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Sonar Estimation of Chinook and Fall Chum Salmon in the Yukon River Near Eagle, Alaska, 2006

by

Roger D. Dunbar

and

Ann Crane

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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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by
Roger D. Dunbar
and
Ann Crane
Alaska Department of Fish and Game, Division of Commercial Fisheries, Fairbanks

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

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Roger D. Dunbar and Ann Crane
Alaska Department of Fish and Game, Division of Commercial Fisheries,
1300 College Rd, Fairbanks, AK, 99701, USA

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ABSTRACT

Dual-Frequency Identification Sonar (DIDSON™) and split-beam sonar equipment were used to estimate Chinook salmon *Oncorhynchus tshawytscha* and fall chum salmon *O. keta* passage in the Yukon River near Eagle, Alaska from July 8 to October 6, 2006. A total of 73,691 Chinook were estimated to have passed the sonar site between July 8 and August 17 and an estimated 236,386 chum salmon passed between August 18 and October 6. A drift and set gillnet test fishery was conducted to collect age, sex, length (ASL), genetic information, information about the presence of non-salmonid species, and to help 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 which migrated upstream. A continued long-term hydroacoustic enumeration project for Chinook and chum salmon near the border will help fishery managers meet conservation and management commitments made by the U.S. and Canada 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 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 come 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. Also, the functional relationship between test fishery catches and abundance is unknown. Mark–recapture projects provide estimates of total abundance, but the information is typically not timely enough to make day-to-day management decisions. Sonar is used to provide 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 principals set by the Yukon River Salmon Agreement (Yukon River Panel 2004). The goal of bi-national, coordinated management of Chinook *Oncorhynchus tshawytscha* and chum *O. keta* salmon stocks is to meet escapement requirements that will ensure sufficient fish availability to provide for subsistence and commercial harvests in both the United States and Canada. A daily estimate of fish crossing the border between Alaska and Canada is crucial to meeting the obligations specified in the Salmon Agreement. Accurate abundance estimates not only help managers adjust harvest in season, they are also used postseason to determine whether treaty obligations were met. The Canadian Department of Fisheries and Oceans (DFO) currently provides estimates of mainstem salmon passage through the Alaska/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, examples include 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 development of the new equipment, most of which have since been addressed.

A recommendation from the early border sonar studies was to find a more appropriate site with smaller rocks and a more 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 more 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 2 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 enumerate fish passage with a combination of split-beam 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 (0.8 km upriver 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).

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

In 2005, a full-scale sonar project was conducted from July 1 to August 13, to estimate Chinook salmon passage on the Yukon River at Six-Mile Bend (Carroll et al. 2007b). As suggested, DIDSON™ was deployed on the right bank and split-beam was deployed on the left bank to produce an estimate of fish passage. The primary goal of the 2006 study was to estimate passage of both Chinook and fall chum salmon at Six-Mile Bend.

STUDY AREA

The study area is a 1.6 km section of the mainstem Yukon River at Six-Mile Bend, 9.6 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).

The 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 Corporation 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 0.8 miles 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 2006 were to use sonar technology to estimate the timing and magnitude of adult Chinook and Fall chum salmon migrating past the sonar site, and to characterize age and sex composition of the Chinook and fall chum salmon runs. Specific objectives are outlined as follows:

- Provide managers with timely estimates of daily and seasonal passage of Chinook and fall chum salmon;
- use gillnets to estimate when the Chinook salmon run ends and the fall chum salmon run begins;
- estimate the age, sex, length (ASL) composition of the Yukon River Chinook and fall chum salmon return based upon sampled portions of the run; and
- collect Chinook and chum salmon tissue samples for genetic stock identification projects.

METHODS

Hydroacoustic Equipment

A fixed location, split-beam sonar developed by Kongsberg Simrad was used to estimate salmon abundance on the left bank. Fish passage was monitored with a model EK60 digital echo sounder which included a general purpose transceiver and a 2.5° by 10° 120 kHz transducer. ER60 data acquisition software installed on a laptop computer connected to the echosounder collected raw data to be saved 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 achieved 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, its low frequency option, using 48 beams, and at 1.2 MHz, its high frequency option, using 96 beams. Both the low and high frequency modes have a viewing angle of 29° by 14°. A 50-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 four 85 W solar panels in array, eight 6 V batteries, a charge controller, and an inverter. The solar system was backed up 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 which ran continuously.

Sonar Deployment and Operation

Bottom profiling transects were made in 2005 to find a suitable specific location for sonar deployment on both banks. Sonar deployment 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; with sufficient current containing no eddies; and sufficient beach above water line to house topside sonar equipment. The specific sites used in 2005 were again used for deployment in 2006. To ensure the original sites chosen in 2005 remained adequate for ensonification in 2006 based on the above criteria, a bottom profile was obtained after initial transducer placement. Data was collected from a total of 10 transects made from bank to bank at roughly 30 m intervals 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 7 on the left bank. The transducer and rotators were mounted on a pod constructed of aluminum pipe and deployed approximately 15 m offshore. The pod was secured with sandbags and the transducer height was adjusted by sliding the mount 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 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 over different ranges. The target, an airtight 250-ml weighted plastic bottle tied with fishing line, was drifted downstream along the river bottom and through the acoustic beams. Several drifts were made with the target in an attempt to pass it through as much of the counting range as possible. Because the target was only used to test the aim and the range of detection, x-y plots of the target strength of the target were not used to test if it was comparable to that of a fish. 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 calibration was verified in-situ using a 1.5-in tungsten carbide sphere (nominal target strength of -39.5dB at 200 kHz). The target was held with monofilament line from a pole along the river bottom and in the acoustic beams at multiple distances to ensure that the full counting range of the transducer was covered.

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 distance for offshore diversion of fish swimming upstream to be detected in the sonar beam. Ten free-standing weir sections were built using 2-in steel pipes connected with adjustable fittings to form tripods. Aluminum stringers were then attached to the tripods and set with vertical lengths of aluminum conduit 1.5 inches 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 drops over the duration of the summer, the transducer and weir require frequent relocation to deeper water. The split-beam system was aimed to ensonify to a range of approximately 150 m when counting Chinook salmon, and was later reduced to 75 m when counting chum salmon. Settings for data acquisition included: 256µs transmit pulse lengths, 500 W power output, 5 pings per second at 150 m range, and 10 pings per second at 75 m range.

The DIDSON™ unit was deployed July 7, on the right bank. The unit was mounted on an aluminum pod 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 (0–40 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 pod 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 1–20 m and 20–40m. Sonar control parameters included: 0.83 m window start, 20.01-m window length, high frequency mode, and 7 frames per second for the nearshore zone, and 20.84-m window start, 20.01-m window length, low frequency mode, and 4 frames per second for the offshore zone.

SONAR DATA PROCESSING AND ABUNDANCE ESTIMATION

Split-beam data were collected by the data acquisition software in 60-minute samples each hour of the day (no temporal sampling) and saved as .RAW files to an external hard drive for tracking and counting. The operator opened each .RAW data file in the echogram viewer program and marked each upstream fish trace with a computer mouse. The number of upstream fish for each hour was saved as a text file and recorded on a count form.

DIDSON™ data were 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 (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 trace on the DIDSON™ echogram. Upstream passage of each fish was verified using the DIDSON™ video. These counts are saved as text files and recorded on a count form. The count for each 30-minute sample was multiplied by 2, and the 1–20 m and 20–40 m counts were summed for a total hour count for that bank. 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 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 sample *p* in zone *z* of day *d*.

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) and f_{dz} is the fraction of the day sampled (12/24=0.5). 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. There was no sampling variance for the left bank since the left bank 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 occasionally occurred when routine maintenance (i.e. silt removal), or relocation of the transducer was required. When a portion of a sample was missing, 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 known number of minutes counted and then multiplied by the number of fish counted in that period. If data from 1 or more complete samples was missing, counts were interpolated by averaging counts from samples before and after the missing sample or samples.

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). These range histograms were used to 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 in season and postseason using information from the sonar estimate, fish range distribution, gillnet catches, local subsistence harvest, and Canadian mark–recapture fish wheels.

TEST FISHING AND SAMPLING

To collect ASL and genetic samples, gillnets were drifted through 3 zones: left bank inshore (LBI), left bank nearshore (LBN), and left bank offshore (LBO). Test fishing operations in 2005 determined the right bank to be unsafe for driftnetting due to the presence of large snags and swift current. Four different mesh sizes were drifted over the course of the season: 7.5 in (191 mm), 5.25 in (133 mm), 4.0 in (102 mm), and 2.75 in (70 mm). Nets were 25 fathoms (fm) (45.7 m) long and approximately 5 fm (7.6 m) deep. Nets were 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.

Test fishing was conducted once daily between 0800 and 1400 hours, using mesh sizes described in Table 1. During the sampling period, the 5.25-in and the 7.5-in nets were drifted twice within both the nearshore and offshore zones, for a total of 8 drifts. The shoreward end of the nearshore drift was set as close to shore as water depth would allow, and far enough off shore so as not to hit the fish lead. The offshore drift was set approximately 100 m offshore so as not to overlap with the nearshore zone. The order of drifts was 1) LBN, 2) LBO, 3) LBN, 4) LBO, with a minimum of 20 minutes between drifts in the same zone. Each drift lasted approximately 10 m. The order in which nets were fished alternated each day.

In addition to the standard drifts, the 2.75-in, 4.0-in, and 5.25-in nets were used to investigate the presence of fish close to shore (shore to the inshore extent of the nearshore drift). On alternating days, these nets were drifted once within the inshore zone. On the days that the 2.75-in and 4.0-in nets were used, they were also drifted once within the nearshore zone. The inshore drifts were referred to as "beach walks" (Fleischman et al. 1995), where 1 person held onto the end of the net and led it downstream along the beach, while a boat drifted with the offshore end.

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:

$$t = SI - FO + \frac{FO - SO}{2} + \frac{FI - SI}{2} \tag{4}$$

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:

$$e_{dzfmj} = \frac{25 t_{dzfmj}}{60} \tag{5}$$

Two set gillnets of mesh sizes 7.5 in (191 mm) and 5.75 in (147 mm) were fished periodically throughout the season. The nets were 25 fm in length and approximately 3-fm deep. The setnet site was approximately 100 meters upstream from the split-beam sonar on the left bank. The net was staked on shore and then anchored out into the current with a heavy weight attached to the lead line. The net was not located in an eddy, as the intent was to capture what was passing close to shore near the sonar site.

All captured salmon were sampled in the following ways:

For standard ASL samples, length (mideye to tail fork (METF) to nearest 5 mm), and sex (determined by inspection of external characteristics) were recorded. Three scales from Chinook salmon and 1 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.

Axillary processes were clipped from salmon, stored in vials of ethanol, and sent to the ADF&G genetics lab for processing in Anchorage, Alaska. 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. Any mortality was distributed to local residents after sampling.

Climate and Hydrological Sampling

Climate and hydrologic data were collected daily at approximately 1800 hours at the sonar site. Water temperature was measured in °C near shore at a depth of approximately 30 cm. Air temperatures were recorded in °C. Subjective notes on wind speed and direction, cloud cover, and precipitation were also recorded. Although reported water levels are taken from the U.S. Geological Survey's water gauge at Eagle, a stream gauge was used to track water level at the sonar site in season.

Additional Investigations

From September 8 through October 4 a DIDSON™ was occasionally operated side-by-side with the split-beam sonar on the left bank. The purpose was to collect data that may help us determine how many non-salmon fish are counted by the split-beam sonar. Small non-salmon fish were detected primarily by shape of trace on the DIDSON™ echogram. They often produce a faint, long, wiggly trace, and do not resemble the dense, bright trace of migrating fish moving through at constant, relatively fast speed. If small 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 physical size. To compare these small targets with the larger targets assumed to be upstream migrating Chinook, tracks at equivalent ranges (within 0.5 meter) were picked randomly from the echograms and measured. When small fish targets were found in the DIDSON™ files, they were located at the same time and range on the split-beam files. This allowed us to determine whether the split-beam system was detecting the smaller fish, and what the traces looked like on the split-beam echograms.

RESULTS

SONAR DEPLOYMENT

The left bank sonar was deployed approximately 800 m down river from the camp, and the right bank sonar was deployed across the river and approximately 700 m downriver from camp (Figure 2). Figure 3 shows zones of ensonification and bottom profile of the Yukon River at Six-Mile Bend sonar site. The left bank profile is approximately linear, extending 300 m to the thalweg at a 1.6° slope. The right bank profile is less linear, but shorter and steeper (5.1° slope), extending 100 m to the thalweg. The substrate at Six-Mile Bend is large cobble to small boulder on the right bank, and small to medium size cobble and silt on the left bank.

CHINOOK AND CHUM SALMON ABUNDANCE ESTIMATION

The total passage estimate at the Eagle sonar site for Chinook salmon was 73,691 for the dates July 8 through August 17, 2006. Peak daily passage estimate of 4,269 Chinook occurred on July 29, and 186 fish passed on August 17, the last day of estimating Chinook passage. The total fall chum salmon passage estimate was 236,386 for the dates August 18 through October 6, 2006. Fall chum passage peaked on September 18 with a daily total estimate of 11,654 fish. Although passage was decreasing, 2,534 fish passed on the last day of operation. Tables 2 and 3 show daily and cumulative counts for Chinook and fall chum respectively, as well as passage quartiles.

SPATIAL AND TEMPORAL DISTRIBUTION

Fish were shore oriented on both banks (Figures 4 and 5). On the left bank during the Chinook salmon run, 90% of the fish were detected within 60 m of the transducer, and 96% within 90 m. On the right bank, 91% of the fish were detected within 24 m of the transducer and 96% within 28 m. During the fall chum salmon run on the left bank, 92% of the fish were detected within 15 m of the transducer, and 98% within 20 m. On the right bank, 92% of the fish were detected within 6 m of the transducer and 97% within 8 m. The percentage of fish passage estimated by bank for the Chinook salmon season was 56% on the left bank and 44% 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 a diel fluctuation at the project site during the Chinook salmon run, although each side of the river independently showed a slight diel fluctuation (Figure 6). During the fall chum salmon run there was more pronounced diel fluctuations on both banks, but the river as a whole still shows very little fluctuation (Figure 7).

In season, August 17 was 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 (P. Milligan, Stock Assessment Biologist, Fisheries and Oceans Canada, Whitehorse, Yukon; personal communication). Fish range distribution from the sonar also was an indication that the salmon run was changing from Chinook to chum salmon. Test fish data showed that the last day dominated by Chinook salmon fell between August 13 and 25 (Figure 8). Postseason, the August 17/18 cutoff was verified using a 5-day moving average of the Canadian mark–recapture daily catch (Figure 9).

TEST FISHING AND SAMPLING

A total of 279 Chinook and 226 chum salmon were captured in test fish gillnets during the period July 9–October 1. The setnet was fished from July 14 to August 31, and the LBI zone was fished with drift gillnets from July 19 to October 1. Drift gillnets caught 276 Chinook and 179 chum salmon, while set gillnets caught 3 Chinook and 47 chum salmon. Additionally, 42 longnose sucker *Catostomus catostomus*, 19 Arctic grayling *Thymallus arcticus*, 17 sheefish *Stenodus leucichthys*, 15 whitefish *Coregoninae* (not keyed to species), 3 burbot *Lota lota* and 1 northern pike *Esox lucius* were captured in gillnets. Table 4 shows all fish captured in both drift and set nets. Table 5 shows the number of Chinook and chum salmon captured in the drift gillnets by zone and mesh size.

Chinook salmon samples collected from driftnets were composed of 168 (60.9%) males and 108 (39.1%) females. Chum salmon samples from driftnets were composed of 117 (65.4%) males and 62 (34.6%) females. Readable scale samples from 254 Chinook and 156 chum salmon collected in the drift nets were used to determine age compositions (Bales *In prep*.). From these samples it was determined that Chinook salmon age-1.3 fish predominated (60.2%) followed by age-1.4 (20.9%), age-1.2, age-2.3, and age-2.4 fish, which were 16.9%, 1.6% and 0.4% respectively. From the chum salmon samples it was determined that age-0.4 fish predominated (65.4%) followed by age-0.3 (33.3%), age-0.2 and age-0.5 fish, which were both 0.6%. Genetic samples from 276 Chinook salmon and 225 chum salmon were collected and sent to the ADF&G genetics lab for processing in Anchorage, Alaska.

Except for 1 chum salmon (290 mm), the smallest salmon caught in all gear was 460 mm (METF). Of 345 fish caught in the LBO and LBN drift zones, 15 (4%) were species other than salmon (Table 6). Only one sucker (<0.3%) showed a slight overlap with the lengths of the salmon (>460 mm) caught in these drifts. The beach walk (LBI) caught 188 fish, of which 64 (34%) were not salmon. Only one sheefish and one burbot (1%) showed a slight overlap with the lengths of the salmon (>460 mm) caught in these drifts. The setnet caught 68 fish, 18 (26%) were not salmon, all of which overlapped in length of the salmon. A nearby subsistence fish wheel caught about 2% non-salmon species none of which were measured (Wayne and Scarlet Hall, subsistence fishers, Eagle; personal communication).

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 of 19°C and a minimum of 4°C. Water level also decreased over the duration of the season; however, water level did increase briefly following substantial rain events. Water levels were carefully monitored because changes in water level usually necessitated moving the transducer(s) and fish lead(s) to deeper or shallower water, particularly on the left bank. Overall, the water level decreased 298 cm from July 1 through October 15. While the sonar was in operation the water level decreased 179 cm. Figure 10 shows USGS water levels measured at Eagle during the project as well as the average water levels for 1987 to 2005.

ADDITIONAL INVESTIGATIONS

The DIDSON™ collected 801 thirty-minute samples during the period of side-by-side operation with the split-beam sonar on the left bank. Preliminary information from only a few samples collected during side-by-side operation of DIDSON™ and split-beam sonar suggest that less than 4% of the split-beam sonar estimate is from fish smaller than chum salmon.

DISCUSSION

SONAR DEPLOYMENT, AND OPERATION

The split-beam and DIDSON™ systems performed optimally 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. Addition of solar power on the right bank was a positive change which lowered fuel expenses and eliminated trips to the right bank in the dark that were done previously to refuel the generator. Only during the later part of the season was additional power from a gasoline generator necessary. With the fuel savings, the solar setup on the right bank will pay for itself in 3 years. The split-beam system worked without malfunction, and appeared to have satisfactory detection nearshore, while still detecting targets adequately at 150 m. The new 2.5° by 10° split-beam transducer fit the water column better than the 4° by 10° transducer used in 2005 and substantially reduced surface reverberation. This made the echograms much cleaner and thus easier to identify the fish.

Processing procedures for marking both DIDSON™ and split-beam files appeared to work well for estimating salmon passage at the site. All data files were easily processed in a reasonable amount of time. The new echogram program used for counting fish from the split-beam data files was an improvement over the program used in 2005. Improvements of processing procedure 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, and to characterize age and sex composition of the run. The estimate of 73,691 Chinook is almost double the preliminary Canadian fish wheel mark–recapture estimate of 36,748 (JTC 2007). If all the 2,283 Chinook salmon harvested in the Eagle subsistence fishery in 2006 (Busher et al. *In prep*) are removed from the sonar estimate, then the Canadian estimate is 52% of the sonar estimate. In 2005 the Eagle sonar Chinook estimate was 81,528, while the Canadian border passage estimate of 42,245 was 52% of the sonar estimate. If all the 2,566 Chinook salmon harvested in the Eagle subsistence fishery in 2005 (Busher et al. 2007) are removed from the sonar estimate, then the Canadian estimate is 54% of the sonar estimate. The exact number of salmon harvested above and below the sonar location is not known. In the future, the Eagle subsistence harvest numbers will be recorded as being above or below the sonar site. This will allow us to get a better estimate of the border passage.

The estimate for the fall chum salmon was 236,386 in 2006, which is very close to the preliminary Canadian fish wheel mark–recapture estimate of 217,810 (JTC 2007). The sonar-estimated escapement of chum salmon may be considered conservative because fish that passed the site after sonar sampling ceased were not included. The subsistence harvest from the Eagle area (includes harvest below sonar site) was 16,786 (Busher et al. *In prep*). Removing the subsistence harvest would put the sonar estimate only 1% higher than the Canadian estimate. Continuing both the DFO and ADF&G projects 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 the range distributions observed this season, we do not believe many fish migrate upstream in the unensonified portion of the river. On both banks, the large majority of fish were within 40 m of shore. The same sampling ranges used for Chinook salmon in 2005 were again used in 2006. 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 18 to allow faster ping rates and improved detection nearshore. Overall there does not appear to be much of a diel fluctuation at the project site, although each side of the river independently showed a slight fluctuation, especially for chum salmon.

Though there are chum salmon passing the sonar site during the Chinook run and visa versa, the Chinook and chum salmon runs appear to be discrete in time. The timing of the Chinook and chum salmon runs was monitored in season using sonar data, gillnet catches, local subsistence harvest, and Canadian mark–recapture fish wheel estimates. Postseason, the inseason cutoff date was verified with the final data collected during the season. The Chinook and chum salmon runs overlap; however, the daily estimates during this overlapping period were relatively small so the final estimate is not very sensitive to the cutoff date. Moving the date a week in either direction changes the chum salmon estimate by about 1% and the Chinook salmon estimate by about 3%. Although this is a crude method of determining a species cutoff date, it appears to be justified at this site.

TEST FISHING AND SAMPLING

New methods of test fishing were used this season to catch a representative sample of the fish migrating past the sonar site. First, the setnet was deployed with varied results. The net, being set in the current, billowed and collected a lot of debris rendering it inefficient. It was also apparent when the chum salmon run started, many chum would be captured and killed. Another method that was used we called the “beach walk.” This method, along with the driftnetting, seemed to be a better way of capturing a representative sample of salmon passage at the sonar site. Our hope is to develop reliable test fishing method of determining the date to use for the end of the Chinook and beginning of the chum salmon runs.

Fish species other than salmon were captured in the set and drift gillnets, and a neighboring subsistence fish wheel. Less than 1% of the non-salmon species caught in the drift and beach walks overlapped in length with the salmon larger than 460 mm. The setnet caught 26% non-salmon species, all as large as or larger than the salmon. This discrepancy cannot be explained. Although the fish at the nearby subsistence fish wheel were not measured it is encouraging that only 2% of the total catch was non-salmon species. None of these methods may give us a representative sample of how many non-salmon species may be counted by the split-beam sonar. Another method of estimating how many non-salmon species may be counted by the split-beam sonar is discussed in the next section.

ADDITIONAL INVESTIGATIONS

Preliminary information from side-by-side operation of DIDSON™ and split-beam sonar suggest that less than 4% of the split-beam sonar estimate are from species smaller in length than a chum salmon. 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). This method may be the best way of determining the percentage of non-salmon species that are included in the split-beam sonar estimate of salmon passage. More work, such as collecting data during the Chinook salmon run and fully examining the data already collected needs to be done. Results will be presented in another paper when data collection and analysis is complete.

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TABLES AND FIGURES

Table 1.–Eagle sonar drift gillnet fishing schedule and mesh sizes, 2006.

Zone	Day 1	Day 2	Day 3
Offshore	7.50"	7.50"	7.50"
	5.25"	5.25"	5.25"
Nearshore	7.50"	7.50"	7.50"
	5.25"	5.25"	5.25"
		4.00"	2.75"
Inshore	5.25"	4.00"	2.75"

Table 2.–Estimated daily and cumulative Chinook salmon passage by bank, Eagle Sonar, 2006.

	Daily			Cumulative			
Date	Left Bank	Right Bank	Total	Left Bank	Right Bank	% of Total Passage	Total
7/08	33	51	84	33	51	0.00	84
7/09	62	52	114	95	103	0.00	198
7/10	83	108	191	178	211	0.01	389
7/11	96	84	180	274	295	0.01	569
7/12	120	149	269	394	444	0.01	838
7/13	132	266	398	526	710	0.02	1,236
7/14	253	538	791	779	1,248	0.03	2,027
7/15	335	721	1,056	1,114	1,969	0.04	3,083
7/16	810	1,026	1,836	1,924	2,995	0.07	4,919
7/17	730	1,342	2,072	2,654	4,337	0.09	6,991
7/18	865	1,970	2,835	3,519	6,307	0.13	9,826
7/19	970	2,204	3,174	4,489	8,511	0.18	13,000
7/20	1,542	1,730	3,272	6,031	10,241	0.22	16,272
7/21	1,627	1,538	3,165	7,658	11,779	0.26	19,437 [a]
7/22	2,131	1,378	3,509	9,789	13,157	0.31	22,946
7/23	1,695	1,660	3,355	11,484	14,817	0.36	26,301
7/24	1,734	1,610	3,344	13,218	16,427	0.40	29,645
7/25	2,304	1,344	3,648	15,522	17,771	0.45	33,293
7/26	2,481	1,352	3,833	18,003	19,123	0.50	37,126 [b]
7/27	2,566	784	3,350	20,569	19,907	0.55	40,476
7/28	2,609	1,244	3,853	23,178	21,151	0.60	44,329
7/29	2,833	1,436	4,269	26,011	22,587	0.66	48,598
7/30	2,472	1,760	4,232	28,483	24,347	0.72	52,830
7/31	1,931	1,768	3,699	30,414	26,115	0.77	56,529
8/01	1,833	1,403	3,236	32,247	27,518	0.81	59,765
8/02	1,301	1,186	2,487	33,548	28,704	0.84	62,252
8/03	1,439	385	1,824	34,987	29,089	0.87	64,076
8/04	1,099	428	1,527	36,086	29,517	0.89	65,603
8/05	928	502	1,430	37,014	30,019	0.91	67,033
8/06	796	512	1,308	37,810	30,531	0.93	68,341
8/07	634	386	1,020	38,444	30,917	0.94	69,361
8/08	566	276	842	39,010	31,193	0.95	70,203
8/09	496	244	740	39,506	31,437	0.96	70,943
8/10	427	154	581	39,933	31,591	0.97	71,524
8/11	312	190	502	40,245	31,781	0.98	72,026
8/12	283	150	433	40,528	31,931	0.98	72,459
8/13	236	91	327	40,764	32,022	0.99	72,786
8/14	232	98	330	40,996	32,120	0.99	73,116
8/15	143	61	204	41,139	32,181	0.99	73,320
8/16	145	40	185	41,284	32,221	1.00	73,505
8/17	141	45	186	41,425	32,266	1.00	73,691
Total	41,425	32,266	73,691	41,425	32,266		73,691
SE [c]		245			245		245

[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 3.–Estimated daily and cumulative chum salmon passage by bank, Eagle Sonar, 2006.

	Daily			Cumulative			
Date	Left Bank	Right Bank	Total	Left Bank	Right Bank	% of Total Passage	Total
8/18	143	47	190	143	47	0.00	190
8/19	158	8	166	301	55	0.00	356
8/20	272	20	292	573	75	0.00	648
8/21	279	20	299	852	95	0.00	947
8/22	276	24	300	1,128	119	0.01	1,247
8/23	298	22	320	1,426	141	0.01	1,567
8/24	418	34	452	1,844	175	0.01	2,019
8/25	489	46	535	2,333	221	0.01	2,554
8/26	489	90	579	2,822	311	0.01	3,133
8/27	255	101	356	3,077	412	0.01	3,489
8/28	510	150	660	3,587	562	0.02	4,149
8/29	559	196	755	4,146	758	0.02	4,904
8/30	891	157	1,048	5,037	915	0.03	5,952
8/31	1,107	251	1,358	6,144	1,166	0.03	7,310
9/01	1,408	585	1,993	7,552	1,751	0.04	9,303
9/02	1,674	874	2,548	9,226	2,625	0.05	11,851
9/03	1,949	1,284	3,233	11,175	3,909	0.06	15,084
9/04	2,881	1,420	4,301	14,056	5,329	0.08	19,385
9/05	3,562	1,890	5,452	17,618	7,219	0.11	24,837
9/06	3,172	2,071	5,243	20,790	9,290	0.13	30,080
9/07	3,079	2,124	5,203	23,869	11,414	0.15	35,283
9/08	3,826	1,552	5,378	27,695	12,966	0.17	40,661
9/09	3,575	2,274	5,849	31,270	15,240	0.20	46,510
9/10	3,562	2,508	6,070	34,832	17,748	0.22	52,580
9/11	3,624	2,686	6,310	38,456	20,434	0.25	58,890 [a]
9/12	3,561	2,599	6,160	42,017	23,033	0.28	65,050
9/13	3,681	2,776	6,457	45,698	25,809	0.30	71,507
9/14	4,276	3,104	7,380	49,974	28,913	0.33	78,887
9/15	4,826	3,062	7,888	54,800	31,975	0.37	86,775
9/16	6,186	3,092	9,278	60,986	35,067	0.41	96,053
9/17	5,783	4,829	10,612	66,769	39,896	0.45	106,665
9/18	4,838	6,816	11,654	71,607	46,712	0.50	118,319 [b]
9/19	4,962	6,446	11,408	76,569	53,158	0.55	129,727
9/20	4,172	6,640	10,812	80,741	59,798	0.59	140,539
9/21	4,513	6,146	10,659	85,254	65,944	0.64	151,198
9/22	4,610	5,072	9,682	89,864	71,016	0.68	160,880
9/23	4,258	4,714	8,972	94,122	75,730	0.72	169,852
9/24	3,225	5,296	8,521	97,347	81,026	0.75	178,373
9/25	2,779	4,510	7,289	100,126	85,536	0.79	185,662
9/26	3,102	4,147	7,249	103,228	89,683	0.82	192,911
9/27	2,504	4,090	6,594	105,732	93,773	0.84	199,505
9/28	2,504	3,698	6,202	108,236	97,471	0.87	205,707
9/29	2,555	3,328	5,883	110,791	100,799	0.90	211,590
9/30	1,729	3,396	5,125	112,520	104,195	0.92	216,715

-continued-

Table 3.–Page 2 of 2.

	Daily			Cumulative			
Date	Left Bank	Right Bank	Total	Left Bank	Right Bank	% of Total Passage	Total
10/01	1,699	2,550	4,249	114,219	106,745	0.93	220,964
10/02	1,460	2,606	4,066	115,679	109,351	0.95	225,030
10/03	1,242	2,116	3,358	116,921	111,467	0.97	228,388
10/04	1,465	1,496	2,961	118,386	112,963	0.98	231,349
10/05	1,609	894	2,503	119,995	113,857	0.99	233,852
10/06	1,266	1,268	2,534	121,261	115,125	1.00	236,386
Total	121,261	115,125	236,386	121,261	115,125		236,386
SE [c]		727			727		727

[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 4.–Fish caught with gillnets at the Eagle sonar project site, 2006.

Species	Driftnet	Setnet	Total
Chinook	276	3	279
chum	179	47	226
sucker	42	0	42
grayling	19	0	19
whitefish	12	3	15
sheefish	3	14	17
burbot	2	1	3
pike	1	0	1
Total	534	68	602

Table 5.–Effort, salmon catch, and percentage of Chinook and chum catch, by zone and mesh size, Eagle sonar project site, 2006.

	Mesh Size	Effort	Catch			
Zone	(inches)	(fathom hours)	Chinook	Chum	% of Chinook Catch	% of Chum Catch
LBI	2.75	93.65	0	17	0.0	9.5
	4.00	106.09	0	46	0.0	25.7
	5.25	62.17	0	62	0.0	34.6
Total		261.90	0	125	0.0	69.8
LBN	2.75	107.19	6	1	2.2	0.6
	4.00	97.86	9	3	3.3	1.7
	5.25	734.86	104	31	37.7	17.3
	7.50	717.75	76	17	27.5	9.5
Total		1657.66	195	52	70.7	29.1
LBO	5.25	719.16	33	0	12.0	0.0
	7.50	711.95	48	2	17.4	1.1
Total		1431.11	81	2	29.3	1.1
Grand Total		3350.67	276	179	100	100

Table 6.–Lengths of fish caught by fishing method, Eagle sonar project site, 2006.

	Driftnet (LBO, LBN)				Beachwalk (LBI)				Setnet			
		Length (mm)				Length (mm)				Length (mm)		
Species	Catch	Minimum	Maximum	Mean	Catch	Minimum	Maximum	Mean	Catch	Minimum	Maximum	Mean
Chinook	276	460	1005	736	0				3	660	890	757
chum	54	460	710	603	124	530	710	592	47	290	690	585
sucker	9	305	475	359	33	275	420	337	0			
whitefish	3	385	400	392	9	310	435	357	3	540	585	562
grayling	3	240	335	298	16	210	330	295	0			
sheefish	0				3	395	655	518	14	610	725	660
burbot	0				2	450	580	515	1	865	865	865
pike	0				1	510	510	510	0			

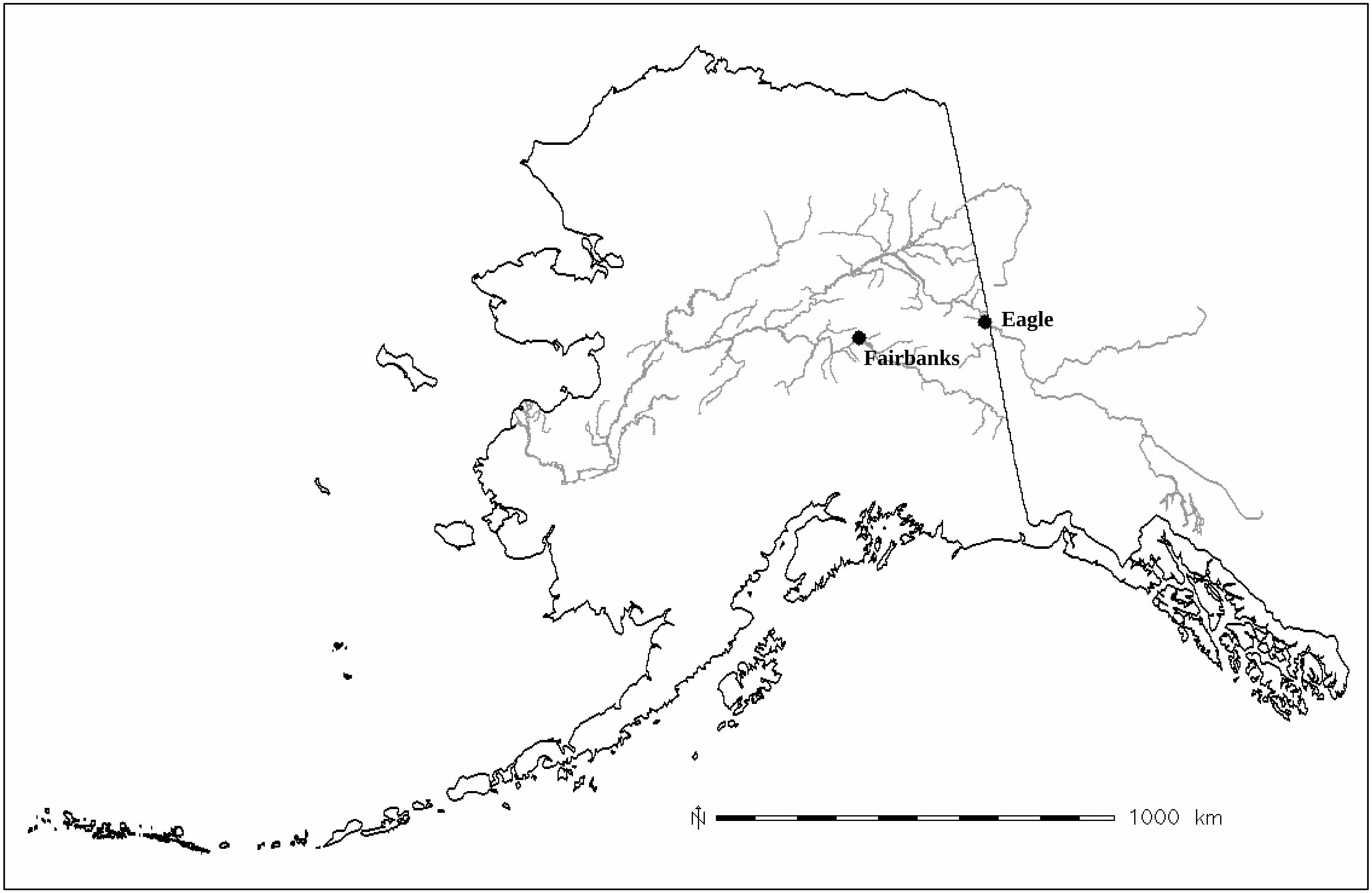


Figure 1.–Yukon River drainage.

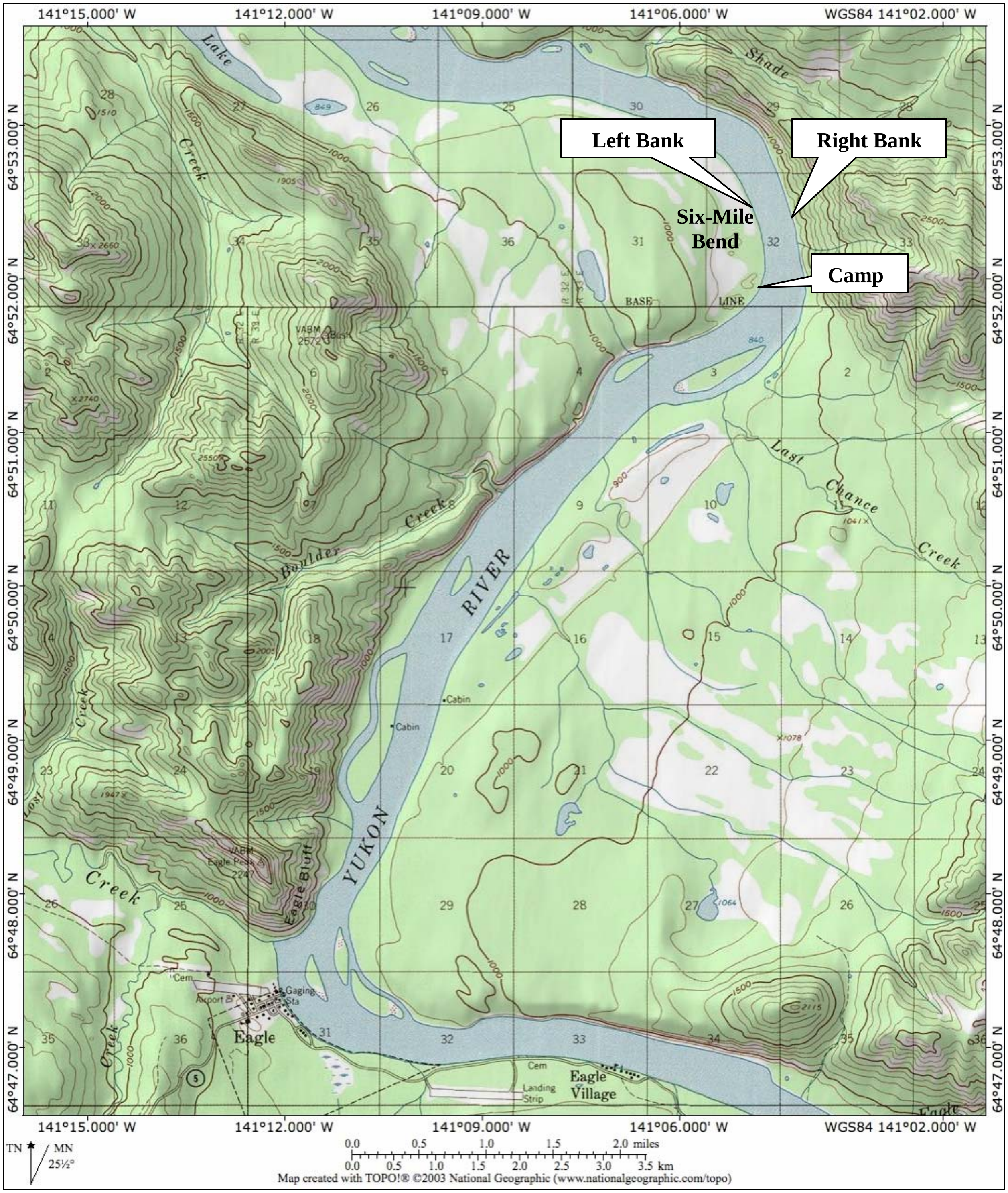
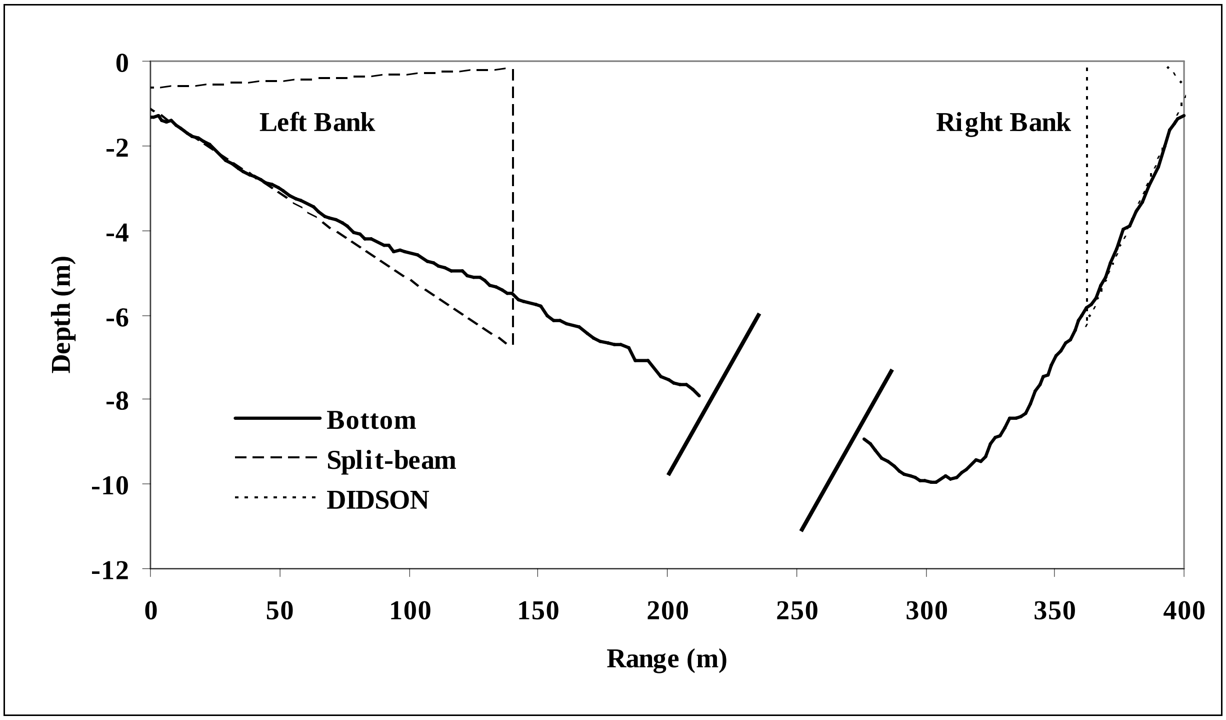
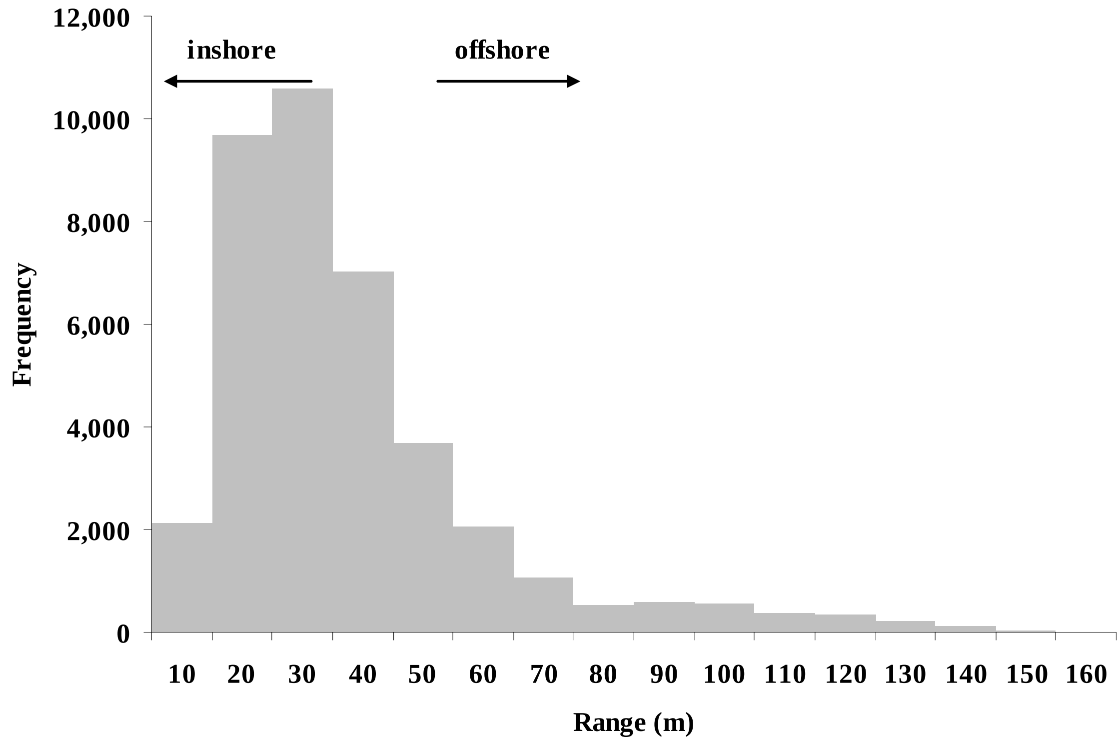


Figure 2.–Eagle sonar project site at Six-Mile Bend.



Note: parallel bars represent missing data.

Figure 3.–Depth profile (downstream view), and ensonified zones of Yukon River at Eagle sonar project site, 2006.



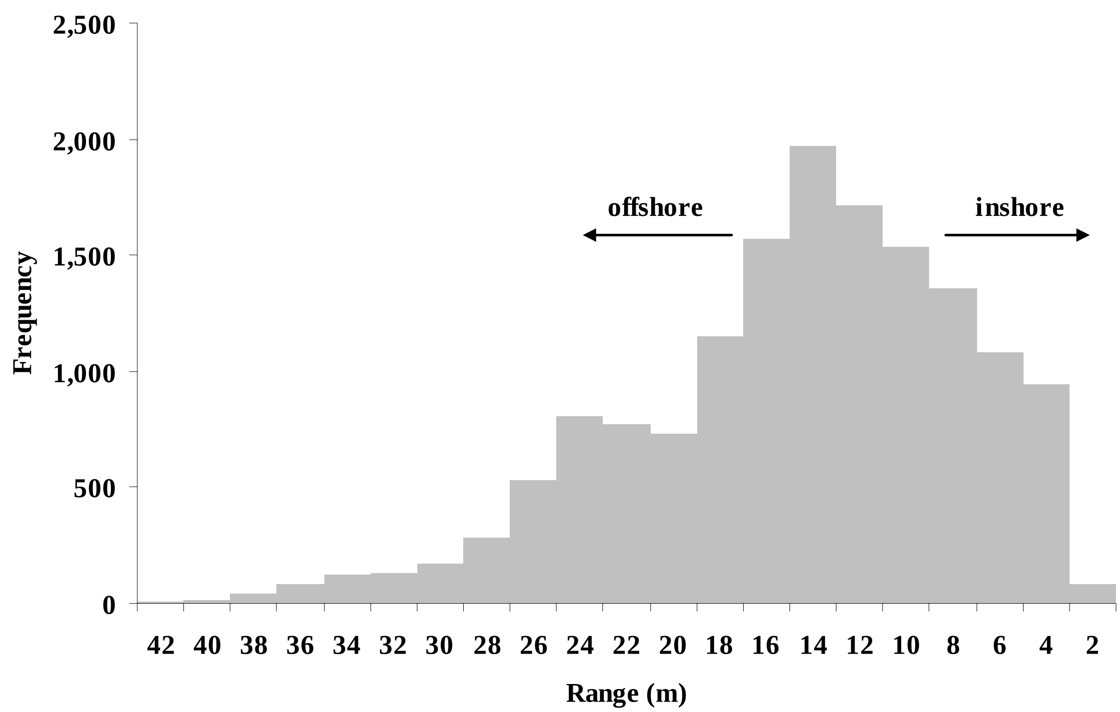


Figure 4.–Left bank (above) and right bank (below) horizontal distribution of upstream Chinook salmon passage in the Yukon River at Eagle sonar project site, July 8–August 17, 2006.

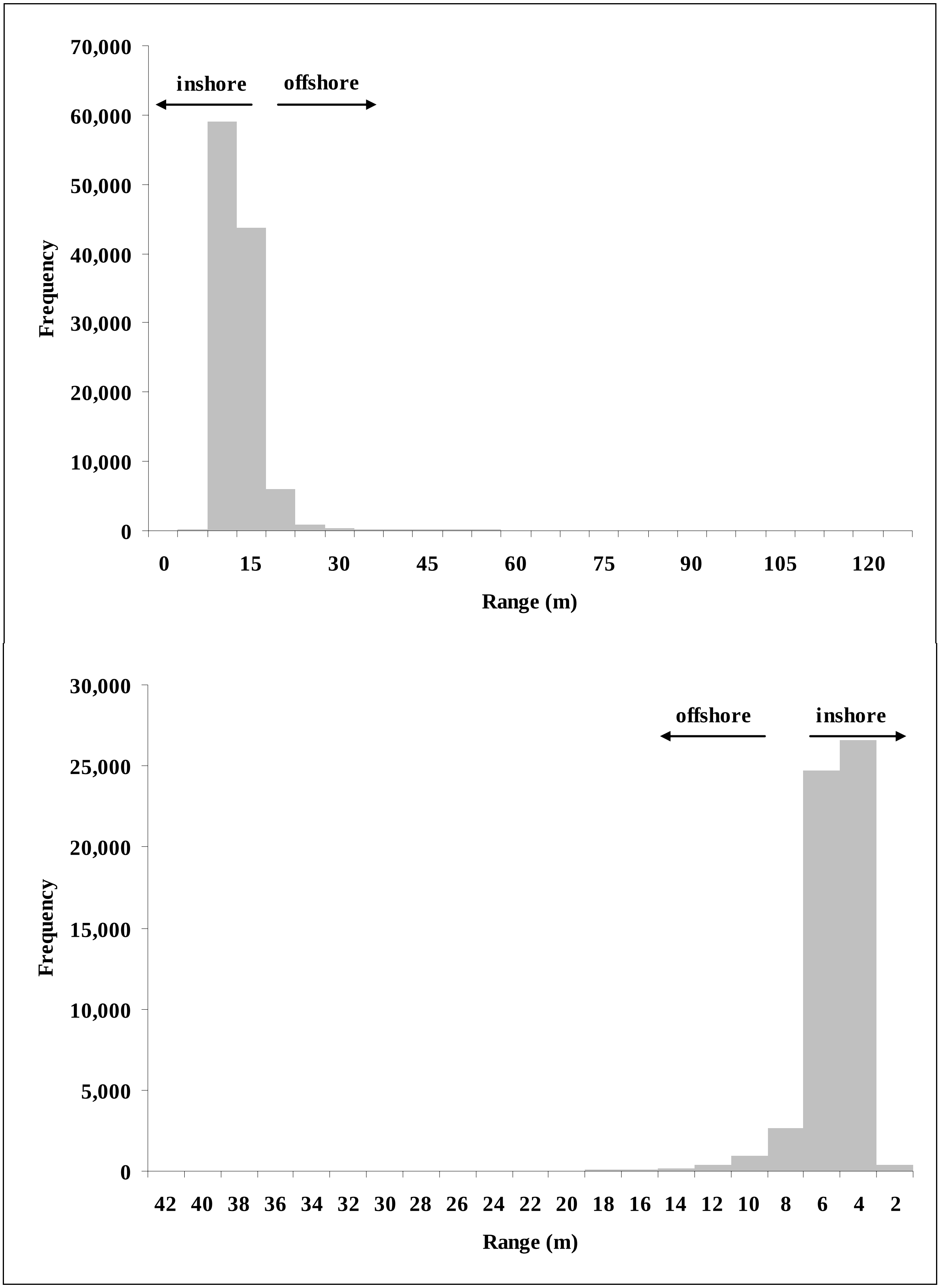


Figure 5.–Left bank (above) and right bank (below) horizontal distribution of upstream chum salmon passage in the Yukon River at Eagle sonar project site, August 18–October 6, 2006.

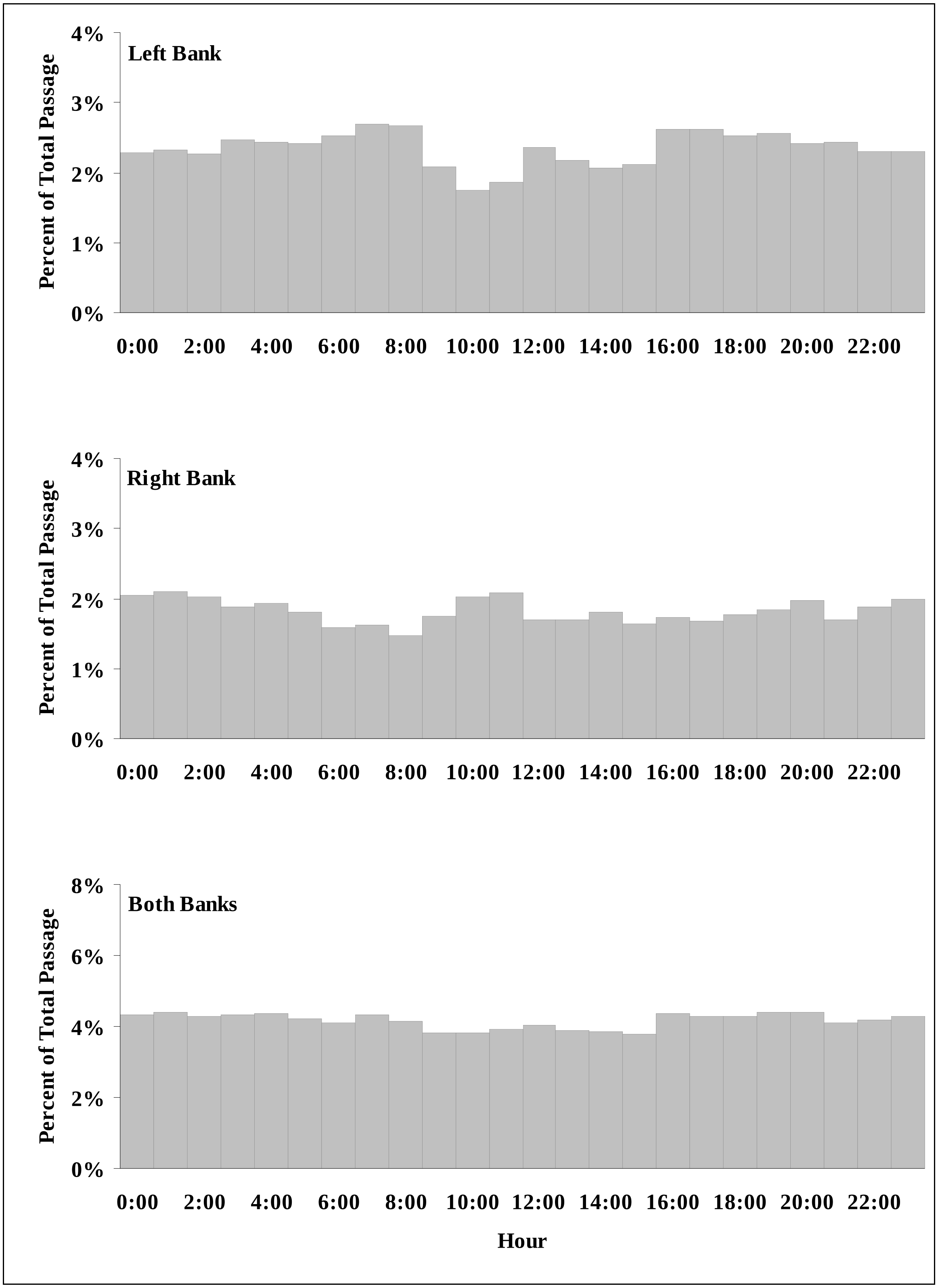


Figure 6.–Diel Chinook salmon migration pattern observed on the left bank (top), right bank (middle), and both banks combined (bottom) of the Yukon River, Eagle sonar project site, July 8–August 17, 2006.

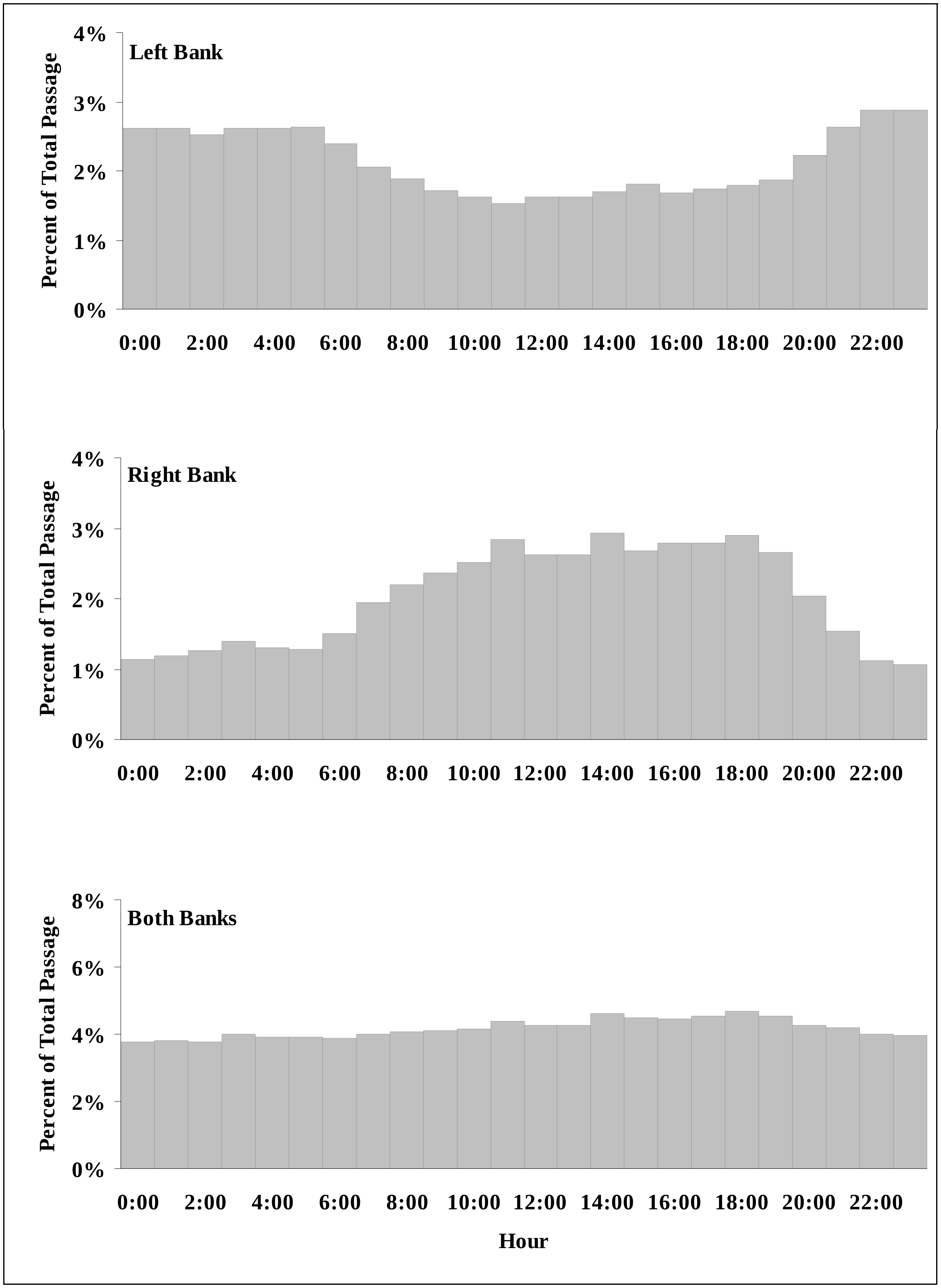
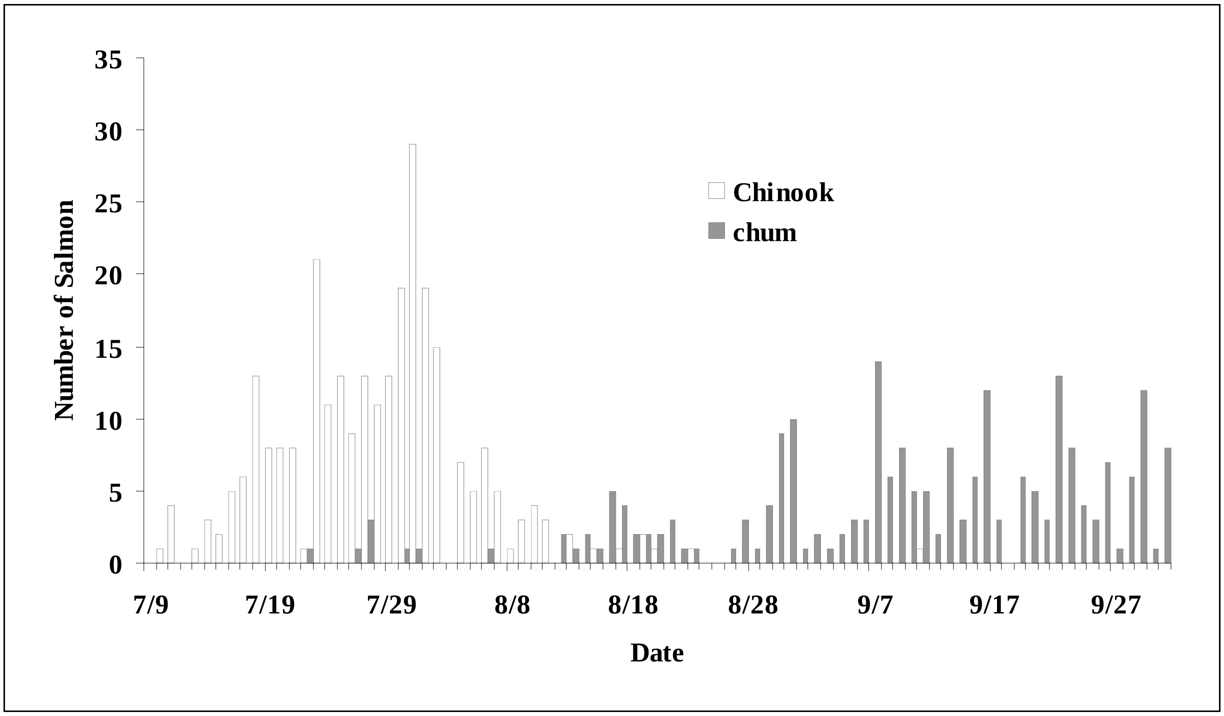
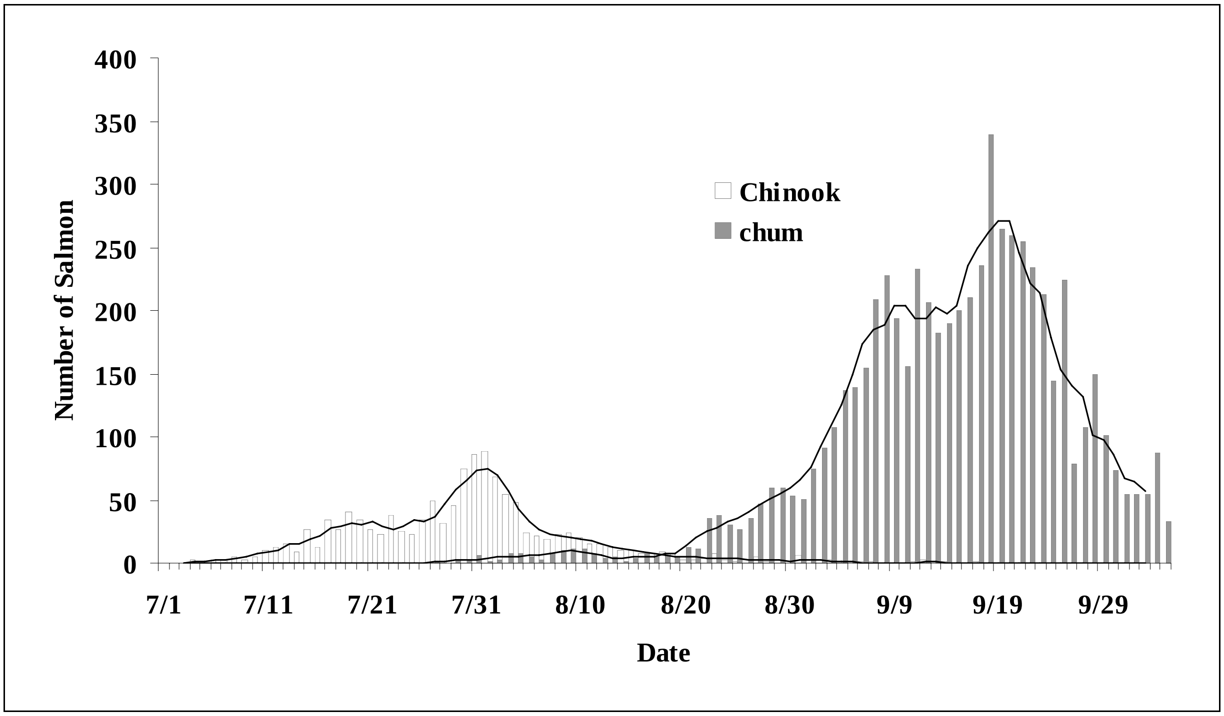


Figure 7.–Diel chum salmon migration pattern observed on the left bank (top), right bank (middle), and both banks combined (bottom) of the Yukon River, Eagle sonar project site, August 18–October 6, 2006.



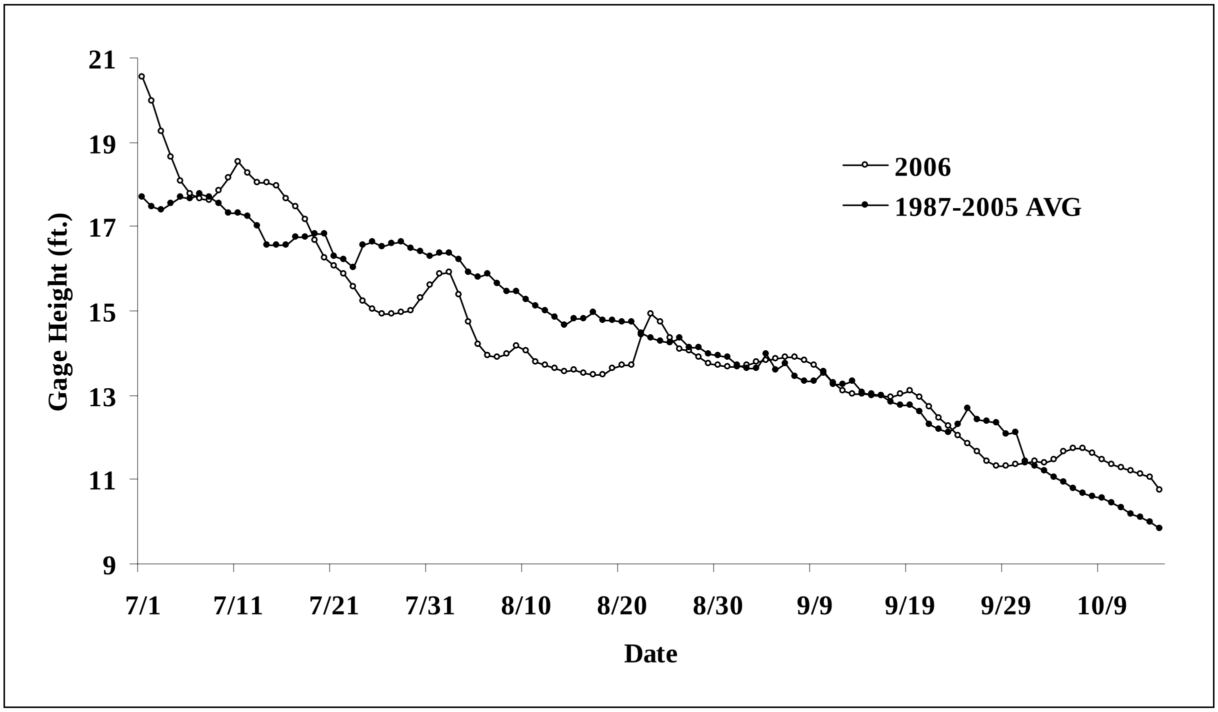
Source: Canadian Department of Fisheries and Oceans.

Figure 8.–Chinook and chum salmon test fish (gillnet) catch at the Eagle sonar project site, July 9–October 1, 2006.



Note: Fish wheel catch comprised of the sum of Whiterock and Sheeprock fish wheels.

Figure 9.–Salmon catch from Canadian mark–recapture fish wheels (sum of Whiterock and Sheeprock wheels) and 5-day average showing Chinook and chum salmon run crossover dates of August 17–18, 2006.



Source: United States Geological Survey.

Figure 10.–Daily water elevation measured at Eagle, July 1–October 15, 2006.

APPENDIX A. CLIMATE AND HYDROLOGICAL OBSERVATIONS

Appendix A1.–Climate and hydrological observations taken daily at 1800 hours at the Eagle sonar project site, 2006.

Date	Precipitation (code) [a]	Wind Direction	Wind Speed (mph)	Sky (code) [b]	Temperature (C°) Air	Temperature (C°) Water
7/08	A	S	7	B	19	16
7/09	A	N	5	S	23	16
7/10	A	calm	0	C	26	16
7/11	A	calm	0	B	23	16
7/12	A	calm	0	S	25	17
7/13	A	S	5	S	22	16
7/14	A	calm	0	S	20	17
7/15	B	N	5	B	16	16
7/16	A	calm	0	B	19	16
7/17	A	calm	0	B	20	16
7/18	A	calm	0	B	20	16
7/19	A	calm	0	S	23	17
7/20	A	S	10	C	25	18
7/21	A	S	5	S	23	18
7/22	B	S	1	B	20	17
7/23	A	calm	0	C	25	18
7/24	A	calm	0	S	29	19
7/25	B	E	5	B	18	18
7/26	B	calm	0	O	15	17
7/27	A	N	3	C	24	19
7/28	A	S	4	C	27	19
7/29	A	N	20	B	26	17
7/30	A	S	5	O	14	15
7/31	A	calm	0	S	18	17
8/01	A	N	1	B	25	17
8/02	B	S	3	B	12	16
8/03	A	N	3	C	25	18
8/04	A	N	1	S	25	17
8/05	A	N	2	S	23	17
8/06	A	N	3	S	20	17
8/07	A	N	10	S	20	17
8/08	B	calm	0	B	16	16
8/09	A	calm	0	C	23	17
8/10	B	S	5	B	20	16
8/11	B	S	10	O	16	15
8/12	B	calm	0	B	16	15
8/13	A	calm	0	C	20	16
8/14	A	calm	0	B	20	17
8/15	A	S	10	B	16	17
8/16	A	S	1	S	15	16
8/17	C	calm	0	O	13	15
8/18	A	N	10	O	14	14
8/19	C	S	20	O	11	13
8/20	C	calm	0	O	12	14
8/21	B	calm	0	O	8	12

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	Precipitation	Wind		Sky	Temperature (C°)	
Date	(code) [a]	Direction	Speed (mph)	(code) [b]	Air	Water
8/22	A	no data	no data	S	no data	no data
8/23	A	calm	0	S	12	13
8/24	A	S	3	S	15	14
8/25	A	S	20	B	11	13
8/26	A	SE	10	C	13	12
8/27	A	calm	0	S	13	12
8/28	A	N	3	C	12	12
8/29	A	calm	0	S	13	13
8/30	A	S	2	C	17	12
8/31	A	calm	0	B	11	12
9/01	A	calm	0	O	10	11
9/02	A	N	2	S	13	12
9/03	A	N	2	S	14	12
9/04	A	calm	0	O	17	12
9/05	A	calm	0	O	16	12
9/06	A	calm	0	B	11	11
9/07	A	N	3	S	17	12
9/08	A	N	5	C	16	11
9/09	A	calm	0	C	17	11
9/10	A	calm	0	B	16	11
9/11	B	calm	0	O	11	11
9/12	A	calm	0	B	12	11
9/13	A	N	1	C	15	12
9/14	A	S	7	C	15	11
9/15	A	N	10	C	17	10
9/16	B	S	10	C	8	9
9/17	A	S	2	B	9	9
9/18	A	calm	0	B	13	10
9/19	A	S	2	B	11	9
9/20	A	N	2	B	12	9
9/21	A	S	5	C	13	9
9/22	A	calm	0	B	12	8
9/23	B	calm	0	O	8	8
9/24	A	calm	0	C	9	8
9/25	A	E	15	C	8	7
9/26	A	S	10	O	9	7
9/27	A	calm	0	S	10	8
9/28	A	calm	0	B	9	8
9/29	C	calm	0	O	5	7
9/30	A	calm	0	O	4	6
10/01	A	S	7	C	6	6

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Appendix A1.–Page 3 of 3.

Date	Precipitation (code) [a]	Wind		Sky (code) [b]	Temperature (C°)	
		Direction	Speed (mph)		Air	Water
10/02	A	S	2	C	7	6
10/03	A	S	1	O	8	5
10/04	A	calm	0	B	6	5
10/05	A	calm	0	S	4	5
10/06	A	S	3	C	2	4
Average					15	13

[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.