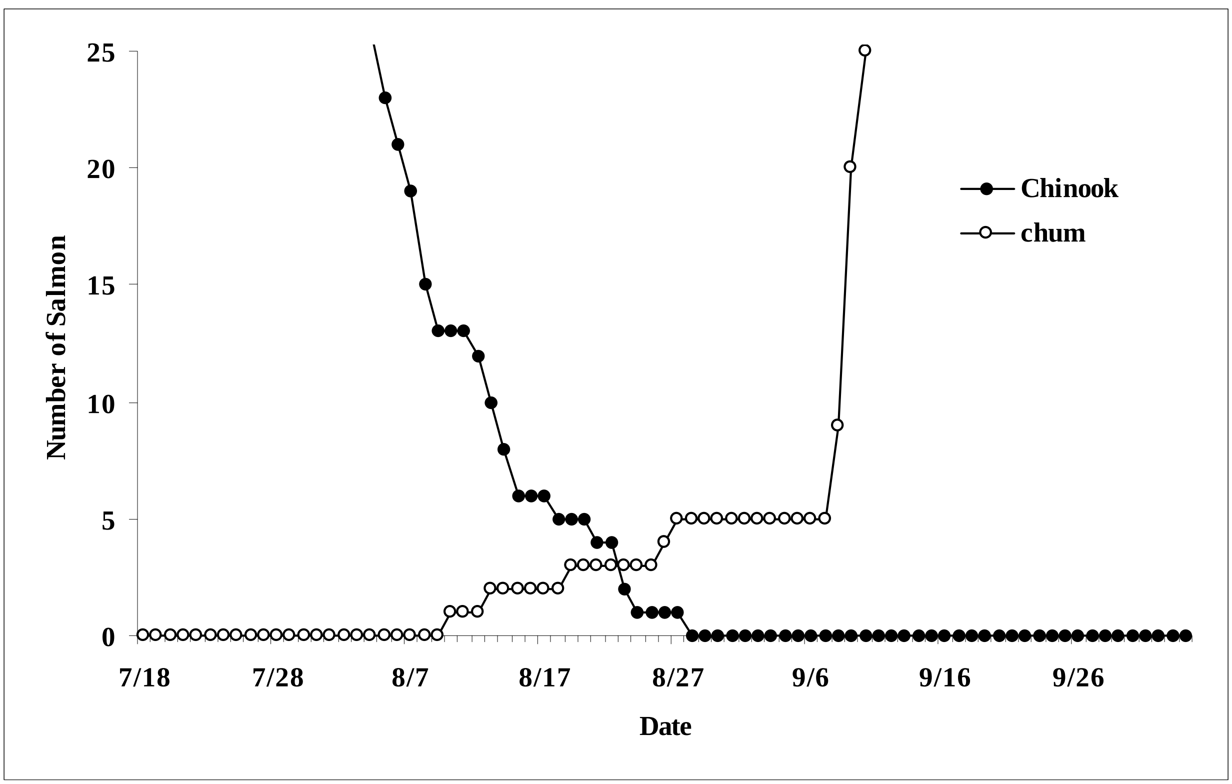


Figure 6.–Species changeover date determined from reverse cumulative Chinook and cumulative chum salmon catches at the Eagle sonar project site, 2007.

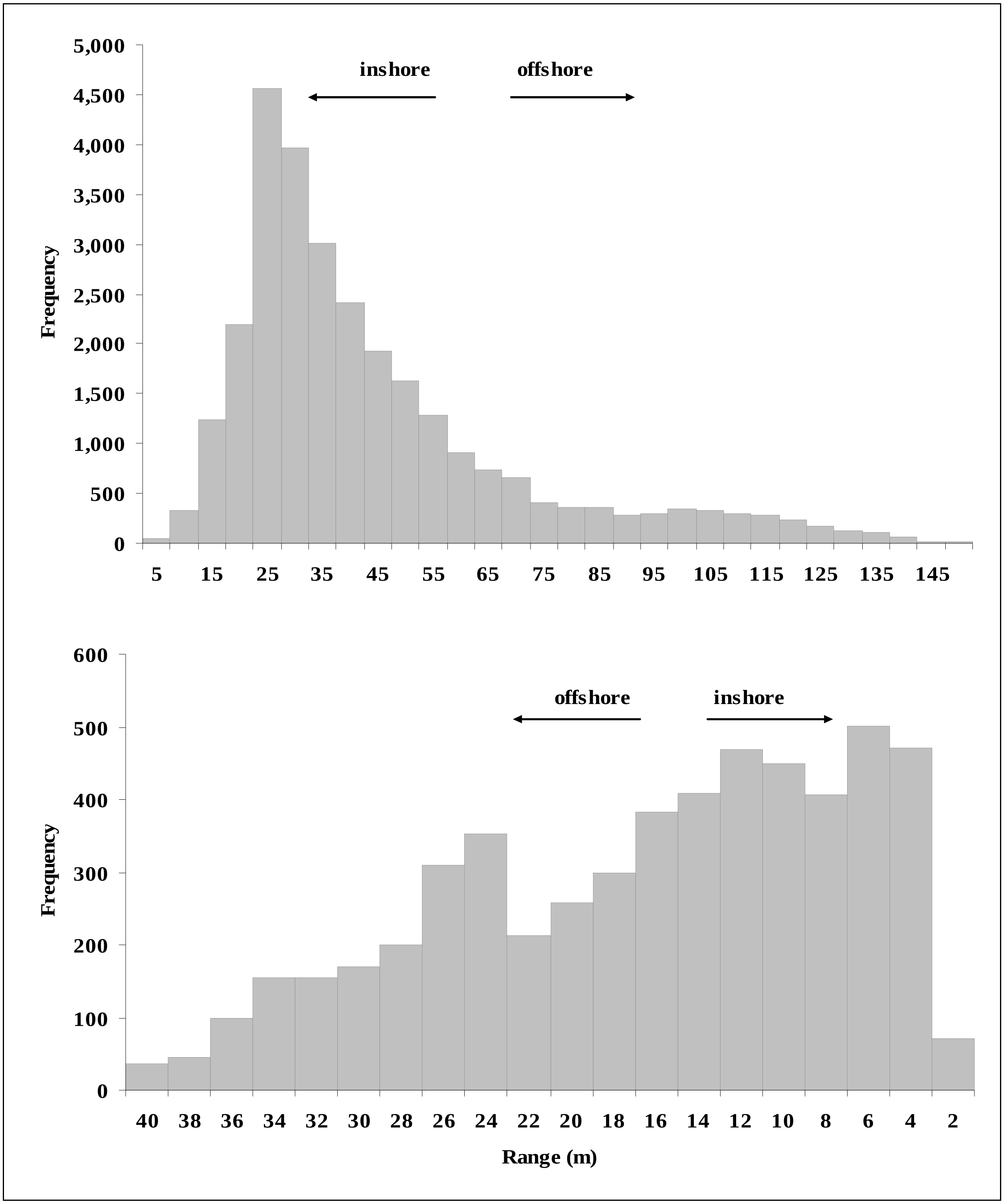


Figure 7.–Left bank (top) and right bank (bottom) horizontal distribution of upstream Chinook salmon passage in the Yukon River at Eagle sonar project site, July 7 through August 22, 2007.

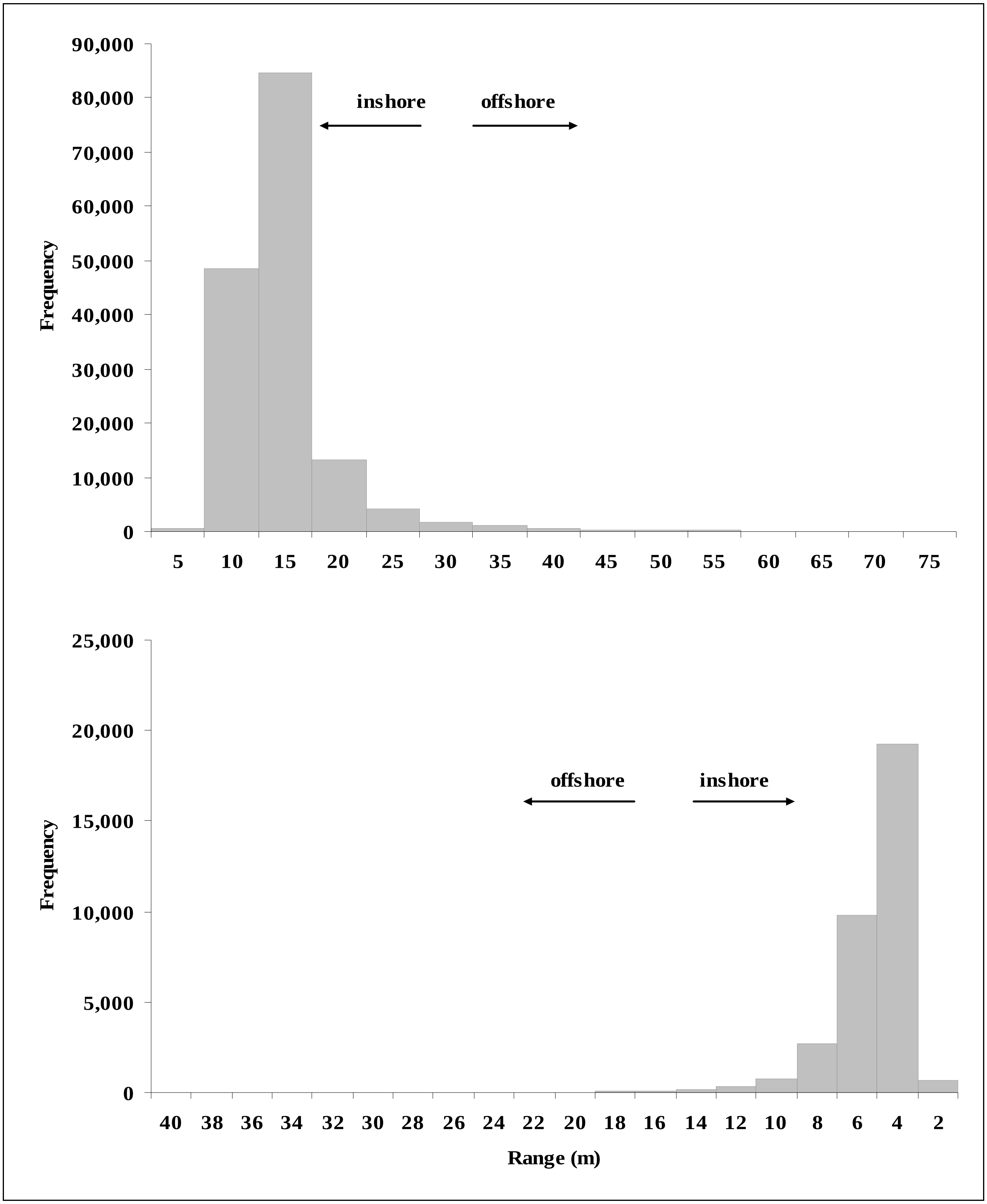


Figure 8.–Left bank (top) and right bank (bottom) horizontal distribution of upstream chum salmon passage in the Yukon River at Eagle sonar project site, August 23 through October 6, 2007.

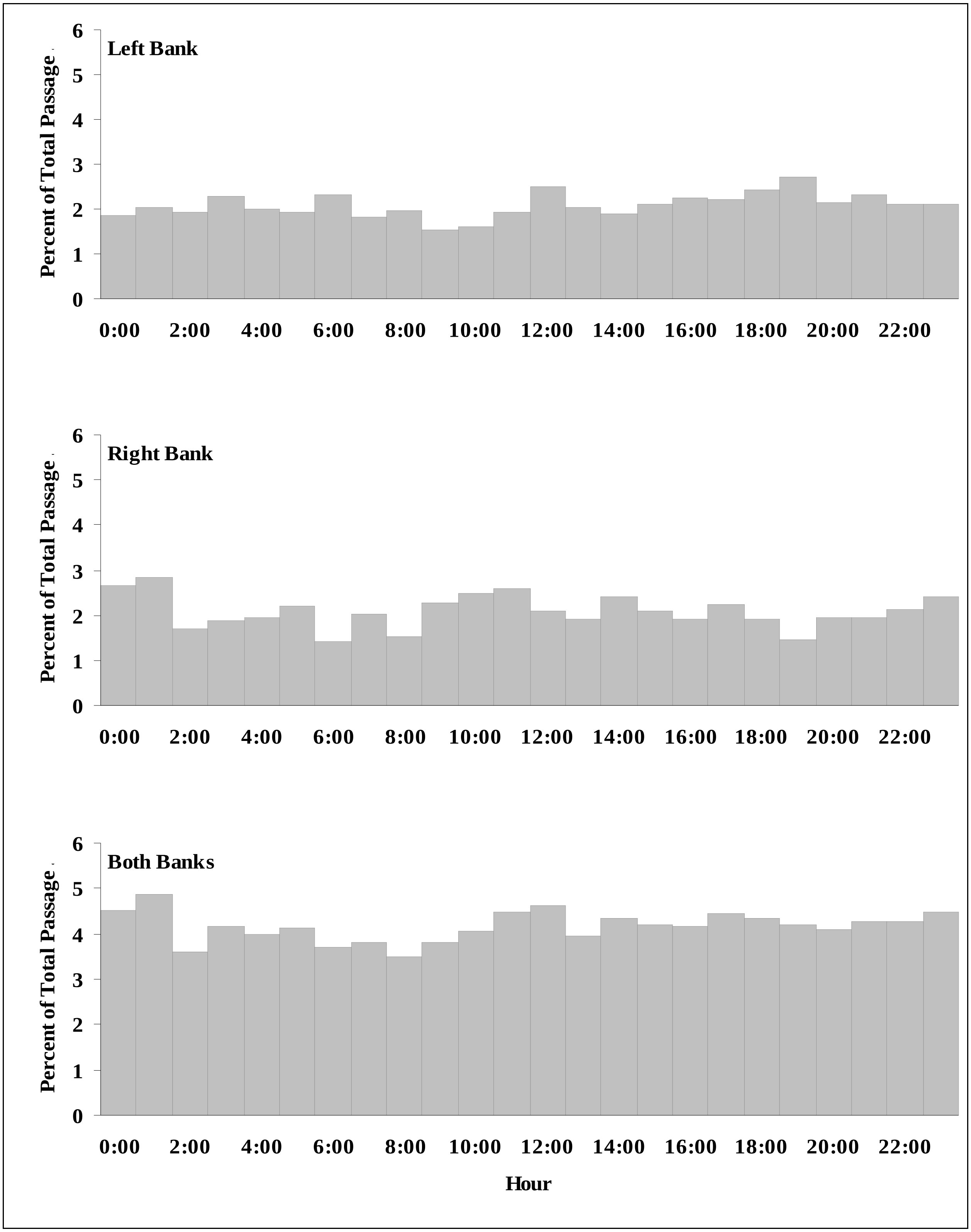


Figure 9.–Diel Chinook salmon migration pattern observed on the left bank (top), right bank (middle), and both banks combined (bottom) of the Yukon River at the Eagle sonar project site from July 7 through August 22, 2007.

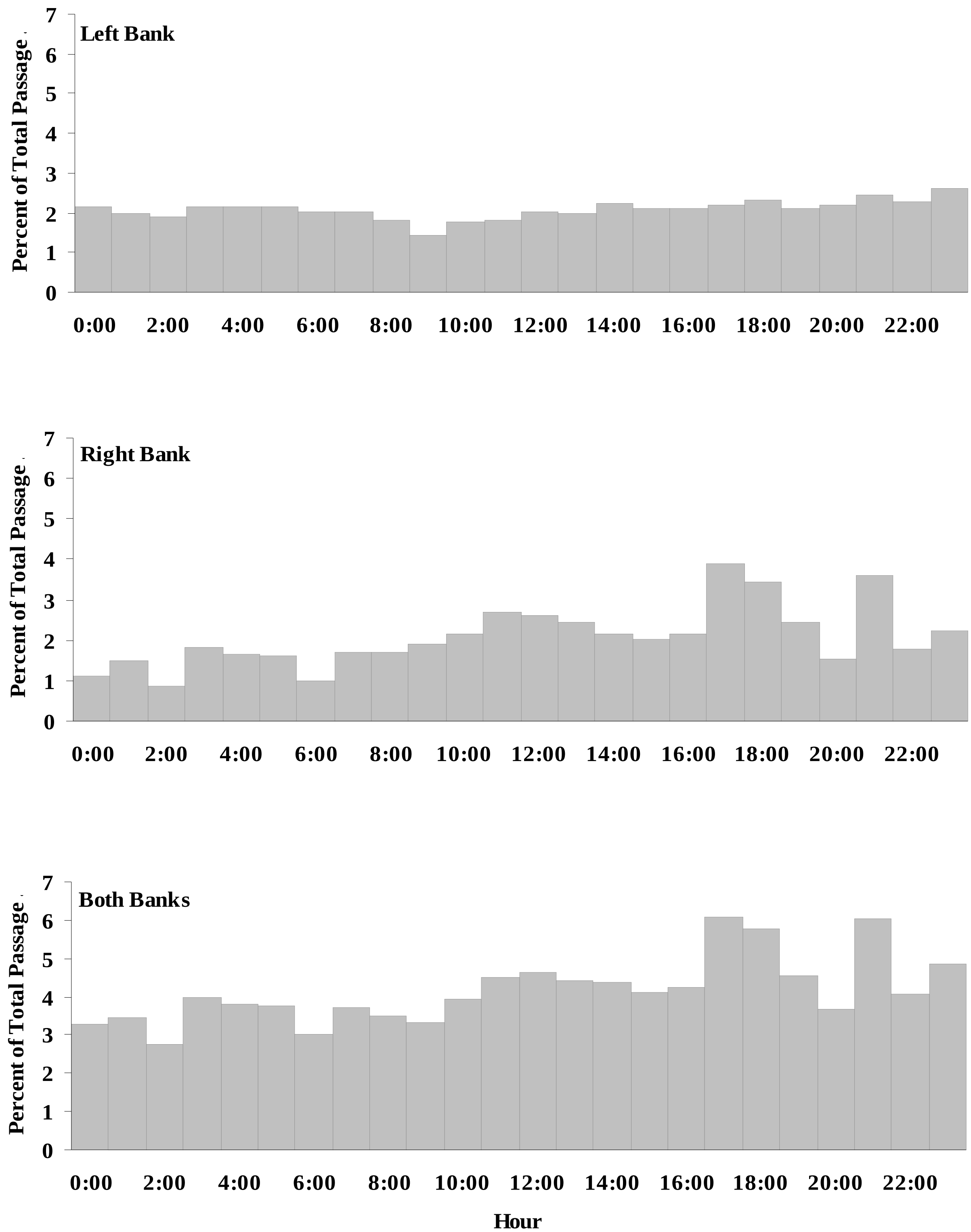
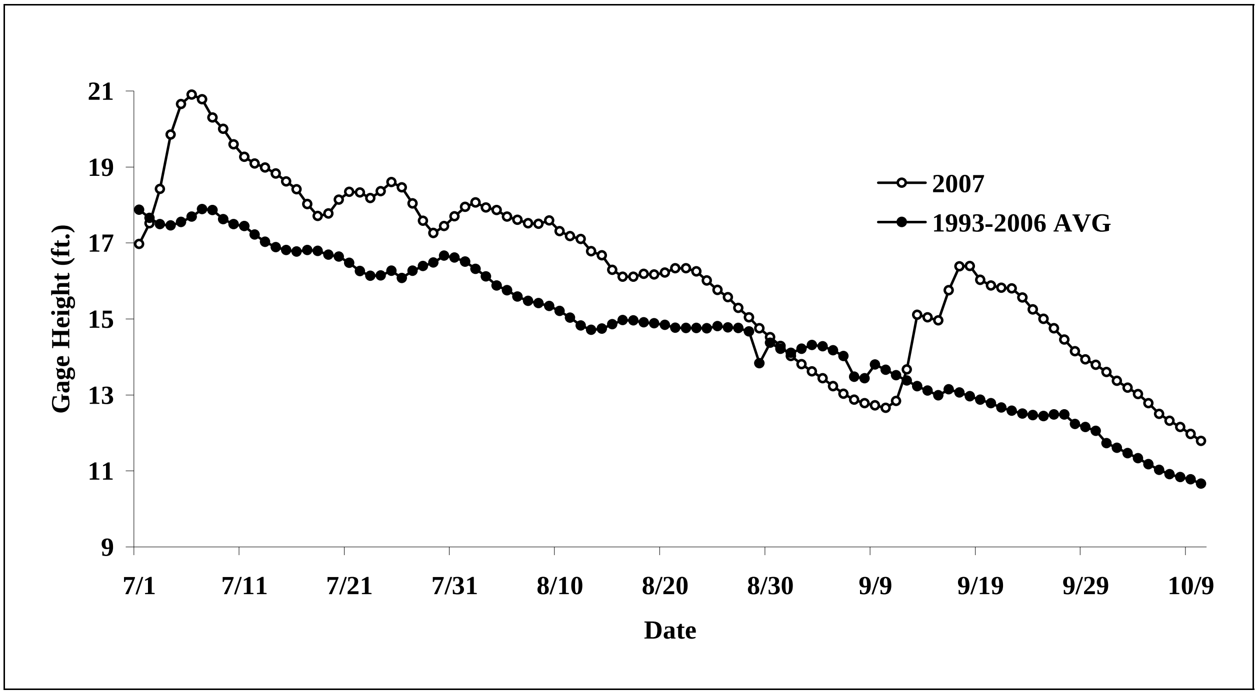


Figure 10.–Diel chum salmon migration pattern observed on the left bank (top), right bank (middle), and both banks combined (bottom) of the Yukon River at the Eagle sonar project site from August 23 through October 6, 2007.



Source: United States Geological Survey.

Figure 11.–Daily water elevation measured at Eagle, July 1 through October 10, 2007.

APPENDIX A. CLIMATE AND HYDROLOGICAL OBSERVATIONS

Appendix A1.–Climate and hydrological observations taken daily at 1800 hours at the Eagle sonar project site, 2007.

	Precipitation	Wind		Sky	Temperature (C°)	
Date	(code)[a]	Direction	Speed (mph)	(code)[b]	Air	Water
7/07	A	calm	calm	B	20.8	ND
7/08	A	S	5	S	29.0	ND
7/09	A	S	5	C	28.9	ND
7/10	A	NW	5	B	26.0	18.2
7/11	A	S	3	S	26.0	16.1
7/12	C	N	30	B	17.6	15.9
7/13	A	calm	calm	B	27.7	15.4
7/14	B	calm	calm	O	16.7	15.5
7/15	A	S	10	B	21.0	15.9
7/16	A	SW	10	C	23.0	16.4
7/17	C	calm	calm	O	15.9	16.4
7/18	B	calm	calm	B	26.1	17.0
7/19	A	E	5	S	28.3	17.3
7/20	B	calm	calm	B	23.2	17.2
7/21	A	E	10	S	27.3	17.4
7/22	A	E	5	B	24.6	18.1
7/23	B	NW	5	O	18.0	18.1
7/24	B	E	5	B	21.3	17.8
7/25	A	calm	calm	B	22.8	17.9
7/26	A	E	10	B	27.1	17.9
7/27	A	calm	calm	A	26.7	17.9
7/28	A	W	5	S	24.4	18.1
7/29	A	N	5	S	25.8	18.0
7/30	A	E	10	B	23.6	18.0
7/31	B	W	10	B	16.1	17.3
8/01	B	calm	calm	S	22.6	17.0
8/02	A	calm	calm	B	9.4	16.9
8/03	B	S	calm	S	18.5	16.6
8/04	B	calm	calm	B	18.6	16.9
8/05	B	calm	calm	B	18.8	17.0
8/06	B	calm	calm	O	14.0	16.5
8/07	A	N	5	B	15.7	16.1
8/08	A	N	5	S	20.3	15.5
8/09	A	N	5	C	21.5	15.1
8/10	A	N	5	B	18.8	14.7
8/11	A	N	5	S	23.1	14.8
8/12	A	S	5	B	23.1	14.8
8/13	C	calm	calm	F/O	15.3	14.6
8/14	B	calm	calm	B	18.7	14.3
8/15	A	calm	calm	S	22.8	15.0
8/16	A	calm	calm	C	20.9	15.9
8/17	A	calm	calm	C	21.5	16.3
8/18	A	north	0-5	C	26.0	16.4
8/19	A	calm	calm	O	15.6	16.0
8/20	A	N	5	S	18.5	15.5

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Appendix A1.–Page 2 of 3.

Date	Precipitation	Wind		Sky	Temperature (C°)	
	(code)[a]	Direction	Speed (mph)	(code)[b]	Air	Water
8/21	A	calm	calm	C	24.3	15.2
8/22	A	calm	calm	S	19.1	15.3
8/23	A	S	5	S	19.2	15.2
8/24	A	S	10	C	17.2	15.1
8/25	A	calm	calm	B	17.3	14.7
8/26	A	calm	calm	C	23.3	14.9
8/27	A	5	5	S	23.7	14.5
8/28	A	calm	calm	B	23.0	14.3
8/29	A	calm	calm	C	23.0	14.2
8/30	A	calm	calm	C	21.5	13.7
8/31	A	calm	calm	C	17.2	13.5
9/01	A	calm	calm	S	18.4	13.8
9/02	A	calm	calm	C	17.7	13.4
9/03	A	calm	calm	S	18.2	13.0
9/04	B	S	5	S	15.4	13.2
9/05	B	S	10	B	15.8	12.5
9/06	B	calm	calm	A	7.2	12.1
9/07	A	calm	calm	B	15.8	11.7
9/08	B	calm	calm	O	9.4	11.2
9/09	C	calm	calm	O	11.9	11.1
9/10	A	calm	calm	C	14.9	11.1
9/11	A	S	0-5	S	17.0	11.1
9/12	A	calm	calm	B	17.4	11.2
9/13	A	calm	calm	C	13.5	11.5
9/14	A	calm	calm	O	13.7	10.7
9/15	B	N	5	O	9.6	10.6
9/16	C	calm	calm	O	3.6	10.2
9/17	A	calm	calm	B	5.7	9.4
9/18	A	south	5	C	8.8	8.8
9/19	B	calm	calm	O	5.0	8.1
9/20	A	calm	calm	O	7.5	8.1
9/21	A	calm	calm	O	2.1	7.8
9/22	A	calm	calm	C	4.6	7.2
9/23	A	calm	calm	S	5.2	6.4
9/24	A	N	30	O	4.9	5.6
9/25	E	calm	calm	O	1.5	5.4
9/26	A	N	3	B	5.7	5.4
9/27	A	calm	calm	C	6.8	5.3
9/28	A	S	20	B	7.0	5.0
9/29	A	S	10	O	5.9	5.1
9/30	A	S	3	S	7.1	5.3

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Appendix A1.–Page 3 of 3.

	Precipitation	Wind		Sky	Temperature (C°)	
Date	(code)[a]	Direction	Speed (mph)	(code)[b]	Air	Water
10/1	A	calm	calm	S	5.5	5.0
10/2	C	calm	calm	O	1.9	4.8
10/3	A	calm	calm	O	1.1	4.5
10/4	A	S	20	C	-3.0	3.6
10/5	A	S	10	S	-3.0	3.1
10/6	A	calm	calm	C	-1.0	2.3
Average					16.3	13.0

[a] Precipitation code for the preceding 24 hr 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.