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Sonar Estimation of Chinook and Fall Chum Salmon Passage in the Yukon River Near Eagle, Alaska, 2019

by

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and

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Weights and measures (metric)	
centimeter	cm
deciliter	dL
gram	g
hectare	ha
kilogram	kg
kilometer	km
liter	L
meter	m
milliliter	mL
millimeter	mm
Weights and measures (English)	
cubic feet per second	ft^3/s
foot	ft
gallon	gal
inch	in
mile	mi
nautical mile	nmi
ounce	oz
pound	lb
quart	qt
yard	yd
Time and temperature	
day	d
degrees Celsius	°C
degrees Fahrenheit	°F
degrees kelvin	K
hour	h
minute	min
second	s
Physics and chemistry	
all atomic symbols	
alternating current	AC
ampere	A
calorie	cal
direct current	DC
hertz	Hz
horsepower	hp
hydrogen ion activity (negative log of)	pH
parts per million	ppm
parts per thousand	ppt, ‰
volts	V
watts	W

General	
Alaska Administrative Code	AAC
all commonly accepted abbreviations	e.g., Mr., Mrs., AM, PM, etc.
all commonly accepted professional titles	e.g., Dr., Ph.D., R.N., etc.
at	@
compass directions:	
east	E
north	N
south	S
west	W
copyright	©
corporate suffixes:	
Company	Co.
Corporation	Corp.
Incorporated	Inc.
Limited	Ltd.
District of Columbia	D.C.
et alii (and others)	et al.
et cetera (and so forth)	etc.
exempli gratia (for example)	e.g.
Federal Information Code	FIC
id est (that is)	i.e.
latitude or longitude	lat or long
monetary symbols (U.S.)	$, ¢
months (tables and figures): first three letters	Jan,...,Dec
registered trademark	®
trademark	™
United States (adjective)	U.S.
United States of America (noun)	USA
U.S.C.	United States Code
U.S. state	use two-letter abbreviations (e.g., AK, WA)

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

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by
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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF APPENDICES

ABSTRACT

Adaptive resolution imaging sonar (ARIS) 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 1 through October 6, 2019. A total of 45,560 (SE = 274) Chinook salmon were estimated to have passed the sonar site from July 1 through August 14. The midpoint of the Chinook salmon migration occurred on July 26, which was 2 days later than the historical mean date. A total of 101,678 (SE = 544) fall chum salmon were estimated to have passed the sonar site from August 15 through October 6. The fall chum salmon passage estimate was subsequently expanded to a total of 113,256 to include fish that may have passed after operations ceased. The midpoint of the fall chum salmon migration (based on the expanded estimate) occurred on September 25, which was 2 days later than the historical mean date. Drift gillnetting was conducted to collect age, sex, and length samples and tissue samples for genetic information. Species composition was analyzed to determine when the Chinook salmon migration ended, and the fall chum salmon migration began.

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

INTRODUCTION

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

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

Alaska is obligated to manage Canadian-origin Yukon River Chinook and fall chum salmon stocks according to precautionary, abundance-based harvest-sharing principles set by the Yukon River Salmon Agreement (Yukon River Panel 2005). The goal of bilateral, coordinated management is to meet negotiated escapement goals and provide for subsistence and commercial harvests of surplus, in both the United States and Canada. Timely estimates of abundance not only help managers adjust harvest inseason, they are crucial for postseason analysis to determine whether treaty obligations were met. The Canadian Department of Fisheries and Oceans (DFO) provided estimates of mainstem salmon passage across the U.S./Canada border using mark–recapture techniques from 1980 to 2008 (JTC 2019). Because of the highly turbid water of the Yukon River, and the width of the mainstem (approximately 400 m across at the study site) daily passage estimation methods that rely on visual observation, such as counting towers and

[1] Yukoninfo. c1997–2021. PR Services Ltd. https://yukoninfo.com/ (accessed July 1, 2021).

weirs, are not feasible. Split-beam sonar technology is used successfully by the Alaska Department of Fish and Game (ADF&G) to produce daily inseason estimates of salmon passage in turbid rivers, including the lower Yukon River at Pilot Station (Dreese and Lozori 2019). Multi-beam imaging sonar (dual-frequency identification sonar [DIDSON] and adaptive resolution imaging sonar [ARIS]) have been used at several sites including the Anvik (Brodersen 2019) and Teslin Rivers (Mercer 2016) to give daily passage estimates where bottom profiles and river width are appropriate for the wider beam angle and shorter-range capabilities of this technology.

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

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

In 2005, a full-scale sonar project was conducted July 1–August 13 to estimate Chinook salmon passage in the Yukon River at Six Mile Bend (Carroll et al. 2007b). As suggested, DIDSON was deployed on the right bank and split-beam sonar was deployed on the left bank.

In 2015, an ARIS replaced the DIDSON sonar (Lozori and McDougall 2016). This equipment has been used in subsequent years to estimate border passage for both Chinook and fall chum salmon.

The project duration was extended in 2006 to provide an estimate of fall chum salmon passage. There are 2 genetically distinct runs of chum salmon that enter the Yukon River, an early summer component, and a later fall component (Estensen et al. 2018). Summer chum salmon spawn primarily in runoff streams in the lower 700 mi of the Yukon River drainage, and the Tanana River drainage. Fall chum salmon, which migrate past the Eagle sonar project, primarily spawn in the upper portion of the Yukon River drainage in streams that are spring fed or have major upwelling features. Major fall chum salmon spawning areas include the Tanana, Porcupine, and Chandalar River drainages as well as various streams in the Yukon Territory, Canada, including the mainstem Yukon River.

In 2019, the project deployed split-beam and ARIS sonar to estimate Chinook and fall chum salmon migrating across the U.S./Canada border. Sample fisheries were conducted to determine the transition between Chinook and fall chum salmon migrations, and to collect age, sex, and length (ASL) data and tissue samples for genetic stock identification. This report will describe the methods used to collect sonar and sample fishery data, and provide passage estimates, species distributions, and run timing, in addition to climate and hydrologic observations.

OBJECTIVES

The goal of this project in 2019 was to provide daily inseason estimates of Chinook and fall chum salmon migrating across the U.S./Canada border to fishery managers. Primary objectives were as follows:

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

Secondary objectives were as follows:

4. Collect biological data from all fish captured in the sample fisheries, including species, sex, length, and scales, as applicable.
5. Collect Chinook and fall chum salmon tissue samples for genetic stock identification.
6. Collect daily climatic and hydrologic measurements representative of the study area.

METHODS

Chinook and fall chum salmon passage was estimated using split-beam sonar on the left bank and ARIS imaging sonar on the right bank. Both sonars operated continuously, 24 h/d, and sampled 2 horizontal strata per bank, each for 30 min/h (Figure 2). Because of the low proportion of comigrating species, sonar estimates were designated as either Chinook or fall chum salmon. Although Chinook and fall chum salmon migrations are considered discrete in time, some temporal overlap does occur. The transition date between Chinook and fall chum salmon migrations was determined using daily CPUE proportions from the species composition sample fishery that was conducted once per day from August 1 through September 30.

STUDY AREA

The Yukon River Basin is the fourth largest basin in North America, has a drainage area of 857,300 km^2, and an average annual discharge of 6,400 m^3/s. Flows are highest in June, but the greatest flow variability occurs in May, after which discharge and the variability in discharge decline. The upper Yukon River is turbid and silty throughout the summer and fall, and the estimated annual suspended sediment load at Eagle is 33,000,000 tons (Brabets et al. 2000).

The study area was located on the mainstem of the Yukon River at Six Mile Bend (64°52′23.8″N, 141°04′45.12″W), approximately 11.5 km downriver from Eagle, Alaska (Figure 3). The Yukon River is approximately 400 m wide at the study site. The left bank profile is linear, extending approximately 300 m to the thalweg with a gradual slope of approximately 3°. The right bank profile is less linear, shorter, and steeper, extending approximately 100 m to the thalweg with a slope of approximately 9° (Figure 4). The thalweg is approximately 11 m deep, depending on the water level. The substrate at Six Mile Bend is large cobble to small boulder on the right bank and small to medium sized cobble and silt on the left bank. Both banks have been observed to have stable bottom profiles throughout the history of the project.

HYDROACOUSTIC EQUIPMENT

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

An ARIS imaging sonar, manufactured by Sound Metrics Corporation, was deployed on the right bank. The sonar operated at 1.2 MHz (high frequency) for the nearshore stratum and 0.70 MHz (low frequency) for the offshore stratum (Table 2). During periods of high silt, the nearshore stratum was operated at low frequency. Both the low and high frequency modes utilize 48 beams and have a field of view of 28°.

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

SONAR DEPLOYMENT AND OPERATION

River bottom profiles were checked before transducer deployment to ensure the sonar sites remained acceptable for ensonification. Profile data were collected using a boat-mounted Lowrance LCX-15 dual-frequency transducer (down-looking sonar) with a built-in global positioning system (GPS). Data files were then uploaded to a computer and used to generate bottom profile charts (Figure 4).

The split-beam transducer was attached to 2 Hydroacoustic Technology Incorporated (HTI) model 662H single-axis rotators, configured perpendicularly to provide dual-axis rotation. Aiming was performed remotely using an HTI model 660 remote control unit that provided horizontal and vertical positioning. Operators adjusted the aim by viewing the echogram in either the ER60 program or Echotastic. A proper aim was achieved when adequate substrate appeared over a majority of the ensonified range.

The split-beam sonar was deployed from July 1 through October 6 on the left bank, approximately 800 m downriver from the camp (Figure 3). The transducer and rotators were mounted on a freestanding frame constructed of aluminum pipe and deployed approximately 15 m from shore (Figure 5). Transducer height was adjusted by sliding a mounting bar up or down along riser pipes that extended above the water. The transducer was deployed at a depth of approximately 1.5 m and aimed perpendicular to the current at a location with consistent flow and no slack water. When counting Chinook salmon, the split-beam system was configured to ensonify a range of 150 m from the transducer and sampled 2 strata (S1: 0–50 m and S2: 50–150 m; Figure 2). When counting fall chum salmon, the split-beam system was configured to ensonify a range of 75 m and sampled 2 strata (S3: 0–25 m and S4: 25–75 m).

A portable tripod-style fish lead was constructed approximately 1.5 m downstream from the transducer to prevent fish passage inshore of the transducer and provide sufficient offshore distance for upstream migrating fish to be detected in the sonar beam. Freestanding lead sections were constructed of 1.5-inch diameter steel pipes connected with adjustable fittings to form tripods. Aluminum stringers, approximately 2.5 m long, were attached horizontally to the upstream side of the tripods. Vertical lengths of aluminum conduit spaced 3.8 cm apart finished the sections. Depending upon water level, flow, and debris load, lead sections were placed side-by-side in the water from shore to 3–5 m offshore beyond the transducer (Figure 6). The portability of this style of fish lead was important because of the gradual slope found on the left bank. As the water level rose and fell throughout the season, the transducer and lead required frequent relocation to maintain their depth in the water column.

The ARIS was mounted to a Sound Metrics ARIS Rotator AR2, and controlled by ARIScope software, which provided horizontal and vertical positioning. Aiming was performed remotely using a laptop computer. Operators adjusted the aim by viewing the video image for each stratum. A proper aim was achieved when adequate substrate appeared over a majority of the ensonified range.

The ARIS was deployed from July 1 through October 6 on the right bank, approximately 700 m downriver from the camp. The transducer and rotator were mounted on a freestanding aluminum frame similar to the split-beam sonar and deployed approximately 4 m from shore at a depth of approximately 1.5 m (Figure 7). For the duration of the season, the ARIS was configured to ensonify approximately 40 m beginning at 0.7 m from the face of the transducer and sampled 2 strata (S5: 0.7–20.7 m and S6: 20.7–40.7 m; Figure 2).

A fish lead was constructed using 1-inch heavy-duty seine mesh supported by 1-inch PVC pipe. The seine mesh was anchored to the river bottom with heavy chain sewn along its length, which followed the contours of the substrate. Additional flotation for the upper edge was provided by gillnet floats sewn in along the top of the mesh approximately every 1 m. The top edge of the lead, including the gillnet floats, was designed to sit just below the surface of the water to allow for most floating debris to pass overtop (Figure 6). The fish lead was located approximately 1 m downstream of the transducer and extended 2–3 m offshore beyond the transducer. This distance provided sufficient offshore diversion for fish migrating upstream to be detected in the sonar beam. A shorter lead was appropriate for this bank because of the steep slope and the shorter near field view of the ARIS (approximately 0.7 m).

SONAR DATA PROCESSING AND PASSAGE ESTIMATION

Operators opened each data file in Echotastic and marked each upstream fish track (Figures 8 and 9). The counts were saved as text files and manually recorded on a count form. The upstream direction of travel was verified in Echotastic using the video (ARIS files only) or by the color gradation of the fish track when echoes were colored by a horizontal angle (ARIS and split-beam files).

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

$$\hat{y}_{ds} = 24 \cdot \frac{\sum_{p-1}^{n} \frac{y_{dsp}}{h_{dsp}}}{n_{ds}} , \qquad (1)$$

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

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

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

where n_{ds} is the number of samples in the day (typically 24), f_{ds} is the fraction of the day sampled (12/24 = 0.5 when no downtime), and y_{dsp} is the hourly count for day (d) in stratum (s) for sample (p). Assuming passage estimates are independent between strata and among days, the total variance was estimated as the sum of the variances:

$$\widehat{V}ar\left(\hat{y}\right) = \sum_d \sum_s \widehat{V}ar\left(\hat{y}_{ds}\right). \qquad (3)$$

MISSING DATA

Estimating daily passage by multiplying the average hourly passage rates by 24 (Equation 1) compensates for missing data (either shortened or missing periods within a day) and is reflected in the variance (Equation 2) by reducing the number of samples and the fraction of the day sampled. If 1 or more days were missed, then daily passage was interpolated by averaging passage estimates from days before and after the missing day(s) as follows:

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

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

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

Because project operations ceased before the end of the fall chum salmon migration, the estimate was expanded through October 18 using a second-order polynomial equation:

$$y_i = \frac{L}{d^2}(x_i - d)^2, \qquad (5)$$

where y_i is the daily passage estimate on the day (i) of expansion, L is the count on the last day of sonar operation, d is the total number of days expanding for, and x_i is the day number being estimated.

The last day of the fall chum salmon expansion is typically October 18. This date is based on what is considered the most likely run timing scenario derived from historical data (1982–2008) collected at the DFO mark–recapture fish wheel project near the U.S./Canada border.

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

SPATIAL AND TEMPORAL DISTRIBUTIONS

Fish range distributions for Chinook and fall chum salmon were examined by importing text files containing all fish track information into *R* (*R* Development Core Team 2019)[2] where the fish counts were binned by range. The binned data were plotted to monitor the spatial distribution of fish passing the sonar site. Histograms of passage by hour were also created to investigate diel patterns of migration. Chinook and fall chum salmon run timing was examined both inseason and postseason using information from the sonar estimate, fish range distribution, sample fishery catches, and local subsistence harvest.

SAMPLE FISHING

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

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[2] R Development Core Team. 2019. *R*: A language and environment for statistical computing. *R* Foundation for Statistical Computing, Vienna, Austria. Available for download: http://www.R-project.org (accessed 2019).

Chinook salmon sampling occurred from 0800–1200 and 1300–1700 through July 31. The fishery specifically targeted Chinook salmon, which is the predominant species during June and July. From August 1 through August 15, Chinook salmon sampling occurred from 1300 to 1700 each day.

ASL and genetic samples were collected using 4 different mesh sizes (5.25, 6.5, 7.5, and 8.5 inches) that were drifted in a rotating schedule throughout the Chinook salmon sample fishery to effectively capture all size classes present (Table 3). Nets were 25 fathoms long, approximately 8 m deep, and hung "even" at a 2:1 ratio of web to corkline (Table 4). Nets were drifted for approximately 6 minutes each within the left bank nearshore (LBN), left bank offshore (LBF), and right bank nearshore (RBN) zones. The right bank zone was located approximately 2.5 km upriver from the sonar site where river conditions were suitable for drift gillnetting on that bank (Figure 3). This resulted in 9 drifts during each Chinook salmon sample fishing period.

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

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

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

$$e_{dzlm} = \frac{25t_{dzlmj}}{60}. \tag{7}$$

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

Captured fish were identified to species and length was measured to the nearest 1 mm. Salmon species were measured from mid eye to tail fork (METF); nonsalmon species were measured from tip of snout to fork of tail (FL). Sex was recorded only for salmon species and was determined by visual examination of external features, such as the development of the kype, roundness of the belly, presence or absence of an ovipositor, and overall size. This is similar to the sampling routine used on the Kuskokwim River (Froning and Liller 2019). A total of 4 scales from Chinook salmon and 1 scale from fall chum salmon were removed from the preferred area of the fish on the left side approximately 2 rows above the lateral line in an area transected by a diagonal line from the posterior insertion of the dorsal fin to the anterior insertion of the anal fin (Clutter and Whitesel 1956). All scale samples were cleaned, mounted on gum cards, and sent to the ADF&G age determination laboratory in Anchorage for processing.

For genetic stock identification (GSI), an approximately 1 cm^2 section of pelvic fin tissue was collected from each Chinook and fall chum salmon and stored on Whatman cards. All samples were sent to the ADF&G Gene Conservation Laboratory for cataloging and from there, forwarded to the Fisheries and Oceans Canada Molecular Genetics Laboratory in Nanaimo, British Columbia, for processing. ASL and GSI data were paired, and all sampling data were recorded on field data sheets and entered into a Microsoft Access database. Captured fish were handled in a manner that minimized mortalities.

SPECIES DETERMINATION

Inseason, the daily proportions of Chinook and fall chum salmon CPUE from the species composition sample fishery were used to determine the last day of the Chinook salmon migration. The remainder of the passage estimates for the season were then classified as fall chum salmon.

CPUE calculations

CPUE was calculated for each day (*d*) on the left bank (*b*) during species composition fishing using 2 specific sizes of gillnet mesh (*g*), regardless of catch size. Chinook salmon CPUE was calculated using the catch (*c*) and effort (*e*) (calculated in Equation 7) of the large mesh gillnet (7.5 in); fall chum salmon CPUE was calculated using the catch and effort of the small mesh gillnet (5.25 in). Because all nets were 25 fathoms (45.7 m) in length, CPUE estimates (in catch per fathom hour) for each species (*i*) were made daily for the species composition sample fishery using the following formula:

$$CPUE_{dbi} = \frac{\sum_g c_{dbig}}{\sum_g e_{dbg}}. \tag{8}$$

Determination of Chinook and fall chum salmon transition date

The transition from Chinook to fall chum salmon was determined using daily left bank CPUE values for Chinook and fall chum salmon captured in the species composition fishery. The daily CPUE values were smoothed using the function *supsmu* in *R* with the default span (Friedman 1984). The smoothed values were used to compute the estimated daily (*d*) proportions ($\hat{p}$) for the 2 species (*i*) as follows:

$$\hat{p}_{di} = \frac{CPUE_{di}}{\sum_i CPUE_{di}}. \tag{9}$$

The species transition date was defined as the day on which the proportion of fall chum salmon was greater than or equal to 0.5 and was designated as the first day of fall chum salmon estimation.

CLIMATE AND HYDROLOGIC OBSERVATIONS

Climatic and hydrologic observations were collected at approximately 1800 each day. Reported stream levels were taken from the U.S. Geological Survey gauging station at Eagle,[3] although water levels were monitored at the sonar site as well. Surface water temperature was measured approximately 30 cm below the surface using a HOBO U22 water temperature data logger. Data loggers were attached to the sonar transducer pods on each bank and set to record every hour. Air temperature, wind velocity, and wind direction were measured daily using a thermometer and Kestrel handheld wind meter. Other daily observations included the occurrence of precipitation and percent cloud cover.

RESULTS AND DISCUSSION

SONAR DEPLOYMENT

In 2019, both the right and left bank transducers were deployed in approximately the same locations used in recent years (Figure 3). Overall, there were no significant problems with project operations and both sonars performed well the entire season. Occasionally, water level fluctuations and debris made it necessary to move the transducers and fish leads to deeper or shallower water; however, this is not uncommon and did not affect sonar operation. The sonar operated continuously from July 1 through October 6 and achieved the primary project objective.

CHINOOK AND FALL CHUM SALMON PASSAGE ESTIMATION

In season, August 14 was determined to be the last day of the Chinook salmon migration based on CPUE analysis from the species composition sample fishery (Figures 10 and 11; Appendix A1).

The total passage estimate for Chinook salmon was 45,560 (SE = 274) between July 1 and August 14 (Table 5). The first quarter-point of the run was July 20, the midpoint was July 26, and the third quarter-point was August 1 (Table 6). The midpoint of the Chinook salmon run occurred 2 days late compared to the 2005–2018 mean run timing[4] (Figure 12). Chinook salmon passage peaked on July 22 with a daily estimate of 2,326 fish. A total of 282 Chinook salmon were estimated to have passed the sonar on August 14, which was the last day of the Chinook salmon season (Figure 13). Sonar sampling time missed during the Chinook salmon migration varied by stratum and totals ranged between 11.5 hours and 22.2 hours (Table 7). Most time missed was due to generator failures and routine moving and re-aiming of the sonar because of changes in water level.

The total passage estimate for fall chum salmon was 101,678 (SE = 544) fish from August 15 through October 6 (Table 5). Because the fall chum salmon migration continued after project operations ceased, the passage estimate was expanded through October 18 to a total of 113,256 fish. Based on the expanded passage estimate, the first quarter-point of the run was September 16, the midpoint was September 25, and the third quarter-point was October 2 (Table 8). The midpoint of the fall chum salmon run occurred 2 days late compared to the

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[3] USGS (U.S. Geological Survey). National Water Information System: Web Interface. USGS 15356000 Yukon River at Eagle Alaska. http://waterdata.usgs.gov/ak/nwis/inventory/?site_no=15356000&agency_cd=USGS&amp (accessed December 2019).

[4] Differences in the species transition date from year to year confound computation of the historical daily cumulative and mean. As a convenience, the historical daily cumulative percent and mean were computed by assuming that 100% of the run was completed on the date the Chinook salmon run transitioned to fall chum salmon.

2006–2018 mean run timing[5] (Figure 12). Fall chum salmon passage peaked on September 30 with a daily estimate of 4,277 fish and a total of 3,295 fall chum salmon were estimated to have passed the sonar on October 6, the last day of sonar operation (Figure 13). Sonar sampling time missed during the fall chum salmon migration varied by stratum and totals ranged between 20.3 hours and 25.6 hours (Table 9). Most time missed was due to generator failures, routine moving, re-aiming the ARIS because of changes in water level, and routine cleaning of the ARIS.

The river bottom profile remained similar to previous seasons and was acceptable for fish detection throughout the 2019 season. Water levels and silt did not affect fish detection and overall, the project ran smoothly with few breaks in operation.

SPATIAL AND TEMPORAL DISTRIBUTION

Fish were shore-oriented on both banks (Figures 14 and 15). During the Chinook salmon migration, 95% of fish were detected within 50 m of the transducer on the left bank and 95% of fish were detected within 15 m of the transducer on the right bank. During the fall chum salmon migration, 95% of fish were detected within 20 m of the transducer on the left bank and 95% of fish were detected within 15 m of the transducer on the right bank. The objective of operating side-looking split-beam and imaging sonar such that 95% of the migrating salmon were detected within three-quarters of the ensonified range was achieved during both the Chinook and fall chum salmon migrations. Left bank passage was 75% (34,078) Chinook salmon and 46% (46,466) fall chum salmon.

Analysis of hourly sonar passage rates during the Chinook salmon migration showed a diel migration pattern on the right bank with a decrease in passage from 1000 to 1800 hours (Figure 16). However, when both banks were combined, this pattern was no longer evident. A diel migration pattern was also observed for fall chum salmon on the right bank, with an increase in passage from 0700 to 2000 hours (Figure 17). When both banks were combined, this pattern was still evident but less pronounced.

SAMPLE FISHING

Chinook salmon sample fishing occurred from July 1 through August 15 and species composition and fall chum salmon sample fishing occurred from August 1 through September 30. A total of 638 Chinook salmon (including 10 recaptures) and 375 fall chum salmon (including 23 recaptures) were captured in drift gillnets between July 1 and September 30 (Table 10). A total of 7 sheefish *Stenodus leucichthys*, 3 broad whitefish *Coregonus nasus*, 1 burbot *Lota lota*, 2 longnose sucker *Catostomus catostomus*, 2 northern pike *Esox lucius*, and 3 arctic grayling *Thymallus arcticus* were also captured in the sample fisheries.

A total of 1,997 fathom-hours were fished in the Chinook salmon sample fishery, and 2,044 fathom-hours were fished in the species composition and fall chum salmon sample fishery (Tables 11 and 12). The cumulative CPUE for Chinook salmon was slightly above the 2007–2018 mean, whereas the cumulative CPUE for fall chum salmon was below the 2007–2018 mean (Figure 18).

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[5] Differences in the species transition date from year to year confound computation of the historical daily cumulative and mean. As a convenience, the historical daily cumulative percent and mean were computed by assuming that 100% of the Chinook run was completed on the date the Chinook salmon run transitioned to fall chum salmon.

Excluding recaptures, Chinook salmon sampled included 330 (53%) males and 298 females. Fall chum salmon sampled included 206 (59%) males and 146 females. Clipped adipose fins were observed on 3 Chinook salmon, which indicated they held coded wire tags from the hatchery in Whitehorse, Yukon Territory. Fish with adipose fin clips were noted in the field data and released after sampling.

A total of 628 Chinook and 352 fall chum salmon were sampled for ASL and genetic data. Of the scales collected, 554 Chinook and 311 fall chum salmon were analyzed as ageable. ASL analysis will be performed by the ADF&G stock biology program and reported in a separate manuscript (e.g., similar to Eaton 2016). Goals to collect biological data from all fish captured in the sample fisheries, including species and ASL, as applicable, and GSI tissue samples for Chinook and fall chum salmon, were achieved.

CLIMATE AND HYDROLOGIC OBSERVATIONS

Weather and water observations were recorded at the sonar site daily (Appendix B1). The water temperature on the left bank fluctuated, but in general, decreased throughout the season (Figure 19). The maximum water temperature observed was 19.0°C on July 8 and July 23 and the minimum was 5.4°C on October 5. The water level was below the 1995–2018 median the entire season (Figure 20). The water level dropped below the historical minimum on July 1 and from July 7 through July 9. All goals to collect climatic and hydrologic measurements were achieved this season.

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TABLES AND FIGURES

Table 1.–Split-beam sonar system settings at the Eagle sonar project on the Yukon River, 2019.

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

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

Table 2.–Technical specifications and settings for the adaptive resolution imaging sonar (ARIS) at the Eagle sonar project on the Yukon River, 2019.

Setting	Stratum[a]	Value
Mode	S5	Identification
	S6	Detection
Frequency (MHz)	S5	1.2
	S6	0.7
Number of beams	S5	48
	S6	48
Start range (m)	S5	0.7
	S6	20.7
End range (m)	S5	20.7
	S6	40.7
Frame rate (frames/s)	S5	6
	S6	4
Duration (min)	S5, S6	30
Field of view (degrees)	S5, S6	28

[a] The 2 ARIS sampling strata (S5: 0.7–20.7 m and S6: 20.7–40.7 m) were independently aimed using a Sound Metrics ARIS Rotator AR2 and ARIScope software.

Table 3.–Net schedule of mesh sizes (inch) used for Chinook salmon sample fishing and species composition and fall chum salmon sample fishing for all zones at the Eagle sonar project on the Yukon River, 2019.

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

Table 4.–Specifications for drift gillnets used for sample fishing at the Eagle sonar project on the Yukon River, 2019.

	Stretch mesh size		Mesh diameter	Meshes deep	Depth
Method	(in)	(mm)	(mm)	(MD)	(m)
Drift	5.25	133	85	69	8.00
	6.50	165	105	55	7.90
	7.50	191	121	48	8.00
	8.50	216	137	43	8.10
Beach walk	5.25	133	85	26	3.00
	7.50	191	121	18	3.00

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

Table 5.–Cumulative fish passage estimates by bank and species with standard errors (SE) and 95% confidence intervals (CI), at the Eagle sonar project on the Yukon River, 2019.

			Total		95% CI	
Species	Left bank	Right bank	passage	SE	Lower	Upper
Chinook	34,078	11,482	45,560	274	45,023	46,097
Fall chum (excluding expansion[a])	46,466	55,212	101,678	544	100,612	102,744
Fall chum (including expansion[a])	49,267	63,990	113,256	544	112,190	114,323

[a] The last day of sonar operation was October 6. Because sonar operations ceased before the end of the fall chum salmon migration, estimates were expanded through October 18.

Table 6.–Estimated daily and cumulative Chinook salmon passage by bank at the Eagle sonar project on the Yukon River, 2019.

	Daily				Cumulative			
Date	Left bank	Right bank	Total	SE	Left bank	Right bank	Total	Proportion
07/01[a]	81	16	97	17	81	16	97	0.002
07/02	62	58	120	12	143	74	217	0.005
07/03	100	82	182	15	243	156	399	0.009
07/04	140	42	182	13	383	198	581	0.013
07/05	154	68	222	18	537	266	803	0.018
07/06	160	106	266	16	697	372	1,069	0.023
07/07	214	108	322	14	911	480	1,391	0.031
07/08	248	246	494	24	1,159	726	1,885	0.041
07/09	278	140	418	28	1,437	866	2,303	0.051
07/10	296	167	463	29	1,733	1,033	2,766	0.061
07/11	262	163	425	18	1,995	1,196	3,191	0.070
07/12	226	182	408	21	2,221	1,378	3,599	0.079
07/13	347	190	537	25	2,568	1,568	4,136	0.091
07/14	410	213	623	31	2,978	1,781	4,759	0.104
07/15	392	350	742	28	3,370	2,131	5,501	0.121
07/16	460	434	894	34	3,830	2,565	6,395	0.140
07/17	641	456	1,097	43	4,471	3,021	7,492	0.164
07/18	851	376	1,227	47	5,322	3,397	8,719	0.191
07/19	1,073	424	1,497	57	6,395	3,821	10,216	0.224
07/20	887	452	1,339	52	7,282	4,273	11,555	0.254
07/21	1,103	681	1,784	60	8,385	4,954	13,339	0.293
07/22	1,345	981	2,326	74	9,730	5,935	15,665	0.344
07/23	1,341	777	2,118	69	11,071	6,712	17,783	0.390
07/24	1,611	420	2,031	61	12,682	7,132	19,814	0.435
07/25	1,704	316	2,020	55	14,386	7,448	21,834	0.479
07/26	1,409	177	1,586	69	15,795	7,625	23,420	0.514
07/27	1,653	88	1,741	63	17,448	7,713	25,161	0.552
07/28	1,597	258	1,855	54	19,045	7,971	27,016	0.593
07/29	1,756	386	2,142	55	20,801	8,357	29,158	0.640
07/30	1,874	396	2,270	38	22,675	8,753	31,428	0.690
07/31	1,559	268	1,827	59	24,234	9,021	33,255	0.730
08/01	1,704	174	1,878	51	25,938	9,195	35,133	0.771
08/02	1,495	228	1,723	52	27,433	9,423	36,856	0.809
08/03	1,251	318	1,569	51	28,684	9,741	38,425	0.843
08/04	1,001	326	1,327	45	29,685	10,067	39,752	0.873
08/05	839	338	1,177	35	30,524	10,405	40,929	0.898
08/06	731	270	1,001	37	31,255	10,675	41,930	0.920
08/07	588	143	731	30	31,843	10,818	42,661	0.936

-continued-

Table 6.–Page 2 of 2.

	Daily				Cumulative			
Date	Left bank	Right bank	Total	SE	Left bank	Right bank	Total	Proportion
08/08	536	96	632	27	32,379	10,914	43,293	0.950
08/09	458	79	537	26	32,837	10,993	43,830	0.962
08/10	339	68	407	22	33,176	11,061	44,237	0.971
08/11	274	104	378	19	33,450	11,165	44,615	0.979
08/12	230	127	357	23	33,680	11,292	44,972	0.987
08/13	206	100	306	16	33,886	11,392	45,278	0.994
08/14[b]	192	90	282	16	34,078	11,482	45,560	1.000
Total	34,078	11,482	45,560					
Var	56,819	18,398	75,217					
SE	238	136	274					

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

[a] Sonar operational on both banks.

[b] Last day of Chinook salmon estimation.

Table 7.–Sampling time, in minutes, missed by bank, stratum, and date during Chinook salmon sampling at the Eagle sonar project on the Yukon River, 2019.

	Left bank		Right bank	
	Stratum 1 (0–50 m)	Stratum 2 (50–150 m)	Stratum 5 (0.7–20.7 m)	Stratum 6 (20.7–40.7 m)
Date				
07/01	456	480	372	300
07/02	0	0	0	0
07/03	0	0	0	0
07/04	0	0	0	0
07/05	0	0	0	0
07/06	0	0	0	0
07/07	0	0	30	0
07/08	0	0	0	0
07/09	30	6	126	60
07/10	0	0	90	60
07/11	0	0	30	36
07/12	0	0	0	6
07/13	0	0	0	0
07/14	0	0	30	0
07/15	0	0	0	0
07/16	0	0	24	0
07/17	0	0	0	0
07/18	0	0	30	60
07/19	0	0	0	0
07/20	0	0	6	0
07/21	0	0	0	0
07/22	0	0	72	66
07/23	0	0	0	0
07/24	0	0	138	150
07/25	0	30	12	6
07/26	0	0	12	6
07/27	0	0	0	0
07/28	0	0	0	0
07/29	0	0	0	0
07/30	0	0	0	0
07/31	0	0	0	0
08/01	0	0	0	6
08/02	0	0	0	0
08/03	0	0	0	0
08/04	0	0	0	0
08/05	0	0	0	0
08/06	0	0	0	0
08/07	66	90	78	90
08/08	96	120	108	90
08/09	0	0	6	0
08/10	30	30	18	60
08/11	0	0	6	0
08/12	12	60	42	42
08/13	0	0	0	0
08/14	0	0	102	120
Total (min)	690	816	1,332	1,158
Total (h)	11.5	13.6	22.2	19.3

Table 8.–Estimated daily and cumulative fall chum salmon passage by bank at the Eagle sonar project on the Yukon River, 2019.

	Daily				Cumulative			
Date	Left bank	Right bank	Total	SE	Left bank	Right bank	Total	Proportion
08/15[a]	194	74	268	15	194	74	268	0.002
08/16	178	72	250	19	372	146	518	0.005
08/17	168	34	202	15	540	180	720	0.006
08/18	134	44	178	16	674	224	898	0.008
08/19	98	32	130	10	772	256	1,028	0.009
08/20	92	14	106	9	864	270	1,134	0.010
08/21	104	34	138	13	968	304	1,272	0.011
08/22	116	56	172	10	1,084	360	1,444	0.013
08/23	106	46	152	15	1,190	406	1,596	0.014
08/24	110	88	198	14	1,300	494	1,794	0.016
08/25	150	71	221	12	1,450	565	2,015	0.018
08/26	186	96	282	14	1,636	661	2,297	0.020
08/27	190	94	284	17	1,826	755	2,581	0.023
08/28	219	128	347	22	2,045	883	2,928	0.026
08/29	266	136	402	18	2,311	1,019	3,330	0.029
08/30	318	127	445	23	2,629	1,146	3,775	0.033
08/31	310	154	464	24	2,939	1,300	4,239	0.037
09/01	300	106	406	24	3,239	1,406	4,645	0.041
09/02	332	116	448	19	3,571	1,522	5,093	0.045
09/03	310	86	396	21	3,881	1,608	5,489	0.048
09/04	292	102	394	19	4,173	1,710	5,883	0.052
09/05	384	158	542	30	4,557	1,868	6,425	0.057
09/06	522	160	682	30	5,079	2,028	7,107	0.063
09/07	903	365	1,268	50	5,982	2,393	8,375	0.074
09/08	1,285	538	1,823	52	7,267	2,931	10,198	0.090
09/09	1,721	675	2,396	76	8,988	3,606	12,594	0.111
09/10	1,645	1,018	2,663	86	10,633	4,624	15,257	0.135
09/11	1,888	718	2,606	73	12,521	5,342	17,863	0.158
09/12	2,098	586	2,684	77	14,619	5,928	20,547	0.181
09/13	1,794	765	2,559	64	16,413	6,693	23,106	0.204
09/14	1,505	707	2,212	72	17,918	7,400	25,318	0.224
09/15	1,055	833	1,888	72	18,973	8,233	27,206	0.240
09/16	1,124	899	2,023	80	20,097	9,132	29,229	0.258
09/17	1,195	1,333	2,528	59	21,292	10,465	31,757	0.280
09/18	1,468	1,647	3,115	89	22,760	12,112	34,872	0.308
09/19	1,895	1,539	3,434	96	24,655	13,651	38,306	0.338
09/20	1,739	2,258	3,997	120	26,394	15,909	42,303	0.374
09/21	1,900	1,972	3,872	94	28,294	17,881	46,175	0.408

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Table 8.–Page 2 of 2.

Date	Daily				Cumulative			
	Left bank	Right bank	Total	SE	Left bank	Right bank	Total	Proportion
09/22	1,743	1,810	3,553	90	30,037	19,691	49,728	0.439
09/23	1,349	2,032	3,381	78	31,386	21,723	53,109	0.469
09/24	1,263	1,844	3,107	95	32,649	23,567	56,216	0.496
09/25	1,171	2,062	3,233	89	33,820	25,629	59,449	0.525
09/26	1,028	1,961	2,989	248	34,848	27,590	62,438	0.551
09/27	1,249	2,634	3,883	92	36,097	30,224	66,321	0.586
09/28	1,137	2,901	4,038	110	37,234	33,125	70,359	0.621
09/29	1,329	2,847	4,176	116	38,563	35,972	74,535	0.658
09/30	1,559	2,718	4,277	92	40,122	38,690	78,812	0.696
10/01	1,045	2,906	3,951	106	41,167	41,596	82,763	0.731
10/02	1,317	2,464	3,781	76	42,484	44,060	86,544	0.764
10/03	1,065	2,987	4,052	103	43,549	47,047	90,596	0.800
10/04	1,153	2,947	4,100	107	44,702	49,994	94,696	0.836
10/05	967	2,720	3,687	91	45,669	52,714	98,383	0.869
10/06[b]	797	2,498	3,295	104	46,466	55,212	101,678	0.898
10/07[c]	670	2,099	2,769	NA	47,136	57,311	104,447	0.922
10/08[c]	553	1,735	2,288	NA	47,689	59,046	106,735	0.942
10/09[c]	448	1,405	1,853	NA	48,137	60,451	108,588	0.959
10/10[c]	354	1,110	1,464	NA	48,492	61,561	110,053	0.972
10/11[c]	271	850	1,121	NA	48,763	62,411	111,174	0.982
10/12[c]	199	625	824	NA	48,962	63,036	111,998	0.989
10/13[c]	138	434	572	NA	49,101	63,469	112,570	0.994
10/14[c]	89	278	366	NA	49,189	63,747	112,936	0.997
10/15[c]	50	156	206	NA	49,239	63,903	113,142	0.999
10/16[c]	22	69	92	NA	49,261	63,972	113,233	1.000
10/17[c,d]	6	17	23	NA	49,267	63,990	113,256	1.000
Total	49,267	63,990	113,256					
Var[e]	90,483	205,114	295,597					
SE[e]	301	453	544					

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

a First day of fall chum salmon estimation.

b Last day of sonar operation.

c Expanded passage estimate.

d The last day of the expanded passage was October 18, however, the estimate for that day was 0 and was excluded from this table.

e Variance and standard error calculations include data through October 6, the last day of sonar operation.

Table 9.–Sampling time, in minutes, missed by bank, stratum, and date during fall chum salmon sampling at the Eagle sonar project on the Yukon River, 2019.

	Left bank		Right bank	
	Stratum 3	Stratum 4	Stratum 5	Stratum 6
Date	(0–25 m)	(25–75 m)	(0.7–20.7 m)	(20.7–40.7 m)
08/15	0	0	0	30
08/16	0	0	0	0
08/17	132	120	90	72
08/18	0	0	0	0
08/19	0	0	0	0
08/20	0	0	18	30
08/21	0	0	6	0
08/22	0	0	0	0
08/23	0	0	0	0
08/24	0	0	0	0
08/25	0	0	12	0
08/26	0	0	0	0
08/27	0	0	0	0
08/28	6	0	0	0
08/29	0	0	0	0
08/30	30	30	6	6
08/31	0	0	84	78
09/01	0	0	0	0
09/02	0	0	0	0
09/03	0	0	0	0
09/04	0	0	0	0
09/05	0	0	66	60
09/06	0	0	132	132
09/07	0	0	30	6
09/08	0	0	0	0
09/09	0	0	0	0
09/10	126	138	120	120
09/11	0	0	6	12
09/12	0	0	0	0
09/13	0	0	0	0
09/14	0	0	0	0
09/15	300	12	0	0
09/16	60	66	0	0
09/17	0	0	0	0
09/18	30	48	30	48
09/19	0	0	12	0
09/20	0	0	0	18

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Table 9.–Page 2 of 2.

	Left bank		Right bank	
	Stratum 3	Stratum 4	Stratum 5	Stratum 6
Date	(0–25 m)	(25–75 m)	(0.7–20.7 m)	(20.7–40.7 m)
09/21	0	0	0	0
09/22	0	0	12	0
09/23	0	0	0	0
09/24	0	0	0	0
09/25	0	0	0	0
09/26	420	420	468	456
09/27	0	0	0	0
09/28	0	24	12	42
09/29	0	0	6	30
09/30	0	0	0	0
10/01	0	0	0	24
10/02	0	0	0	0
10/03	0	0	30	12
10/04	0	0	0	0
10/05	0	0	0	0
10/06	360	360	360	360
Total (min)	1,464	1,218	1,500	1,536
Total (h)	24.4	20.3	25.0	25.6

Table 10.–Fish caught with gillnets at the Eagle sonar project on the Yukon River, 2019.

	Sampling purpose		
Species	Species composition and fall chum salmon samples	Chinook salmon samples	Total[a]
Chinook salmon	121	517	638
Fall chum salmon	375	0	375
Sheefish	7	0	7
Broad whitefish	3	0	3
Burbot	1	0	1
Long nose sucker	2	0	2
Northern pike	2	0	2
Arctic grayling	3	0	3
Total	514	517	1,031

[a] Totals include any recaptures.

Table 11.–Fishing effort, catch, and proportion by zone and mesh size for Chinook and fall chum salmon in the Chinook salmon sample fishery at the Eagle sonar project on the Yukon River, 2019.

		Mesh size	Fishing effort	Chinook salmon		Fall chum salmon	
Zone[a]		(in)	(fathom hours)	Catch	Proportion	Catch	Proportion
LBN		5.25	170	118	0.228	0	0
		6.50	184	128	0.248	0	0
		7.50	178	102	0.197	0	0
		8.50	166	69	0.133	0	0
	Total		698	417	0.807	0	0
RBN		5.25	164	17	0.033	0	0
		6.50	169	23	0.044	0	0
		7.50	165	15	0.029	0	0
		8.50	161	15	0.029	0	0
	Total		659	70	0.135	0	0
LBF		5.25	155	5	0.010	0	0
		6.50	166	8	0.015	0	0
		7.50	158	8	0.015	0	0
		8.50	161	9	0.017	0	0
	Total		640	30	0.058	0	0
Grand total			1,997	517	1.000	0	0

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

Table 12.–Fishing effort, catch, and proportion by zone and mesh size for Chinook and fall chum salmon in the species composition and fall chum salmon sample fishery at the Eagle sonar project on the Yukon River, 2019.

	Mesh size	Fishing effort	Chinook salmon		Fall chum salmon	
Zone[a]	(in)	(fathom hours)	Catch	Proportion	Catch	Proportion
LBI	5.25	347	8	0.066	236	0.629
	7.50	326	1	0.008	41	0.109
Total		673	9	0.074	277	0.739
LBN	5.25	350	44	0.364	48	0.128
	7.50	348	47	0.388	42	0.112
Total		698	91	0.752	90	0.240
LBF	5.25	338	11	0.091	6	0.016
	7.50	335	10	0.083	2	0.005
Total		673	21	0.174	8	0.021
Grand total		2,044	121	1.000	375	1.000

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

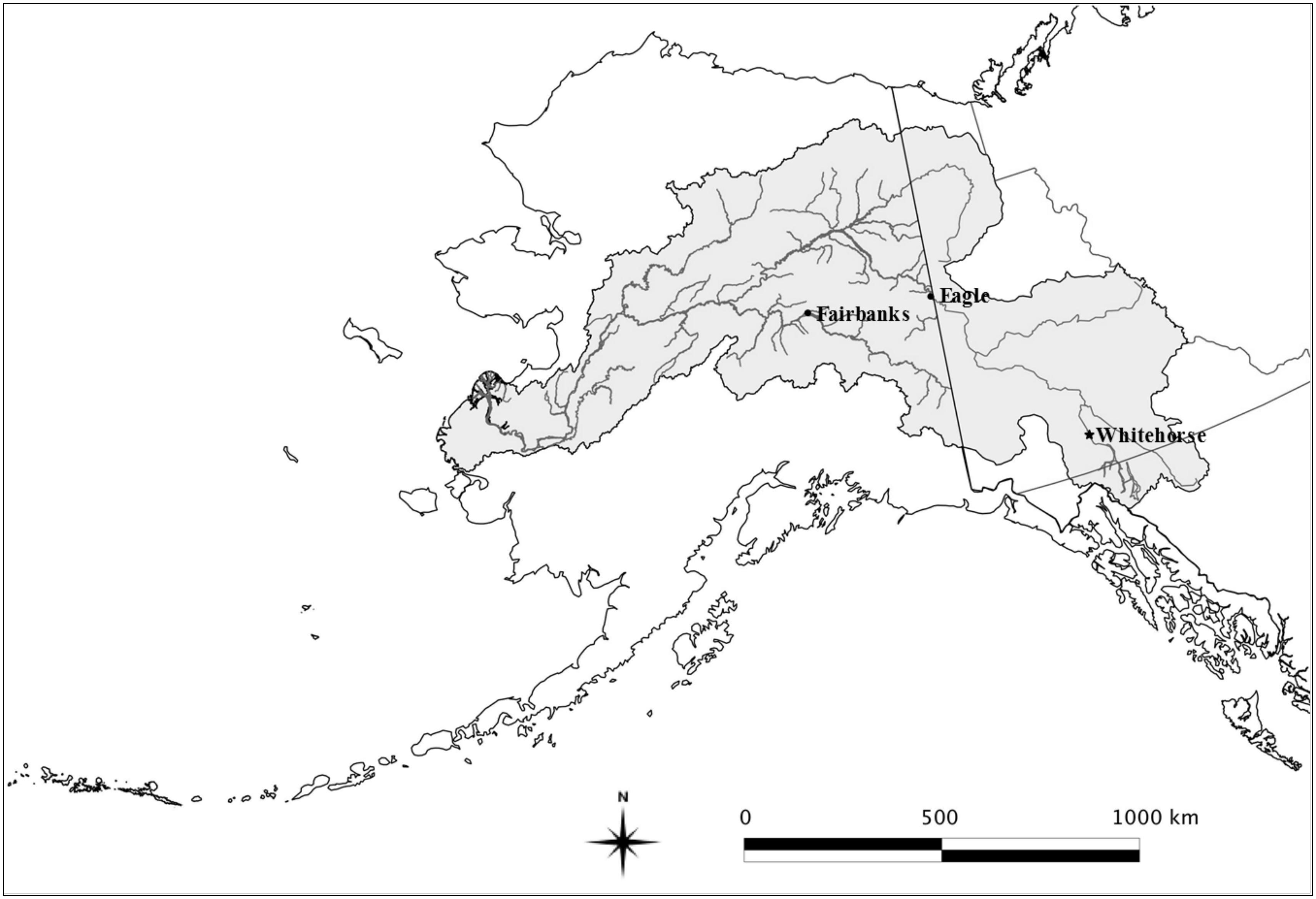


Figure 1.–Yukon River drainage.

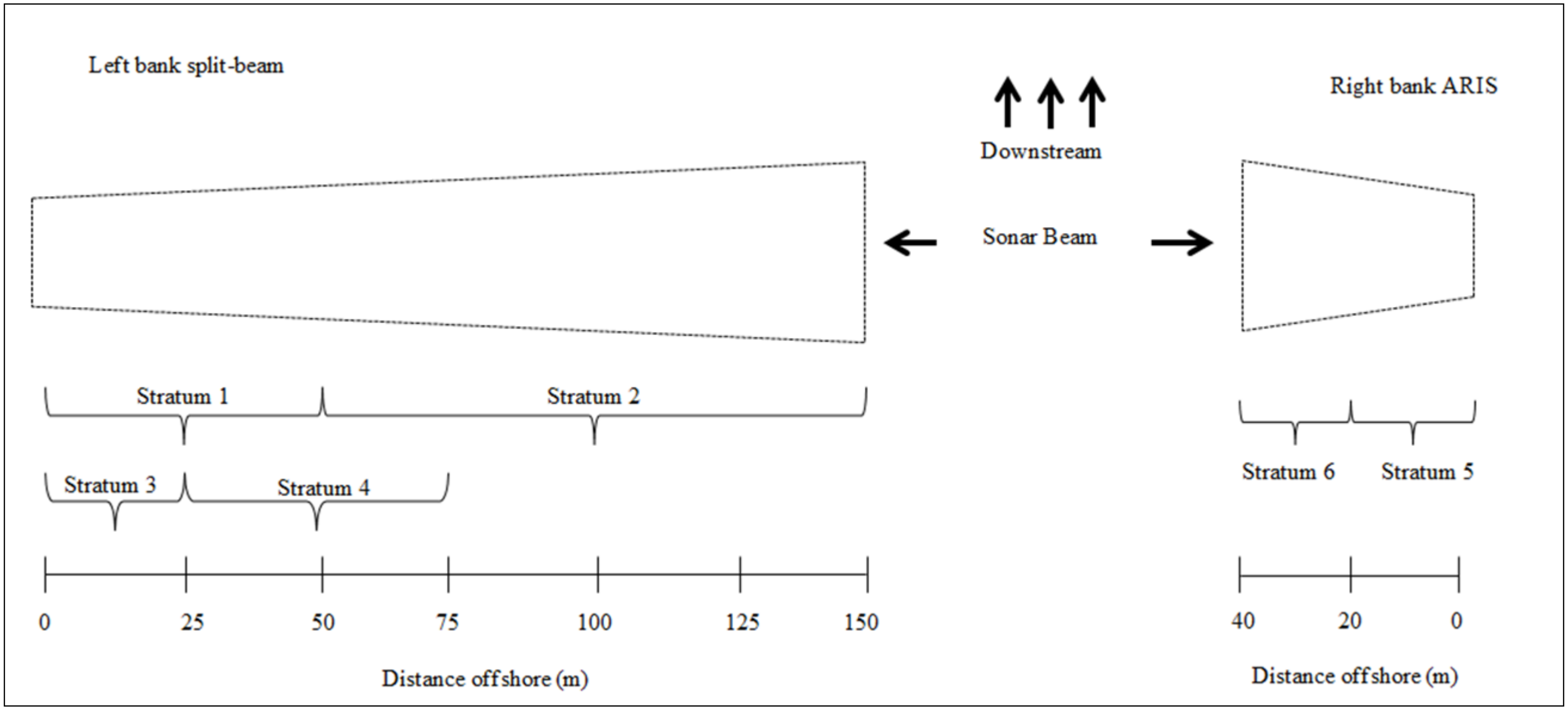


Figure 2.–Illustration of strata and approximate sonar ranges (not to scale) at the Eagle sonar project on the Yukon River, 2019.

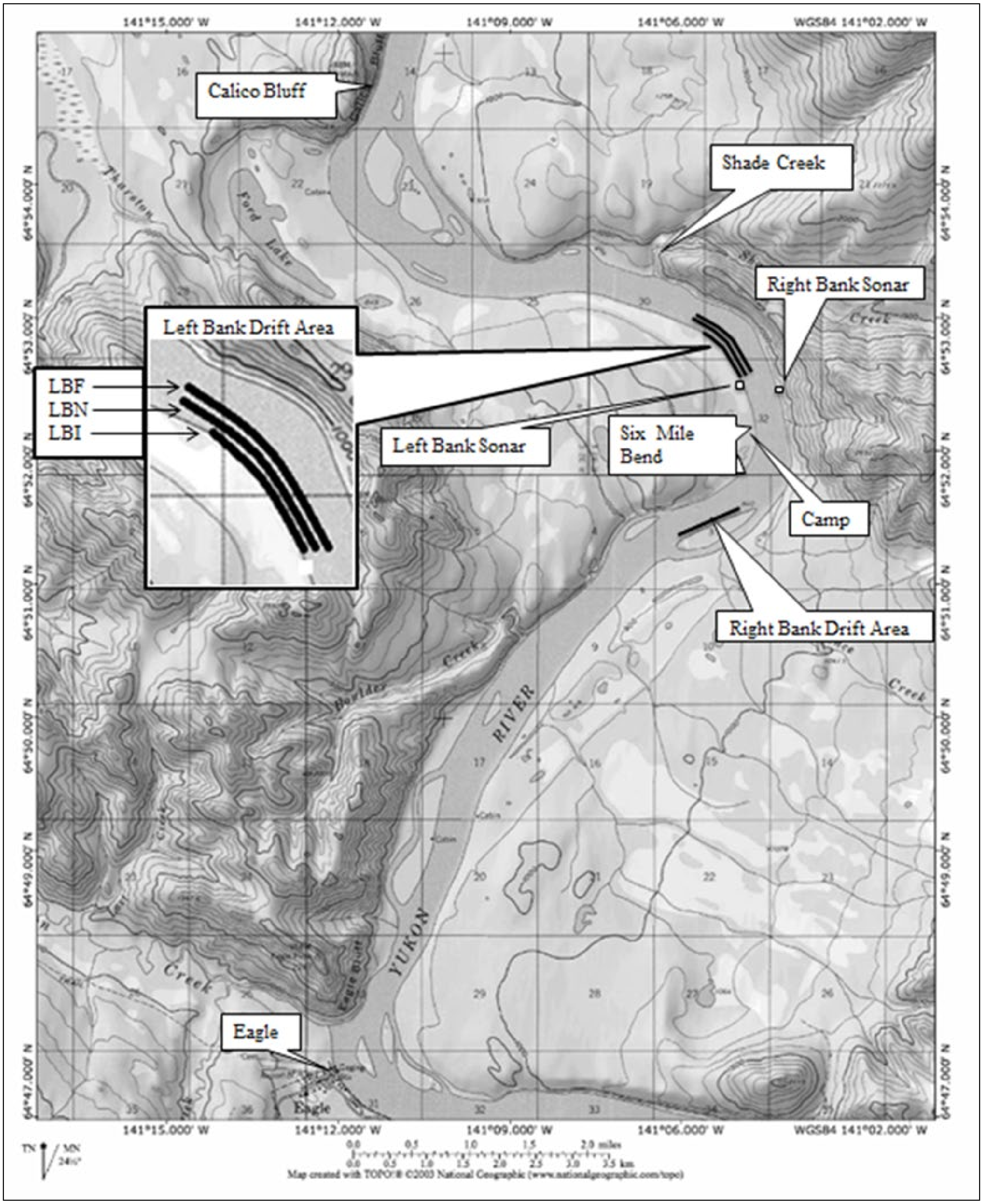


Figure 3.–Eagle sonar project site at Six Mile Bend on the Yukon River showing sonar and drift gillnet fishing locations, 2019.

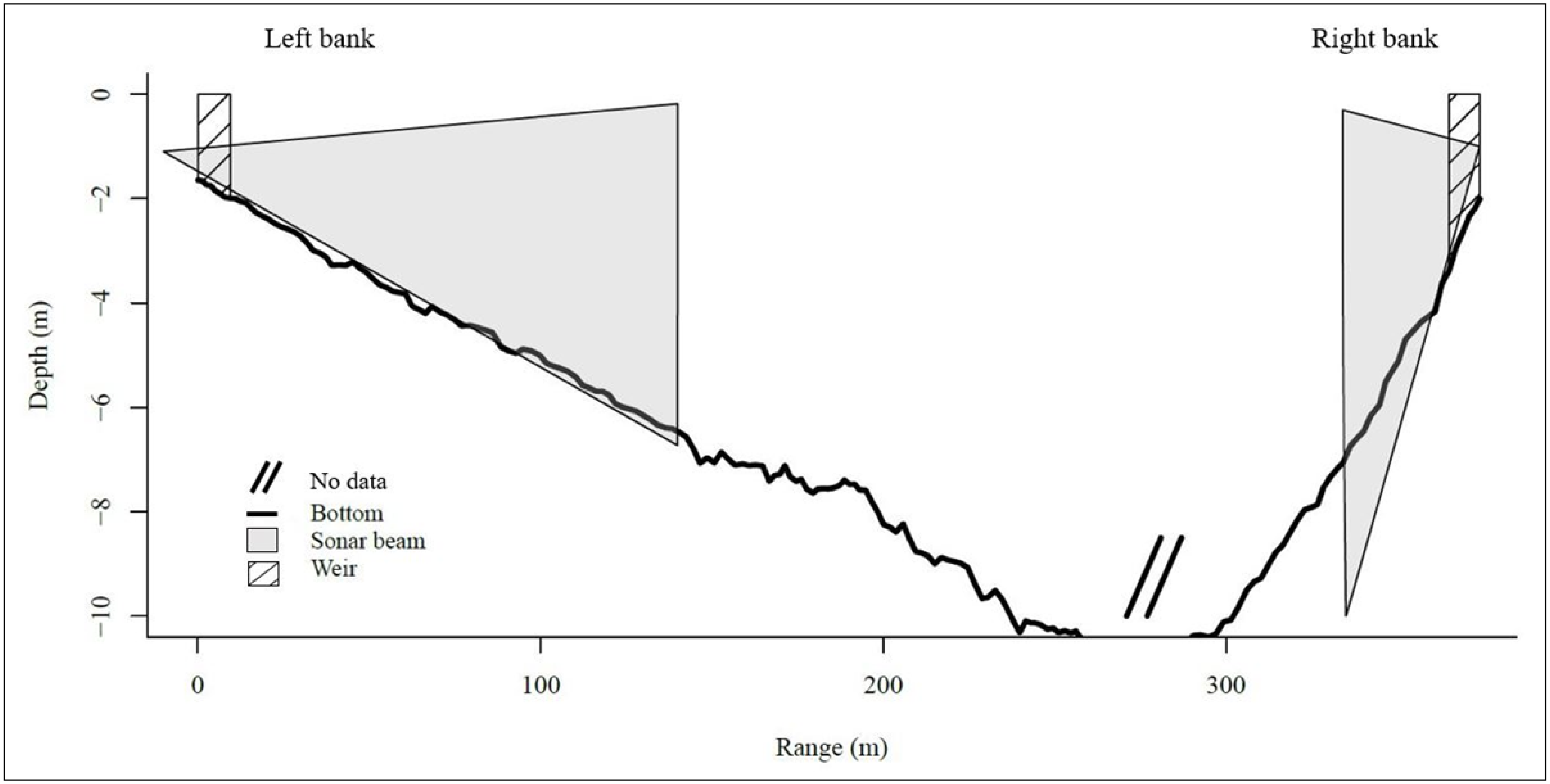


Figure 4.–Depth profile of the Yukon River in front of transducers (looking downstream) and approximate sonar coverage at the Eagle sonar project, 2019.

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

Figure 5.–Split-beam transducer mounted to an aluminum H-mount (top) and the same transducer mounted to 2 single-axis automated rotators (bottom) used on the left bank at the Eagle sonar project on the Yukon River, 2019.

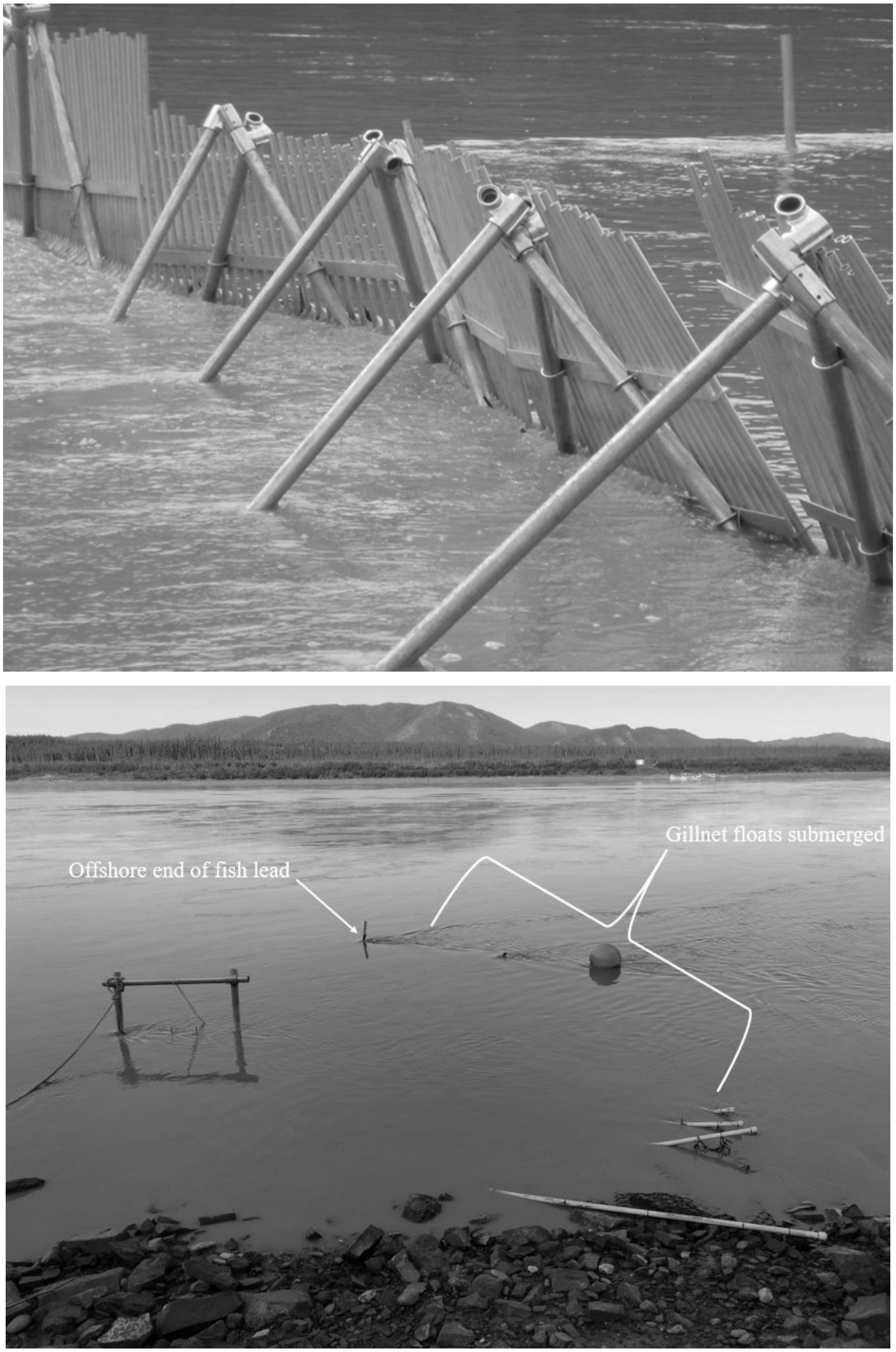


Figure 6.–Portable tripod-style fish lead used on the left bank (top) and seine mesh fish lead used on the right bank (bottom) at the Eagle sonar project on the Yukon River, 2019.

Note: The top edge of the right bank fish lead, including the gillnet floats, was designed to sit just below the surface of the water to allow for most floating debris to pass over the top.

Figure 7.–ARIS imaging sonar and ARIS Rotator AR2 mounted to an aluminum H-mount (top) and close-up view of rotator mount (bottom) at the Eagle sonar project on the Yukon River, 2019.

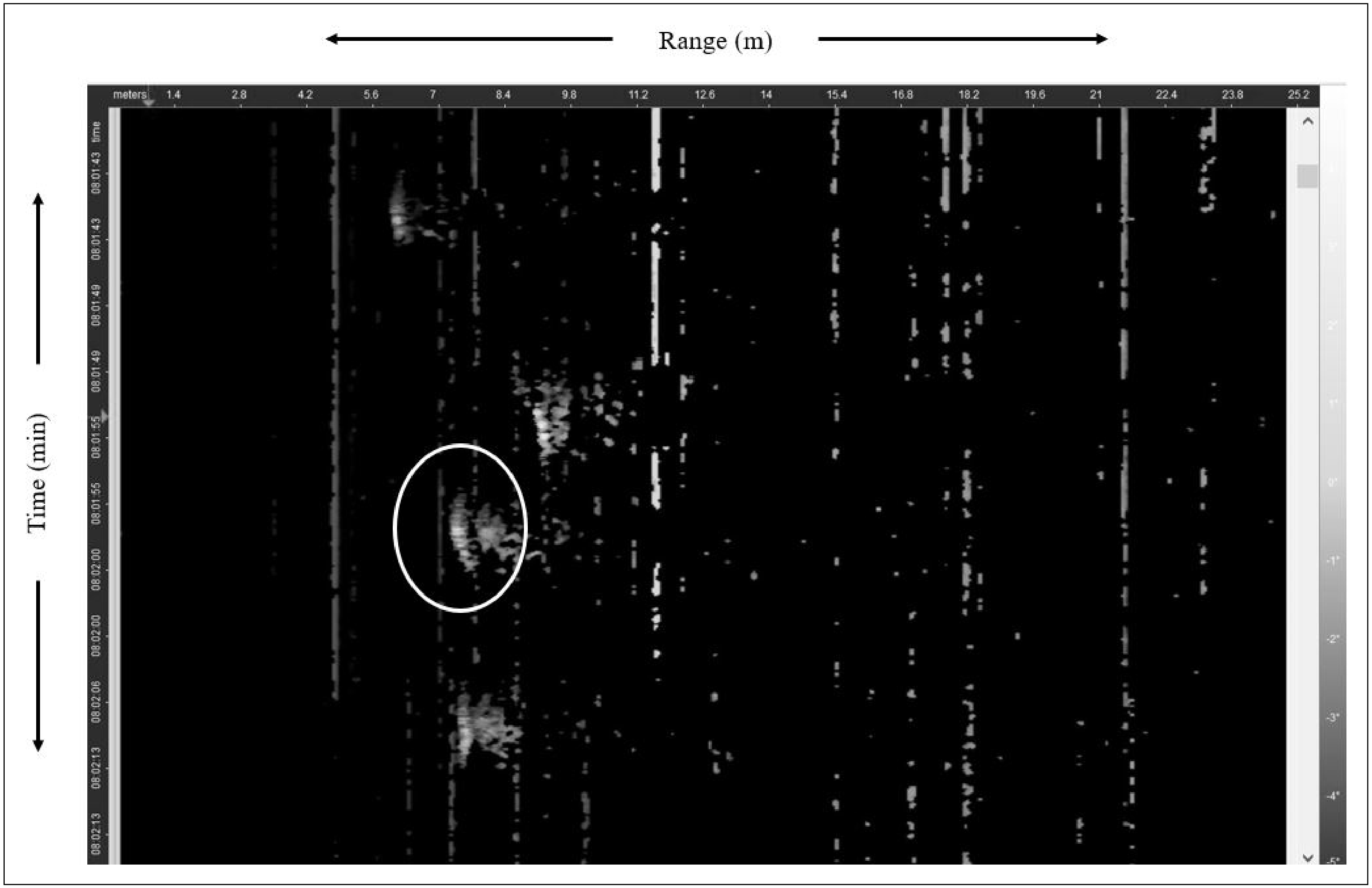


Figure 8.–Screenshot of an echogram from a split-beam sonar data file used to count fish and determine direction of travel at the Eagle sonar project on the Yukon River, 2019.

Note: Ellipse encompasses typical upstream migrating salmon.

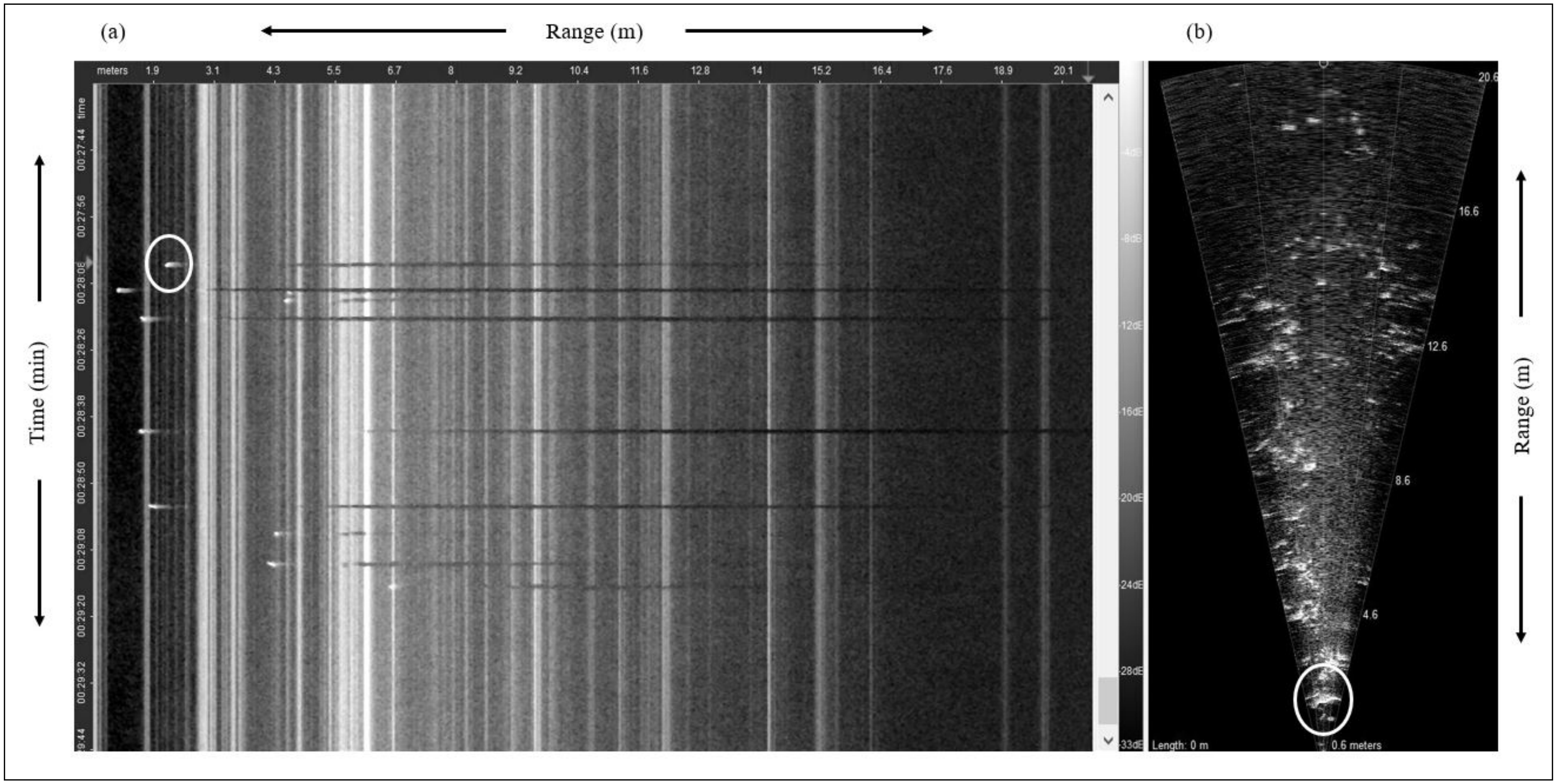


Figure 9.–Screenshots of an echogram (a) and video (b) from an ARIS data file used to count fish and determine direction of travel at the Eagle sonar project on the Yukon River, 2019.

Note: Ellipse encompasses typical upstream migrating salmon.

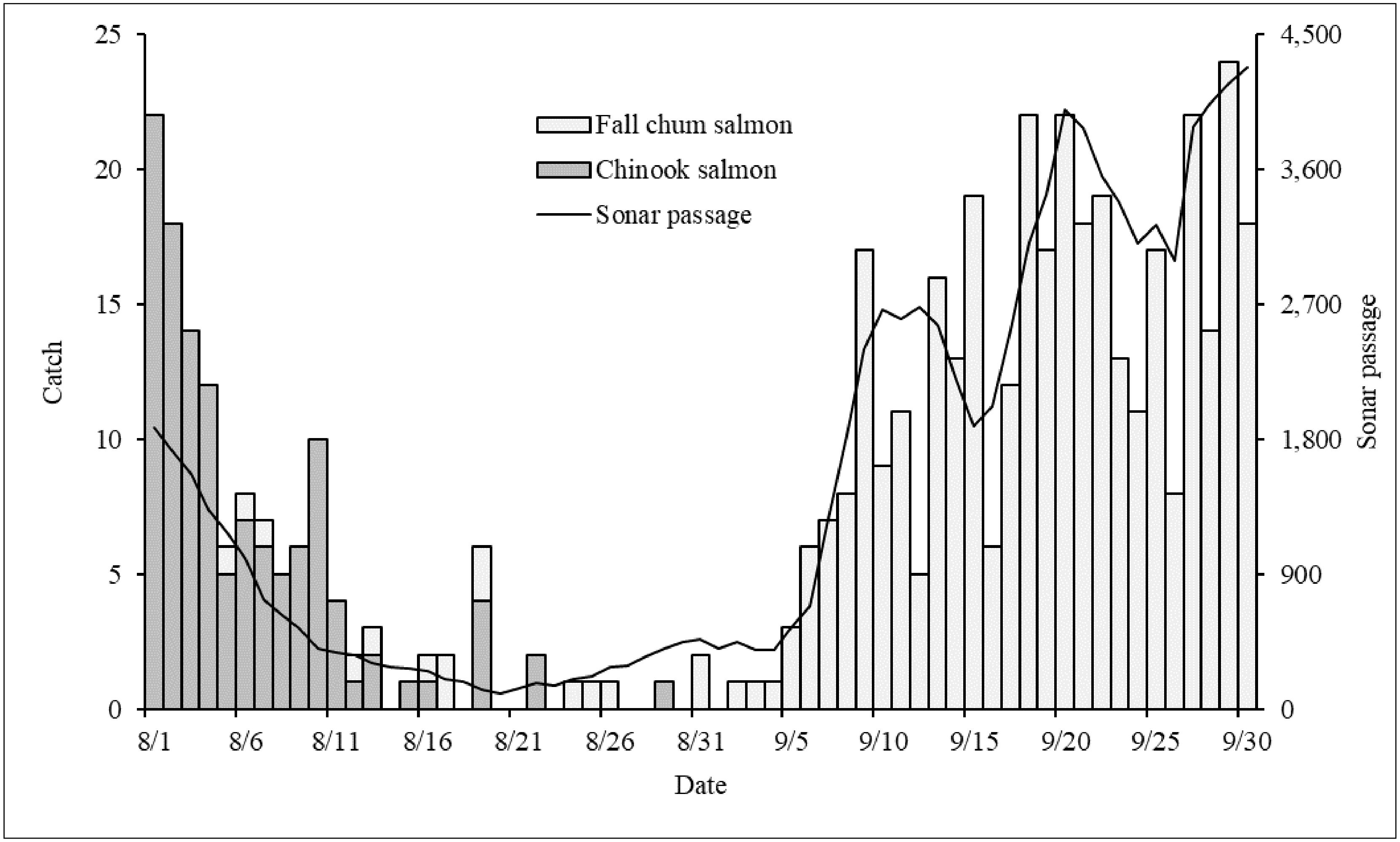


Figure 10.–Daily catch during species composition fishing and sonar passage estimates at the Eagle sonar project on the Yukon River, 2019.

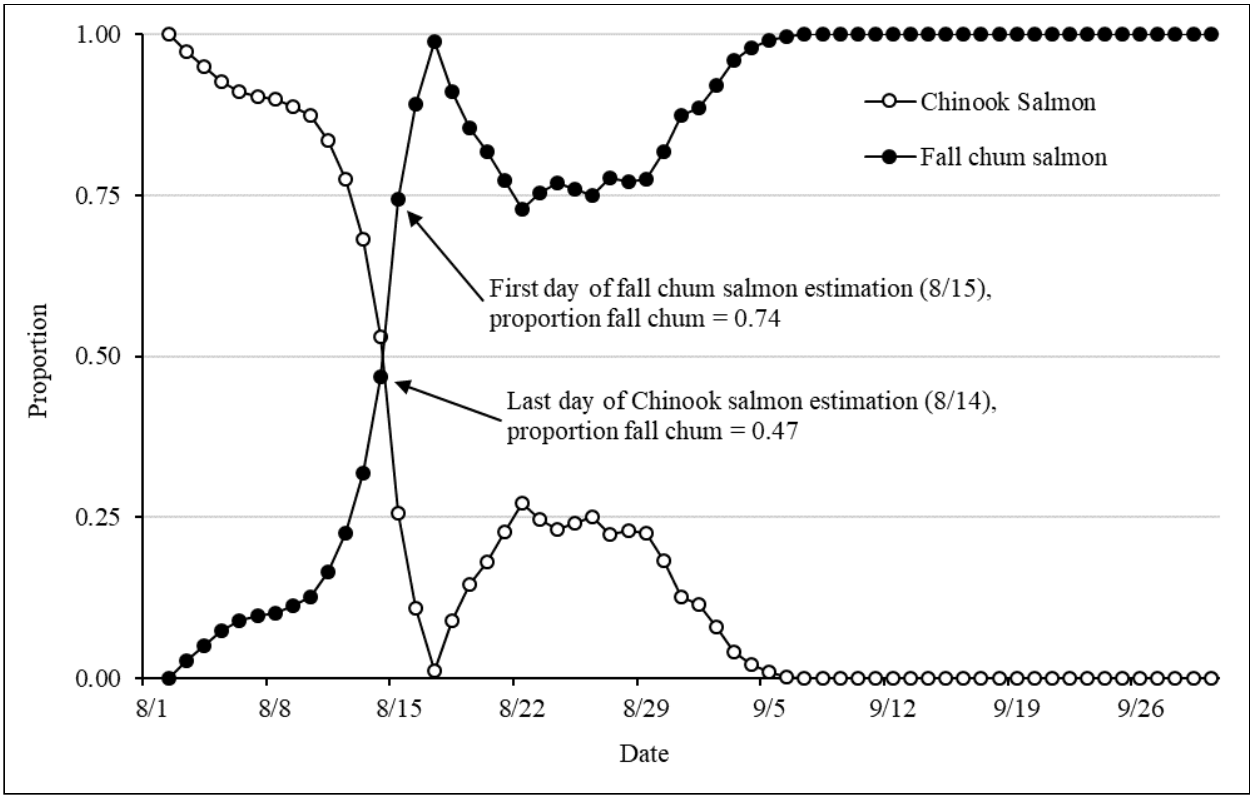
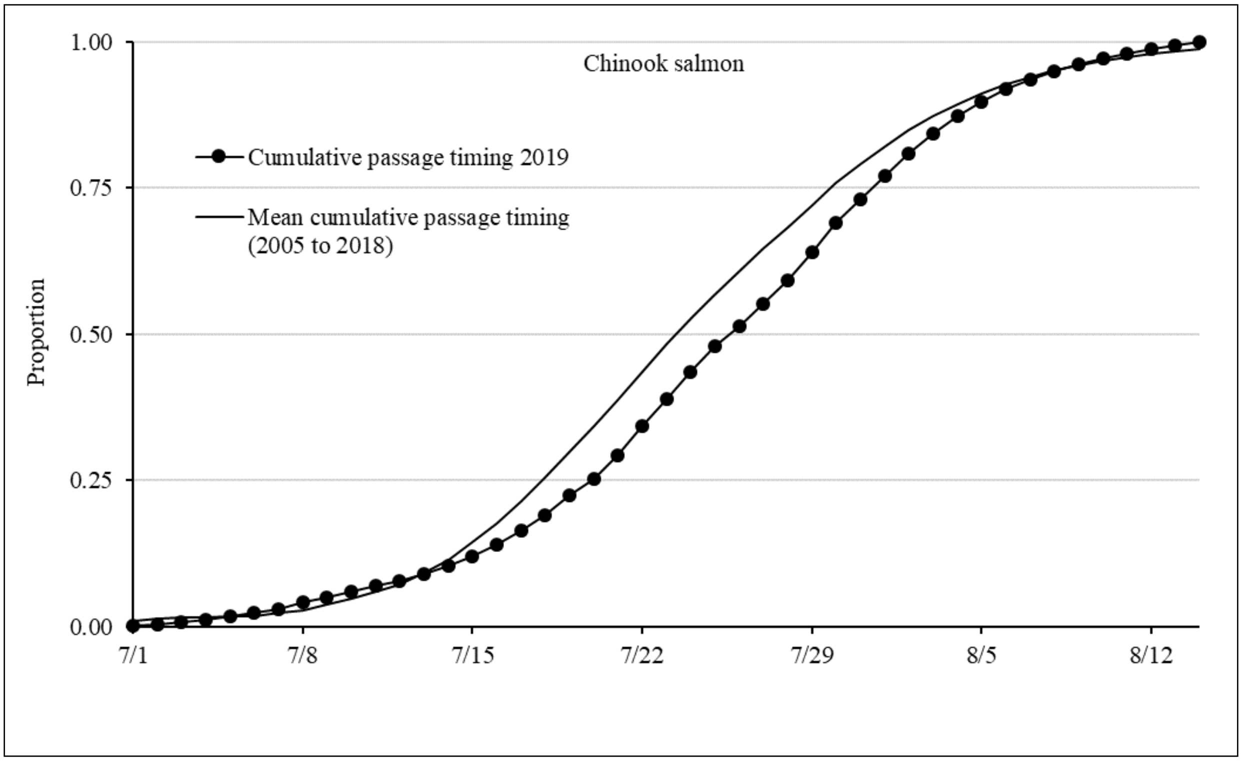


Figure 11.–Proportion of catch based on smoothed Chinook and fall chum salmon species composition CPUE data at the Eagle sonar project on the Yukon River, 2019.

Note: Species transition date (August 15) defined as the day on which the proportion of fall chum salmon was greater than or equal to 0.5 and is designated as the first day of fall chum salmon estimation.



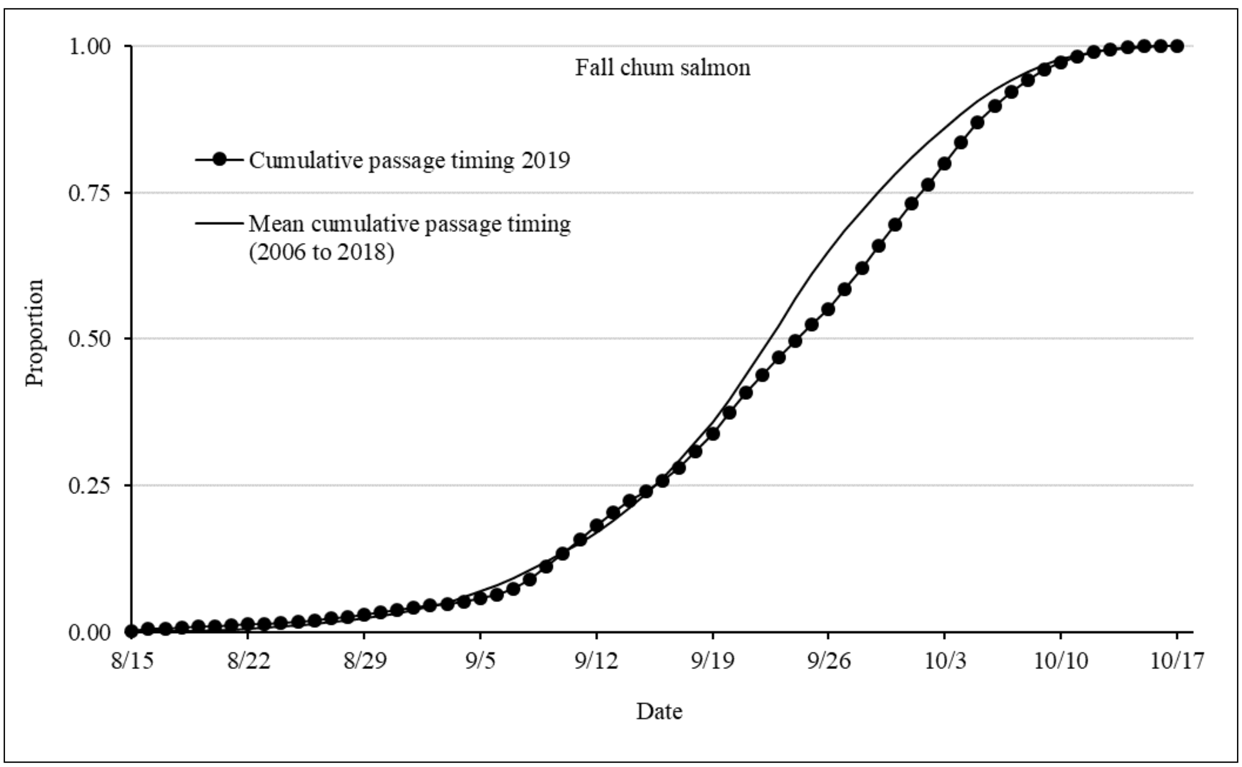
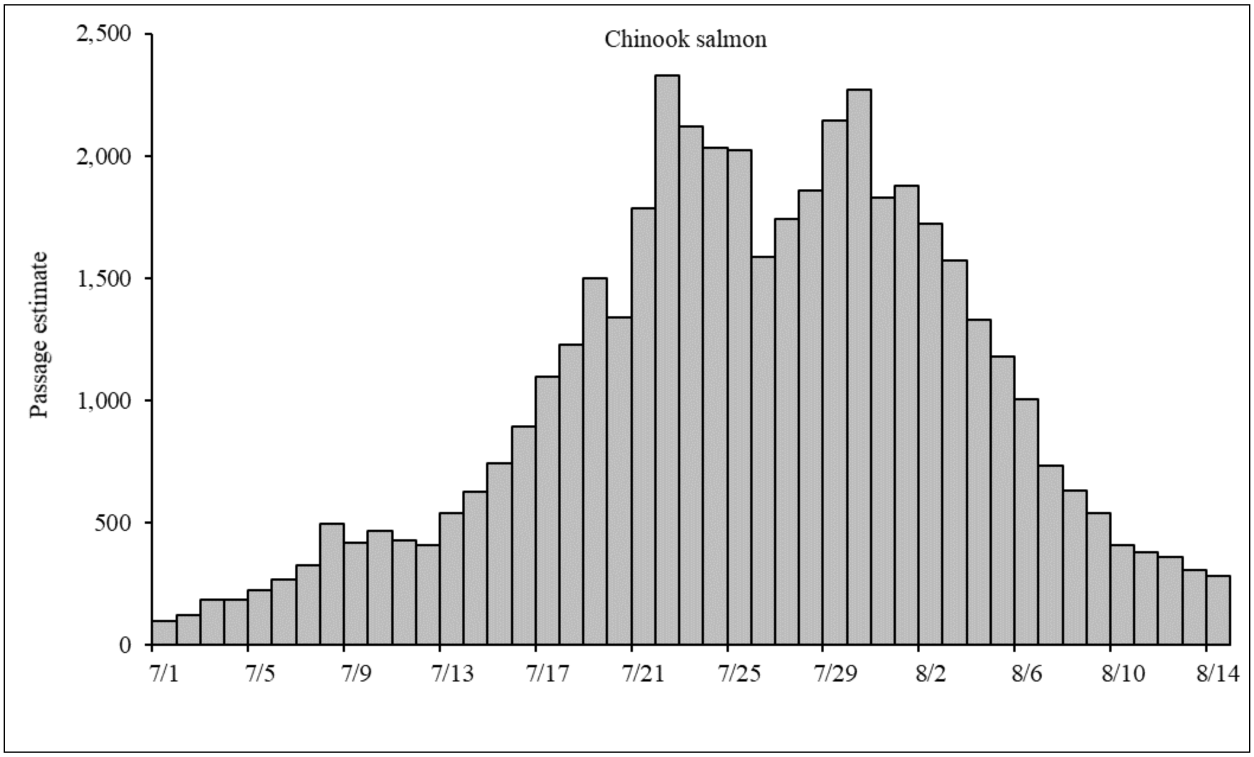


Figure 12.–2019 Chinook and fall chum salmon daily cumulative passage timing compared to the 2005 to 2018 (Chinook salmon) and 2006 to 2018 (fall chum salmon) mean passage timing at the Eagle sonar project on the Yukon River.

Note: Fall chum salmon cumulative passage timing includes postseason expansion estimates through October 17. The expansion estimate on October 18 was 0 and was excluded from this figure.



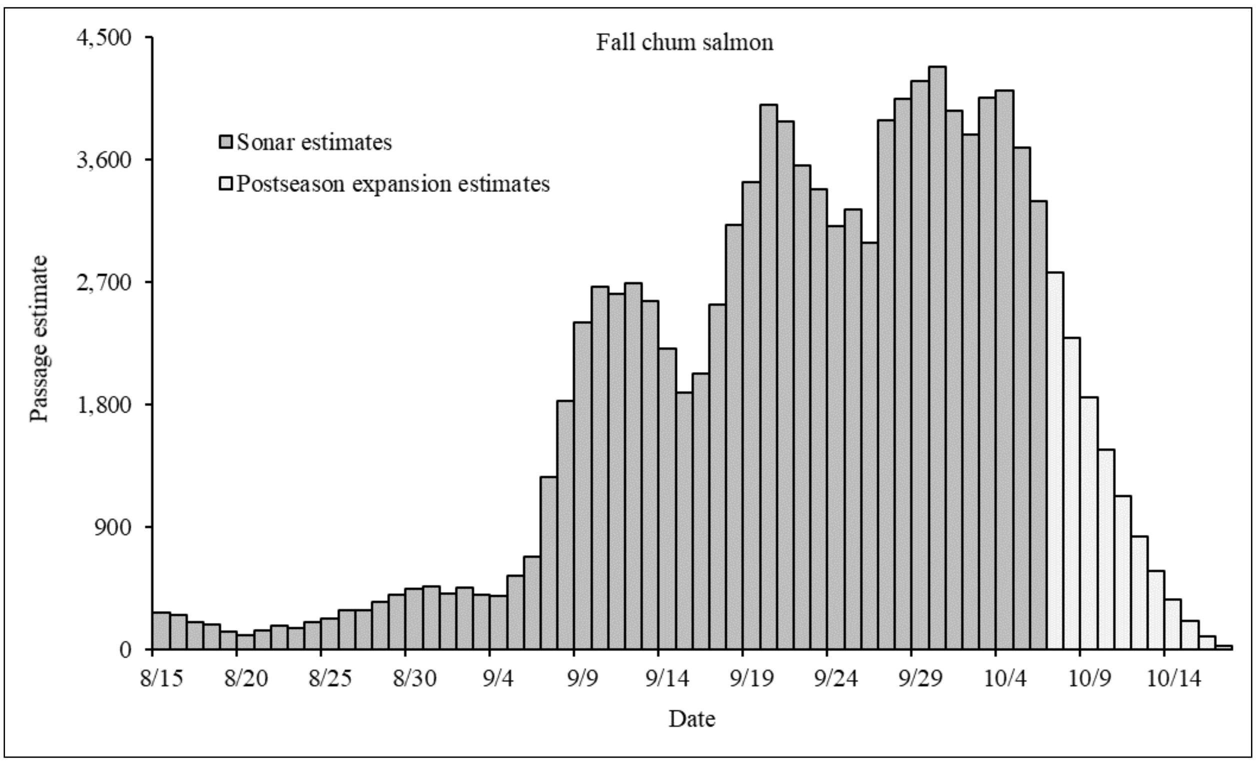


Figure 13.–Daily sonar passage estimates for Chinook salmon from July 1 through August 14 and fall chum salmon from August 15 through October 17 at the Eagle sonar project on the Yukon River, 2019.

Note: Postseason expansion estimates were calculated from October 7 through October 18. The expansion estimate on October 18 was 0 and was excluded from this figure.

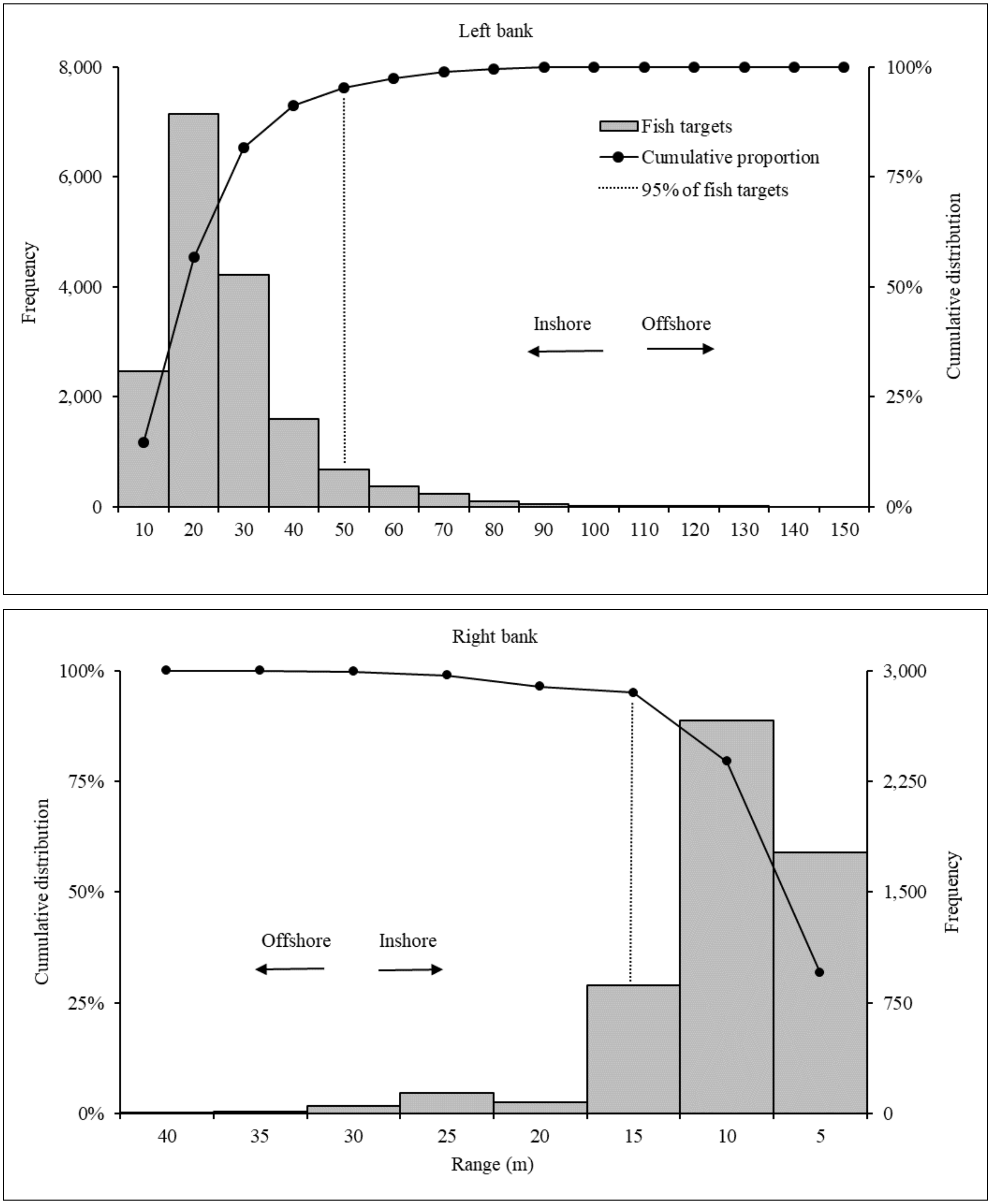


Figure 14.–Left and right bank horizontal distribution of upstream migrating Chinook salmon from July 1 through August 14 at the Eagle sonar project on the Yukon River, 2019.

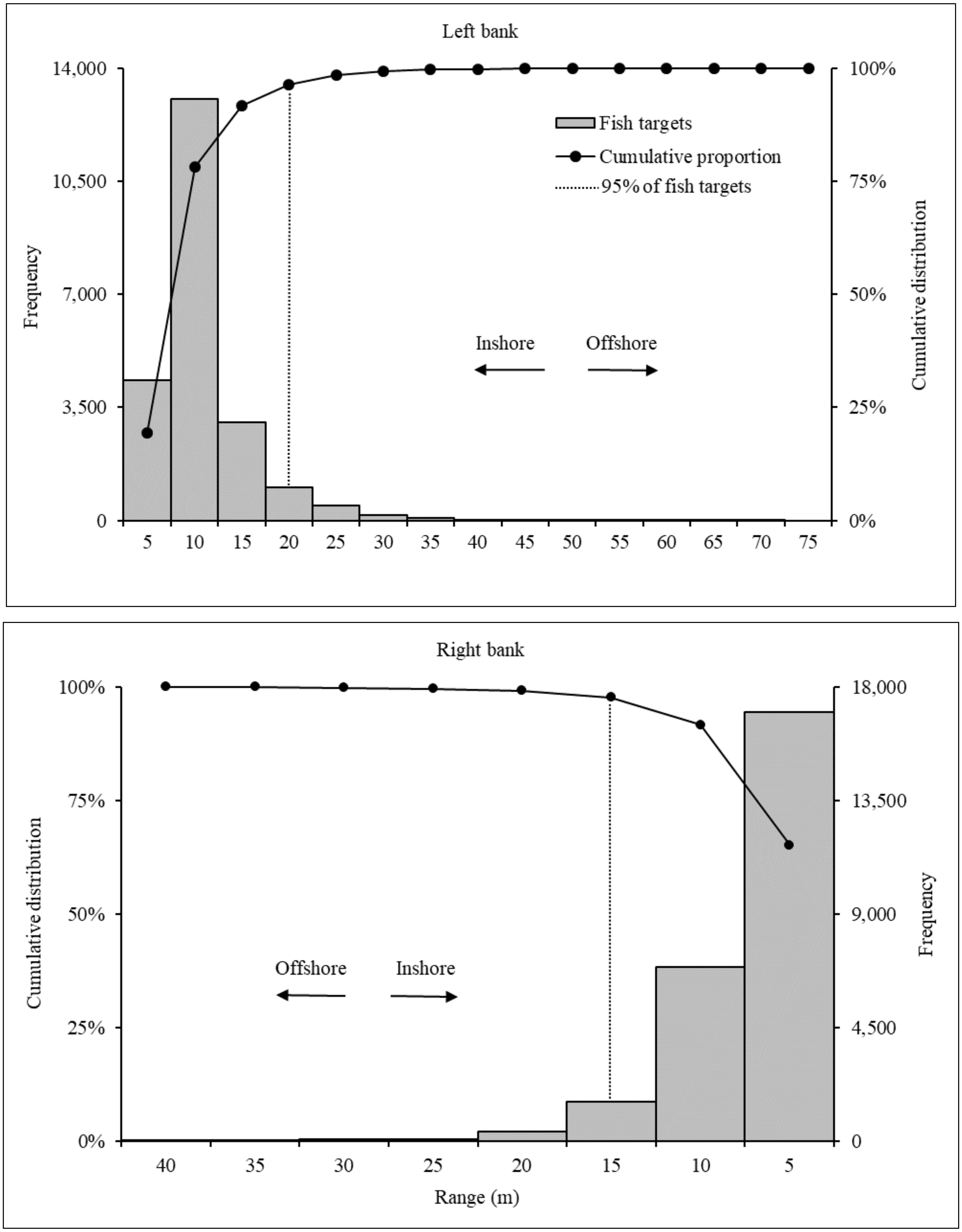


Figure 15.–Left and right bank horizontal distribution of upstream migrating fall chum salmon from August 15 through October 6 at the Eagle sonar project on the Yukon River, 2019.

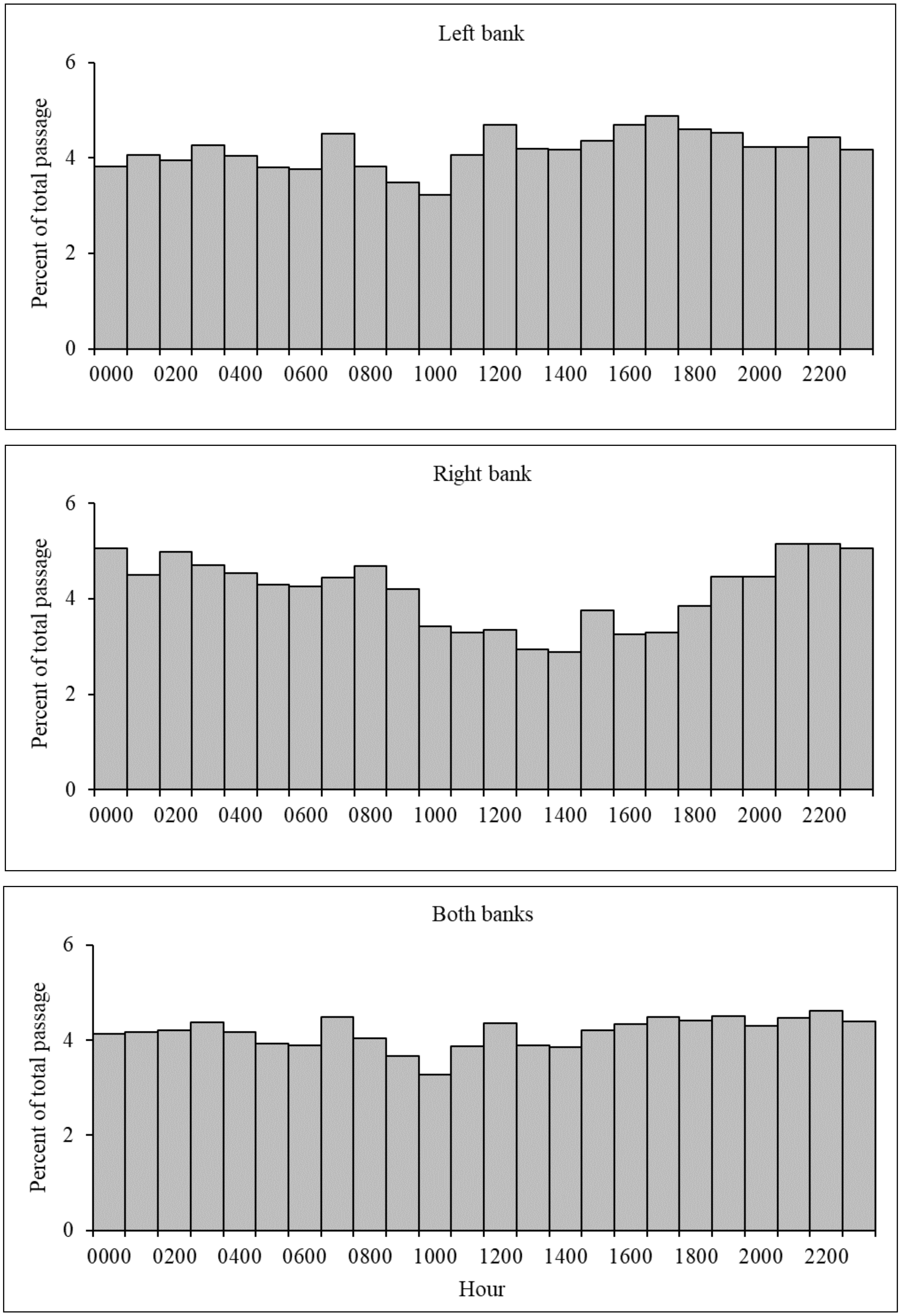


Figure 16.–Percent of total Chinook salmon passage, by hour, observed on the left bank, right bank, and both banks combined from July 1 through August 14 at the Eagle sonar project on the Yukon River, 2019.

Note: Days with missing hourly passage rates were included in the calculations.

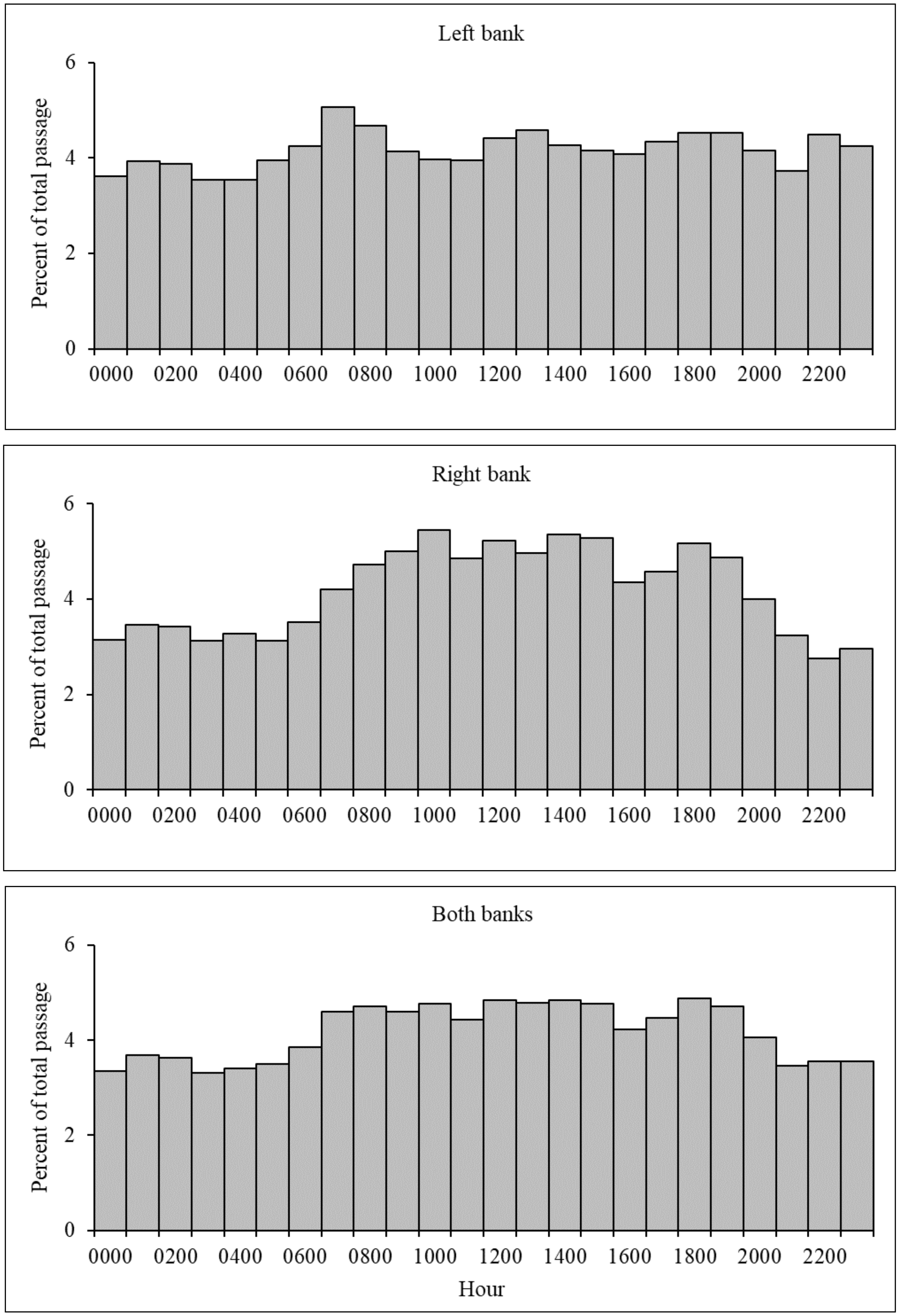


Figure 17.–Percent of total fall chum salmon passage, by hour, observed on the left bank, right bank, and both banks combined from August 15 through October 6 at the Eagle sonar project on the Yukon River, 2019.

Note: Days with missing hourly passage rates were included in the calculations.

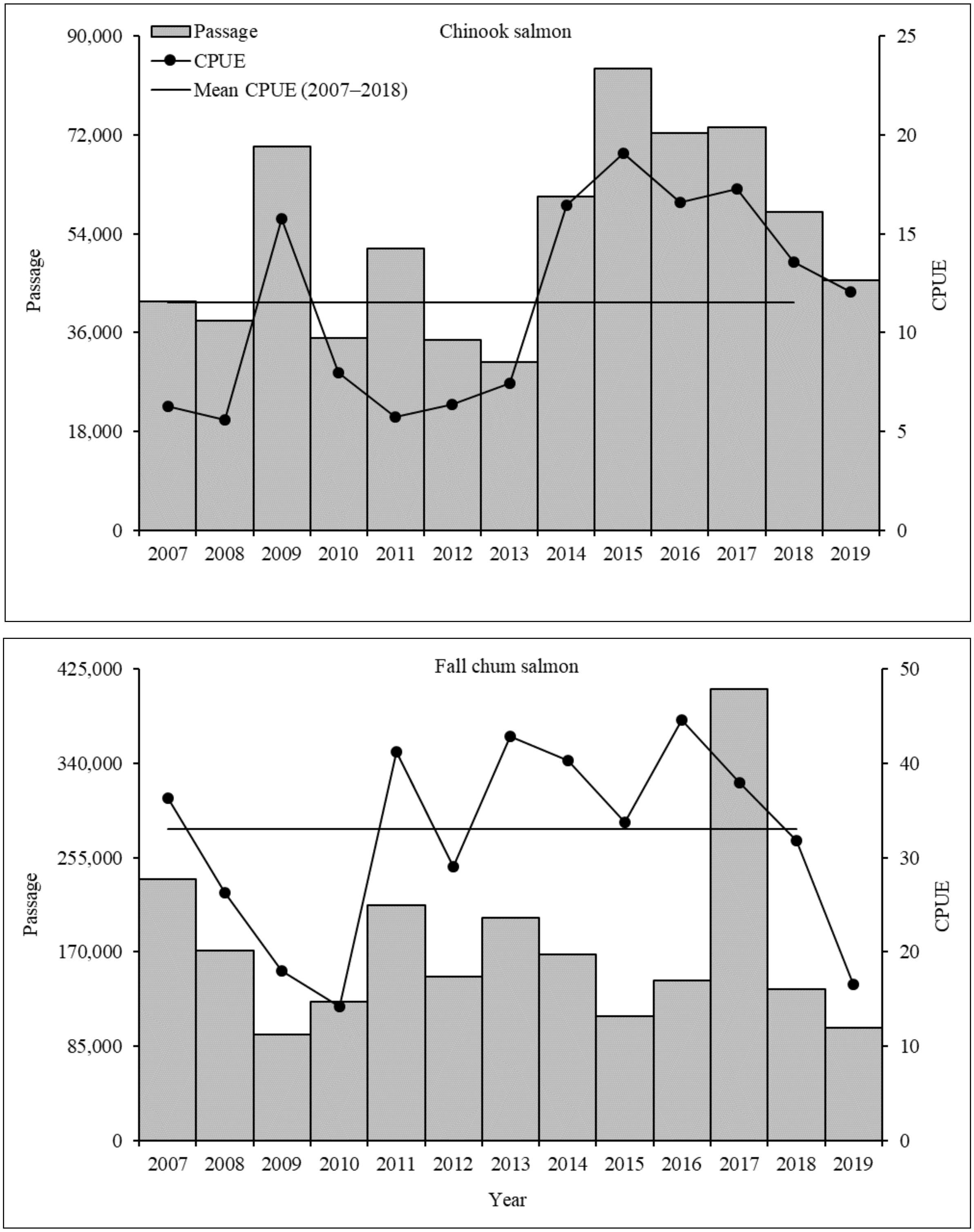


Figure 18.–Chinook and fall chum salmon passage, total cumulative catch per unit effort (CPUE) by year and mean total cumulative CPUE (2007 to 2018) at the Eagle sonar project on the Yukon River, 2019.

Note: Because test fishing sites on the right bank have changed several times throughout the project history, CPUE calculations are derived from the left bank test fishery only. Prior to 2013, fish were occasionally released without being sampled to avoid mortalities. For these years, the CPUE only represents fish sampled.

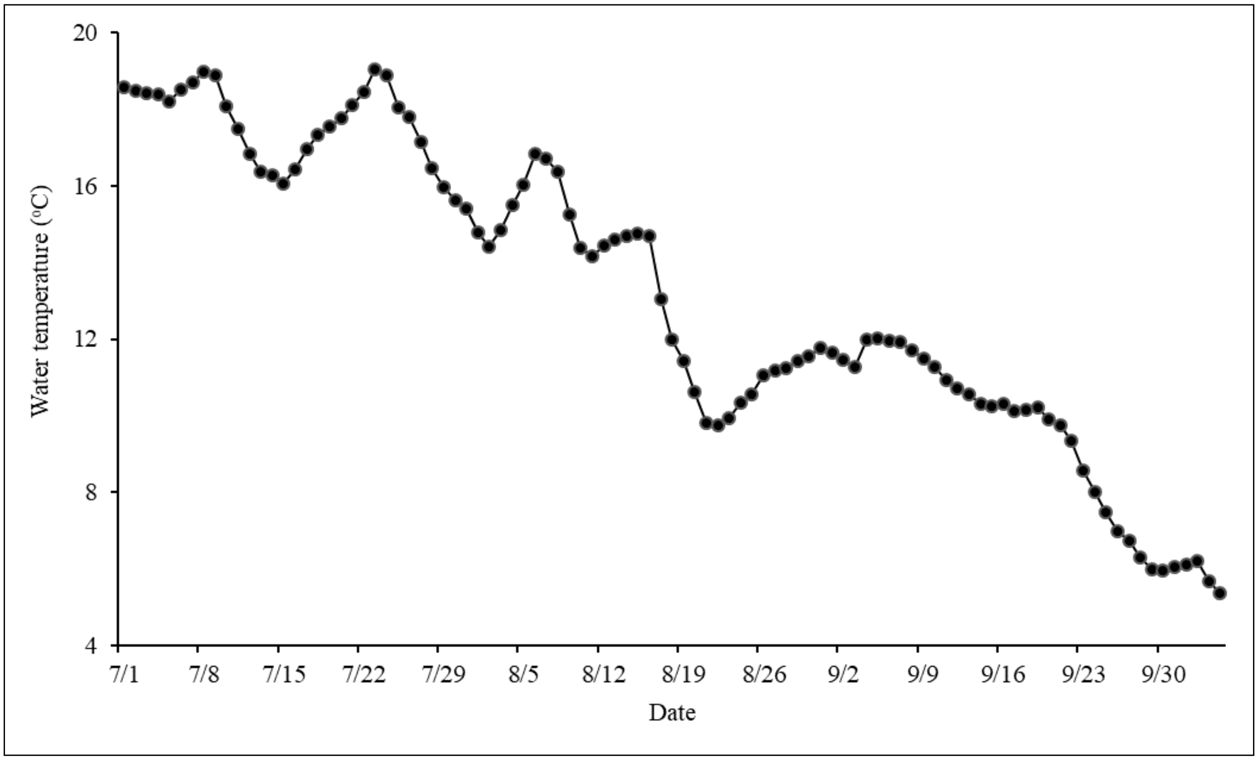


Figure 19.–Median daily water temperature recorded from July 1 through October 5 on the left bank at the Eagle sonar project on the Yukon River, 2019.

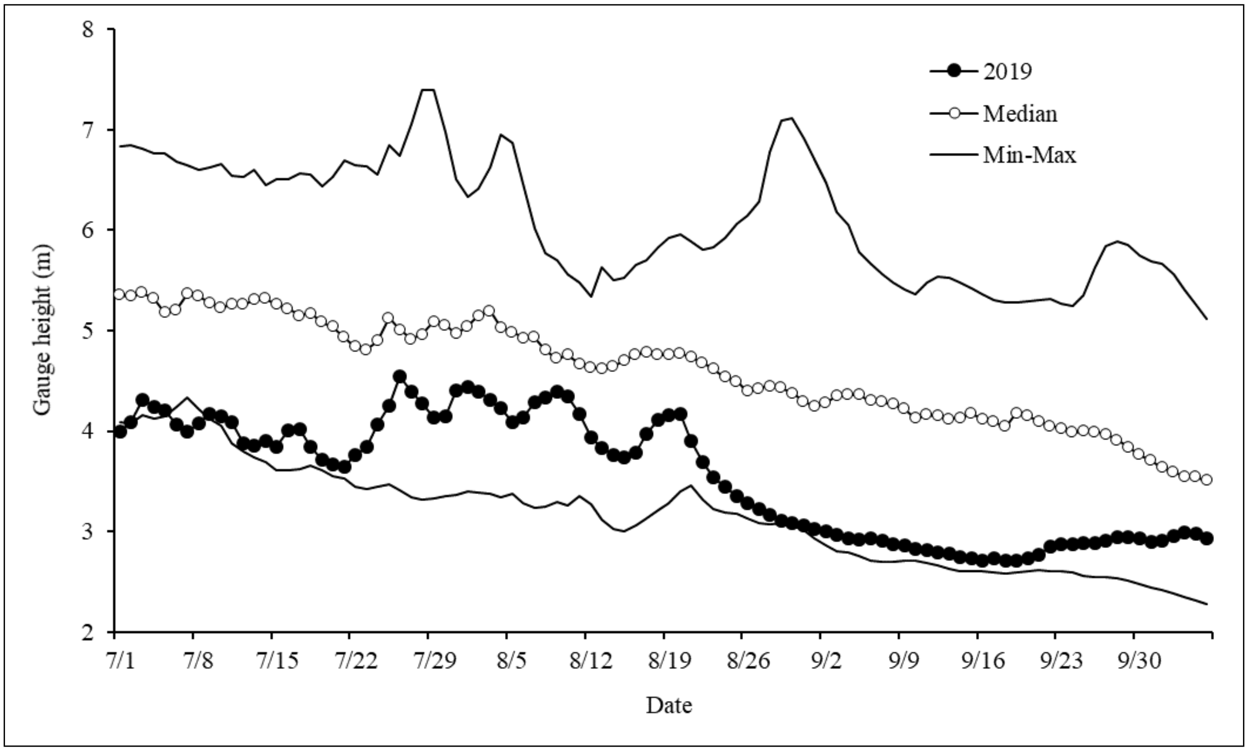


Figure 20.–Yukon River water level recorded daily at 1800 during the 2019 season at the city of Eagle water gage compared to minimum, maximum, and median gage height from 1995 to 2018.

Source: United States Geological Survey (USGS).

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

Appendix A1.–Species composition test fishery catch, CPUE, and smoothed data by day and salmon species at the Eagle sonar project on the Yukon River, 2019.

	Chinook salmon					Fall chum salmon				
Date	Large mesh fathom hours	Catch	CPUE	Catch smoothed	CPUE smoothed	Small mesh fathom hours	Catch	CPUE	Catch smoothed	CPUE smoothed
08/01	18.03	13	0.72	8.68	0.49	17.16	0	0.00	-0.19	-0.01
08/02	17.07	6	0.35	7.86	0.44	17.52	0	0.00	0.00	0.00
08/03	17.46	7	0.40	7.03	0.40	17.20	0	0.00	0.19	0.01
08/04	17.55	6	0.34	6.22	0.36	16.89	0	0.00	0.34	0.02
08/05	16.66	3	0.18	5.38	0.31	17.17	1	1.00	0.43	0.03
08/06	16.79	4	0.24	4.68	0.28	16.89	1	1.00	0.46	0.03
08/07	17.02	4	0.24	4.08	0.24	16.90	1	1.00	0.44	0.03
08/08	16.93	3	0.18	3.52	0.21	16.81	0	0.00	0.40	0.02
08/09	16.66	3	0.18	3.01	0.18	16.80	0	0.00	0.39	0.02
08/10	17.31	5	0.29	2.54	0.15	17.30	0	0.00	0.37	0.02
08/11	16.27	1	0.06	1.89	0.11	16.99	0	0.00	0.37	0.02
08/12	16.66	1	0.06	1.31	0.08	16.22	0	0.00	0.38	0.02
08/13	16.27	0	0.00	0.80	0.05	16.80	1	1.00	0.37	0.02
08/14	16.11	0	0.00	0.40	0.02	16.51	0	0.00	0.35	0.02
08/15	16.08	0	0.00	0.12	0.01	16.55	0	0.00	0.35	0.02
08/16	15.89	0	0.00	0.04	0.00	16.41	1	1.00	0.35	0.02
08/17	16.08	0	0.00	0.00	0.00	16.71	1	1.00	0.37	0.02
08/18	16.31	0	0.00	0.04	0.00	16.26	0	0.00	0.40	0.02
08/19	16.50	0	0.00	0.07	0.00	17.25	1	1.00	0.42	0.03
08/20	16.90	0	0.00	0.10	0.01	16.62	0	0.00	0.44	0.03
08/21	16.34	0	0.00	0.13	0.01	16.77	0	0.00	0.44	0.03
08/22	16.78	1	0.06	0.16	0.01	16.64	0	0.00	0.43	0.03
08/23	16.39	0	0.00	0.15	0.01	16.39	0	0.00	0.45	0.03
08/24	16.34	0	0.00	0.14	0.01	16.27	1	1.00	0.47	0.03
08/25	16.12	0	0.00	0.14	0.01	16.52	1	1.00	0.45	0.03

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Appendix A1.–Page 2 of 3.

	Chinook salmon					Fall chum salmon				
Date	Large mesh fathom hours	Catch	CPUE	Catch smoothed	CPUE smoothed	Small mesh fathom hours	Catch	CPUE	Catch smoothed	CPUE smoothed
08/26	16.33	0	0.00	0.14	0.01	16.21	1	1.00	0.42	0.03
08/27	16.02	0	0.00	0.12	0.01	16.06	0	0.00	0.42	0.03
08/28	16.16	0	0.00	0.12	0.01	16.18	0	0.00	0.39	0.02
08/29	15.98	1	0.06	0.10	0.01	16.53	0	0.00	0.36	0.02
08/30	16.10	0	0.00	0.09	0.01	16.27	0	0.00	0.40	0.02
08/31	16.23	0	0.00	0.08	0.00	16.44	2	0.12	0.52	0.03
09/01	16.04	0	0.00	0.08	0.00	16.27	0	0.00	0.59	0.04
09/02	16.46	0	0.00	0.07	0.00	16.90	0	0.00	0.85	0.05
09/03	16.78	0	0.00	0.06	0.00	16.58	1	0.06	1.38	0.08
09/04	16.39	0	0.00	0.04	0.00	16.49	1	0.06	2.01	0.12
09/05	17.21	0	0.00	0.03	0.00	17.05	1	0.06	2.96	0.17
09/06	16.71	0	0.00	0.01	0.00	16.98	4	0.24	4.05	0.24
09/07	16.46	0	0.00	0.00	0.00	16.94	7	0.41	5.10	0.30
09/08	17.03	0	0.00	0.00	0.00	16.74	5	0.30	5.91	0.34
09/09	16.70	0	0.00	0.00	0.00	17.77	14	0.79	6.68	0.39
09/10	16.49	0	0.00	0.00	0.00	16.75	8	0.48	7.27	0.42
09/11	16.71	0	0.00	0.00	0.00	16.95	7	0.41	7.77	0.45
09/12	16.37	0	0.00	0.00	0.00	16.89	4	0.24	8.23	0.47
09/13	16.78	0	0.00	0.00	0.00	18.03	13	0.72	8.73	0.50
09/14	16.43	0	0.00	0.00	0.00	17.67	10	0.57	9.17	0.52
09/15	17.19	0	0.00	0.00	0.00	17.85	15	0.84	9.51	0.54
09/16	16.30	0	0.00	0.00	0.00	16.85	4	0.24	9.88	0.57
09/17	16.87	0	0.00	0.00	0.00	17.32	10	0.58	10.24	0.59
09/18	16.72	0	0.00	0.00	0.00	19.51	16	0.82	10.62	0.61
09/19	17.08	0	0.00	0.00	0.00	16.81	9	0.54	11.06	0.63

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Appendix A1.–Page 3 of 3.

	Chinook salmon					Fall chum salmon				
Date	Large mesh fathom hours	Catch	CPUE	Catch smoothed	CPUE smoothed	Small mesh fathom hours	Catch	CPUE	Catch smoothed	CPUE smoothed
09/20	16.92	0	0.00	0.00	0.00	17.55	17	0.97	11.52	0.66
09/21	16.75	0	0.00	0.00	0.00	17.46	14	0.80	12.01	0.69
09/22	17.07	0	0.00	0.00	0.00	17.41	13	0.75	12.50	0.72
09/23	16.02	0	0.00	0.00	0.00	17.31	13	0.75	13.00	0.74
09/24	16.69	0	0.00	0.00	0.00	16.92	6	0.36	13.49	0.77
09/25	16.26	0	0.00	0.00	0.00	17.71	14	0.79	13.99	0.80
09/26	15.97	0	0.00	0.00	0.00	16.92	7	0.41	14.48	0.83
09/27	16.45	0	0.00	0.00	0.00	16.97	18	1.06	14.98	0.86
09/28	15.26	0	0.00	0.00	0.00	17.17	13	0.76	15.47	0.89
09/29	15.89	0	0.00	0.00	0.00	17.73	19	1.07	15.97	0.91
09/30	16.18	0	0.00	0.00	0.00	17.31	15	0.87	16.47	0.94

APPENDIX B: CLIMATE AND HYDROLOGIC OBSERVATIONS

Appendix B1.–Climate and hydrologic observations recorded daily at 1800 at the Eagle sonar project site on the Yukon River, 2019.

Date	Precipitation (code)[a]	Wind		Sky (code)[c]	Temperature (°C)	
		Direction[b]	Velocity (kph)		Air	Water[d]
07/01	A	W	3.0	B	20.8	18.6
07/02	A	W	4.9	S	23.4	18.5
07/03	A	ND	ND	ND	ND	18.4
07/04	A	NW	2.4	B	24.1	18.4
07/05	A	NW	4.0	C	28.5	18.2
07/06	A	W	1.7	F	26.7	18.5
07/07	A	NW	3.5	S	25.4	18.7
07/08	A	NA	0.0	S	26.6	19.0
07/09	A	NW	0.7	F	32.1	18.9
07/10	A	NA	0.0	F	25.9	18.1
07/11	C	N	6.9	F	18.2	17.5
07/12	C	NE	1.6	O	16.2	16.8
07/13	A	N	0.8	C	23.3	16.4
07/14	A	E	1.6	C	26.6	16.3
07/15	A	SE	4.5	F	20.8	16.0
07/16	A	E	3.4	S	24.5	16.4
07/17	A	S	9.5	S	24.3	17.0
07/18	A	NW	3.6	S	24.5	17.3
07/19	B	NW	5.7	S	24.1	17.5
07/20	A	NW	4.9	B	24.3	17.8
07/21	A	NW	4.0	B	25.7	18.1
07/22	A	NW	1.8	F	30.5	18.5
07/23	B	NE	9.2	F	22.1	19.0
07/24	A	SE	0.8	S	29.3	18.9
07/25	B	NA	0.0	B	19.9	18.1
07/26	A	S	1.5	B	25.7	17.8
07/27	B	W	3.3	B	18.1	17.2
07/28	B	S	0.3	O	17.3	16.5
07/29	B	NW	6.5	B	19.8	16.0
07/30	A	NW	0.9	S	20.0	15.6
07/31	A	SE	6.1	B	21.9	15.4
08/01	B	SE	3.7	B	16.3	14.8
08/02	B	SE	8.8	O	16.4	14.4
08/03	B	NA	0.0	O	18.0	14.8
08/04	B	NW	4.0	B	19.5	15.5
08/05	A	NA	0.0	S	25.7	16.0
08/06	B	N	1.2	O	15.0	16.8
08/07	B	N	1.3	B	17.3	16.7

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Appendix B1.–Page 2 of 3.

Date	Precipitation (code)[a]	Wind		Sky (code)[c]	Temperature (°C)	
		Direction[b]	Velocity (kph)		Air	Water[d]
08/08	A	NW	2.5	S	21.1	16.4
08/09	B	SE	0.7	B	15.5	15.2
08/10	A	W	1.1	S	18.7	14.4
08/11	A	NE	0.7	B	19.6	14.2
08/12	A	NA	0.0	S	24.6	14.4
08/13	C	E	3.2	O	16.2	14.6
08/14	A	NW	3.5	O	17.4	14.7
08/15	B	NA	0.0	B	17.6	14.7
08/16	C	NW	1.5	O	13.3	14.7
08/17	A	N	4.5	O	11.4	13.1
08/18	B	N	1.1	O	10.1	12.0
08/19	A	E	1.6	O	14.3	11.4
08/20	A	NA	0.0	O	13.7	10.6
08/21	B	W	1.5	B	10.5	9.8
08/22	B	E	1.7	O	9.1	9.8
08/23	A	E	1.2	B	10.6	9.9
08/24	A	NA	0.0	S	15.6	10.3
08/25	A	NA	0.0	S	20.5	10.6
08/26	A	W	0.9	S	17.4	11.0
08/27	A	NA	0.0	B	17.2	11.2
08/28	A	NA	0.0	B	15.8	11.2
08/29	A	W	2.4	S	17.5	11.4
08/30	A	NW	2.0	C	19.0	11.5
08/31	A	NW	1.6	B	16.5	11.8
09/01	A	E	7.5	B	17.1	11.6
09/02	B	W	2.5	B	17.2	11.4
09/03	B	NW	2.8	B	15.3	11.3
09/04	A	NW	1.6	S	16.6	12.0
09/05	A	W	1.4	C	17.2	12.0
09/06	A	E	3.8	C	20.8	12.0
09/07	A	E	2.7	B	22.3	11.9
09/08	A	W	1.2	C	23.9	11.7
09/09	A	S	3.0	C	25.0	11.5
09/10	A	NW	1.6	O	18.1	11.3
09/11	B	N	0.7	F	14.3	10.9
09/12	A	S	1.8	C	18.5	10.7
09/13	A	NW	3.7	S	19.1	10.6
09/14	A	S	1.3	S	14.8	10.3
09/15	A	S	2.0	C	17.3	10.2
09/16	B	NA	0.0	B	11.5	10.3

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Date	Precipitation (code)[a]	Wind		Sky (code)[c]	Temperature (°C)	
		Direction[b]	Velocity (kph)		Air	Water[d]
09/17	A	S	4.4	B	10.3	10.1
09/18	A	S	0.8	B	12.7	10.1
09/19	A	S	4.6	B	16.3	10.2
09/20	B	NA	0.0	O	11.8	9.9
09/21	B	S	0.9	O	9.4	9.7
09/22	A	NW	1.5	C	10.9	9.3
09/23	A	W	2.3	C	8.3	8.6
09/24	A	NA	0.0	S	9.5	8.0
09/25	A	NW	2.8	O	6.9	7.5
09/26	A	NA	0.0	B	8.3	7.0
09/27	A	W	1.3	C	6.6	6.8
09/28	A	W	0.8	B	9.7	6.3
09/29	B	E	2.8	O	8.2	6.0
09/30	B	N	2.9	B	10.0	5.9
10/01	B	N	0.7	O	6.6	6.1
10/02	B	SE	7.8	B	7.6	6.1
10/03	A	SE	1.2	S	6.5	6.2
10/04	B	SE	5.7	B	5.0	5.7
10/05	A	SE	5.8	B	3.7	5.4

Note: ND indicates no data were recorded.

[a] Precipitation code for the preceding 2 h period: A = none; B = intermittent rain; C = continuous rain; D = snow and rain mixed; E = light snowfall; F = continuous snowfall; G = thunderstorm with or without precipitation.

[b] Wind direction code: N = North; S = South; E = East; W = West; V = Variable; NA = Not applicable (no wind).

[c] 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.

[d] Water temperature collected approximately 30 cm below surface with Hobo U22 data logger.