Fishery Data Series No. 19-07

Chinook Salmon Passage in the Kenai River at River Mile 13.7 Using Adaptive Resolution Imaging Sonar, 2016

by

Brandon H. Key

James D. Miller

Steven J. Fleischman

and

Jiaqi Huang

December 2019

Alaska Department of Fish and Game Divisions of Sport Fish and Commercial Fisheries

Symbols and Abbreviations

The following symbols and abbreviations, and others approved for the Système International d'Unités (SI), are used without definition in the following reports by the Divisions of Sport Fish and of Commercial Fisheries: Fishery Manuscripts, Fishery Data Series Reports, Fishery Management Reports, and Special Publications. All others, including deviations from definitions listed below, are noted in the text at first mention, as well as in the titles or footnotes of tables, and in figure or figure captions.

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

FISHERY DATA SERIES NO. 19-07

CHINOOK SALMON PASSAGE IN THE KENAI RIVER AT RIVER MILE 13.7 USING ADAPTIVE RESOLUTION IMAGING SONAR, 2016

by
Brandon H. Key
Alaska Department of Fish and Game, Divison of Sport Fish, Soldotna

James D. Miller
Alaska Department of Fish and Game, Division of Sport Fish, Anchorage

Steven J. Fleischman
Alaska Department of Fish and Game, Division of Sport Fish, Anchorage

and

Jiaqi Huang
Alaska Department of Fish and Game, Division of Sport Fish, Anchorage

Alaska Department of Fish and Game
Division of Sport Fish, Research and Technical Services
333 Raspberry Road, Anchorage, Alaska, 99518-1565

December 2019

This investigation was partially financed by the Federal Aid in Sport Fish Restoration Act (16 U.S.C. 777-777K) under Project F-10-30, 31 Job No. S-2-5b.

ADF&G Fishery Data Series was established in 1987 for the publication of Division of Sport Fish technically oriented results for a single project or group of closely related projects, and in 2004 became a joint divisional series with the Division of Commercial Fisheries. Fishery Data Series reports are intended for fishery and other technical professionals and are available through the Alaska State Library and on the Internet: http://www.adfg.alaska.gov/sf/publications/. This publication has undergone editorial and peer review.

Brandon H. Key,
Alaska Department of Fish and Game, Division of Sport Fish
43961 Kalifornsky Beach Road Suite B, Soldotna Alaska 99669-8276, USA

James D. Miller,
Alaska Department of Fish and Game, Division of Sport Fish
333 Raspberry Road, Anchorage, Alaska 99518-1599, USA

Steven J. Fleischman, Retired,
Alaska Department of Fish and Game, Division of Sport Fish, Research and Technical Services
333 Raspberry Road, Anchorage, Alaska 99518-1599, USA

and

Jiaqi Huang,
Alaska Department of Fish and Game, Division of Sport Fish, Research and Technical Services
333 Raspberry Road, Anchorage, Alaska 99518-1599, USA

This document should be cited as follows:
Key, B. H., J. D. Miller, S. J. Fleischman, and J. Huang. 2018. Chinook salmon passage in the Kenai River at River Mile 13.7 using adaptive resolution imaging sonar, 2016. Alaska Department of Fish and Game, Fishery Data Series No. 19-07, Anchorage.

TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

Appendix **Page**

ABSTRACT

In 2016, Kenai River Chinook salmon (*Oncorhynchus tshawytscha*) passage was estimated using adaptive resolution imaging sonar (ARIS) at river mile 13.7. Net upstream passage of Chinook salmon greater than or equal to 75 cm as measured by ARIS was estimated to be 6,391 (SE 197) during the early run (16 May–30 June) and 17,447 (SE 403) during the late run (1 July–19 August). Net upstream passage of all Chinook salmon regardless of size was estimated to be 9,851 (SE 355) during the early run and 22,537 (SE 480) during the late run.

Key words: ARIS, Chinook salmon, *Oncorhynchus tshawytscha,* acoustic assessment, Kenai River, riverine sonar

INTRODUCTION

Chinook salmon (*Oncorhynchus tshawytscha*) returning to the Kenai River (Figure 1) are managed as 2 distinct runs (Burger et al. 1985): early (mid-May–30 June) and late (1 July–mid-August). Early-run Chinook salmon are harvested primarily by sport anglers, and late-run Chinook salmon are harvested by commercial, sport, subsistence, and personal use fisheries. These fisheries may be restricted or liberalized if the projected escapement falls below or above goals adopted by the Alaska Board of Fisheries (BOF). These goals are defined by Alaska Administrative Codes 5 AAC 57.160 (*Kenai River and Kasilof River Early-Run King Salmon Management Plan*) and 5 AAC 21.359 (*Kenai River Late-Run King Salmon Management Plan*) and are intended to ensure sustainable Chinook salmon stocks. Escapement goals have evolved over the years as stock assessment and our understanding of stock dynamics have improved (McBride et al. 1989; Hammarstrom and Hasbrouck 1998–1999; Bosch and Burwen 1999). During the 2016 season, goals of 5,300–9,000 early-run and 15,000–30,000 late-run Chinook salmon were in effect, as assessed by ARIS-based sonar estimates at river mile (RM) 13.7. Sonar estimates of inriver Chinook salmon passage provide the basis for estimating spawning escapement and implementing management plans that regulate harvest in the competing fisheries for this stock.

From 1987 through 2011, the Alaska Department of Fish and Game (ADF&G) used dual-beam (1987–1994) and split-beam (1995–2011) side-looking sonar technology to estimate Chinook salmon passage in the Kenai River at RM 8.6. These technologies relied on target strength (loudness of returning echoes) and range (distance from shore) thresholds to differentiate between sockeye (*O. nerka*) and Chinook salmon. These criteria were based on the premise that sockeye salmon are smaller and migrate primarily near shore, whereas Chinook salmon are larger and tend to migrate up the middle of the river. However, subsequent studies showed that these criteria can lead to inaccurate estimates (Burwen et al. 1998; Hammarstrom and Hasbrouck 1999). Extensive research was conducted at the Kenai RM 8.6 Chinook salmon sonar site toward improving our ability to identify species from split-beam sonar data (Burwen and Fleischman 1998; Burwen et al. 2003; Miller et al. 2010). Beginning in 2002, ADF&G evaluated the potential for dual-frequency identification sonar (DIDSON) to provide improved discrimination of larger Chinook salmon from smaller species of salmon based on size measurements taken directly from high-resolution images of migrating salmon (Burwen et al. 2007). Split-beam estimates were found to be inaccurate (Miller et al. 2013) and they were discontinued following the 2011 season (Miller et al. 2015). DIDSON-based estimates continued to be produced at the RM 8.6 site through 2014.

The RM 8.6 site was originally selected in 1985, based primarily on its suitability for operating a dual-beam (and subsequently a split-beam) sonar system, which required a near-perfect linear bottom profile over the entire insonified zone or, in this case, from the nearshore region to the thalweg. A comprehensive history of sonar research and development at the Kenai River RM 8.6 site can be found in Key et al. (2016b). The RM 8.6 site has many disadvantages, primarily related to its location within tidal influence: 1) incomplete coverage of the river during high tides that flood the region behind the transducers, 2) milling fish behavior related to tidal flux, 3) physical risk to gear by large debris carried by extreme tidal fluxes, and 4) lack of legal access to the property on one bank. It became evident that relocating the site farther upriver could improve the estimates of Chinook salmon passage by minimizing or eliminating these negative factors. In 1999, ADF&G evaluated a second sonar site at RM 13.2 for use of split-beam sonar to assess fish passage, but the bottom topography was less acoustically favorable and fish were more difficult to detect due to increased background noise levels from bottom irregularities and boat traffic (Burwen et al. 2000).

Because DIDSON multibeam technology was better able to insonify irregular bottom profiles, the search for a site above tidal influence was resumed in 2011. A potential new site at RM 13.7 (Figure 2) was identified and evaluated during a 2-week period in 2012 using the newest generation of DIDSON technology, referred to as Adaptive Resolution Imaging Sonar (ARIS). ADF&G operated a full-scale experimental project at the RM 13.7 site using ARIS during 2013 (Miller et al. 2016a) and again during 2014 while also continuing to operate the DIDSON at the RM 8.6 site. Near bank-to-bank sonar coverage of the river was achieved at RM 13.7 (Figure 3). Starting in 2015, sonar operations were discontinued at RM 8.6, and daily estimates of net upstream Chinook salmon passage at RM 13.7 were used for inseason fisheries management.

This report documents data collection methods, analyses, and results from sonar operations at RM 13.7 in 2016.

OBJECTIVES

The primary objective of this study was to estimate upstream passage of Chinook salmon at RM 13.7 of the Kenai River such that early- and late-run estimates are within 10% of the true value 95% of the time. This estimate was based on fitting a mixture model to ARIS fish-length measurements and RM 8.6 netting data (midriver and nearshore drifts, see Perschbacher and Eskelin [2016]). The secondary objective of this study was to estimate upstream passage of fish greater than 75 cm (as measured by ARIS) at RM 13.7 of the Kenai River such that early- and late-run estimates are within 10% of the true value 95% of the time. This estimate was based solely on ARIS fish-length measurements.

METHODS

STUDY AREA

The Kenai River drainage is approximately 2,150 square miles. It is glacially influenced, with discharge rates lowest during winter (less than 1,800 ft^3/s), increasing throughout the summer, and peaking in August (greater than 14,000 ft^3/s) (Benke and Cushing 2005). The Kenai River has 10 major tributaries, many of which provide important spawning and rearing habitat for salmon. Tributaries include the Russian, Killey, Moose, and Funny Rivers.

The Kenai River drainage is located in a transitional zone between a maritime climate and a continental climate (USDA 1992). The geographic position and local topography influence both rainfall and temperature throughout the drainage. Average annual (1981–2010) precipitation for the City of Kenai, located at the mouth of the Kenai River, is 46 cm and average summer (June, July, and August) temperature for the City of Kenai is 13°C[1].

SITE DESCRIPTION

The sonar site is located 22 km (13.7 river miles) from the mouth of the Kenai River (Figure 2). This location was identified during bathymetric surveys conducted in 2012 (Miller et al. 2015) and was selected for its location above tidal influence, its favorable physical characteristics for deploying ARIS multibeam technology, its accessibility via an adjacent boat launch facility, and legal access to property on either bank of the main channel. The main channel on the west side of the river is approximately 94 m wide and the minor channel located along the east side is approximately 30 m wide (Figure 3). The minor channel has sufficient water for fish passage at higher water levels from approximately mid-June through August. Tidal fluctuation at this site is minimal (less than 1 ft) and is observable only during the large spring tide sequence. The substrate in both the main channel and the minor channel is composed of small cobble, rocks, and gravel.

ACOUSTIC SAMPLING

Acoustic sampling was conducted using Sound Metrics Corporation (SMC[2]) ARIS systems. Daily abundance estimates were generated from 16 May through 19 August 2016. Components of the ARIS systems are listed in Table 1. Appendices A1–A12 provide greater detail on ARIS technology. A comparison of ARIS technology with DIDSON technology used during previous years at the RM 8.6 site is given in Key et al. (2017).

Sonar System Configuration and River Coverage

Site characteristics at RM 13.7 allow for near complete sonar coverage of the river cross-section. A vertically mounted DIDSON-LR set to low frequency (0.7 MHz) and configured with a high-resolution lens was used to generate river bottom profiles of the main channel left and right bank transducer locations (Figure 4) using methods described in Faulkner and Maxwell (2009).

A total of 5 sonars were required to provide coverage: a nearshore and offshore sonar on each bank of the main channel plus 1 sonar on the minor channel (Figure 3). During the early part of the season, when the water level was low, 1 sonar on each bank was sufficient to insonify most of the 60–70 m of river cross-section in the main channel (Table 2), but later in the season, as water levels rose, a second sonar was deployed on each bank to insonify the nearshore zone and the first 3–5 m in front of the offshore sonars (Figure 4). The nearshore sonars were first deployed on 18 May (left bank) and 25 May (right bank; Table 2) and were moved closer to shore as the water level rose. At its highest water stage, the main channel increased to approximately 94 m in width. In the main channel, the original (now offshore) sonars were not moved closer to shore as water levels rose because they were already insonifying the maximum range recommended for operation in high-frequency mode (approximately 30 m; Appendix A2). The minor channel was dry when the project began in mid-May but had sufficient water for fish passage by the time the sonar was deployed on 1 June (Table 2). This channel was approximately

---

1 WRCC (Western Region Climate Center). 2017. Kenai FAA Airport, Alaska. Website Western U.S. Climate Historical Summaries, Climatological Data Summaries, Alaska, accessed November 28, 2017. http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?ak4550.

2 Product names used in this publication are included for completeness but do not constitute product endorsement.

30 m wide at high water and was covered by a single sonar combined with a fixed weir, both deployed on the left bank[3] of the minor channel (Figures 3 and 5).

Two different ARIS models were used to provide optimal cross-river coverage of the main channel (Figure 4 and Table 1). ARIS 1200 models with high-resolution lenses (+HRL) were used as offshore sonars because they have the longer range capabilities (up to about 33 m in high frequency mode) needed to insonify most of the main channel at lower water levels as well as the offshore region of the main channel during higher water levels. An ARIS model 1200 +HRL was also used to cover the right bank nearshore region (Figure 4) and on the minor channel due to the longer (approximately 25 m) range requirements. An ARIS 1800 with a standard lens was deployed as the nearshore sonar on the left bank of the main channel because only a limited range needed to be covered, and this sonar model is advantageous for covering close-range targets. The ARIS 1800 is more advantageous for insonifying close-range targets and nearshore areas because it operates at a higher frequency, yielding higher resolution without the use of a large (high-resolution) lens. The standard lens has the advantage of better focusing capabilities at closer ranges (Appendix A5) and wider beam dimensions (14° × 28° versus 3° × 15°) to provide better coverage in both vertical and horizontal dimensions at short ranges. Finally, using sonars with different operating frequencies allowed nearshore and offshore strata to be sampled simultaneously without crosstalk interference.

All sampling was controlled by computers housed in a tent located on the left (west) bank of the river (Figure 3). The ARIS units were mounted on SMC AR2 pan-and-tilt units for remote aiming in the horizontal and vertical axes. The sonar and rotator units were deployed in the river using either a tripod-style mount (capable of being deployed from a boat at higher water levels) or an H-style mount (used for nearshore deployment; Figure 6). In the horizontal plane, the sonars were aimed perpendicular to the flow of the river current to maximize the probability of insonifying migrating salmon from a lateral aspect. In the vertical plane, the sonars were aimed to insonify the near-bottom region of the river (Figure 4). Internal sensors in the ARIS units provided measurements of compass heading, pitch, and roll, as well as water temperature.

Communication cables from the left bank ARIS units fed directly into the left-bank ARIS Command Modules and data collection computers (Figure 7). On the right bank, data from the 3 ARIS systems were transmitted via 3 wireless bridges to 3 data collection computers on the left bank (Figures 7 and 8). Two battery banks, charged daily using generators, provided power to the right-bank sonar electronics and wireless bridges (Figure 8).

Sampling Procedure

Dividing the total insonified range into shorter range strata allowed the aim of each sonar to be optimized for sampling a given river section (i.e., generally the aim must be raised in the vertical dimension because strata are sampled farther from shore). In the vertical plane, the sonars were aimed to insonify the near-bottom region of the river (Figure 4) where fish passage is known to be concentrated (Key et al. 2017). The ARIS can be programmed to automatically sample each range stratum using the ARIScope software interface . At the start of the season, 2 sonars were deployed on the mainstem, each sampling 3 strata. Table 2 summarizes the range coverage by each range stratum along with the changes in range parameters throughout the season as the water level rose and aims were refined. By 1 June, when all 5 sonars were deployed, a total of

[3] The left bank is on the left-hand side of the river as one faces downstream.

11 strata were sampled (8 on the main channel and 3 on the minor channel), each with a unique set of data collection parameters (Table 3 and Figure 9). By 25 July, water levels were more or less stable and no significant changes were made to any parameters or to the positions of the sonars through the end of the season on 19 August. A systematic sampling design (Cochran 1977) was used to sample each stratum for 10 minutes each hour following the schedule in Table 3. Backup sets collected in case of malfunction were used only when the primary set was unavailable. Only one sample was processed per stratum per hour. This routine was followed 24 hours per day and 7 days per week unless a transducer was inoperable.

A test of the systematic sampling design at the RM 8.6 sonar site in 1999 found no significant difference between estimates of Chinook salmon passage obtained using 1-hour counts and estimates obtained by extrapolating 20-minute counts to 1 hour (Miller et al. 2002). Systematic 10-minute counts have been used for decades at counting towers elsewhere in Alaska (Seibel 1967).

Favorable weather created an opportunity to deploy the project early. Sonars were deployed 5 May, a full 10 days earlier than the scheduled start date. This was done in order to assess the project's current start date and determine if significant upstream passage of Chinook salmon occurred. These data were processed only for the targets greater than or equal to 75 cm. These estimates were not collected for previous years, so in order to keep data sets more comparable between years, these estimates are listed in Table 5 but are not included in other tables. Sonar settings used during this early deployment were the same as the normal project start date.

Data Collection Parameters

In designing ARIS, the manufacturers separated the data collection (ARIScope) and data processing (ARISFish) software components. ARIScope has several data collection parameters that are user selectable, including "Window Length," transmit "Pulse" width, "Sample Period," number of "Samples/Beam," and "Detail" (Tables 3 and 4, Appendix A1). ARIS user-selectable parameters are described in Appendix A1, and parameters that varied among strata were frame rate, frequency, start range, end range, sample period (which controls samples per beam and "Detail"), and transmit pulse width (Table 3).

Frame Rate

The maximum allowable frame rate was used for each stratum (Table 3). In practice, frame rates for each stratum were arrived at empirically by first fixing the parameters for start and end ranges and sample period for each stratum and then finding the maximum achievable frame rate. Frame rate is dependent on the number of beams used (96 beams for ARIS 1800, 48 beams for ARIS 1200), the number of samples per beam (4000 max), and the end range of the stratum. The farther the end range, the longer the return time for each ping and therefore the longer it takes to accumulate the number of pings required for each frame (6 pings for ARIS 1800, 3 pings for the ARIS 1200). Higher resolution images with large frame sizes will also restrict the maximum frame rate. On the right bank, frame rates were also limited by the bandwidth of the wireless radios.

Window Length

Window length is defined as the difference between the start range and the end range. The range interval covered by each of the 5 sonars was divided into 1 to 3 discrete strata, primarily based on the need to change the vertical aim to better cover the near-bottom region of the river as the slope of the river changed with range from the sonar (Figures 4 and 9). Window lengths for the first strata sampled by the ARIS 1200 sonars were always set to approximately 5 m to minimize the bias due to focal length caused by the high-resolution lens (Appendix A1). Window lengths for the other strata were selected to optimize bottom coverage while still considering frame rates. For example, the right bank offshore Stratum 2 and Stratum 3 could be combined based on aiming criteria only (note the similar vertical aiming angles or pitch in Figure 10). However, the frame rate of 5 frames per second (fps) needed to extend the range to approximately 35 m is too slow for ranges close to 10 m, where the beam width is narrow and the number of frames per fish would not provide good measurements. At longer ranges, where the beam is wide and fish spend a longer time transiting the beam, getting a sufficient number of frames is not an issue.

Frequency

All strata were sampled at high frequency (1.2 MHz for ARIS 1200 and 1.8 MHz for ARIS 1800) to optimize the cross-range resolution (Appendix A1) with 1 exception. The last stratum on the right bank offshore sonar was sampled at low frequency (0.7 MHz) from 16 May to 9 July (as well as during the 5–15 May early deployment period [see below]). Two factors typically necessitate sampling the last stratum of the right bank offshore sonar using low frequency. First, colder water temperatures (as low as 8°C) resulted in transmission loss at far range and required the use of low frequency mode to improve image quality in the last stratum (22–35 m). Second, the right bank offshore sonar experienced high background noise from an unknown source when sampling at high frequency but not low frequency. Although the noise was present in the first 2 strata as well, it was not sufficiently strong to warrant the change to low frequency mode. The background noise appeared to decline (possibly related to higher water level) as the season progressed. Additionally, low frequency was used for data collection in right bank Stratum 3 for almost a month longer than usual due to periodic transmission loss possibly caused by an exceptional level of pollen observed in and around the river during that time. As the pollen concentration subsided, the high frequency mode became useable.

Sample Period

In combination with transmit pulse width, the parameter “Sample Period” (or equivalently “Detail”) controls the downrange resolution for the image. Sample period was not necessarily set at the maximum resolution for a stratum because of the costs in terms of frame rate and frame or file size. All ARIS strata were collected at a sample period of 10 µs because this resolution was recommended by the manufacturer (Bill Hanot, personal communication, Sound Metrics Corporation, Seattle, WA) and because tethered fish experiments conducted by Miller et al. (2016b) indicated a sample period of 10 µs provides an adequate balance between the accuracy of ARIS length (AL) measurements and the amount of storage space required for processing and archiving data.

Transmit Pulse Width

Transmit pulse width varied by stratum. As the insonified range increases, longer transmit pulse widths are generally required for sufficient power to achieve the greater range. At farther ranges (beyond approximately 10 m), the transmit pulse width for each stratum was set to “Auto” or was manually set to ensure the transmit pulse width was long enough to get 2 samples within the transmit pulse as recommended by the manufacturer (Bill Hanot, personal communication, Sound Metrics Corporation, Seattle, WA). At ranges less than approximately 10 m, transmit pulse width was set long enough to get 1 sample within the transmit pulse (sample period plus 2 microseconds, also recommended by the manufacturer).

Other Settings

The autofocus feature was enabled for all data collection so that the sonar automatically set the lens focus to the midrange of the selected range window. "Transmit Level" (transmit power) was set to maximum for each stratum and "Gain" varied by stratum from 0 to 24 dB.

MANUAL ARIS FISH LENGTH MEASUREMENTS

Measurements of fish length were obtained using ARISFish V2.5 software supplied by SMC. Detailed instructions for taking manual measurements and the software settings and parameters that were used for this project are explained in Appendix B1. Electronic echograms provided a system to manually count, track, and size individual fish (Figure 11).

Measured fish were subjected to a "centerline rule" (Appendices B1–B3). Only those fish that crossed the longitudinal central axis of the ARIS video image were candidates for measuring. Fish that did not cross the centerline were ignored. This removed the opportunity for fish to be counted in multiple spatial strata, which would create a positive bias in the passage estimates. Note that the 2010–2014 DIDSON-based abundance estimates at the RM 8.6 site (Miller et al. 2013–2015; Key et al. 2016a, 2016b) were not subjected to a centerline rule.

For the purpose of this report, fish size was divided into 3 categories based on ARIS length (AL) measurements. Fish with AL measurements greater than or equal to 40 cm and less than 75 cm are referred to as "small fish." Fish with AL measurements greater than or equal to 75 cm and less than 90 cm are referred to as "medium fish." Fish with AL measurements greater than or equal to 90 cm are referred to as "large fish."

Estimates of medium- and large-fish abundance were produced by the sonar alone. Throughout the season, all medium and large fish were counted and measured, and travel direction (upstream or downstream) was recorded. The sampling protocol, where a sample is defined as a specific spatial stratum monitored for 10 minutes, is described below:

1) During samples without dense aggregations of fish, length and direction of travel were recorded for all salmon-shaped fish greater than or equal to 40 cm AL that met the centerline rule (Appendix B3).
2) During individual samples with dense aggregations of fish, length and direction of travel were recorded for all fish greater than or equal to 75 cm AL. However, length was recorded for only a subsample of fish with ARIS length greater than or equal to 40 cm and less than 75 cm. The first F fish in the sampled period were measured, where choice of F depended on daily staff time constraints. For the remainder of the sample (after the first F fish), only fish appearing to be approximately 75 cm AL or larger were measured and only those fish that actually measured greater than or equal to 75 cm AL were recorded. During these times, fish measuring less than 75 cm AL were not recorded in any way, including fish chosen for measurement that turned out to be less than 75 cm.
3) Direction of travel was automatically recorded for all measured targets.

Additional detail on procedures and software settings used to obtain manual fish length measurements can be found in Appendices A1–A12.

NETTED FISH LENGTH MEASUREMENTS

An established test gillnetting project at RM 8.6[4] provided information on fish length by species, which was needed for some of the estimates produced in this report. Fish length measurements from the netting project were one source of input data required for mixture model estimates of Chinook salmon abundance (see below). Beginning in 2014, sampling effort was equally distributed between midriver and nearshore drifts. The Chinook salmon abundance estimates in this report used all inriver gillnetting data, including midriver and nearshore. This differs from methods used to produce the 2013 RM 13.7 Chinook salmon abundance estimates (Miller et al. 2016a), when only pilot netting data were available from the nearshore stratum, and the estimates were derived from midriver data alone.

DATA ANALYSIS

Methods used to estimate fish passage are detailed below. The ARIS estimates reported here assess net upstream (upstream minus downstream) passage and are germane to the entire river cross-section.

Fish Passage

The ARIS sonar system was composed of multiple individual transducers scheduled to operate 10 minutes per hour for each spatial stratum, 24 hours per day. There were 1–3 spatial strata sampled per transducer and 2–5 transducers deployed in the river at any given time. The number of fish y that satisfied the set **X** of criteria under investigation (e.g., fish with ARIS length equal to or greater than 75 cm and that migrated in an upstream direction) during day i was estimated as follows:

$$\hat{y}_i = \sum_k \sum_s \hat{y}_{iks}, \tag{1}$$

where y_{iks} is net fish passage in stratum s of transducer k during day i and is estimated by

$$\hat{y}_{ijk} = \frac{24}{h_{iks}} \sum_j \hat{y}_{ijks} \tag{2}$$

where h_{iks} is the number of hours during which fish passage was estimated for stratum s of transducer k during day i, and y_{ijks} is hourly fish passage for stratum s of transducer k during hour j of day i, which is estimated by

$$\hat{y}_{ijks} = \frac{60}{m_{ijks}} c_{ijks}, \tag{3}$$

where

m_{ijks} = number of minutes (usually 10) sampled for stratum s of transducer k during hour j of day i, and

c_{ijks} = number of fish satisfying criteria **X** in stratum s of transducer k during hour j of day i.

[4] Perschbacher, J. *In prep*. Chinook salmon creel survey and inriver gillnetting study, lower Kenai River, Alaska, 2016. Alaska Department of Fish and Game, Fishery Data Series, Anchorage.

The variance of the daily estimates of y, due to systematic sampling in time, was approximated (successive difference model[5]; Wolter 1985) with adjustments for missing data as follows:

$$\hat{V}[\hat{y}_i] \cong 24^2(1-f)\frac{\sum_{j=2}^{24}\phi_{ij}\phi_{i(j-1)}\left(\hat{y}_{ij}-\hat{y}_{i(j-1)}\right)^2}{2\sum_{j=1}^{24}\phi_{ij}\sum_{j=2}^{24}\phi_{ij}\phi_{i(j-1)}}, \tag{4}$$

where

f = is the sampling fraction (temporal sampling fraction, usually 0.17),

ϕ_{ij} = is 1 if $\hat{y}_{ij}$ exists for hour j of day i, or 0 if not, and

$$\hat{y}_{ij} = \sum_k \sum_s \hat{y}_{ijks} . \tag{5}$$

Other estimates of passage were obtained by changing the criteria **X** for fish counts c_{ijks} in Equation 3. For example, estimates of medium and large fish were obtained by setting criteria to upstream travel with ARIS lengths greater than or equal to 75 cm and less than 90 cm or ARIS lengths greater than or equal to 90 cm, respectively. Estimates of daily net upstream passage were obtained by calculating separate estimates of upstream and downstream passage (Equations 1–3) and subtracting the downstream estimate from the upstream estimate. The estimated variance of net upstream daily passage was the sum of the upstream and downstream variances.

Chinook Salmon Passage

Upstream Chinook salmon passage, regardless of size, was estimated by fitting a mixture model to upstream ARIS length data and inriver netting data. Upstream Chinook salmon passage on day i was estimated as follows[6]:

$$\hat{z}_i = \hat{w}_i\hat{\pi}_{Ci}, \tag{8}$$

where

w_i = upstream passage of measured fish on day i, obtained by applying Equations 1–3 for measured upstream fish greater than or equal to 40 cm AL, and

π_{Ci} = the proportion of measured fish that are Chinook salmon on day i, derived by fitting an ARIS length mixture model (ALMM) to upstream ARIS length data and inriver netting data[7] as described in Appendices C1–C6.

---

5 This is an assessment of the uncertainty due to subsampling (counting fish for 10 minutes per hour and expanding). The formulation in Equation 4 is conservative in the sense that it has been shown to overestimate the true uncertainty when applied to salmon passage data (Reynolds et al. 2007; Xie and Martens 2014).

6 During periods with dense aggregations of fish when some small (40–75 cm AL) fish are not measured and counted, estimates of w_i and π_{Ci} are intermediate quantities only, in the sense that they are required in order to estimate z_i and N_i but have no biological interpretation themselves. Estimates of z_i and N_i remain valid.

7 Perschbacher, J. *In prep*. Chinook salmon creel survey and inriver gillnetting study, lower Kenai River, Alaska, 2016. Alaska Department of Fish and Game, Fishery Data Series, Anchorage.

The variance estimate followed Goodman (1960):

$$\hat{\text{var}}(\hat{z}_i) = \hat{w}_i^2 \hat{\text{var}}(\hat{\pi}_{Ci}) + \hat{\pi}_{Ci}^2 \hat{\text{var}}(\hat{w}_i) - \hat{\text{var}}(\hat{\pi}_{Ci}) \hat{\text{var}}(\hat{w}_i). \quad (9)$$

During 16–25 May 2016, a pooled estimate of π_C was calculated because daily sample sizes from the netting were too small to produce reliable estimates during that period.

Upstream ARIS data were used to be consistent with the inriver gillnetting data, most of which come from drift nets and presumably capture only upstream-bound fish. Midriver and nearshore netting data from RM 8.6 were used.

Daily net upstream Chinook salmon passage was approximated as

$$\hat{N}_i \approx \hat{z}_i \frac{u_i - d_i}{u_i}, \quad (10)$$

where u_i and d_i are daily estimates of upstream and downstream passage of fish greater than or equal to 75 cm AL, respectively, obtained using Equations 1–3.

RESULTS

EARLY DEPLOYMENT

Due to warm spring temperatures, early snow melt, and above average water levels, sonar was deployed early (6 May) in 2016 to determine if significant numbers of Chinook salmon might migrate upstream prior to the normal project start date of 16 May. Only estimates of net upstream passage of Chinook salmon 75 cm AL or longer were produced for the 6–15 May early deployment period.

An estimated 36 (SE 17) fish 75 cm AL or longer migrated upstream past RM 13.7 during 6–15 May. On 5 of 10 days, net upstream passage was 0 or negative (negative fish passage occurred on days when only downstream fish were observed), whereas the largest net upstream passage was 18 fish on 15 May (Table 5).

STANDARD DATA COLLECTION

Standard data collection began on 16 May for the main channel offshore transducers, 18 May for the main channel left bank nearshore transducer, 25 May for the main channel right bank nearshore transducer, and 1 June for the minor channel transducer (Table 2). All sampling ended after 19 August.

Size Distribution and Species Composition

Small fish (presumably sockeye salmon) predominated in both early and late runs, as evidenced by large left-hand modes in the ARIS length (AL) frequency distributions (Figure 12, top panels). The modes of the AL distributions line up well[8] with mid eye to tail fork (METF) length distributions from salmon measured by the inriver netting project (Figure 12, bottom panels). The AL distributions appear to be broader than the corresponding METF distributions due to greater error associated with measuring length from ARIS images (Miller et al. 2016b).

8 Length frequency distributions from the netting data in this figure are not representative across species because non-Chinook salmon were sampled (measured) at a rate less than that of Chinook salmon. Chinook salmon are therefore disproportionately over-represented in the netting length data.

Non-Chinook salmon captured in the inriver gillnets rarely exceeded 65–70 cm METF (Figure 12, bottom panels). From inspection of AL frequency distributions (Figure 12, top panels), it is evident that the right tail of the left-hand mode (presumably non-Chinook salmon) very rarely exceeded 75 cm AL. The frequency distributions of early- and late-run ARIS lengths possess a small separate mode near 40 cm (Figure 12, top panels) that is more prominent on the right bank and in the offshore strata during both runs (Figure 12, middle panels). This mode was also observed during the 2013–2015 early runs and was attributed to resident fish (e.g., rainbow trout [*O. mykiss*] and Dolly Varden [*Salvelinus malma*]) rather than sockeye salmon[9].

Spatial and Temporal Distribution

Spatial and temporal patterns of migration are displayed for medium (75 cm ≤ AL < 90 cm) and large (AL ≥ 90 cm) fish in Appendices D1–D7. Small (40 cm ≤ AL < 75 cm) fish that were measured are also displayed, although they are underrepresented, especially during the late run. In general, small fish migrated closer to the riverbank than did medium and large fish, although fish of all sizes were present midriver.

During both the early and late runs, a majority (68% early run, 66% late run) of upstream-bound medium and large (AL ≥ 75 cm) fish migrated past the sonar site on the right bank of the main channel (Table 6, Figure 13). A small proportion of early- and late-run upstream-bound medium and large (AL ≥ 75 cm) fish (6% early run, 10% late run) were found migrating in the minor channel. This represents an increase from 2015 (3% for both early and late runs) that is possibly due to high water flow, which was consistently above average throughout the summer, thereby making the shallow minor channel more conducive to fish passage. During both runs, a greater percentage of upstream-bound medium and large fish migrated up the nearshore right bank than the nearshore left bank (Table 6, Figure 13, Appendices D1–D7).

In 2016, passage rates were slower at night. When upstream-bound medium and large fish were classified as day (sunrise to sunset) versus night (sunset to sunrise) migrators, the proportion migrating at night was disproportionately small compared to the relative length of night (Figure 14) throughout most of the early and late runs. The relative ratio of day to night migrators was 87:13 in the early run and 77:23 in the late run (Table 6). These ratios are similar to those observed during past years at the RM 13.7 site (Miller et al. 2016a; Miller et al. 2016b; Key et al. 2017).

Direction of Travel

Relative upstream and downstream passage rates differed by size of fish, run, and spatial location.

Among medium and large fish (AL ≥ 75 cm), a greater fraction traveled downstream in the late run (15.4%) than in the early run (3.2%) (Table 7). During both the early and late run, relatively more medium and large fish migrated downstream in the minor channel (13.0% and 34.4%, respectively) than on the left (2.1% and 7.5%) or right (2.7% and 14.5%) banks of the main channel.

---

9 Three-year-old sockeye salmon (which average approximately 40 cm METF and are the main component of early-run Kenai River sockeye salmon; Jason Pawluk, Sport Fish Biologist, ADF&G, Soldotna; personal communication) were sampled during the early run at the Russian River weir in 2016.

Daily percentages of medium and large fish (AL $\geq$ 75 cm) that were traveling upstream versus downstream are tabulated in Appendices E1–E2.

CHINOOK SALMON PASSAGE

Daily proportions of upstream-bound fish that were Chinook salmon (regardless of size) were estimated using an ARIS-length mixture model (ALMM). These proportions were multiplied by ARIS estimates of upstream fish passage and corrected for downstream-bound fish to produce ARIS estimates of net upstream Chinook salmon passage: 9,851 (SE 355) Chinook salmon during the early run (16 May–30 June; Table 8) and 22,537 (SE 480) during the late run (1 July–19 August; Table 9).

The ALMM also produced daily estimates of Chinook salmon age group composition (Tables 10 and 11). These estimates incorporate length information from ARIS as well as from inriver gillnet catches.

Daily estimates of net upstream Chinook salmon passage are plotted in Figure 15. Other measures of abundance are plotted for comparison in Figures 16 and 17.

Median early-run Chinook salmon (regardless of size) passage in 2016 occurred on 10 June, 2 days earlier than the 2013–2015 average of 12 June. Median late-run passage occurred on 20 July, 5 days earlier than the 2013–2015 average of 25 July (Table 12; Figures 18 and 19).

MEDIUM AND LARGE FISH PASSAGE

Daily net upstream passage of medium (75 cm $\leq$ AL < 90 cm) and large (AL $\geq$ 90 cm) fish was estimated directly by the ARIS sonar. During the 2016 early run (16 May–30 June), an estimated 6,391 (SE 197) fish greater than or equal to 75 cm AL passed RM 13.7, including 4,786 (SE 172) medium and 1,605 (SE 95) large fish (Table 13). During the 2016 late run (1 July–19 August), an estimated 17,447 (SE 403) fish greater than or equal to 75 cm AL passed RM 13.7, including 8,547 (SE 260) medium and 8,900 (SE 283) large (AL $\geq$ 90 cm) fish (Table14).

Assuming all medium and large fish ($\geq$75 cm AL) are Chinook salmon, median passage of Chinook salmon greater than or equal to 75 cm AL during the early run occurred on 11 June, 1 day later than the median passage of all Chinook salmon (regardless of size, based on the mixture model). Median passage of Chinook salmon greater than or equal to 75 cm AL during the late run occurred on 23 July, 3 days later than the median passage of all Chinook salmon regardless of size (Table 12, Figures 18 and 19).

SMALL FISH PASSAGE

Daily net upstream passage of small (AL < 75 cm) Chinook salmon was estimated by subtracting the estimate of medium and large fish from the estimate of Chinook salmon regardless of size. During the 2016 early run (16 May–30 June), an estimated 3,460 (SE 406) Chinook salmon less than 75 cm AL passed RM 13.7 (Table 8). During the 2016 late run (1 July–19 August), an estimated 5,090 (SE 627) Chinook salmon less than 75 cm AL passed RM 13.7 (Table 9).

All ARIS-based estimates of Chinook salmon passage in this report (small, medium, and large, and all Chinook salmon regardless of size) are germane to the entire river cross-section at RM 13.7.

DISCUSSION

During the early deployment of ARIS, the estimated net upstream passage of 36 fish 75 cm AL or longer during 6–15 May represents only 0.6% of the total 2016 early-run passage, despite an unusually early spring. We conclude that the standard project start date of 16 May is adequate when considering labor, maintenance schedules, and potential site access issues early in the season (river ice, boat launch availability). Often bank ice is still present up until mid-May, which can cause unnecessary damage to boats and put technicians in potentially dangerous situations. The current project start date allows for a safe, yet timely setup schedule that also allows for network setup, troubleshooting, and software upgrades that are a yearly requirement, while minimizing the necessity for overtime for technicians.

The 2016 early-run Chinook salmon (regardless of size) net upstream passage estimate of 9,851 fish was the highest recorded since data collection began at the RM 13.7 site in 2013, and was substantially larger than the 2013–2015 average of 6,449 fish (Miller et al. 2016a, 2016b; Key et al. 2017). The late-run net upstream passage estimate of 22,535 Chinook salmon (regardless of size) was the second highest since 2013, but it was similar to the 2013–2015 average of 21,924 fish.

The 2016 early-run estimate of Chinook salmon 75 cm AL or longer (6,391 fish) was the largest recorded at the RM 13.7 site, and was well above the 2013–2015 average of 3,681 fish. The 2016 late-run estimate of Chinook salmon greater than or equal to 75 cm AL (17,447 fish) was similar to the 2015 estimate (17,687 fish), but greater than the 2013–2015 average of 14,665 fish. Small Chinook salmon (AL $\leq$ 75 cm) passage during the 2016 early run (3,460 fish) was above the 2013–2015 average of 2,768 fish, whereas late-run small Chinook salmon passage (5,090 fish) was below the 2013–2015 average of 7,260 fish.

Prior to 2016, historical size data from the RM 8.6 netting project were used in inseason mixture model estimates during periods of small netting catches when Chinook salmon abundance was low (Miller et al. 2016a, 2016b; Key et al. 2017). This made the inseason estimates sensitive to inseason size compositions that differed greatly from the historical average, resulting in bias in inseason estimates and significant differences between inseason and final postseason estimates of Chinook salmon of all sizes. This issue was partially addressed in 2015 by statistically reducing the influence of prior historical information on inseason estimates, yet the final estimates of Chinook salmon regardless of size were still significantly higher than inseason estimates (Key et al. 2017). In 2016, the use of historical data for inseason estimate production was eliminated completely. As a result, 2016 inseason estimates of Chinook salmon regardless of size were similar to postseason estimates published herein.

ACKNOWLEDGEMENTS

We would like to thank John Sigurdsson, Shaylee Cowling, and Nathan Plate for their positive and enthusiastic attitudes during many hours processing ARIS data. We would also like to thank Mike Hopp for his assistance inseason deploying and breaking down the project, managing all our network needs and measuring fish images. We would also like to thank Jason Pawluk for all his help processing data. We would like to express our gratitude to Don and John Cho with Kenai Riverbend Resort for allowing daily access to the RM 13.7 site via their property, for providing a source of electricity to operate the left bank electronics, and for the use of their boat

launch for project deployment and breakdown. Finally, thanks to Division of Sport Fish staff in Soldotna who provided logistical support throughout the season.

REFERENCES CITED

Benke, A. C., and C. E. Cushing. 2005. Rivers of North America. Elsevier Academic Press, Burlington, Massachusetts.

Bosch, D., and D. Burwen. 1999. Estimates of Chinook salmon abundance in the Kenai River using split-beam sonar, 1997. Alaska Department of Fish and Game, Fishery Data Series No. 99-3, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/fds99-03.pdf.

Burger, C. V., R. L. Wilmot, and D. B. Wangaard. 1985. Comparison of spawning areas and times for two runs of Chinook salmon (*Oncorhynchus tshawytscha*) in the Kenai River, Alaska. Canadian Journal of Fisheries and Aquatic Sciences 42(4):693-700.

Burwen, D., J. Hasbrouck, and D. Bosch. 2000. Investigations of alternate sites for Chinook salmon sonar on the Kenai River. Alaska Department of Fish and Game, Fishery Data Series No. 00-43, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/fds00-43.pdf.

Burwen, D. L., D. E. Bosch, and S. J. Fleischman. 1998. Evaluation of hydroacoustic assessment techniques for Chinook salmon on the Kenai River, 1995. Alaska Department of Fish and Game, Fishery Data Series No. 98-3, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/fds98-03.pdf.

Burwen, D. L., and S. J. Fleischman. 1998. Evaluation of side-aspect target strength and pulse width as hydroacoustic discriminators of fish species in rivers. Canadian Journal of Fisheries and Aquatic Sciences 55(11):2492-2502.

Burwen, D. L., S. J. Fleischman, and J. D. Miller. 2007. Evaluation of a dual-frequency imaging sonar for estimating fish size in the Kenai River. Alaska Department of Fish and Game, Fishery Data Series No. 07 44, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/fds07-44.pdf.

Burwen, D. L., S. J. Fleischman, J. D. Miller, and M. E. Jensen. 2003. Time-based signal characteristics as predictors of fish size and species for a side-looking hydroacoustic application in a river. ICES Journal of Marine Science 60:662-668.

Cochran, W. G. 1977. Sampling techniques. 3rd edition. John Wiley and Sons, New York.

Faulkner, A. V., and S. L. Maxwell. 2009. An aiming protocol for fish-counting sonars using river bottom profiles from a Dual-Frequency Identification Sonar (DIDSON). Alaska Department of Fish and Game, Fishery Manuscript No. 09-03, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/fms09-03.pdf.

Gelman, A., J. B. Carlin, H. S. Stern, and D. B. Rubin. 2004. Bayesian data analysis. 3rd edition. Chapman and Hall, Boca Raton, Florida.

Gilks, W. R., A. Thomas, and D. J. Spiegelhalter. 1994. A language and program for complex Bayesian modeling. The Statistician 43:169-178. http://www.mrc-bsu.cam.ac.uk/bugs Accessed 01/2010.

Glick, W. J., and T. M. Willette. 2015. Upper Cook Inlet sockeye salmon escapement studies, 2013. Alaska Department of Fish and Game, Fishery Data Series No. 15-25, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/FDS15-25.pdf.

Goodman, L. A. 1960. On the exact variance of products. Journal of the American Statistical Association 55:708-713.

Hammarstrom, S. L., and J. J. Hasbrouck. 1998. Estimation of the abundance of late-run Chinook salmon in the Kenai River based on exploitation rate and harvest, 1996. Alaska Department of Fish and Game, Fishery Data Series No. 98-6, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/fds98-06.pdf.

Hammarstrom, S. L., and J. J. Hasbrouck. 1999. Estimation of the abundance of late-run Chinook salmon in the Kenai River based on exploitation rate and harvest, 1997. Alaska Department of Fish and Game, Fishery Data Series No. 99-8, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/fds99-08.pdf

REFERENCES CITED (Continued)

Key, B. H., J. D. Miller, D. L. Burwen, and S. J. Fleischman. 2016a. Estimates of Chinook salmon passage in the Kenai River at river mile 8.6 using dual-frequency identification sonar, 2013. Alaska Department of Fish and Game, Fishery Data Series No. 16-13, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/FDS16-13.pdf.

Key, B. H., J. D. Miller, D. L. Burwen, and S. J. Fleischman. 2016b. Estimates of Chinook salmon passage in the Kenai River at river mile 8.6 using dual-frequency identification sonar, 2014. Alaska Department of Fish and Game, Fishery Data Series No. 16-14, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/FDS16-14.pdf.

Key, B. H., J. D. Miller, S. J. Fleischman, and J. Huang. 2017. Chinook salmon passage in the Kenai River at River Mile 13.7 using adaptive resolution imaging sonar, 2015. Alaska Department of Fish and Game, Fishery Data Series No. 17-33, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/FDS17-33.pdf.

McBride, D. N., M. Alexandersdottir, S. Hammarstrom, and D. Vincent-Lang. 1989. Development and implementation of an escapement goal policy for the return of Chinook salmon to the Kenai River. Alaska Department of Fish and Game, Fishery Manuscript No. 8, Juneau. http://www.adfg.alaska.gov/FedAidPDFs/fms-008.pdf.

Miller, J. D., D. Bosch, and D. Burwen. 2002. Estimates of Chinook salmon abundance in the Kenai River using split-beam sonar, 1999. Alaska Department of Fish and Game, Fishery Data Series No. 02-24, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/fds02-24.pdf.

Miller, J. D., D. L. Burwen, and S. J. Fleischman. 2010. Estimates of Chinook salmon passage in the Kenai River using split-beam sonar, 2006. Alaska Department of Fish and Game, Fishery Data Series No. 10-40, Anchorage. http://www.adfg.alaska.gov/FedAidpdfs/FDS10-40.pdf.

Miller, J. D., D. L. Burwen, and S. J. Fleischman. 2013. Estimates of Chinook salmon passage in the Kenai River using split-beam and dual-frequency identification sonars, 2010. Alaska Department of Fish and Game, Fishery Data Series No. 13-58, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/FDS13-58.pdf.

Miller, J. D., D. L. Burwen, and S. J. Fleischman. 2014. Estimates of Chinook salmon passage in the Kenai River using split-beam and dual-frequency identification sonars, 2011. Alaska Department of Fish and Game, Fishery Data Series No. 14-18, Anchorage. http://www.adfg.alaska.gov/FedAidpdfs/FDS14-18.pdf.

Miller, J. D., D. L. Burwen, and S. J. Fleischman. 2015. Estimates of Chinook salmon passage in the Kenai River at river mile 8.6 using dual-frequency identification sonar, 2012. Alaska Department of Fish and Game, Fishery Data Series No. 15-09, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/FDS15-09.pdf.

Miller, J. D., D. L. Burwen, B. H. Key, and S. J. Fleischman. 2016a. Chinook salmon passage in the Kenai River at River Mile 13.7 using adaptive resolution imaging sonar, 2013. Alaska Department of Fish and Game, Fishery Data Series No. 16-15, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/FDS16-15.pdf

Miller, J. D., D. L. Burwen, B. H. Key, and S. J. Fleischman. 2016b. Chinook salmon passage in the Kenai River at River Mile 13.7 using adaptive resolution imaging sonar, 2014. Alaska Department of Fish and Game, Fishery Data Series No. 16-44, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/FDS16-44.pdf.

Perschbacher, J. 2015. Chinook salmon creel survey and inriver gillnetting study, lower Kenai River, Alaska, 2013. Alaska Department of Fish and Game, Fishery Data Series No. 15-46, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/FDS15-46.pdf.

Perschbacher, J., and T. Eskelin. 2016. Chinook salmon creel survey and inriver gillnetting study, Lower Kenai River, Alaska, 2014. Alaska Department of Fish and Game, Fishery Data Series No. 16-54, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/FDS16-54.pdf.

Reynolds, J. H., C. A. Woody, N. E. Gove, and L. F. Fair. 2007. Efficiently estimating salmon escapement uncertainty using systematically sampled data. Pages 121-129 [*In*] C. A. Woody, editor. Sockeye salmon evolution, ecology, and management. American Fisheries Society, Symposium No. 54, Anchorage.

Seibel, M. C. 1967. The use of expanded ten-minute counts as estimates of hourly salmon migration past counting towers on Alaskan rivers. Alaska Department of Fish and Game, Division of Commercial Fisheries, Informational Leaflet 101, Juneau., Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/afrbil.101.pdf.

REFERENCES CITED (Continued)

USDA (United States Department of Agriculture). 1992. Kenai River landowner's guide. Prepared by the U.S. Department of Agriculture, Soil conservation Service (SCS) for the Kenai Soil and Water Conservation District, Kenai, Alaska.

Wolter, K. M. 1985. Introduction to variance estimation. Springer-Verlag, New York.

Xie, Y., and F. J. Martens. 2014. An empirical approach for estimating the precision of hydroacoustic fish counts by systematic hourly sampling. North American Journal of Fisheries Management 34(3):535-545.

TABLES

Table 1.–On-site components of the ARIS systems used in 2016.

System component	Model (number of units)	Description
Sounders	ARIS 1200 (4)	Left bank mainstem offshore
		Right bank mainstem offshore
		Right bank mainstem nearshore
		Right bank minor channel
	ARIS 1800 (1)	Left bank mainstem nearshore
Lens assembly	ARIS 1800 (1)	Standard lens with ~14°×28° beam pattern
	ARIS 1200 (4)	High-resolution lens with ~3°×15° beam pattern
Data collection computers	Dell Latitude E6430 (5)	One for each sonar
Wireless bridge radio sets	Cisco Aironet 1310 (3)	One for each sonar located on the right bank
Remote pan and tilts	Sound Metrics AR2 rotators (5)	Controlled via ARISCOPE software
Storage media (on site)	Western Digital 2TB Passport Drives with USB 3.0 (10)	Two per computer
Internet access	AT&T MiFi Liberate mobile hot spot (1) AT&T Beams 4G (4)	

Table 2.–Summary of sonar stratum range changes by date at RM 13.7 Kenai River, 2016.

Sonar location	Range stratum	Time (min) [a]	Coverage range (m) by date							
			5 May [b]	18 May	May 25	1 June	2 Jun [c]	6 Jun [c]	7 Jul	25 Jul
Left nearshore	1	:00 / :30	[d]	2.5–10.5	2.5–10.0	2.5–10.0	2.5–14.0	2.5–14	1.0–14	1.0–14
Left offshore	1	:00 / :30	3.5–8.0	3.5–8.0	3.5–8.0	3.5–8.0	3.5–8.0	3.5–8.0	3.5–8.0	3.5–8.0
	2	:10 / :40	8.0–22.0	8.0–22.0	8.0–22.0	8.0–22.0	8.0–22.0	8.0–22.0	8.0–22.0	8.0–22.0
	3	:20 / :50	22.0–33.5	22.0–33.5	22.0–33.5	22.0–33.0	22.0–33.0	22.0–33.0	22.0–33.0	22.0–35.0
Right offshore	1	:00 / :30	3.5–8.0	3.5–8.0	[e]	[e]	[e]	[e]	[e]	[e]
	2	:10	8.0–22.0	8.0–22.0	8.0–22.0	8.0–22.0	8.0–22.0	8.0–22.0	8.0–22.0	8.0–22.0
	3	:20	22.0–33.5	22.0–33.5	22.0–33.5	22.0–33.0	22.0–33.0	22.0–33.0	22.0–33.0	22.0–34.0
Right nearshore	1	:40	[f]	[f]	3.5–8.0	3.5–8.0	3.5–8.0	3.5–8.0	3.5–8.0	3.5–8.0
	2	:50	[f]	[f]	8.0–15.5	8.0–15.5	8.0–15.5	8.0–20.0	8.0–20.0	8.0–19.0
Minor channel	1	:00	[g]	[g]	[g]	2.5–6.0	2.5–6.0	2.5–6.0	2.5–6.0	2.5–6.0
	2	:10	[g]	[g]	[g]	6.0–12.0	6.0–12.0	6.0–12.0	6.0–12.0	6.0–12.0
	3	:30	[g]	[g]	[g]	12.0–21.0	12.0–21.0	12.0–21.0	12.0–21.0	12.0–21.0

[a] Sample start time in number of minutes past the top of the hour. Two samples were made for some strata; start times are separated by "/".

[b] Sonars were deployed 10 days early to assess the number of large Chinook salmon that migrate past the RM 13.7 sonar site prior to the normal project start date of 16 May.

[c] Nearshore sonars were moved closer to shore as water level rose, resulting in increased coverage range.

[d] Sonar was not deployed in this stratum until 18 May.

[e] Beginning 25 May, right offshore Stratum 1 was covered by right nearshore Stratum 2.

[f] Sonar was not deployed in this stratum until 25 May.

[g] Sonar was not deployed in this stratum until 1 June.

Table 3.–Sampling schedule and parameter values on 28 June 2016 for each range stratum sampled by 5 ARIS systems in 2016.

Sonar location	ARIS serial no.	Range stratum	Time (min) [a]	Frame rate (fps) [b]	Start range (m)	End range (m)	Frequency (MHz)	Transmit level	Gain (dB)	Pulse width (µs)	Start delay (µs)	Sample period (µs) [d]	Samples per beam	Pitch (°)	Heading (°)
Left nearshore	1096	1	:00 / :30	8	2.5	14	High (1.8)	Max	16	20	3,074	10	1,640	–6.9	165
Left offshore	1064	1	:00 / :30	10	3.5	8.0	High (1.2)	Max	3	13	4,821	10	620	−6.8	78
		2	:10 / :40	10	8.0	22.0	High (1.2)	Max	10	20	11,021	10	1,929	−4.0	78
		3	:20 / :50	6	22.0	33	High (1.2)	Max	16	31	30,308	10	1,515	−2.0	78
Right offshore	1063	1	[c]	[c]	[c]	[c]	[c]	[c]	[c]	[c]	[c]	[c]	[c]	[c]	[c]
		2	:00/:20	8	8.0	22.0	High (1.2)	Max	16	20	11,113	10	1,944	−2.9	333
		3	:10/:30	6	22.0	33	High (1.2)	Max	16	32	30,273	10	1,514	−2.5	338
Right nearshore	1098	1	:40	9	3.5	8.0	High (1.2)	Max	6	20	4,887	10	628	−4.0	231
		2	:50	9	8.0	20.0	High (1.2)	Max	6	20	11,171	10	1,676	−4.5	231
Minor channel	1095	1	:00	9	2.5	6.0	High (1.2)	Max	16	13	3,464	10	485	−11.0	23
		2	:10	8	6.0	12.0	High (1.2)	Max	16	13	8,314	10	832	−7.0	23
		3	:30	9	12.0	21.0	High (1.2)	Max	16	20	16,629	10	1247	−2.1	23

[a] Sample start time in number of minutes past the top of the hour. Two samples were made for some strata; start times are separated by "/".

[b] Frame rate in frames per second.

[c] Normal data collection in right-bank offshore Stratum 1 occurred until 24 May. Increased water level allowed the right bank inshore sonar to be deployed on 25 May and from that date forward, the area formerly covered by right bank offshore Stratum 1 was covered by right bank inshore Stratum 2 (see Figure 9).

[d] Optimal sample period was selected using tethered fish data and manufacturer recommendations (Key et al. 2016b)

Table 4.–Select user-configurable parameters in Sound Metrics Corporation ARIScope data collection software (high frequency identification mode only).

Parameter	ARIS 1200	ARIS 1800
Transmit pulse length	4–100 µs	4–100 µs
Detail a	3–100 mm	3–100 mm
Source level	~206–212 dB re 1 µPa at 1 m	~200–206 dB re 1 µPa at 1 m
Window length	Any	Any
Samples per beam	128–4,000	128–4,000

[a] Window length per number of samples.

Table 5.–Daily upstream, downstream, and net upstream passage of Chinook salmon ≥75 cm ARIS length, 6 May–15 May 2016.

	Upstream		Downstream		Net Upstream	
Date	Passage	SE	Passage	SE	Passage	SE
6 May	6	6	0	0	6	8
7 May	0	0	0	0	0	9
8 May	0	0	6	6	−6	10
9 May	6	6	0	0	6	12
10 May	0	0	0	0	0	16
11 May	6	6	6	6	0	15
12 May	12	4	0	0	12	12
13 May	6	4	0	0	6	28
14 May	0	0	6	4	−6	19
15 May	18	8	0	0	18	18
Total	54	14	18	9	36	17

Table 6.–Spatial and temporal distribution (percent of total run) of upstream-bound medium and large fish (≥75 cm ARIS length), by river bank, transducer, and time (day or night) at RM 13.7 for the Kenai River early and late runs, 2016.

		Main channel left bank		Main channel right bank		Main channel			
		Transducer location		Transducer location		Left	Right	Minor	All
Run	Day or night	Nearshore	Offshore	Offshore	Nearshore	bank	bank	channel	strata
Early									
	Day	11	12	21	38	23	59	5	87
	Night	2	2	4	5	3	9	0	13
	Both	12	14	26	42	26	68	6	100
Late									
	Day	5	15	14	37	20	51	7	77
	Night	3	2	3	12	4	16	3	23
	Both	7	17	17	49	24	66	10	100

Note: Columns may not sum due to rounding.

Table 7.–Percentage of all fish migrating downstream by river bank, transducer, and fish size at RM 13.7 for the 2016 Kenai River early and late runs.

		Main channel left bank		Main channel right bank		Main Channel			
		Transducer location		Transducer location					
Run	Fish size [a]	Nearshore	Offshore	Offshore	Nearshore	Left bank	Right bank	Minor channel	All strata
Early									
	Small	2.5%	9.0%	6.7%	1.3%	3.8%	2.2%	9.8%	5.7%
	Medium	3.0%	1.8%	6.0%	0.8%	2.4%	2.7%	13.3%	3.3%
	Large	0.0%	2.6%	5.4%	0.0%	1.4%	2.7%	11.8%	2.9%
	Med and large	2.2%	2.0%	5.8%	0.7%	2.1%	2.7%	13.0%	3.2%
Late									
	Small[b]								
	Medium	2.0%	6.6%	13.7%	13.4%	5.1%	13.5%	32.9%	14.5%
	Large	10.9%	9.8%	15.5%	15.2%	10.1%	15.3%	36.4%	16.3%
	Med and large	5.8%	8.3%	14.8%	14.4%	7.5%	14.5%	34.4%	15.4%

[a] Small fish are 40 cm ≤ AL < 75 cm, medium fish are 75 cm ≤ AL < 90 cm, and large fish are ≥ 90 cm AL.

[b] Sampling of small fish is inconsistent and probably not representative during the late run; therefore, small fish data are not tabulated for the late run.

Table 8.–ARIS-length mixture model (ALMM) estimates of net upstream passage for all Chinook salmon (regardless of size) and small Chinook salmon (AL < 75 cm), RM 13.7 Kenai River, early run 2016.

	ALMM Chinook salmon (all sizes)			ALMM Chinook salmon < 75 cm AL		
Date	Passage	SE	CV	Passage	SE	CV
16 May	29	9	0.30	17	12	0.69
17 May	29	7	0.25	11	12	1.05
18 May	16	5	0.30	10	11	1.11
19 May	66	19	0.29	53	23	0.43
20 May	68	17	0.25	26	23	0.90
21 May	49	11	0.23	19	19	0.99
22 May	36	9	0.26	24	15	0.62
23 May	95	20	0.21	29	34	18.0
24 May	96	31	0.32	66	36	0.55
25 May	98	25	0.25	62	31	0.50
26 May	183	49	0.27	92	56	0.61
27 May	138	47	0.34	60	50	0.84
28 May	411	84	0.21	170	93	0.55
29 May	252	57	0.23	83	68	0.81
30 May	268	66	0.25	86	81	0.94
31 May	309	57	0.19	92	64	0.69
1 Jun	232	64	0.28	93	70	0.8
2 Jun	174	41	0.24	53	52	0.97
3 Jun	286	60	0.21	105	66	0.63
4 Jun	328	68	0.21	105	80	0.76
5 Jun	179	47	0.26	52	52	1.00
6 Jun	316	68	0.21	101	79	0.78
7 Jun	424	69	0.16	99	80	0.81
8 Jun	300	57	0.19	89	65	0.74
9 Jun	308	58	0.19	100	68	0.68
10 Jun	242	53	0.22	73	59	0.81
11 Jun	398	76	0.19	157	90	0.57
12 Jun	385	65	0.17	114	76	0.66
13 Jun	365	60	0.16	82	75	0.91
14 Jun	342	67	0.19	65	75	1.15
15 Jun	212	50	0.24	34	63	1.85
16 Jun	232	50	0.22	51	59	1.15
17 Jun	191	53	0.28	64	62	0.97
18 Jun	195	51	0.26	62	57	0.91
19 Jun	136	40	0.30	45	46	1.02
20 Jun	127	38	0.30	46	44	0.97
21 Jun	208	50	0.24	81	54	0.66
22 Jun	151	43	0.29	66	48	0.72
23 Jun	256	58	0.23	119	63	0.53
24 Jun	281	63	0.23	121	70	0.58
25 Jun	190	53	0.28	88	59	0.67
26 Jun	182	51	0.28	79	57	0.72
27 Jun	245	55	0.22	82	61	0.74
28 Jun	199	49	0.25	71	55	0.77
29 Jun	400	89	0.22	189	93	0.49
30 Jun	224	54	0.24	74	62	0.84
Total	9,851	355	0.04	3,460	406	0.12

Note: CV not defined when passage equals zero.

Table 9.–ARIS-length mixture model (ALMM) estimates of net upstream passage for all Chinook salmon (regardless of size) and small Chinook salmon (AL < 75 cm), RM 13.7 Kenai River, late run 2016.

	ALMM Chinook salmon (all sizes)			ALMM Chinook salmon < 75 cm AL		
Date	Passage	SE	CV	Passage	SE	CV
1 Jul	473	112	0.24	209	121	0.58
2 Jul	709	133	0.19	335	156	0.47
3 Jul	377	76	0.20	148	87	0.59
4 Jul	364	86	0.24	165	93	0.56
5 Jul	517	81	0.16	180	105	0.58
6 Jul	384	81	0.21	178	89	0.50
7 Jul	328	66	0.20	120	71	0.59
8 Jul	463	85	0.18	186	94	0.51
9 Jul	497	96	0.19	244	111	0.45
10 Jul	758	120	0.16	302	137	0.45
11 Jul	902	115	0.13	305	139	0.46
12 Jul	1111	108	0.10	333	140	0.42
13 Jul	788	92	0.12	215	112	0.52
14 Jul	784	92	0.12	206	120	0.58
15 Jul	531	70	0.13	133	94	0.71
16 Jul	300	50	0.17	60	62	1.03
17 Jul	471	61	0.13	108	81	0.75
18 Jul	591	64	0.11	97	99	1.02
19 Jul	527	68	0.13	144	79	0.55
20 Jul	357	50	0.14	59	70	1.19
21 Jul	429	57	0.13	91	72	0.80
22 Jul	637	79	0.12	130	90	0.69
23 Jul	532	71	0.13	97	88	0.91
24 Jul	544	66	0.12	103	85	0.82
25 Jul	548	68	0.12	105	85	0.81
26 Jul	410	51	0.12	51	72	1.41
27 Jul	612	68	0.11	60	92	1.54
28 Jul	634	73	0.11	93	97	1.04
29 Jul	589	68	0.11	105	94	0.90
30 Jul	493	58	0.12	62	84	1.36
31 Jul	250	36	0.15	20	64	3.21
1 Aug	305	40	0.13	20	62	3.10
2 Aug	186	29	0.15	8	59	7.42
3 Aug	327	40	0.12	5	66	13.30
4 Aug	468	53	0.11	51	74	1.45
5 Aug	458	56	0.12	66	92	1.39
6 Aug	308	45	0.15	42	63	1.50
7 Aug	406	49	0.12	47	73	1.56
8 Aug	327	48	0.15	50	68	1.37
9 Aug	301	39	0.13	36	55	1.53
10 Aug	385	43	0.11	11	70	6.38
11 Aug	109	14	0.13	7	76	10.83
12 Aug	365	43	0.12	21	70	3.33

-continued-

Table 9.–Page 2 of 2.

Date	ALMM Chinook salmon (all sizes)			ALMM Chinook salmon < 75 cm AL		
	Passage	SE	CV	Passage	SE	CV
13 Aug	394	44	0.11	14	69	4.96
14 Aug	300	37	0.12	10	66	6.63
15 Aug	186	26	0.14	5	54	10.76
16 Aug	327	36	0.11	13	92	7.06
17 Aug	83	13	0.16	4	46	11.48
18 Aug	179	27	0.15	16	66	4.11
19 Aug	213	32	0.15	20	59	2.97
Total	22,537	480	0.02	5,090	627	0.12

Note: Project operations concluded 19 August in accordance with the 1 percent rule (3 consecutive days of daily passage less than 1 percent of cumulative passage).

Table 10.–Daily estimates of Chinook salmon age composition derived from fitting a mixture model to length measurements from ARIS at RM 13.7 and gillnet catches from RM 8.6, Kenai River early run 2016.

	Ages 3 and 4		Age 5		Ages 6 and 7	
Date	Proportion	SE	Proportion	SE	Proportion	SE
16 May	0.53	0.10	0.42	0.09	0.05	0.05
17 May	0.53	0.10	0.42	0.09	0.05	0.05
18 May	0.53	0.10	0.42	0.09	0.05	0.05
19 May	0.53	0.10	0.42	0.09	0.05	0.05
20 May	0.53	0.10	0.42	0.09	0.05	0.05
21 May	0.53	0.10	0.42	0.09	0.05	0.05
22 May	0.53	0.10	0.42	0.09	0.05	0.05
23 May	0.53	0.10	0.42	0.09	0.05	0.05
24 May	0.53	0.10	0.42	0.09	0.05	0.05
25 May	0.53	0.10	0.42	0.09	0.05	0.05
26 May	0.51	0.12	0.37	0.15	0.12	0.11
27 May	0.46	0.12	0.42	0.16	0.12	0.12
28 May	0.41	0.10	0.49	0.10	0.09	0.06
29 May	0.39	0.10	0.54	0.11	0.07	0.06
30 May	0.38	0.10	0.54	0.10	0.08	0.06
31 May	0.34	0.10	0.57	0.10	0.09	0.06
1 Jun	0.29	0.14	0.67	0.13	0.03	0.04
2 Jun	0.25	0.10	0.64	0.11	0.11	0.06
3 Jun	0.34	0.10	0.64	0.10	0.03	0.02
4 Jun	0.25	0.10	0.68	0.10	0.06	0.04
5 Jun	0.25	0.10	0.67	0.10	0.07	0.05
6 Jun	0.32	0.09	0.61	0.09	0.07	0.04
7 Jun	0.27	0.07	0.70	0.07	0.03	0.03
8 Jun	0.32	0.08	0.57	0.08	0.11	0.04
9 Jun	0.33	0.08	0.62	0.08	0.05	0.03
10 Jun	0.31	0.09	0.64	0.09	0.05	0.04
11 Jun	0.33	0.09	0.65	0.09	0.02	0.02
12 Jun	0.35	0.08	0.62	0.08	0.04	0.03
13 Jun	0.24	0.08	0.74	0.08	0.02	0.02
14 Jun	0.17	0.08	0.78	0.08	0.05	0.03
15 Jun	0.17	0.09	0.77	0.10	0.06	0.04
16 Jun	0.25	0.10	0.73	0.10	0.02	0.03
17 Jun	0.30	0.14	0.68	0.14	0.02	0.03
18 Jun	0.33	0.11	0.63	0.11	0.04	0.04
19 Jun	0.33	0.10	0.63	0.11	0.04	0.04
20 Jun	0.43	0.10	0.53	0.10	0.04	0.05
21 Jun	0.43	0.10	0.54	0.10	0.03	0.04
22 Jun	0.43	0.09	0.56	0.09	0.02	0.02
23 Jun	0.45	0.09	0.53	0.09	0.02	0.02
24 Jun	0.44	0.09	0.54	0.09	0.02	0.03

-continued-

Table 10.–Page 2 of 2.

	Ages 3 and 4		Age 5		Ages 6 and 7	
Date	Proportion	SE	Proportion	SE	Proportion	SE
25 Jun	0.47	0.09	0.50	0.10	0.02	0.03
26 Jun	0.46	0.10	0.51	0.10	0.03	0.04
27 Jun	0.39	0.10	0.53	0.11	0.08	0.08
28 Jun	0.40	0.10	0.49	0.11	0.11	0.08
29 Jun	0.45	0.10	0.50	0.10	0.05	0.06
30 Jun	0.34	0.10	0.36	0.11	0.30	0.10
Weighted mean	0.31	0.02	0.62	0.03	0.07	0.01

Note: Mean proportions are weighted by daily ALMM estimates in Table 8.

Table 11.–Daily estimates of Chinook salmon age composition derived from fitting a mixture model to length measurements from ARIS at RM 13.7 and gillnet catches from RM 8.6, Kenai River late run 2016.

	Ages 3 and 4		Age 5		Ages 6 and 7	
Date	Proportion	SE	Proportion	SE	Proportion	SE
1 Jul	0.47	0.10	0.32	0.13	0.22	0.11
2 Jul	0.44	0.10	0.18	0.11	0.38	0.10
3 Jul	0.41	0.10	0.32	0.12	0.28	0.10
4 Jul	0.47	0.10	0.24	0.11	0.29	0.09
5 Jul	0.39	0.09	0.33	0.10	0.27	0.08
6 Jul	0.49	0.09	0.29	0.11	0.22	0.10
7 Jul	0.50	0.08	0.41	0.11	0.09	0.09
8 Jul	0.46	0.11	0.46	0.10	0.07	0.04
9 Jul	0.55	0.07	0.42	0.08	0.03	0.04
10 Jul	0.47	0.07	0.51	0.08	0.02	0.04
11 Jul	0.43	0.06	0.55	0.07	0.02	0.03
12 Jul	0.35	0.05	0.61	0.06	0.03	0.03
13 Jul	0.34	0.06	0.63	0.06	0.03	0.03
14 Jul	0.29	0.06	0.66	0.06	0.05	0.03
15 Jul	0.29	0.06	0.64	0.08	0.07	0.06
16 Jul	0.22	0.06	0.73	0.07	0.05	0.05
17 Jul	0.24	0.06	0.67	0.07	0.09	0.06
18 Jul	0.20	0.05	0.76	0.06	0.04	0.03
19 Jul	0.27	0.06	0.69	0.07	0.05	0.05
20 Jul	0.20	0.05	0.64	0.14	0.16	0.14
21 Jul	0.20	0.06	0.63	0.14	0.17	0.14
22 Jul	0.21	0.06	0.68	0.13	0.11	0.12
23 Jul	0.21	0.06	0.37	0.19	0.42	0.20
24 Jul	0.18	0.06	0.53	0.22	0.28	0.22
25 Jul	0.17	0.05	0.37	0.28	0.46	0.28
26 Jul	0.12	0.05	0.44	0.33	0.44	0.32
27 Jul	0.13	0.05	0.59	0.33	0.28	0.32
28 Jul	0.13	0.05	0.73	0.11	0.14	0.10
29 Jul	0.07	0.04	0.76	0.09	0.17	0.09
30 Jul	0.06	0.03	0.76	0.10	0.18	0.09
31 Jul	0.05	0.03	0.79	0.08	0.16	0.08
1 Aug	0.03	0.02	0.78	0.10	0.19	0.10
2 Aug	0.05	0.03	0.77	0.11	0.18	0.10
3 Aug	0.07	0.03	0.84	0.07	0.10	0.07
4 Aug	0.07	0.04	0.79	0.09	0.14	0.08
5 Aug	0.10	0.05	0.64	0.15	0.25	0.14
6 Aug	0.12	0.06	0.63	0.11	0.26	0.11
7 Aug	0.10	0.05	0.72	0.08	0.18	0.07
8 Aug	0.14	0.07	0.68	0.13	0.18	0.12
9 Aug	0.10	0.06	0.68	0.11	0.22	0.10

-continued-

Table 11.–Page 2 of 2.

Date	Ages 3 and 4		Age 5		Ages 6 and 7	
	Proportion	SE	Proportion	SE	Proportion	SE
10 Aug	0.02	0.03	0.38	0.33	0.60	0.32
11 Aug	0.03	0.04	0.60	0.14	0.37	0.14
12 Aug	0.03	0.04	0.33	0.23	0.64	0.22
13 Aug	0.02	0.03	0.54	0.18	0.43	0.18
14 Aug	0.03	0.03	0.19	0.18	0.79	0.18
15 Aug	0.02	0.03	0.60	0.20	0.38	0.20
16 Aug	0.03	0.04	0.51	0.23	0.47	0.23
17 Aug	0.03	0.04	0.50	0.30	0.47	0.30
18 Aug	0.04	0.05	0.56	0.16	0.40	0.15
19 Aug	0.04	0.06	0.55	0.20	0.40	0.20
Weighted mean	0.24	0.01	0.56	0.03	0.20	0.02

Note: Mean proportions are weighted by daily ALMM estimates in Table 9.

Table 12.–Median passage dates for Chinook salmon early and late runs by year and size class (≥75 cm vs. all sizes), Kenai River RM 13.7, 2013–2016.

Year	Early run		Late run	
	Chinook salmon [a] ≥75 cm	All Chinook salmon [b]	Chinook salmon [a] ≥75 cm	All Chinook salmon [b]
2013	14 Jun	12 Jun	30 Jul	26 Jul
2014	11 Jun	13 Jun	30 Jul	26 Jul
2015	9 Jun	10 Jun	25 Jul	22 Jul
Average [c] 2013–2015	11 Jun	12 Jun	29 Jul	25 Jul
2016	11 Jun	10 Jun	23 Jul	20 Jul

[a] All fish of AL greater than or equal to 75 cm are assumed to be Chinook salmon.

[b] Based on AL mixture model.

[c] Dates were determined by the average of the median passage date.

Table 13.–Estimates of net upstream daily passage of medium (75 cm ≤ AL < 90 cm) and large (AL ≥ 90 cm) fish at RM 13.7 Kenai River, early run 2016.

	75 cm ≤ AL < 90 cm		AL ≥ 90 cm		AL ≥ 75 cm	
Date	Passage	SE	Passage	SE	Passage	SE
16 May	12	8	0	0	12	8
17 May	12	7	6	0	18	9
18 May	6	10	0	0	6	10
19 May	6	6	7	7	13	12
20 May	30	14	12	8	42	16
21 May	12	8	18	10	30	15
22 May	12	8	0	8	12	12
23 May	36	17	30	17	66	28
24 May	30	15	0	8	30	19
25 May	30	16	6	10	36	18
26 May	48	22	42	13	91	27
27 May	30	13	48	17	78	18
28 May	175	29	66	19	241	39
29 May	131	29	38	17	169	36
30 May	146	37	36	17	182	46
31 May	151	28	66	14	217	28
1 Jun	121	25	18	8	139	29
2 Jun	85	24	36	13	121	31
3 Jun	163	30	18	8	181	28
4 Jun	199	41	24	9	223	42
5 Jun	109	21	18	10	127	22
6 Jun	149	31	66	21	215	40
7 Jun	247	36	78	21	325	40
8 Jun	157	28	54	14	211	32
9 Jun	151	28	56	17	208	37
10 Jun	139	24	30	11	169	27
11 Jun	223	44	18	8	241	47
12 Jun	193	29	78	26	271	40
13 Jun	229	42	54	14	283	44
14 Jun	211	37	66	21	277	34
15 Jun	121	33	57	16	178	38
16 Jun	133	23	48	17	181	31
17 Jun	113	30	14	9	127	33
18 Jun	97	22	36	13	133	25
19 Jun	60	14	30	19	91	22
20 Jun	57	14	24	14	81	23
21 Jun	91	17	36	11	127	19
22 Jun	79	20	6	6	85	20
23 Jun	113	29	25	9	137	26
24 Jun	110	29	50	15	160	30
25 Jun	72	25	30	14	102	26
26 Jun	66	15	36	14	103	25
27 Jun	91	23	72	21	163	27
28 Jun	67	18	61	16	128	24
29 Jun	175	31	36	13	211	27
30 Jun	96	27	54	14	150	31
Total	4,786	172	1,605	95	6,391	197

Table 14.–Estimates of net upstream daily passage of medium (75 cm ≤ AL < 90 cm) and large (AL ≥ 90 cm) fish at RM 13.7 Kenai River, late run 2016.

	75 cm ≤ AL < 90 cm		AL ≥ 90 cm		AL ≥ 75 cm	
Date	Passage	SE	Passage	SE	Passage	SE
1 Jul	196	47	68	20	264	46
2 Jul	217	37	157	52	374	82
3 Jul	139	30	91	22	229	42
4 Jul	109	20	90	25	199	36
5 Jul	202	52	135	32	337	67
6 Jul	109	24	97	25	206	36
7 Jul	118	19	91	21	208	26
8 Jul	205	30	72	20	277	40
9 Jul	139	32	115	33	253	56
10 Jul	209	43	247	40	456	66
11 Jul	289	38	309	59	597	78
12 Jul	452	61	326	62	778	89
13 Jul	259	45	313	47	573	64
14 Jul	289	42	289	51	578	78
15 Jul	205	42	193	31	398	63
16 Jul	123	22	117	26	240	36
17 Jul	230	42	133	27	363	53
18 Jul	197	40	296	56	494	75
19 Jul	185	34	198	27	383	41
20 Jul	127	26	171	36	298	49
21 Jul	217	28	121	31	338	44
22 Jul	211	33	296	38	507	44
23 Jul	212	37	223	40	435	53
24 Jul	259	28	181	39	441	54
25 Jul	182	31	262	40	443	51
26 Jul	157	35	203	36	359	51
27 Jul	259	35	293	44	552	62
28 Jul	249	45	292	31	541	64
29 Jul	273	52	211	31	484	66
30 Jul	167	49	264	37	431	61
31 Jul	115	30	115	32	230	53
1 Aug	122	29	164	48	285	48
2 Aug	73	26	105	41	178	52
3 Aug	179	36	143	45	322	53
4 Aug	155	25	263	43	417	52
5 Aug	163	40	229	48	392	73
6 Aug	157	31	109	32	266	44
7 Aug	135	38	226	35	359	55
8 Aug	133	33	145	38	277	49
9 Aug	163	27	102	34	265	39
10 Aug	151	26	223	53	374	55
11 Aug	54	48	48	51	102	75
12 Aug	121	33	224	47	344	55

-continued-

Table 14.–Page 2 of 2.

Date	75 cm ≤ AL < 90 cm		AL ≥ 90 cm		AL ≥ 75 cm	
	Passage	SE	Passage	SE	Passage	SE
13 Aug	169	35	212	46	380	54
14 Aug	91	43	199	48	290	55
15 Aug	67	31	114	40	181	47
16Aug	126	47	187	59	314	85
17Aug	48	35	31	35	79	44
18Aug	60	33	102	42	163	60
19Aug	84	36	109	39	193	50
Total	8,547	260	8,900	283	17,447	403

Table 15.–Inverse predictions of fish size from ARIS lengths (AL) of 40 cm, 75 cm, and 90 cm.

Size measurement	Unit	Description	ARIS length (cm)		
			40	75	90
FL	cm	Fork length (snout to tail fork)	42.7 cm	83.1 cm	100.4 cm
METF	cm	Mid eye to tail fork	38.6 cm	75.4 cm	91.1 cm
TL	in	Total length (snout to tail tip)	17.1 in	33.3 in	40.2 in

FIGURES

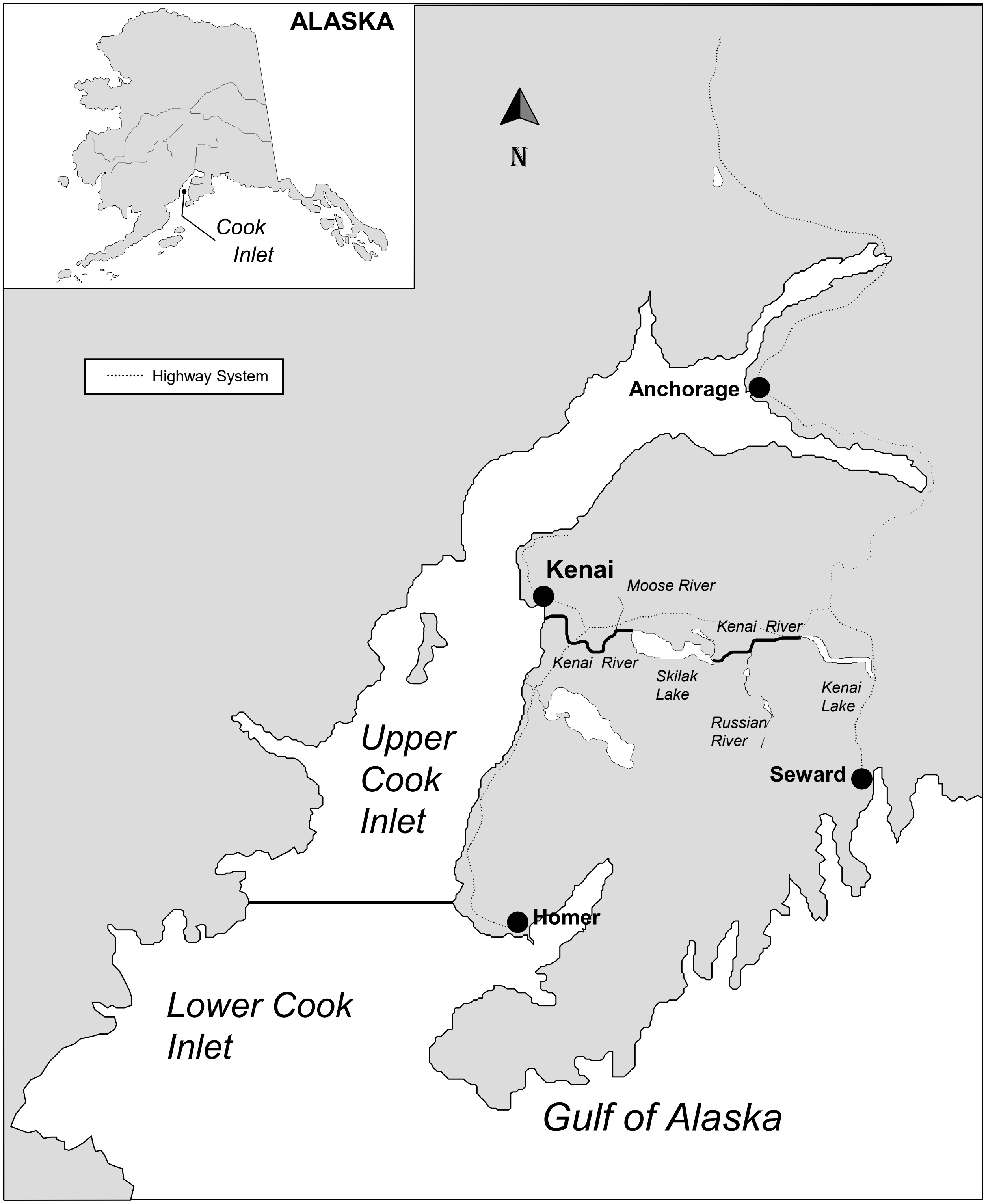


Figure 1.–Cook Inlet showing the location of the Kenai River.

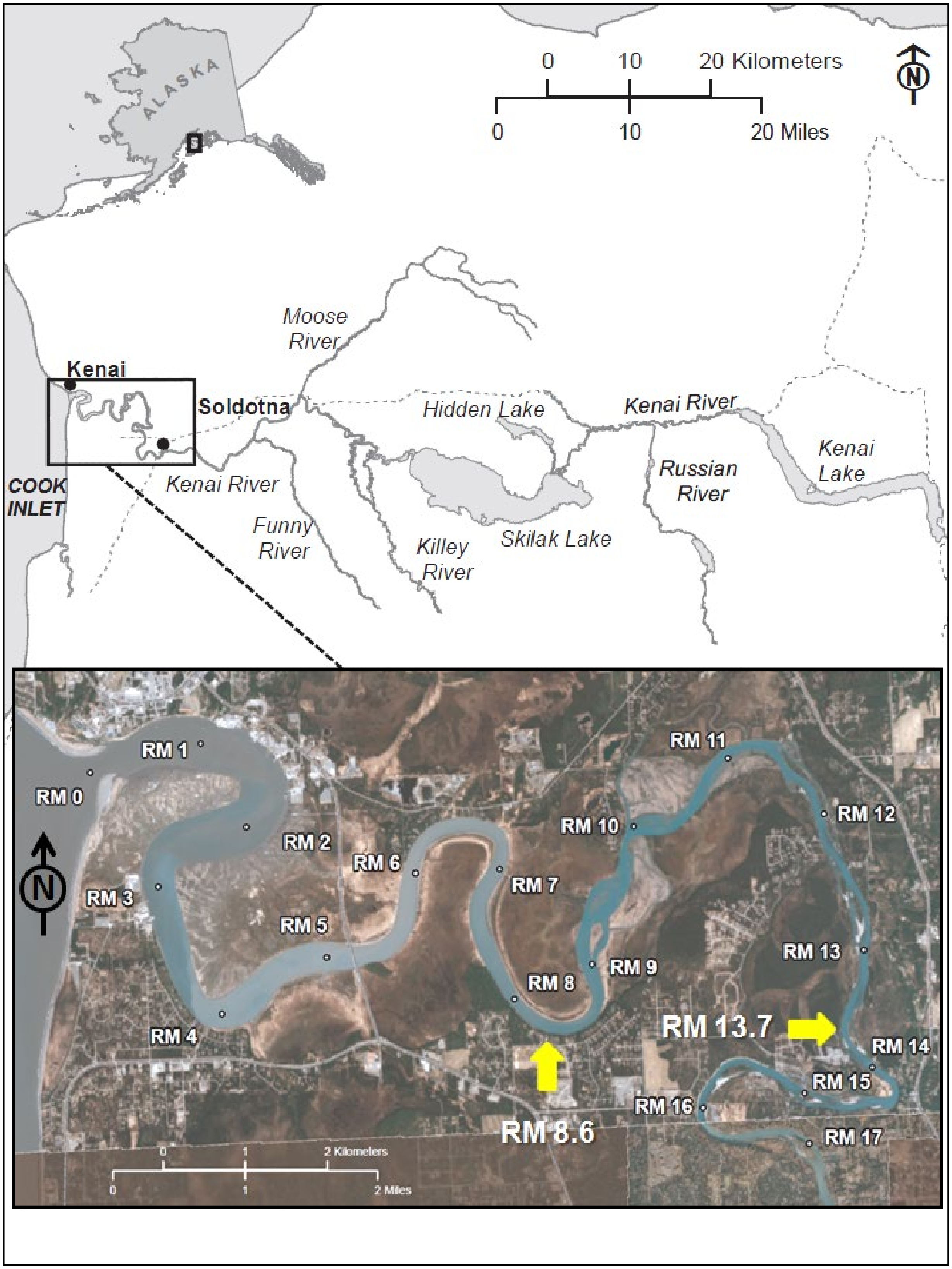


Figure 2.–Map of Kenai River showing location of RM 8.6 netting project and RM 13.7 Chinook salmon sonar site.

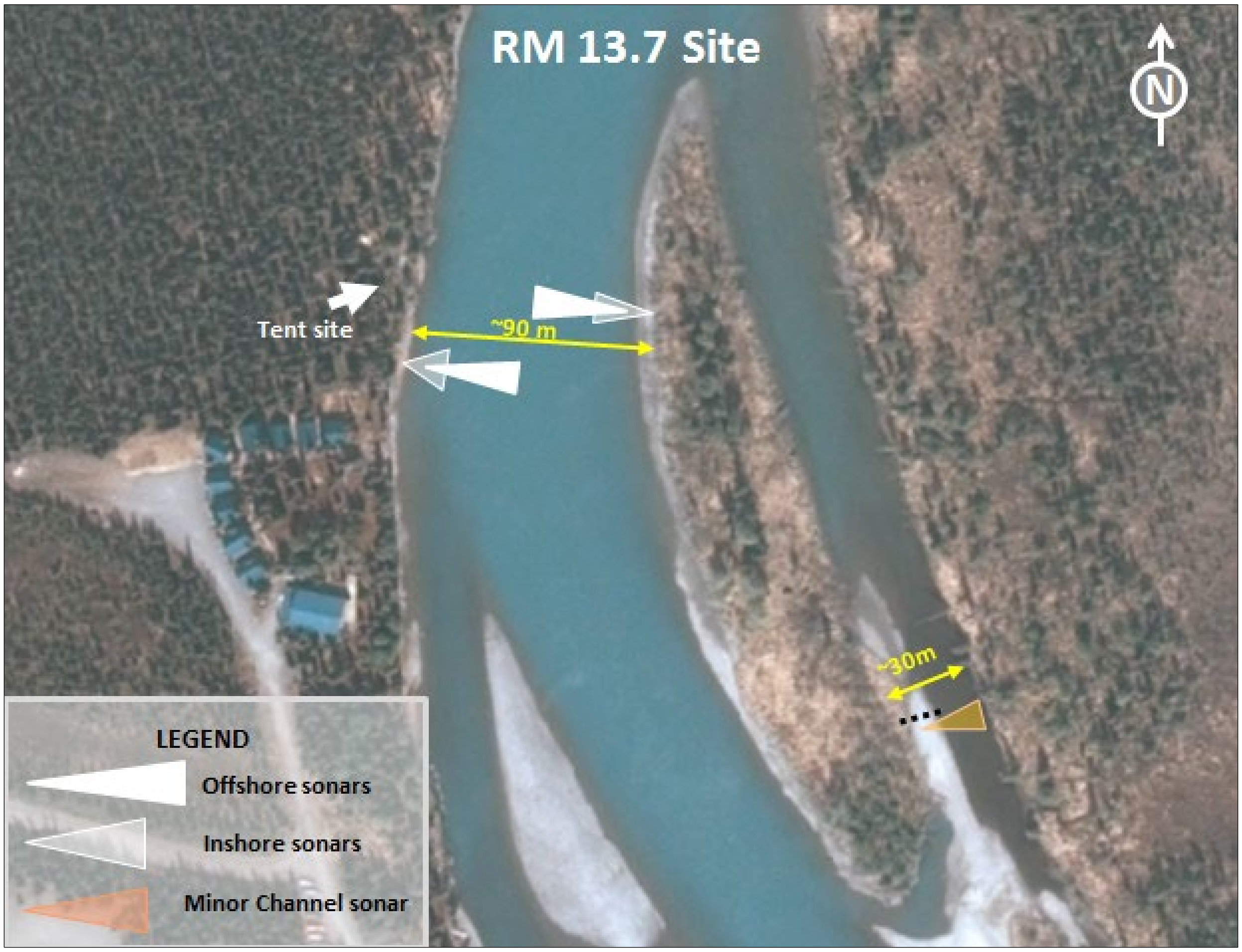


Figure 3.–Kenai River RM 13.7 sonar site showing approximate beam coverage.

Note: Diagram is not to scale. Tent site indicates location where sonar electronics are housed. River flows north.

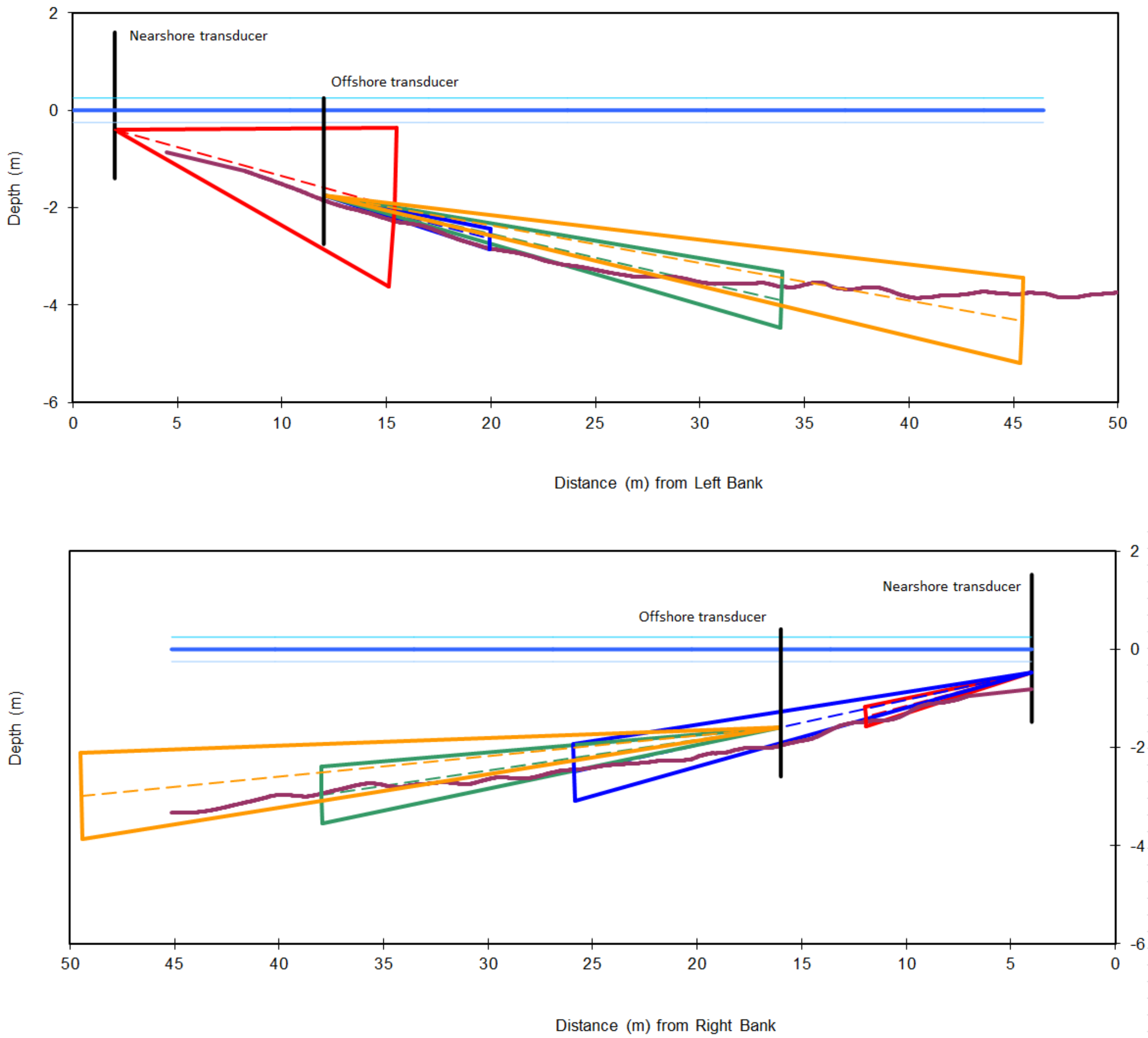


Figure 4.–Kenai River RM 13.7 main channel left and right bank bottom profiles collected on 8 July 2015 with nearshore and offshore sonar beams superimposed.

Note: On the left bank, an ARIS 1800 with a standard lens and a 14° vertical field of view was deployed nearshore (red beam), and an ARIS 1200 with a high-resolution lens and a 3° vertical field of view was deployed offshore (blue, green, and yellow beams indicate individual sampling strata). On the right bank, an ARIS 1200 with a high-resolution lens and a 3° vertical field of view was deployed both nearshore (red and blue beams) and offshore (green and yellow beams).

Figure 5.–Sonar coverage of the minor channel at the RM 13.7 sonar site was achieved using an ARIS 1200 deployed on a tripod mount combined with a fixed weir.

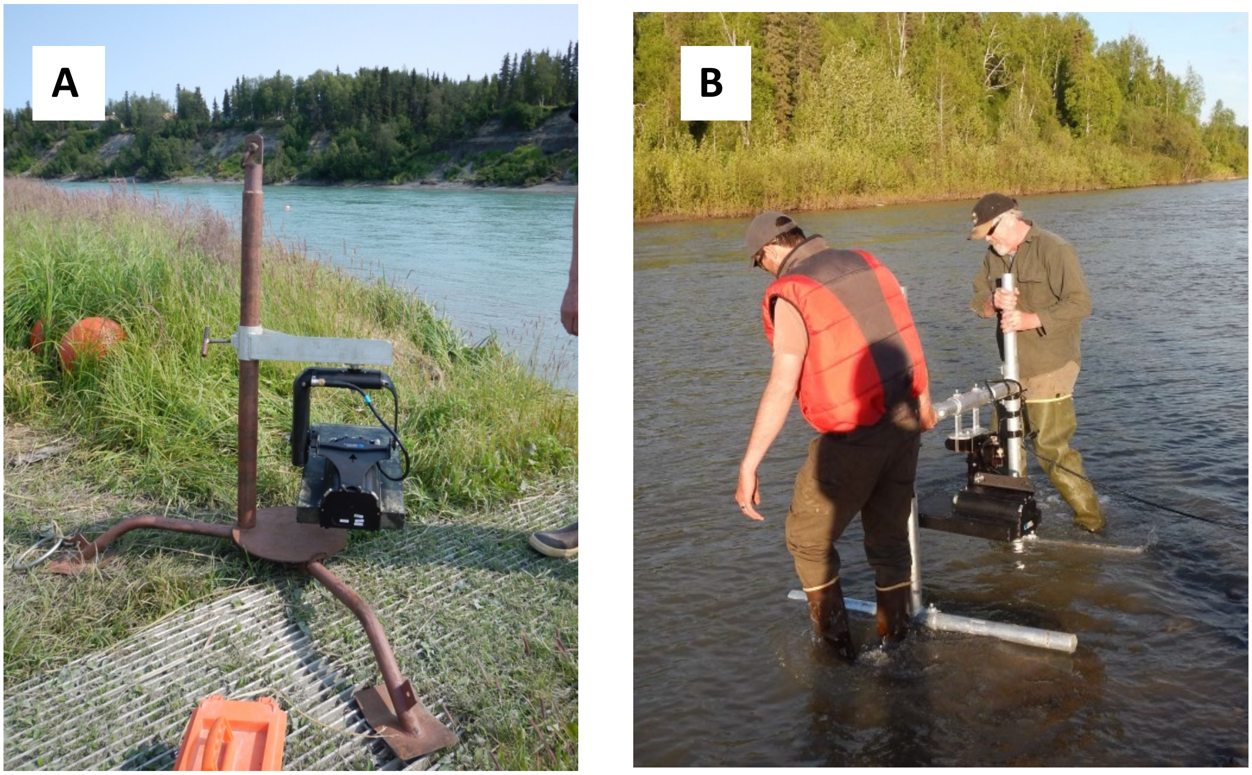


Figure 6.–An ARIS 1200 with a high-resolution lens mounted on a steel tripod for offshore deployment (A) and on an aluminum H-mount for nearshore deployment (B).

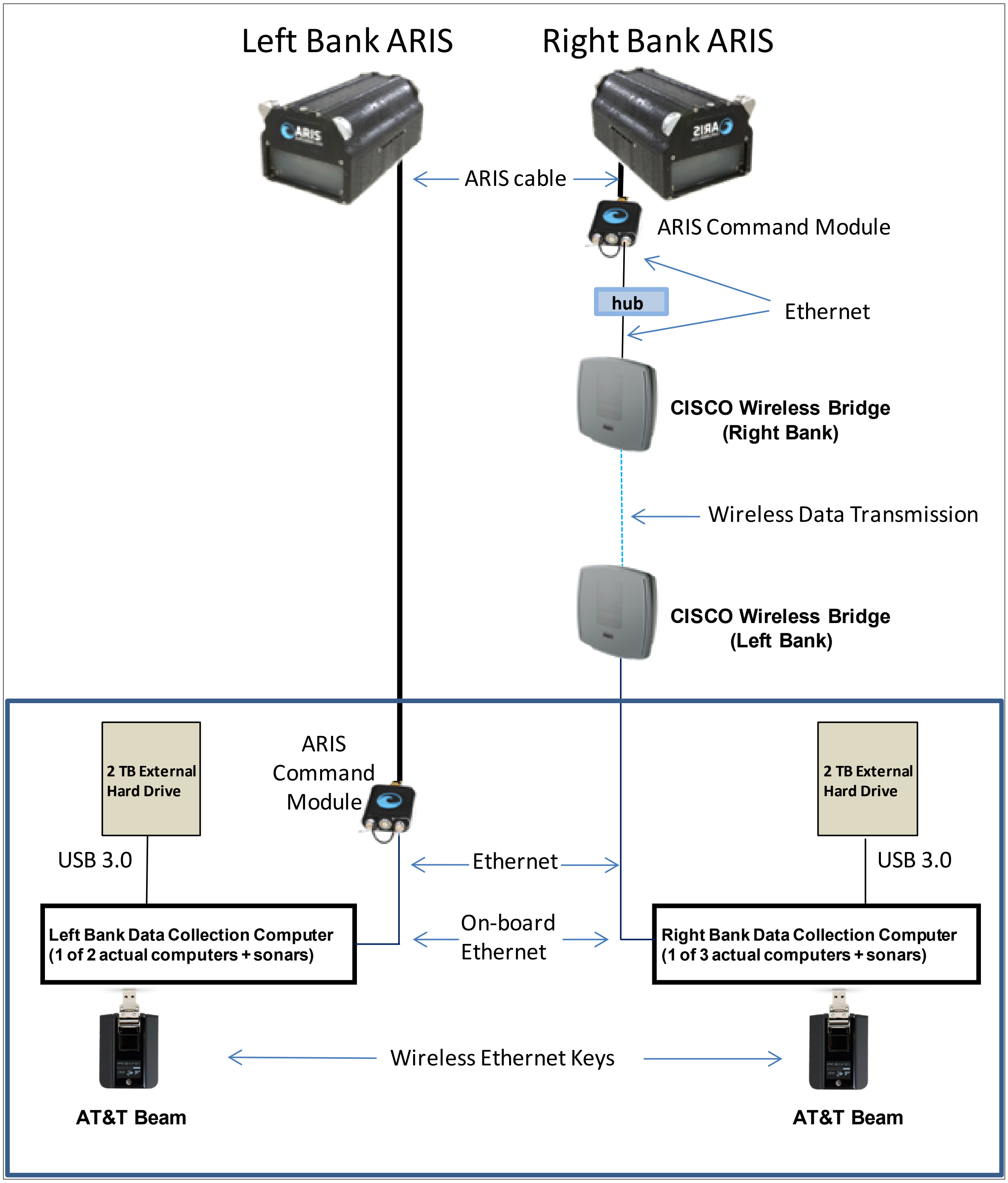


Figure 7.–ARIS data collection schematic for the RM 13.7 site on the Kenai River.

Note: For simplicity, this diagram shows only 1 of 3 right-bank data-collection computer–sonar pairs and 1 of 2 left-bank data-collection computer–sonar pairs. Each computer is equipped with wireless Ethernet through AT&T Beams (providing 4G LTE service) and can be accessed remotely using GoToMyPC accounts.

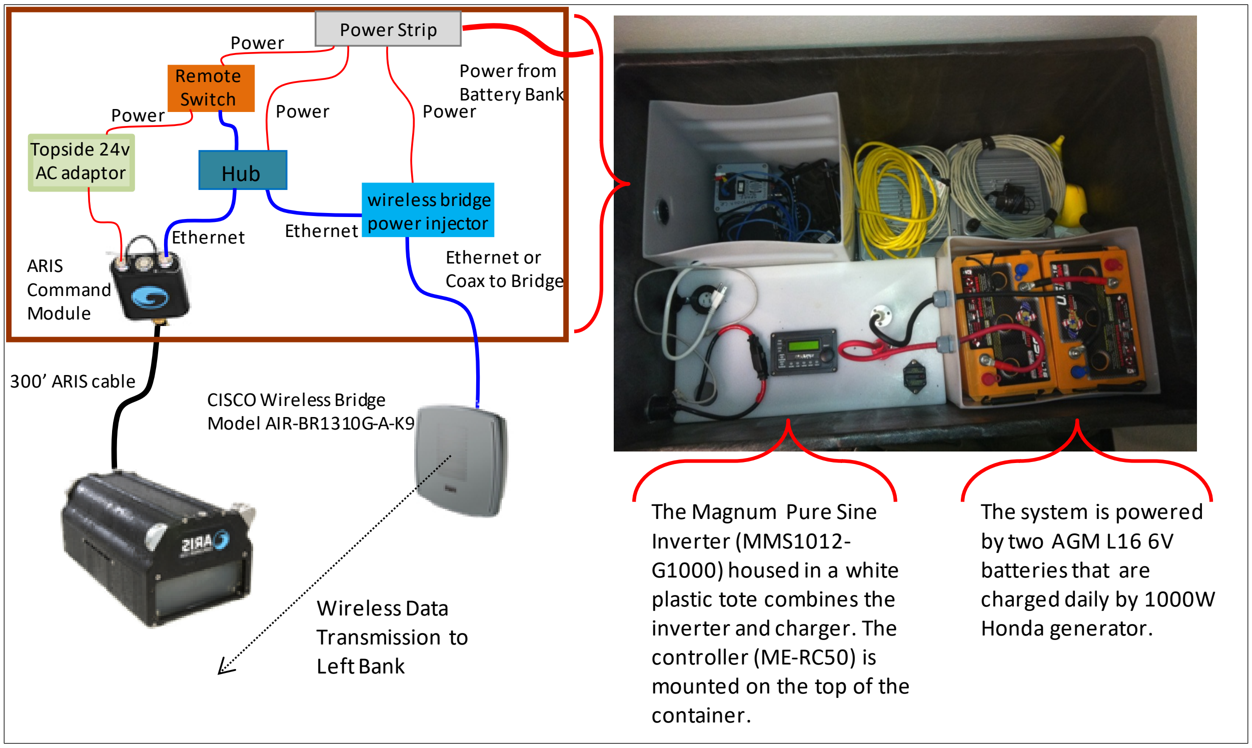


Figure 8.–Diagram showing components required on the right bank for wireless transmission of ARIS data to a data-collection computer located in the left-bank sonar tent.

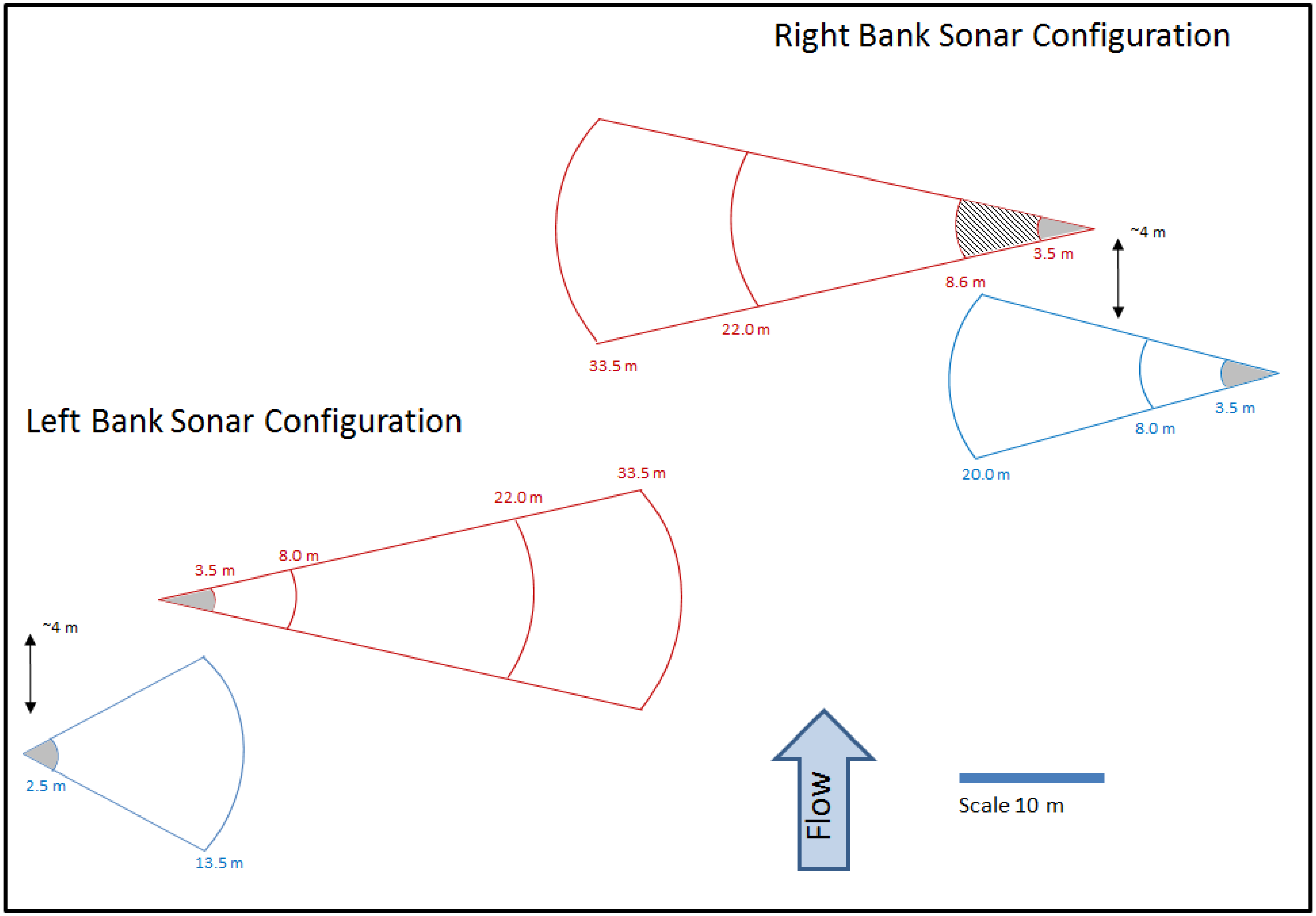


Figure 9.–Schematic for 4 left-bank (1 nearshore range [blue], 3 offshore ranges [red]) and 4 right-bank (2 nearshore ranges [blue], 2 offshore ranges [red]) range strata on the main channel of the Kenai River at RM 13.7.

Note: No data are collected between the face of the transducer and the start of the first range stratum in order to avoid range-related size bias caused by poor focal resolution at such close ranges (see Appendix A1). Normal data collection in the right bank offshore 3.5–8.6 m stratum began 16 May and went to 24 May. Increased water level allowed the right bank inshore sonar to be deployed on 25 May and from that date forward, the area formerly covered by the right bank offshore 3.5–8.6 m stratum was covered by the right bank inshore 8.0–20.0 m stratum.

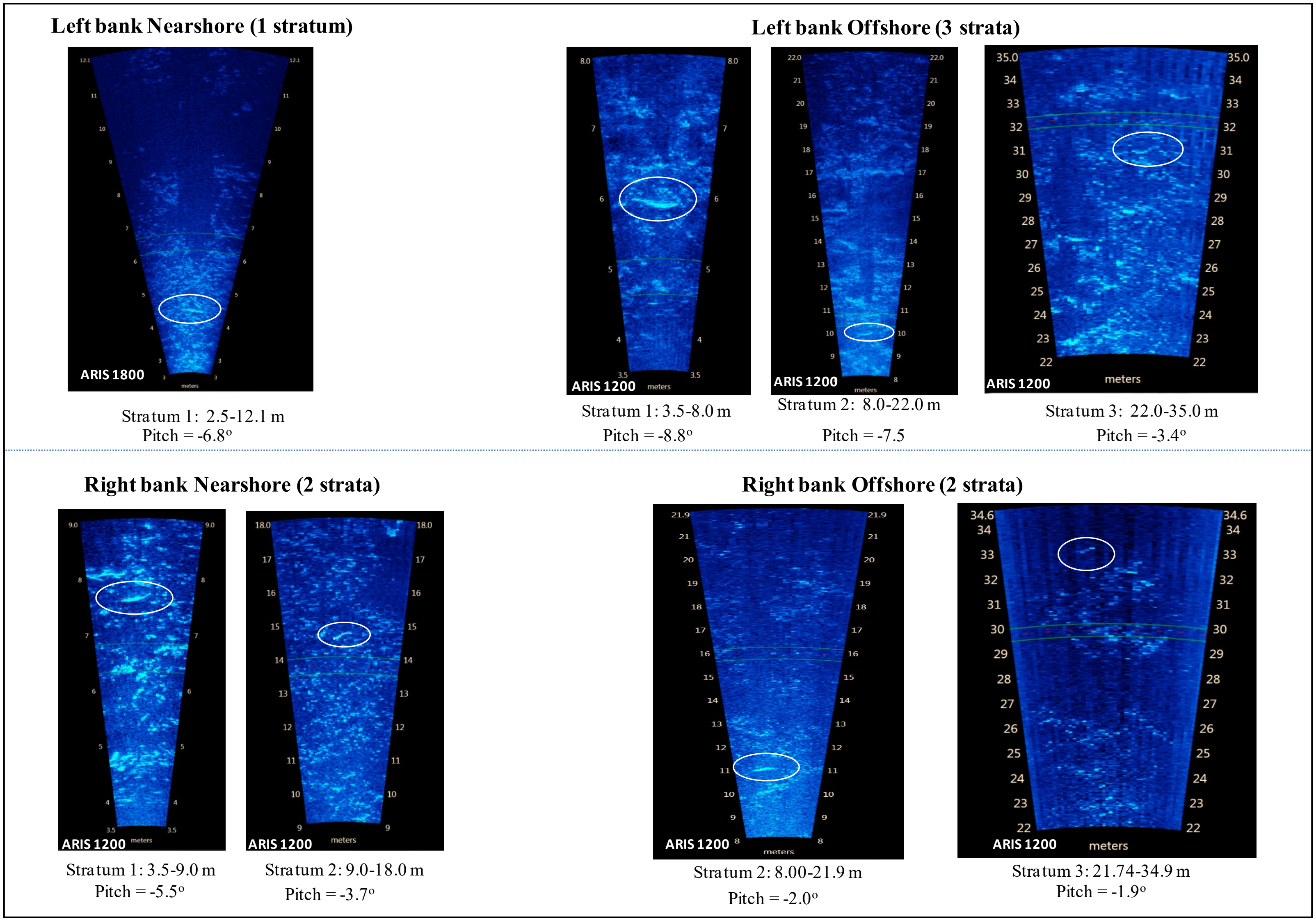


Figure 10.–Example images from each of the 4 left-bank (top) and 4 right-bank (bottom) range strata taken at RM 13.7 Kenai River on 1 July 2014.

Note: Fish swimming through the beams are circled on each image.

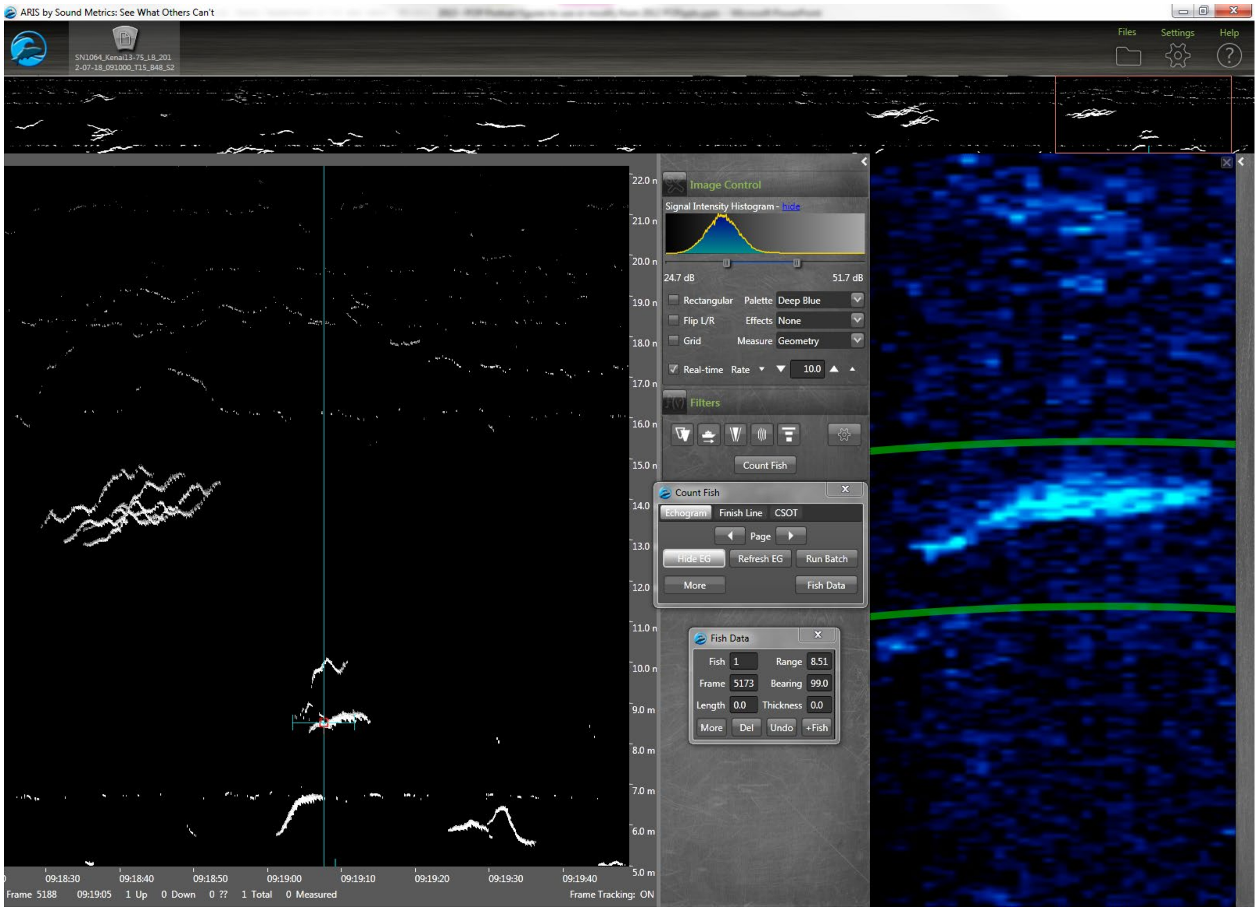


Figure 11.–ARISFish display window showing an echogram (at left) with traces of migrating fish that can be simultaneously displayed in video mode (at right) where fish images can be enlarged and measured.

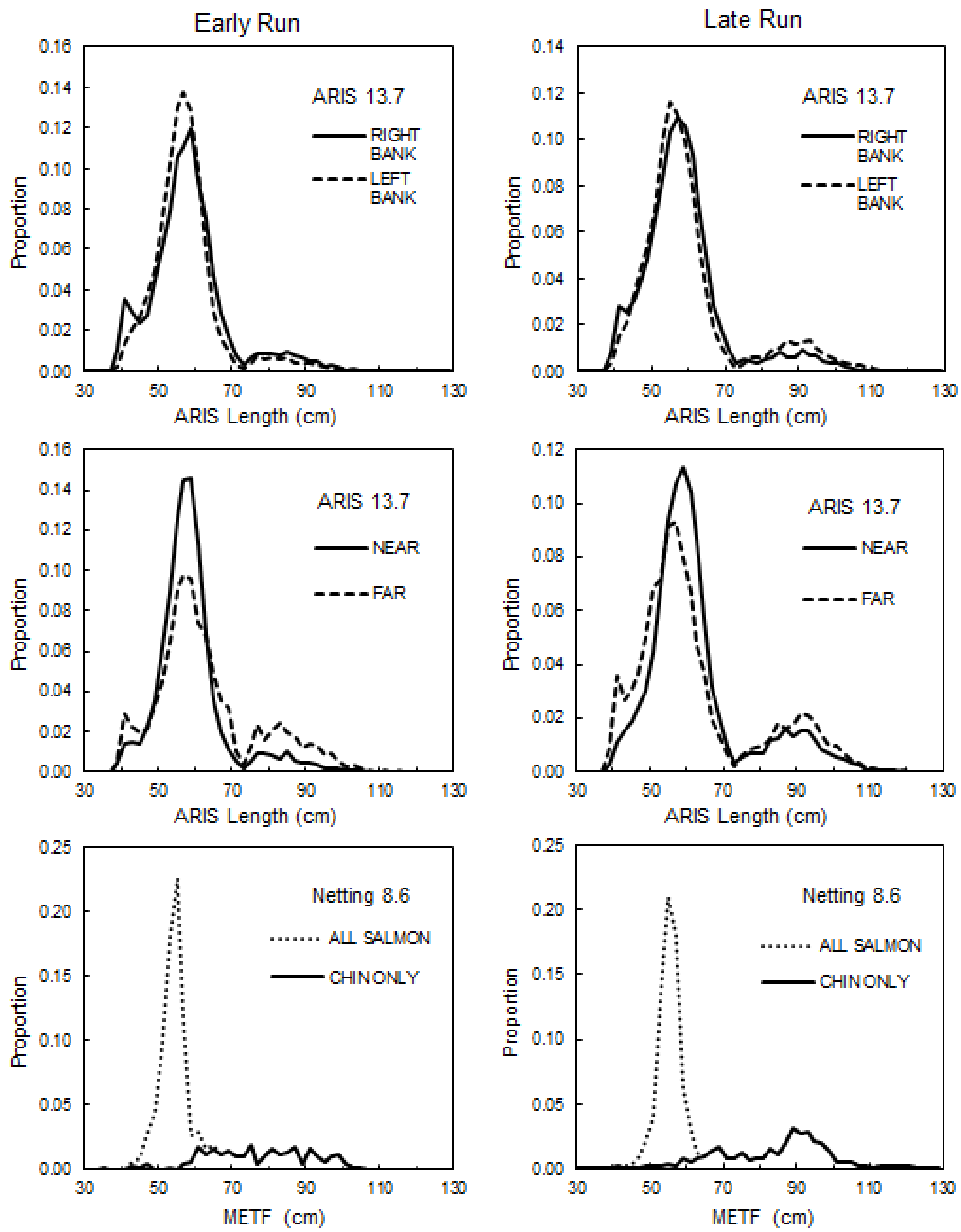


Figure 12.–Frequency distributions of ARIS lengths by bank at RM 13.7 (top), ARIS lengths by near and far transducers (middle), and mid eye to tail fork (METF) lengths by species (all salmon versus Chinook salmon only) from an inriver netting project at RM 8.6 (bottom), Kenai River early and late runs, 2016.

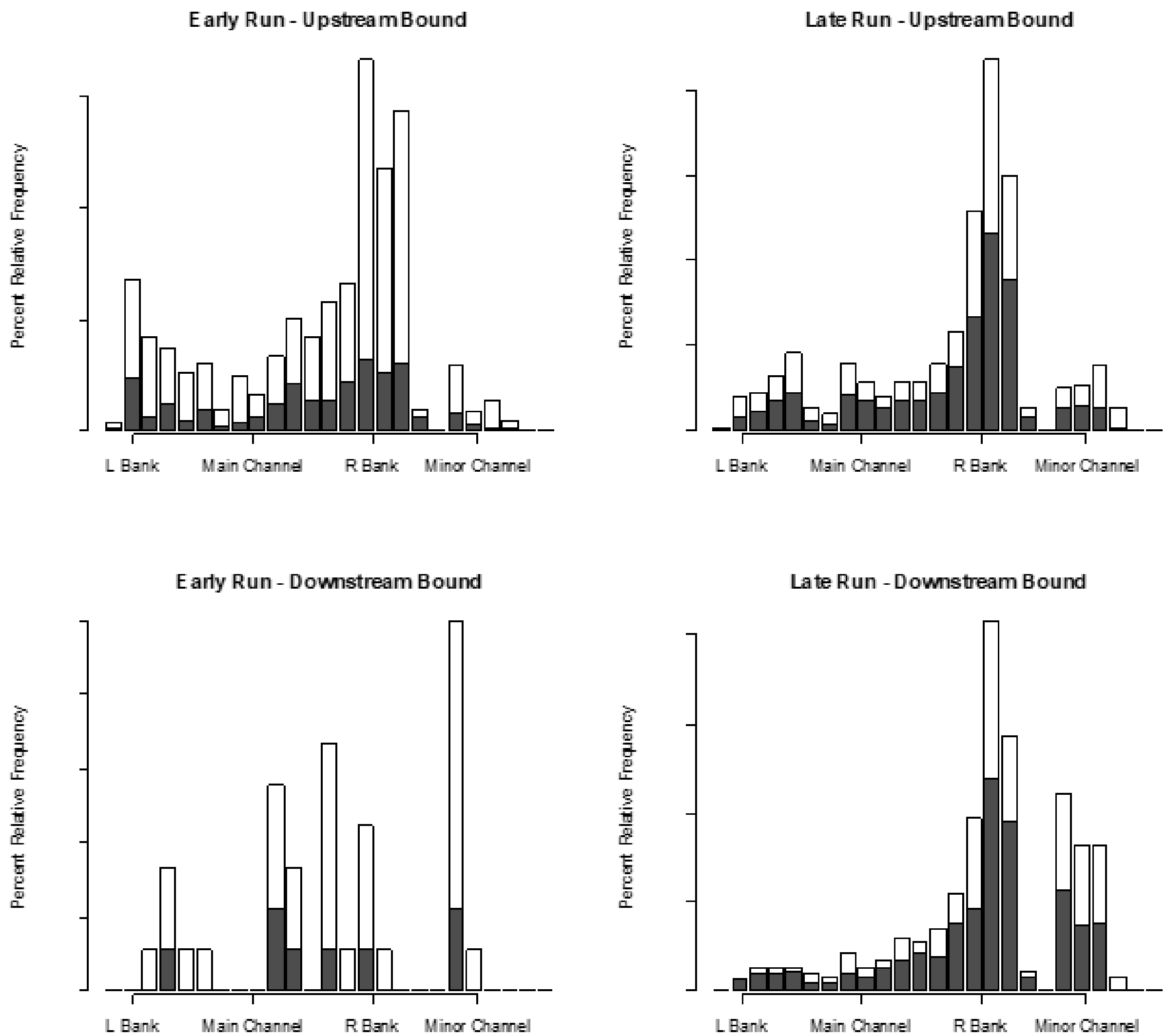


Figure 13.–Horizontal distribution, in 5 m increments from the left-bank main channel shore to the right-bank minor channel shore, of medium (75 cm ≤ AL < 90 cm, open bars) and large (AL ≥ 90 cm, solid bars) early- and late-run fish measured from ARIS, RM 13.7 Kenai River, 2016.

Note: Vertical axis shows percent relative frequency by run and direction of travel. Bar lengths sum to 1 for each panel.

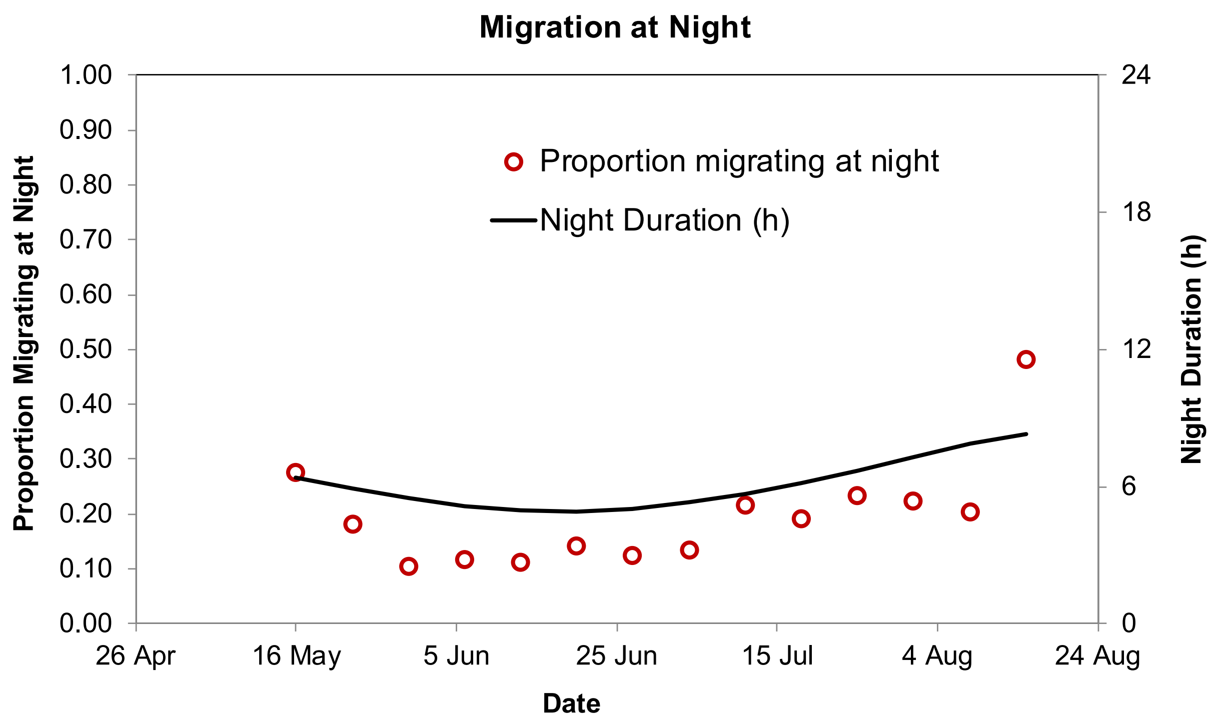


Figure 14.–Weekly proportions of fish greater than 75 cm AL migrating upstream at night (between sunset and sunrise; red circles), compared to night duration (solid line) in Kenai, Alaska.

Note: Although the night duration is presented in "hours," the scale of the hours-axis is the same as the proportion-axis and therefore comparable. Proportions falling along the solid line would be expected if passage rate did not differ between night and day. Proportions below the solid line indicate slower rates of passage at night; proportions above the solid line indicate faster rates at night.

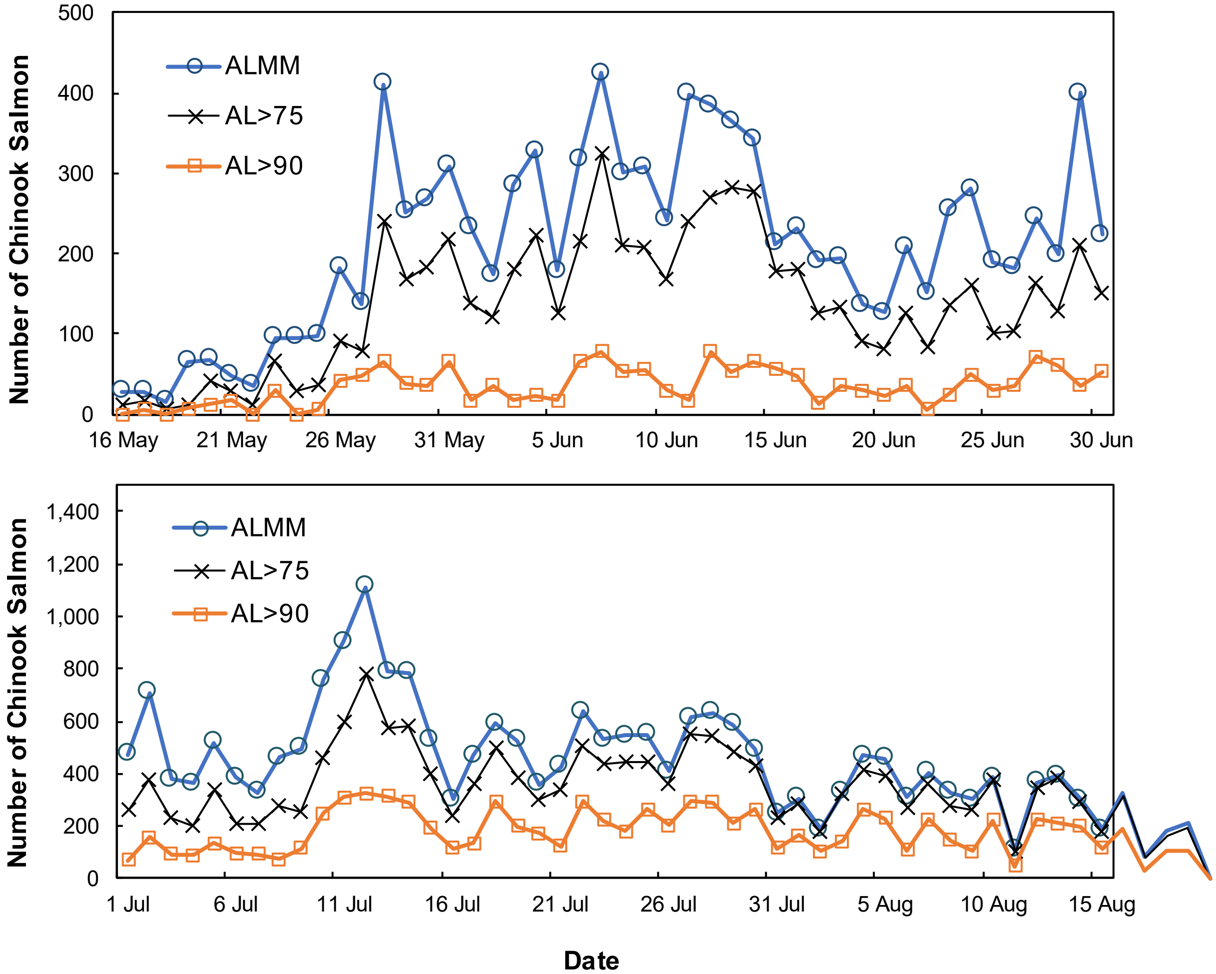


Figure 15.–Estimated net upstream passage of Chinook salmon based on an ARIS-length mixture model (ALMM) and estimated net upstream passage of medium and large Chinook salmon (AL ≥ 75 cm) and large Chinook salmon (AL ≥ 90 cm) for early- (top) and late-run (bottom) Kenai River Chinook salmon, 2016.

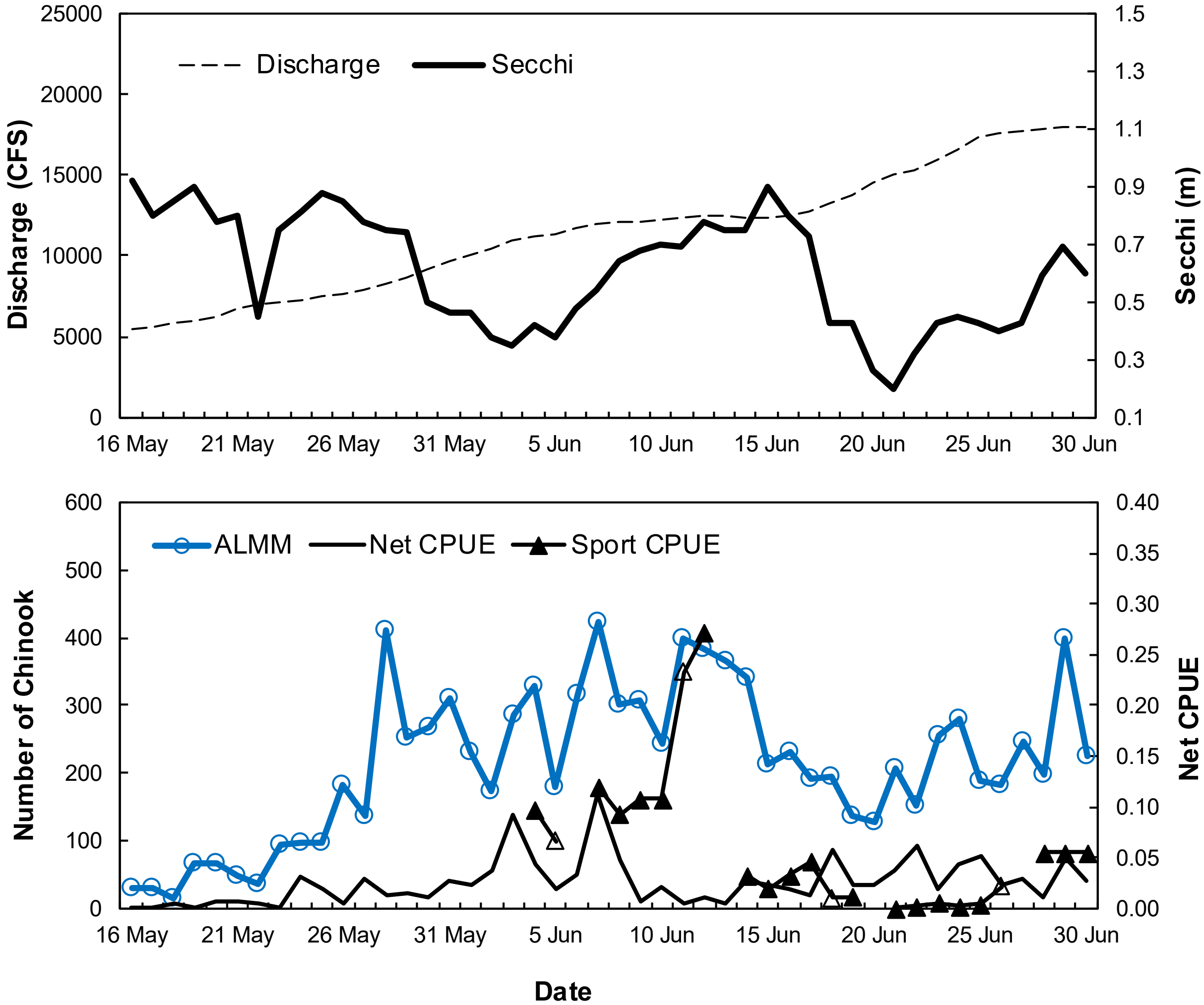


Figure 16.–Daily discharge rates collected at the Soldotna Bridge and Secchi disk readings taken at the RM 13.7 sonar site (top); and ARIS-length mixture model (ALMM) estimates of net upstream Chinook salmon passage at RM 13.7 and inriver gillnet Chinook salmon CPUE at RM 8.6 (bottom) during the Kenai River Chinook salmon early run, 2016.

Note: River discharge taken from USGS[10]. Net CPUE and sport fish CPUE from Perschbacher (*In prep*)[11]. The sport fishery was closed to all Chinook salmon fishing from 1 May to 3 June, and was closed to harvest of Chinook salmon 4 to 17 June 2016.

---

[10] USGS Water resource data, Alaska, water year 2015. Website Daily Streamflow for Alaska, Soldotna gauging station, site #15266300, accessed October 16, 2017. http://water.usgs.gov/ak/nwis/discharge.

[11] Perschbacher, J. *In prep*. Chinook salmon creel survey and inriver gillnetting study, lower Kenai River, Alaska, 2016. Alaska Department of Fish and Game, Fishery Data Series, Anchorage.

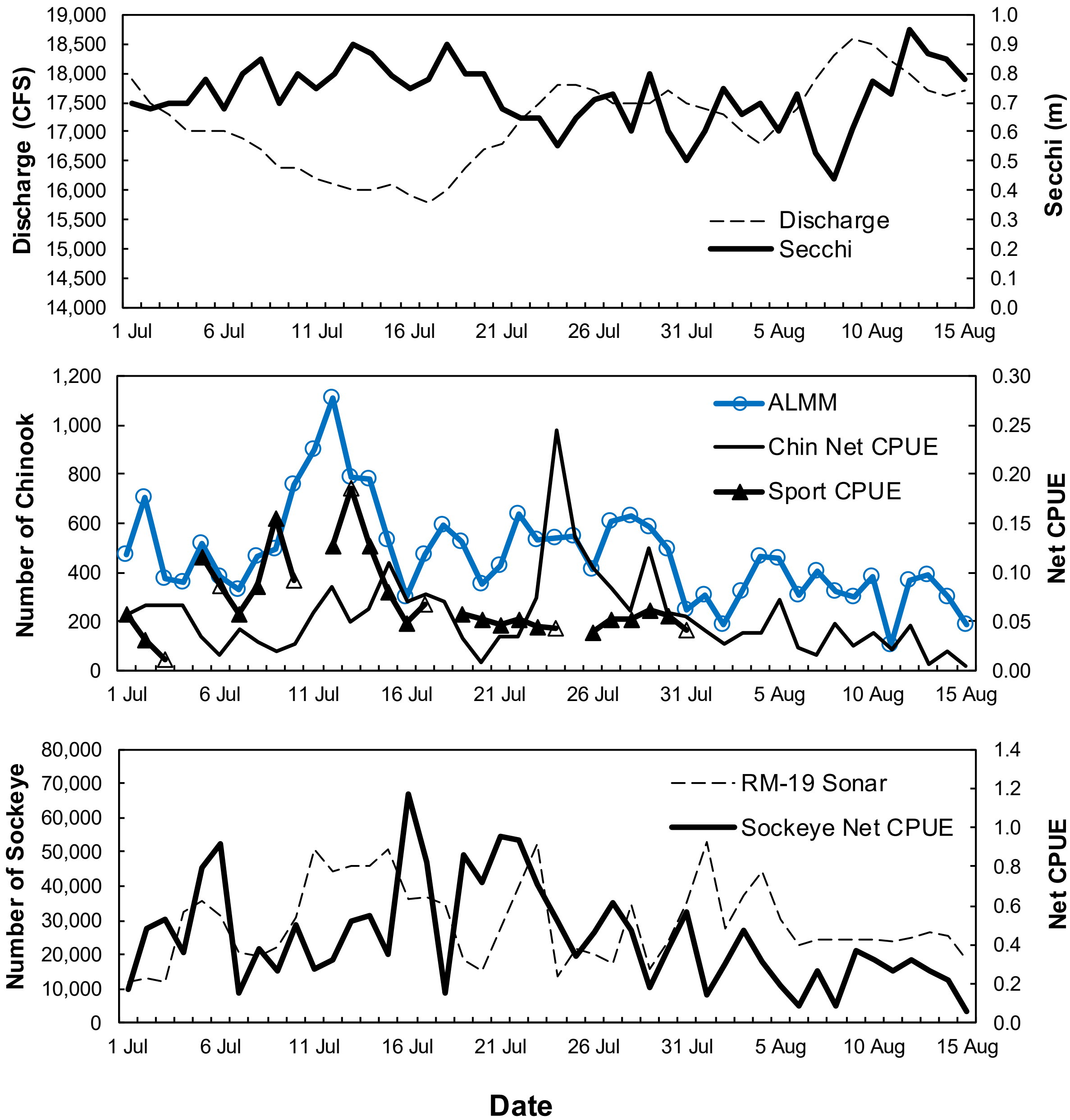


Figure 17.–Daily discharge rates collected at the Soldotna Bridge and Secchi disk readings taken at the RM 8.6 netting site (top); ARIS-length mixture model (ALMM) estimates of net upstream Chinook salmon passage at RM 13.7, inriver gillnet Chinook salmon CPUE at RM 8.6, and Chinook salmon sport fishery CPUE (middle); and RM 19 sockeye salmon sonar passage and inriver gillnet sockeye salmon CPUE at RM 8.6 (bottom) during the Kenai River Chinook salmon late run, 2016.

Note: River discharge taken from USGS[12]. Net CPUE and sport fish CPUE from Perschbacher (*In prep*)[13]. RM 19 sonar estimates from Glick and Willette (2015). Open triangles represent days on which only unguided anglers were allowed to fish. The late-run sport fishery prohibited the use of bait 1 to 8 July.

---

[12] USGS Water resource data, Alaska, water year 2016. Website Daily Streamflow for Alaska, Soldotna gauging station, site #15266300, accessed December 18, 2017. http://water.usgs.gov/ak/nwis/discharge.

[13] Perschbacher, J. *In prep*. Chinook salmon creel survey and inriver gillnetting study, lower Kenai River, Alaska, 2016. Alaska Department of Fish and Game, Fishery Data Series, Anchorage.

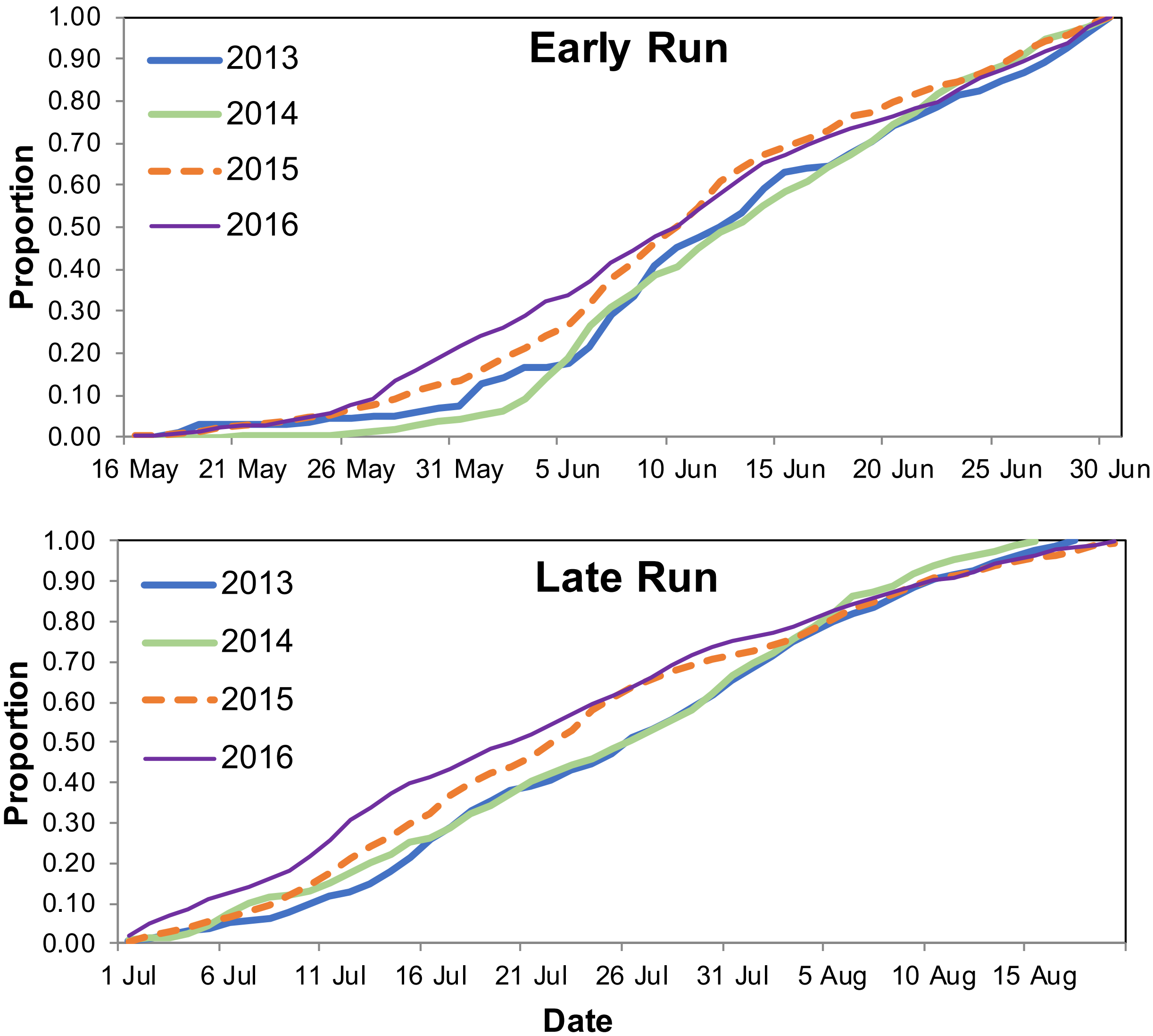


Figure 18.–Cumulative proportion of passage by day for all Chinook salmon (regardless of size) during the early (top) and late (bottom) runs, Kenai River RM 13.7, 2013–2016.

Note: Proportions of Chinook salmon are based on the ARIS-length mixture model (ALMM).

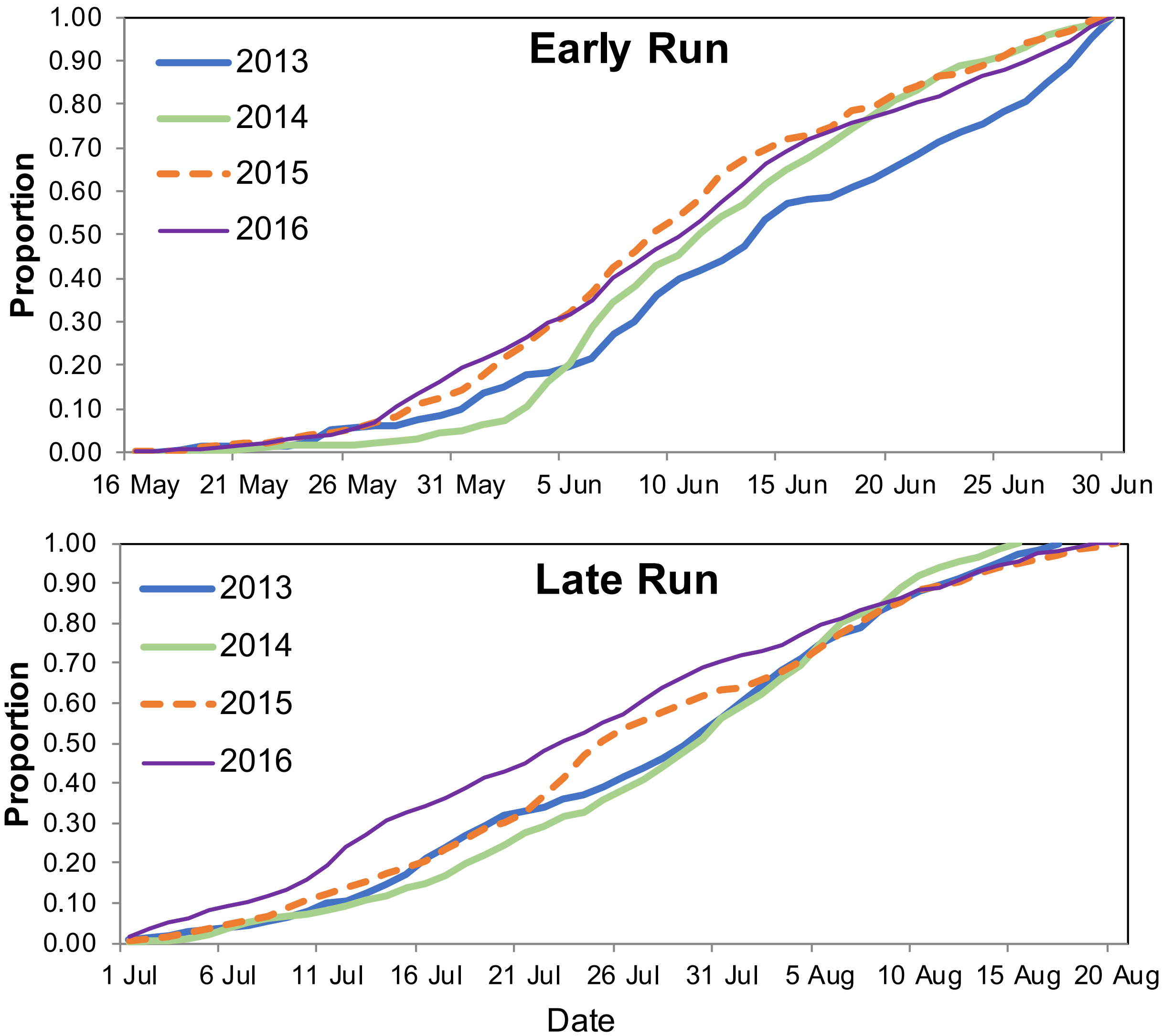


Figure 19.–Cumulative proportion of passage by day for Chinook salmon ≥75 cm AL during the early (top) and late (bottom) runs, Kenai River RM 13.7, 2013–2016.

Note: All fish ≥75 cm AL are assumed to be Chinook salmon.

APPENDIX A: ARIS CONFIGURATIONS

Appendix A1.–ARIS configurations including an overview of features that affect resolution and range capabilities.

Frequency

Adaptive resolution imaging sonar (ARIS) systems operate at 2 frequencies: a higher frequency that produces higher resolution images and a lower frequency that detects targets at farther ranges but at a reduced image resolution. The two ARIS models used on this project, ARIS 1800 and ARIS 1200, were operated in high frequency mode when possible to achieve maximum image resolution.

Beam Dimensions and Lens Selection

ARIS 1200 can be used with a high-resolution lens (+HRL) to increase the image resolution to the level achieved by the ARIS 1800 (this modification is referred to as ARIS 1200 +HRL). The high-resolution lens has a larger aperture that increases the image resolution over the standard lens by approximately a factor of 2 by reducing the width of the individual beams and spreading them across a narrower field of view (Appendix A2). Overall nominal beam dimensions for an ARIS 1200 with a standard lens are approximately 28° in the horizontal axis and 15° in the vertical axis. Operating at 1.2 MHz, the 28° horizontal axis is a radial array of 48 beams that are nominally 0.50° wide and spaced across the array at approximately 0.60° intervals. With the addition of the high-resolution lens, the overall nominal beam dimensions of the ARIS 1200 are reduced to approximately 15° in the horizontal axis and 3° in the vertical axis and the 48 individual beams are reduced to approximately 0.3° wide and spaced across the array at approximately 0.3° intervals (Appendices A2 and A4). The combined concentration of horizontal and vertical beam widths also increases the returned signal from a given target by 10 dB, an effect that increases the maximum range of the sonar over the standard lens.

Four ARIS 1200 fitted with high-resolution lenses were used for most of the data collected at the RM 13.7 site. However, an ARIS 1800 with a standard lens was used on the left bank nearshore stratum because the coverage range was shorter and because the wider beam dimensions of the ARIS 1800 are preferred for increasing the beam coverage at close range and reducing biases associated with focal resolution at close range (see below).

Focal Resolution of ARIS Lenses: considerations for measurement accuracy

When sizing fish from ARIS images, there can be a bias beyond the geometric beam spreading issue, depending on the start range and end range of the image window. Depth of field is reduced at closer focusing ranges with the effect that defocused targets will appear smeared in the horizontal direction. The degree of bias is dependent on both the set focus range and the distance of the target from that set focus range. It is also dependent on the lens set. In general, if the focus is set to 4 m or longer for a standard lens, or 7 m or longer for a large (+HRL) lens, targets will be in good focus from there out to infinity. Inside of that range, focus will degrade significantly (Bill Hanot, Sound Metrics Corporation, Seattle Washington, personal communication). One way to minimize out-of-focus images is to create a smaller range window to insonify targets at close range. For example, we often use a 5 m range window from about 3 to 8 m for the first range stratum when using a large (+HRL) lens.

-continued-

For the ARIS 1200 and 1800, focus counts of 0–1000 represent the total range of travel (0.1% per unit). Appendix A5 shows the ARIS lens position (indicated by the numbers in the range 0–1000) versus focus range for the ARIS +HLR. There is a nonlinear relationship between lens position and focus range, with short ranges requiring large position movements for small increments of change in focus range and long ranges having small position movements for several meters of change in focus range. Also, beyond a certain range, images are generally in focus. Based on the focus curves in Appendix A5, images are at least 75% in focus starting at 4 m for the standard lens and starting at 7 m for the large lens.

Image Resolution Basics

The resolution of an ARIS image is defined in terms of downrange and crossrange resolution where crossrange resolution refers to the width and downrange resolution refers to the height of the individual pixels that make up the image (Appendix A6). Each image pixel in an ARIS frame has (x, y) rectangular coordinates that are mapped back to a beam and sample number defined by polar coordinates. The pixel height defines the downrange resolution and the pixel width defines the crossrange resolution of the image.

Crossrange Resolution

The crossrange resolution is primarily determined by the individual beam spacing and beam width, both of which are approximately 0.3° for all the sonar configurations used in this study (i.e., ARIS 1800 at 1.8 MHz with standard lens and ARIS 1200 +HRL at 1.2 MHz; Appendix A2). Targets at closer range are better resolved because the individual beam widths and corresponding image pixels increase with range following the formula below:

$$X = 2R\tan\frac{\theta}{2} \tag{A1}$$

where

X = width of the individual beam or “image pixel” in meters,

R = range of interest in meters, and

θ = individual beam angle in degrees (approximately 0.3°).

Optimizing Crossrange Resolution

Achieving the highest crossrange resolution is important when taking fish length measurements from images. Collecting data at high frequency with a high-resolution lens produces the highest crossrange resolution for each ARIS model. However, the high-resolution lens is not always used because it also decreases the vertical beam width dimension from about 14° to about 3° and the field of view from about 30° to about 15° (Appendix A2). Also, reduced focal resolution at close range must be considered. The high-resolution lens is used in this study on ARIS 1200 models, both to extend the range at which high-frequency data can be collected (~35 m) and to double the crossrange resolution. The standard lens is used on the ARIS 1800 to achieve better water column coverage over the short range.

-continued-

Downrange Resolution

Data acquisition parameters affecting downrange resolution, or image pixel height, can be selected using the “Detail” parameter (measured in millimeters) from the ARIScope Sonar Control menu or by fixing the “Sample Period” parameter (measured in microseconds) in the Advanced Sonar Settings menu (Appendix A7). Decreasing the detail or sample period (or increasing resolution) will automatically increase the number of samples per beam. Additionally, if the window length parameter is changed, the number of samples per beam will automatically increase or decrease to maintain the selected sample period or detail setting. These parameters are described in Appendix A8.

Some General Rules for Better Measurements

When sampling at close range (less than about 8 m with a long-range lens or less than about 4 m with a standard lens; Appendix A5), a shorter range window is used for the first range stratum to minimize the effect of poor focal resolution at close range (Appendix A9).

We find that a 5 m range window is adequate for sampling a 3.5–8.5 m stratum using a long-range lens, and we do not generally sample at less than 3.5 m when using a long-range lens to avoid range-related size bias due to poor focal resolution (Appendix A10).

Tethered fish studies showed that a 10 µs sample period (SP) is a good compromise yielding high-resolution images at manageable file sizes.

Sound Metrics Corporation (SMC) recommends using a transmit pulse width (PW) that is long enough to get a minimum of 2 samples within the transmit pulse at farther ranges (e.g., for a constant SP = 10 µs, at 20 m use PW ≈ 20 µs, and at 30 m use PW ≈ 30 µs). This maintains a better downrange to crossrange ratio and should provide a better image for “beam-edge-to-beam-edge” measurements. At closer ranges less than about 10 m, a PW that is long enough to get 1 sample within the transmit pulse is acceptable (e.g., PW = 10–15 µs). Poor images can result when the SP is equal to or greater than the transmit pulse (Appendix A11: Panel 3).

Avoid aiming the sonar too far into the bottom. It’s a common mistake to optimize the image of the bottom, using the logic that the fish should be optimally insonified too. But, as shown in Appendix A12, aiming the sonar farther into the bottom than required to cover the near-bottom region can cause unnecessary loss of vertical beam width and water column coverage and degrade the image quality. This can be a problem especially when using a long-range lens accessory because the beam width has been reduced from about 12° to about 3°; unless the river is extremely shallow, losing more vertical beam width than necessary is undesirable.

Appendix A2.–Summary of manufacturer specifications for maximum range, individual beam dimensions, and spacing for ARIS 1800 and ARIS 1200 systems at 2 frequencies, with and without the addition of a high-resolution lens (specifications from Sound Metrics Corporation).

System	Frequency	Maximum range (m) [a]	Horizontal beam width	Vertical beam width	Number of beams	Individual beam width [b,c]	Individual beam spacing [b,c]
ARIS 1800	1.8 MHz	15	28°	14°	96	0.30°	0.30°
	1.1 MHz [d]	35	28°	14°	48	0.50°	0.60°
	1.8 MHz + high-resolution lens	20	15°	3°	96	0.17°	0.15°
	1.1 MHz + high-resolution lens	40+	15°	3°	48	0.22°	0.30°
ARIS 1200	1.2 MHz	25	28°	14°	48	0.50°	0.60°
	0.7 MHz	80	28°	14°	48	0.80°	0.60°
	1.2 MHz + high-resolution lens	30	15°	3°	48	0.27°	0.30°
	0.7 MHz + high-resolution lens	100+	15°	3°	48	0.33°	0.30°

Note: A more complete summary is given in Appendix A3.

[a] Actual range will vary depending on site and water characteristics.

[b] Beam width values are for 2-way transmission at −3 dB points.

[c] Values for beam spacing and beam width are approximate. Beam widths are slightly wider near the edges of the beam and the beam spacing is slightly narrower. Conversely, beams are slightly narrower near the center of the beam, and the beam spacing is slightly wider. Nonlinear corrections are applied in software to correct for these effects in the ARIS with both the standard and high-resolution lenses.

[d] ARIS 1800 uses 96 beams at low frequency by default. If ARIS 1800 is set for 96 beams, then beam spacing is 0.3° at both low frequency and high frequency. If ARIS 1800 is set for 48 beams, then beam spacing is 0.6° at both low frequency and high frequency.

Appendix A3.–Manufacturer specifications for sonar models ARIS 1200 and ARIS 1800.

ARIS 1800 Specifications

Detection Mode
Operating Frequency 1.1 MHz
Beamwidth (2-way) 0.5° H by 14° V
Source Level (average) ~204 dB re 1 μPa at 1 m
Nominal Effective Range 35 m

Identification Mode
Operating Frequency 1.8 MHz
Beamwidth (2-way) 0.3° H by 14° V
Source Level (average) ~195 dB re 1 μPa at 1 m
Nominal Effective Range 15 m

Both Modes
Number of beams 96 or 48
Beam Spacing 0.3° nominal
Horizontal Field-of-View 28°
Max frame rate (96 beams) 3–15 frames/s (6–15 frames/sec with 48 beams)
Minimum Range Start 0.7 m
Downrange Resolution 3 mm to 10 cm
Transmit Pulse Length 4 μs to 100 μs
Remote Focus 0.7 m to max range
Power Consumption 15 Watts typical
Weight in Air 5.5 kg (12.1 lb)
Weight in Water *TBD*, ~1.4kg (3 lb)
Dimensions 31 cm × 17 cm × 14 cm
Depth rating 300 m
Data Comm Link 100BaseT Ethernet or HomePlug
Maximum cable length (Ethernet) 90 m (300 ft)
Maximum cable length (HomePlug) 300 m (1000 ft)

ARIS 1200 Specifications

Detection Mode
Operating Frequency 0.7 MHz
Beamwidth (2-way) 0.8° H by 14° V
Source Level (average) ~216 dB re 1 μPa at 1 m
Nominal Effective Range 80 m

Identification Mode
Operating Frequency 1.2 MHz
Beamwidth (2-way) 0.5° H by 14° V
Source Level (average) ~206 dB re 1 μPa at 1 m
Nominal Effective Range 25 m

-continued-

ARIS 1200 Specifications (continued)

Both Modes

Number of beams 48

Beam Spacing 0.6° nominal

Horizontal Field-of-View 28°

Max frame rate (range dependent) 2.5–15 frames/s

Minimum Range Start 0.7 m

Downrange Resolution 3 mm to 10 cm

Transmit Pulse Length 4 µs to 100 µs

Remote Focus 0.7 m to max range

Power Consumption 18 Watts typical

Weight in Air 5.5 kg (12.1 lb)

Weight in Water ~1.4 kg (3 lb)

Dimensions 31 cm × 17 cm × 14 cm

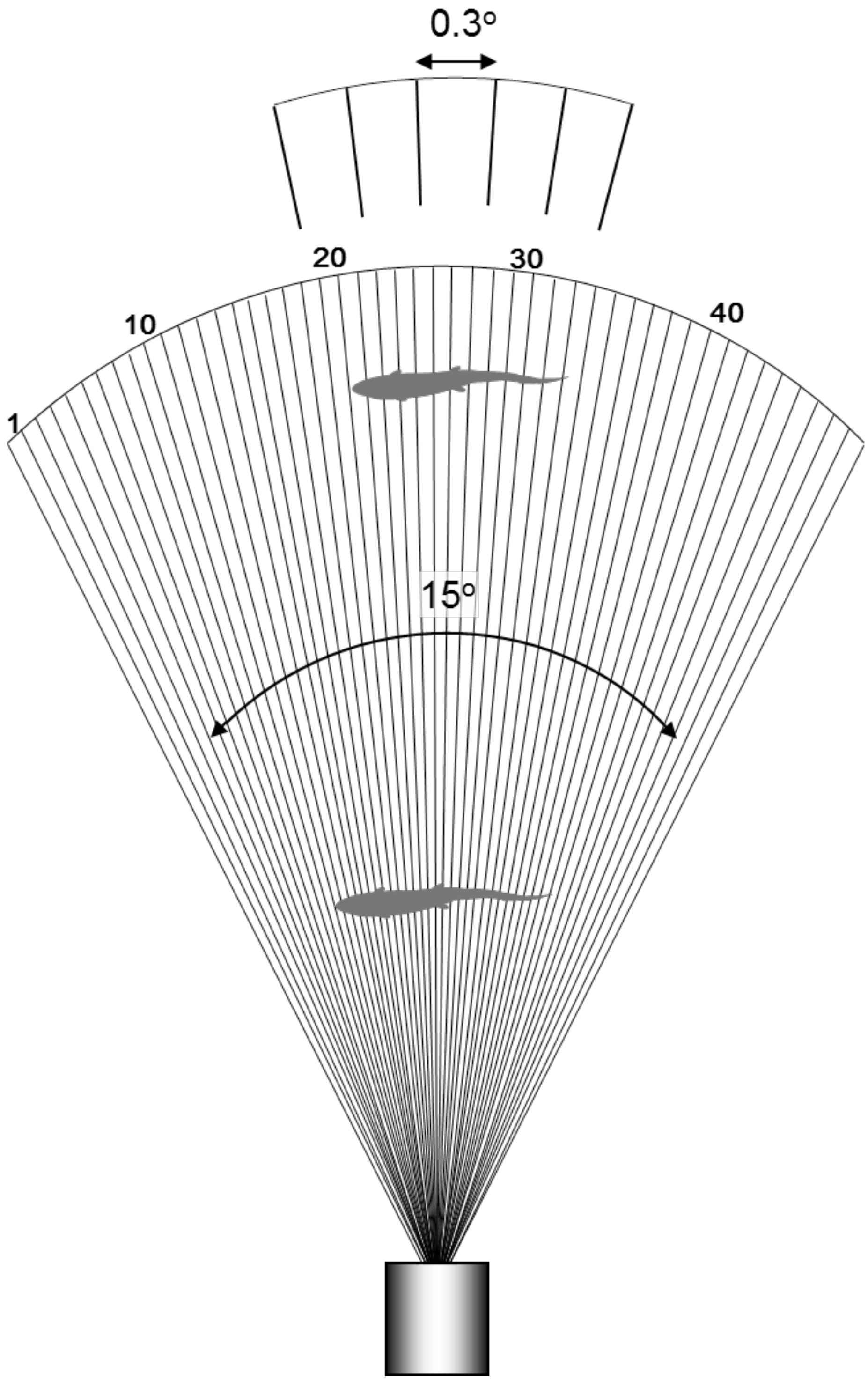
Depth rating 300 m

Data Comm Link 100BaseT Ethernet or HomePlug

Maximum cable length (Ethernet) 90 m (300 ft)

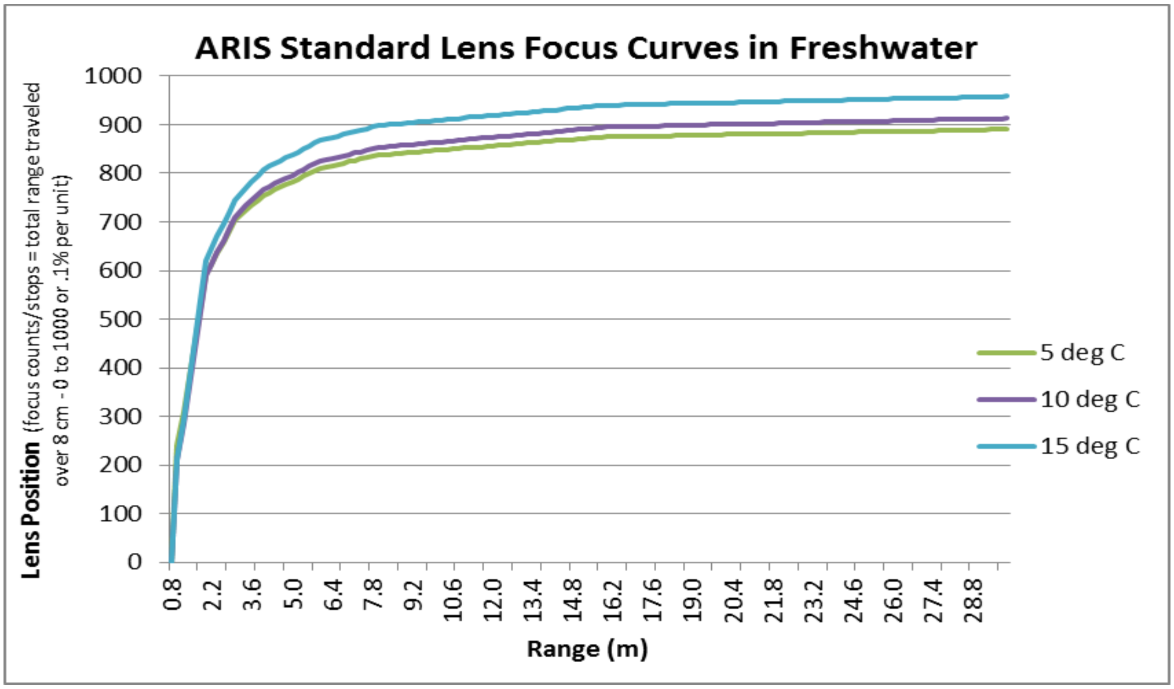
Maximum cable length (HomePlug) 300 m (1000 ft)

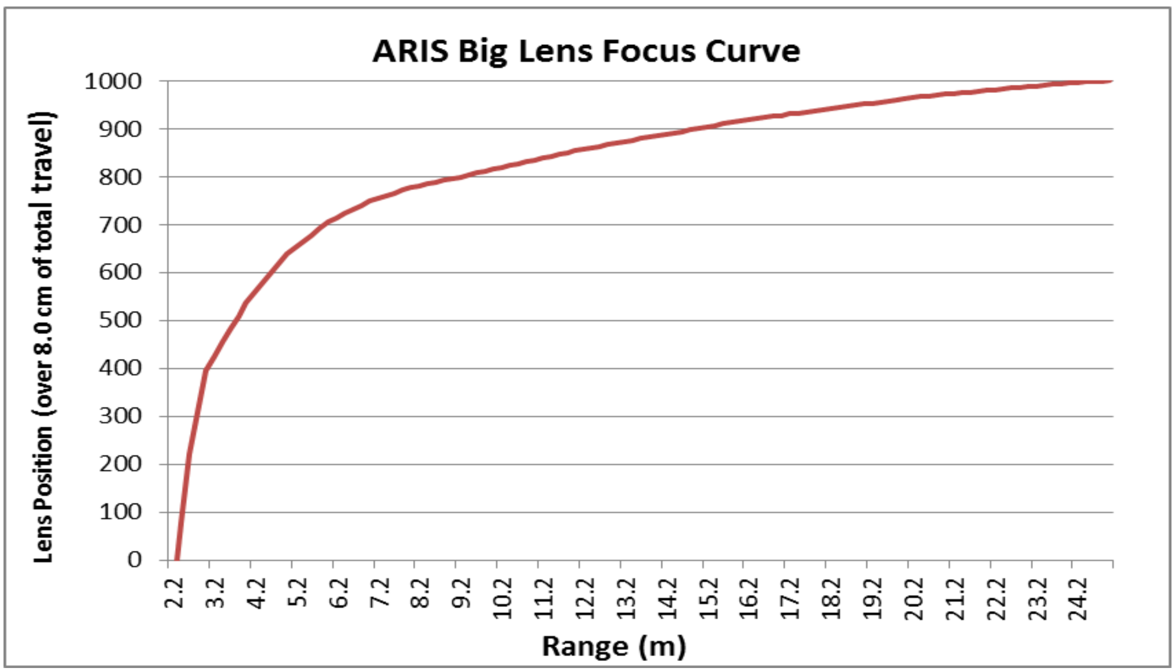
Appendix A4.–Diagram showing the horizontal plane of an ARIS 1200 with a high-resolution lens.



Note: The overall horizontal beam width of 15° is composed of 48 sub-beams with approximately 0.3° beam widths. Because sub-beams grow wider with range, fish at close range are better resolved than fish at far range (adapted from Burwen et al. [2007]).

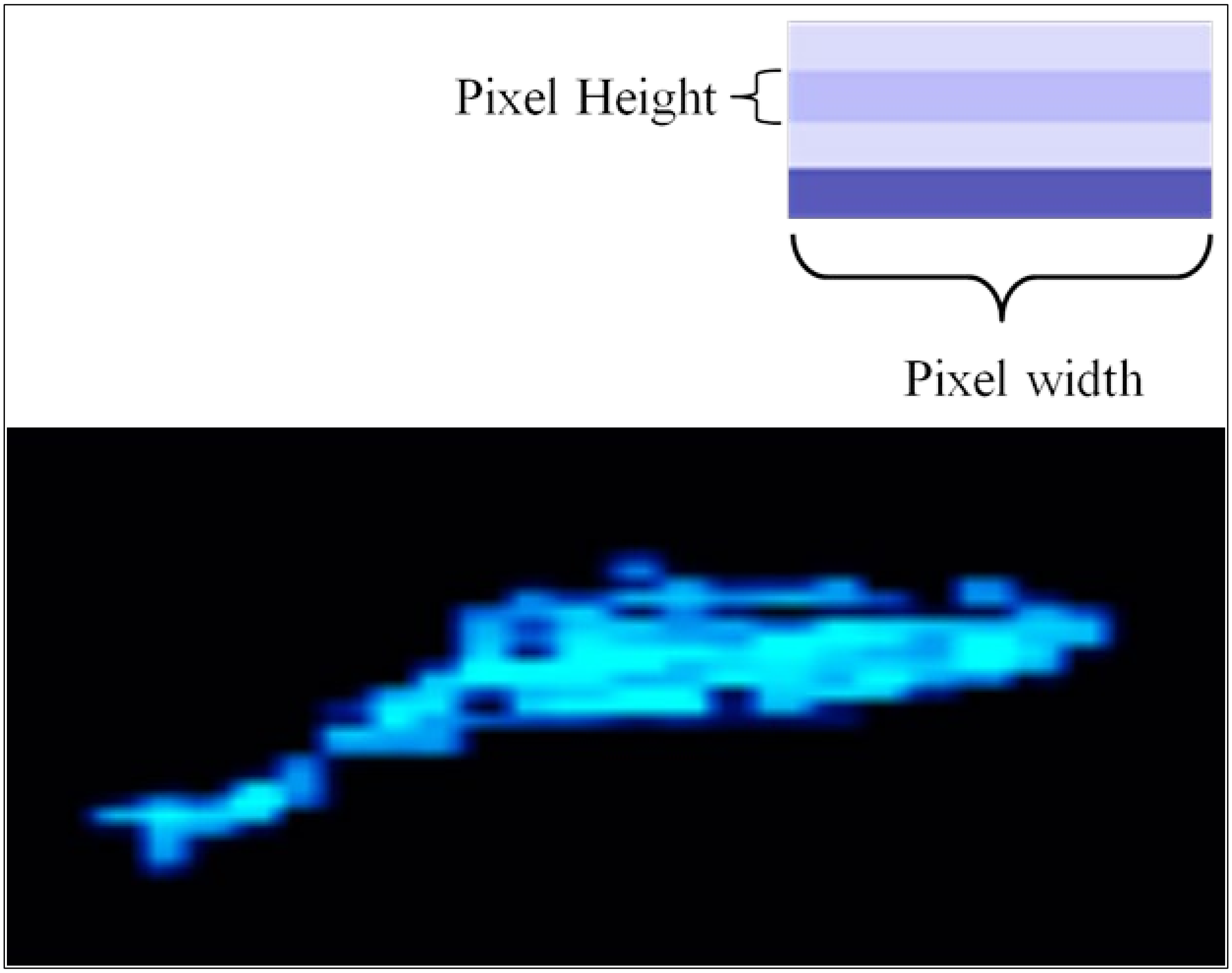
Appendix A5.–Relationships between focal length and lens position for ARIS standard lens (top) and high-resolution lens (bottom).



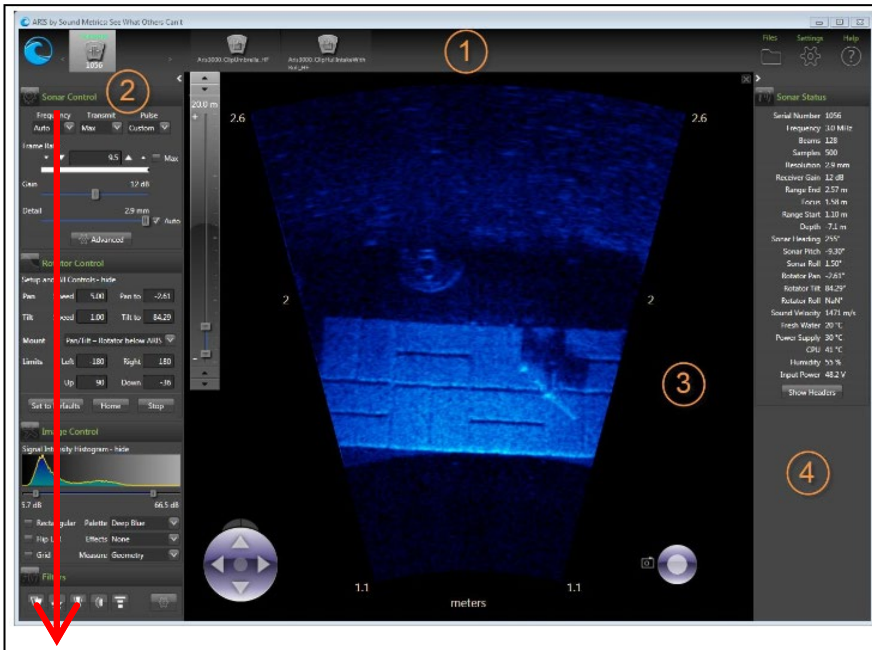


Note: “Big Lens” refers to the high-resolution lens.

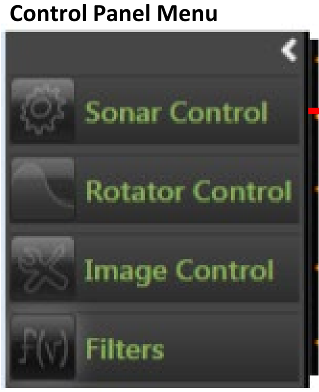
Appendix A6.–An enlargement showing individual pixels that compose an image (top) and an ARIS image of a free-swimming Chinook salmon (bottom).



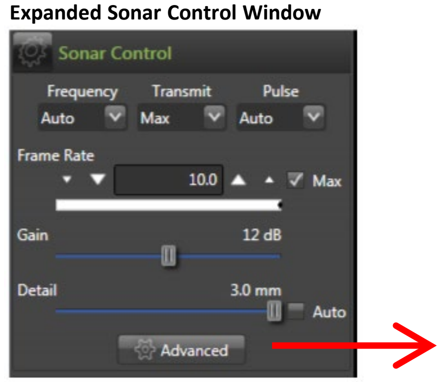
Appendix A7.–Downrange resolution for ARIS images is set using the "Detail" slider under the expanded "Sonar Control" dialog window or by setting the "Sample Period" under the "Advanced Sonar Settings" dialog window.



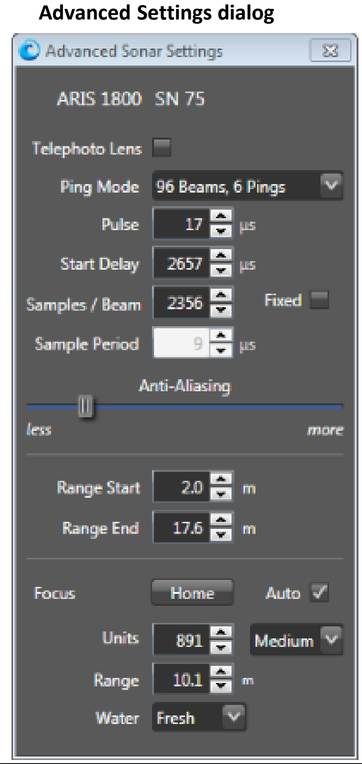
Control Panel Menu



Expanded Sonar Control Window



Advanced Settings dialog



The *Advance Settings* dialog allows direct access to all sonar data acquisition parameters, sample start and end range, and fine manual focus control.

In practice, we have found it easiest to set certain parameters in the *Advance Settings* dialog rather than using the sliders in other control windows (e.g. Sample Period versus Detail). The sliders are useful for exploring the best parameters during initial sonar set up. Once the approximate range and resolution have been selected using sliders, more exact values can be set in the *Advance Settings* dialog.

Appendix A8.–Summary of ARIScope data acquisition parameters that affect downrange resolution.

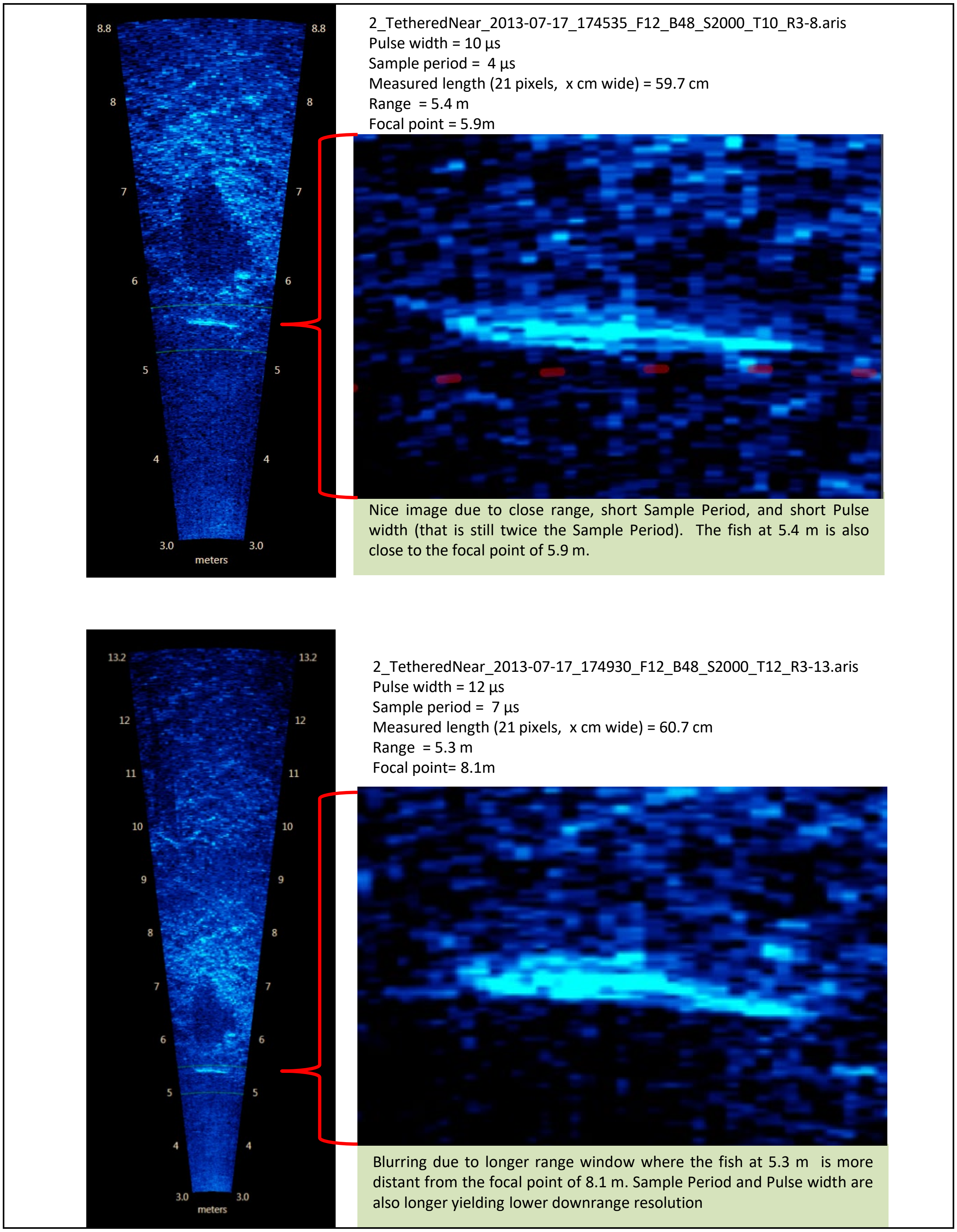
Parameter	Description
Detail (mm)	Downrange resolution refers to the "height" of the ARIS image pixel and can be set in ARIScope using the <**Detail**> or <**Sample Period**> parameters. Setting the <**Detail**> parameter, measured in millimeters, in turn sets the data for <**Sample Period**>, which is the equivalent parameter in microseconds. The downrange resolution can be set using the <**Detail**> slider in the ***Sonar Control*** dialog window under ECHOScope's ***Control Panel*** (Appendix A7), which then automatically sets the <**Sample Period**>. Downrange resolution can also be set more exactly and directly by entering a value for <**Sample Period**> in the ***Advanced Sonar Settings*** dialog window (Appendix A7). These parameters, in combination with the transmit pulse width, control downrange resolution. Slide the <**Detail**> control to the left for less detail (longer sample period) or to the right for more detail (shorter sample period). Images with greater detail have more samples per beam, leading to larger frame sizes. As a consequence, file sizes will be larger and frame rates may need to be reduced to handle the data throughput. This may also be a consideration when transmitting data via wireless radio where bandwidth may limit frame size and frame rate. <**Samples/Beam**> has a limit of 4096, so at maximum <**Detail**> that translates to about 12 m (39 ft) maximum range (2.9 mm maximum downrange resolution × 4096 samples ≈ 12 m). Using **<Auto>** (<**Detail**>): Checking the <**Auto**> box (default) will attempt to provide a good balance between <**Detail**> and file size and frame rate. For our purposes, we find that using **<Auto>** does not provide the level of resolution we prefer, particularly at farther ranges. Also note that when the <**Auto**> box is checked, the number for <**Samples/Beam**> is automatically fixed at the current number when starting to record a file. Checking the <**Auto**> box automatically unchecks the <**Fixed**> (<**Samples/Beam**>) box in the ***Advanced Sonar Settings*** dialog window.
Pulse (µs)	Transmit <**Pulse**> width determines the downrange resolution and brightness of the image. Shorter pulses make for better resolution but put less energy into the water, reducing the brightness of the image and the maximum effective range. Longer pulses will reduce downrange resolution but make the image brighter with a longer maximum effective range. In general, choosing between narrow, medium, and wide settings in the ***Sonar Control*** window will give you sufficient control over the tradeoff between maximum range and resolution. Transmit <**Pulse**> width can be manually set in the ***Advanced Sonar Setting*** dialog window (Appendix A7). **<Pulse>** width settings: • Narrow (default) transmit <**Pulse**> width is set to ~1.2 × the <**Sample Period**>**.** • Medium transmit <**Pulse**> width is set to ~2.0 × the <**Sample Period**>. • Wide transmit <**Pulse**> width is set to ~3.3 × the <**Sample Period**>. • Auto transmit <**Pulse**> width is set to approximately the end range in microseconds (µs). • Custom settings in µs can be selected in the ***Advanced Sonar Settings*** dialog window (Appendix A7).

-continued-

Parameter	Description
Sample Period (µs)	The <**Sample Period**> parameter sets the image data sample period within a beam in microseconds. Shorter values provide higher downrange resolution at the expense of larger frame sizes and potentially restricted frame rates. <**Sample Period**> can be set with the Sonar Control <**Detail**> slider or <**Auto**> checkbox or in the ***Advanced Sonar Settings*** dialog window.
Samples/Beam	The <**Samples/Beam**> parameter is the number of data samples in a sonar beam, from 128 to 4096. Changing this value manually to a larger number will increase the image window end range and decrease the end range to a smaller number. Check the <**Fixed**> box to force a fixed number in <**Samples/Beam**>. This allows changing the range start and the range end of the image window while recording without starting a new output file. Checking the <**Fixed**> box automatically unchecks the <**Auto**> (<**Detail**>) box in the ***Advanced Sonar Settings*** window (if the <**Auto**> box is checked when <**Fixed**> is unchecked, then the number for <**Samples/Beam**> is automatically fixed at the current number while recording a file). Avoid trying to set the resolution using the <**Samples/Beam**> parameter because increasing the number for <**Samples/Beam**> will automatically increase the window end range rather than increase **<Sample Period>** or <**Detail**> parameters.

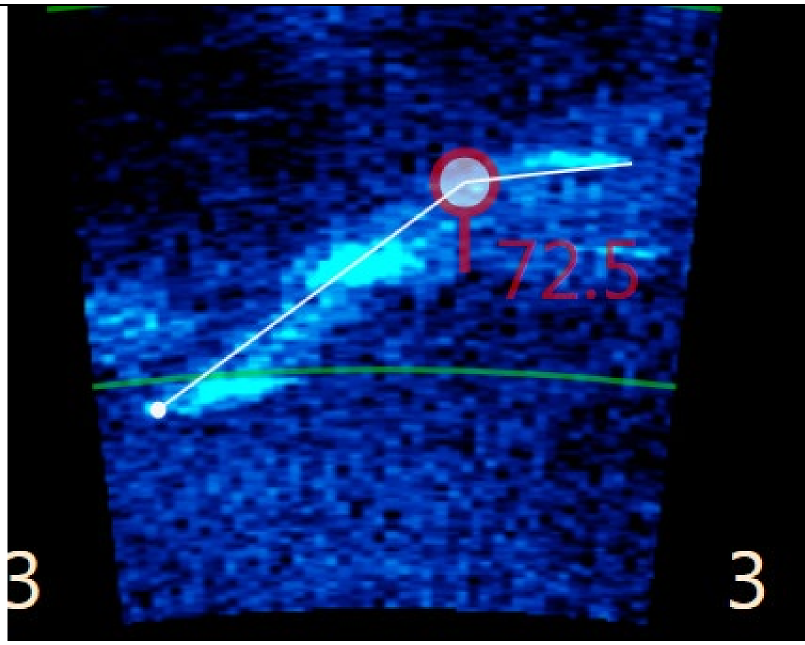
Note: Parameters can be found in Appendix A7. Names of parameters that can be set in ARIScope are listed in **<bold>**; names of dialog windows are shown in ***bold italics***.

Appendix A9.–Images from a close-range tethered fish at 2 different range windows demonstrate the advantage of a shorter range window and higher sample period for close-range sampling.

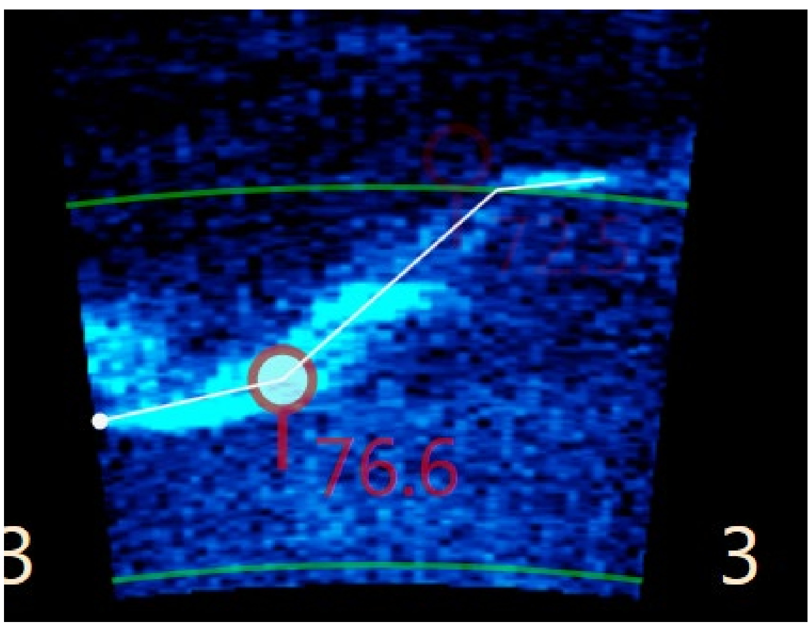


Note: The top image has better resolution because of the shorter range window with better focal resolution and a higher sample period than the bottom image.

Appendix A10.–Images from a 68.5 cm sockeye salmon demonstrate a measurement bias at ranges less than 3.5 m, even with the short 5 m range window.

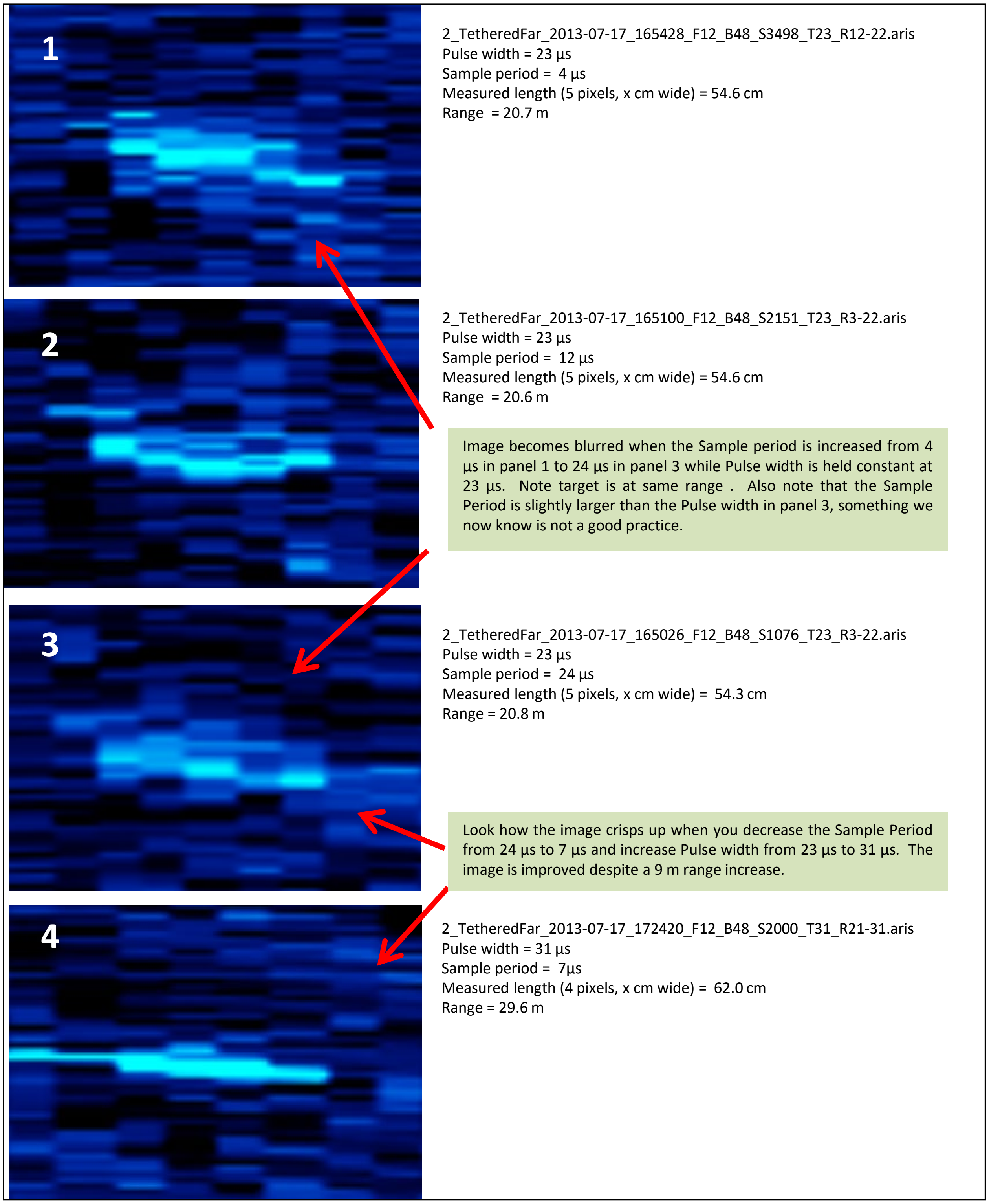


3_TetheredNear_2013-07-17_182746_F12_B48_S1724_T08_R3-8.aris
Fish Range: 3.35 m
Frame 2498
Fish size 72.5 cm



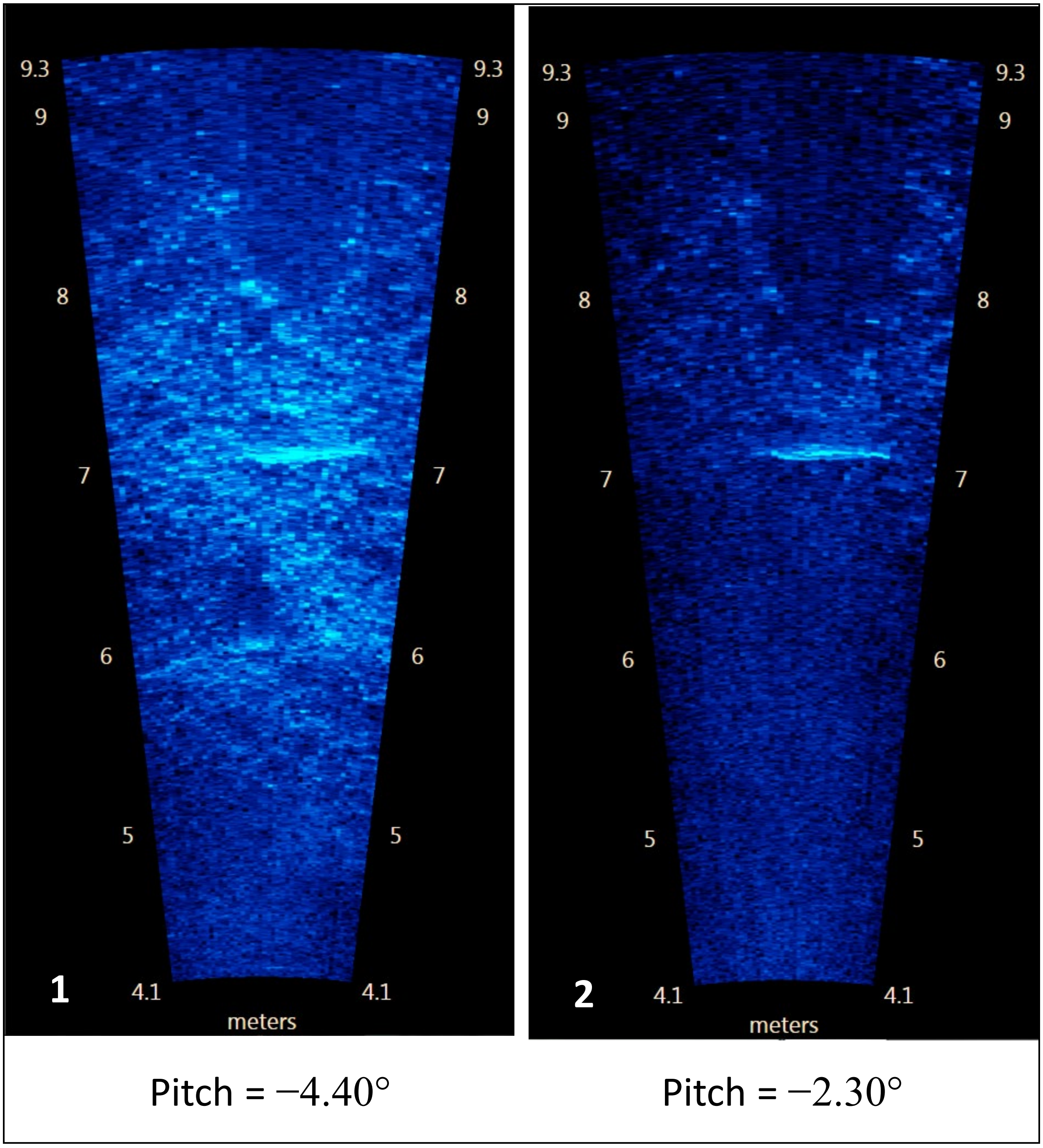
3_TetheredNear_2013-07-17_182746_F12_B48_S1724_T08_R3-8.aris
Fish Range: 3.17 m
Frame 1896
Fish size 76.6 cm

Appendix A11.–Data collected from tethered fish provided the opportunity to compare the effects and interrelationship between 2 parameters affecting image resolution: transmitted pulse length and sample period.



Note: This is a 60 cm sockeye salmon.

Appendix A12.–Images of a tethered fish taken at 2 different aims: Panel 1, where the bottom is better defined but measuring the fish is actually more difficult against the bright background, and Panel 2, where the sonar pitch is raised 2° and the fish outline is better defined for easier measuring and bottom structures still show at all ranges.



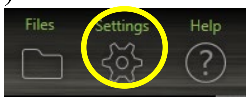
Note: Aiming the sonar farther into the bottom than required to cover the near-bottom region can cause unnecessary loss of vertical beam width and water column coverage and degrade the fish image.

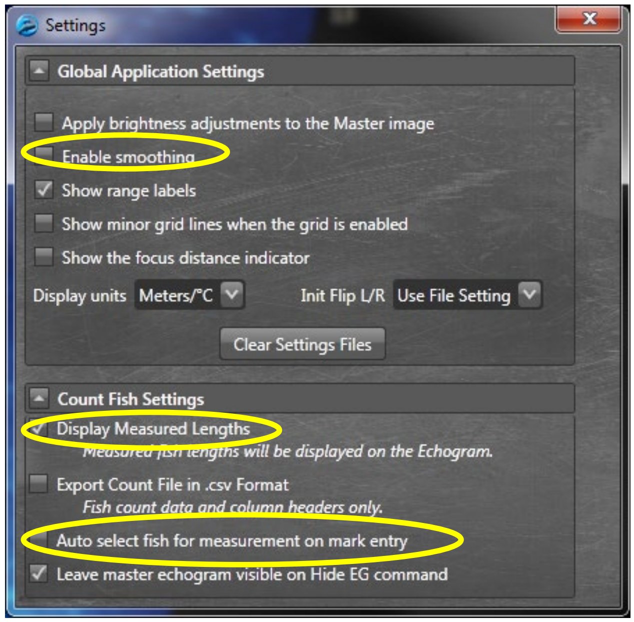
APPENDIX B: INSTRUCTIONS AND SETTINGS FOR MANUAL FISH LENGTH MEASUREMENTS

Appendix B1.–Instructions and settings for manual length measurements from ARIS images generated in 2014 using SMC ARISFish software Version 1.5 REV 575.

Set Global Settings after a new installation of ARISFish

1. Open the ARISFish **<Global Application Settings>** menu (using the **<Settings>** cog in the upper-right corner) and use the following settings:



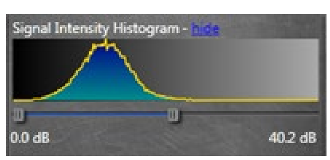


2. **<Enable smoothing>** is off.
3. **<Display Measured Lengths>** is on.
4. **<Auto select fish for measurement ….>** can be either on or off, as desired.

Set processing parameters for a new set of files for a new day or stratum

1. Select **<Files> <Open Recently Viewed>**.

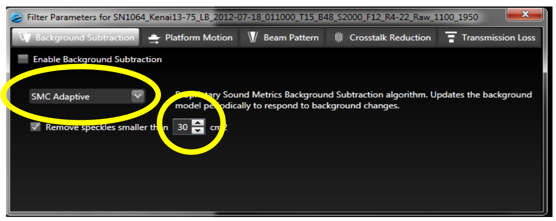
2. Navigate to the appropriate directory and open file (or simply **<double click>** on the file).
3. Set **<Signal Intensity Histogram>** sliders to 0.0 and 40.2 dB (or other recommended values for a specific stratum).



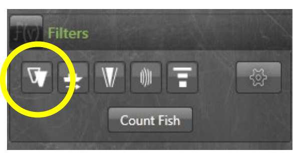
-continued-

4. Select the **<Settings>** cog from the **<Filters**> menu.

5. Select **<SMC adaptive background>** and set **<Remove speckles smaller than>** to 30 cm^2. Setting can be varied to optimize image.

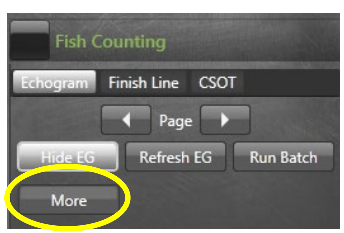


6. Select the **<Background Subtraction>** icon on the **<Filters>** menu (toggle); this will enable background subtraction for producing the echogram.



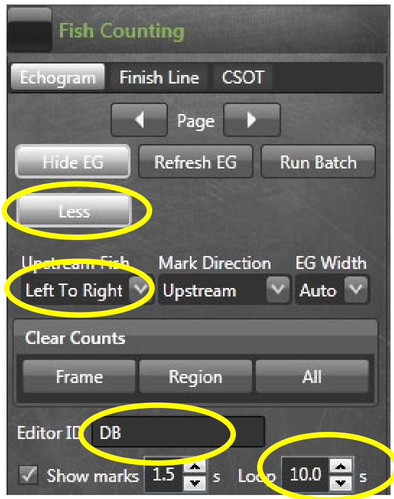
7. Select **<Echogram**> **<Show EG>** from the **<Fish Counting>** menu to display the echogram.

8. Select **<More>** to get expanded options in the **<Fish Counting>** menu.

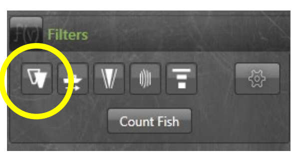


-continued-

9. *Increase **<Loop>** length to at least 8 seconds.
   *Enter initials for **<Editor ID>.**
   *set **<Mark Direction>** "upstream" and **<Upstream Fish>** direction parameter (usually "left to right" for left bank sonar files and "right to left" for right bank sonar files).
   *Select **<Less>** to shrink fish counting window.



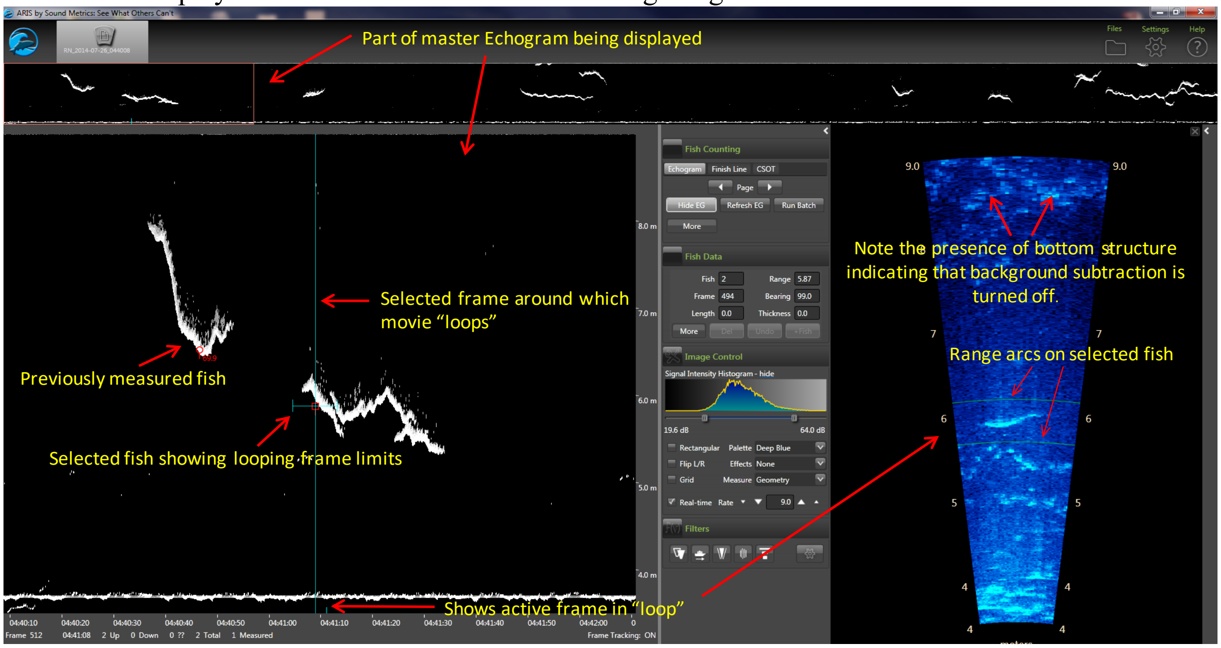
Now select the **<Background Subtraction>** icon on the **<Filters>** menu (toggle) to turn the background subtraction "off" on the video image. Failing to turn background subtraction off prior to measuring the fish image length may result in an underestimate of actual fish length [14].



-continued-

[14] Unlike with DIDSON data, we do not usually use the background subtraction (BS) option while measuring ARIS fish image lengths. The new SMC ARISFish BS algorithm is more aggressive than the DIDSON algorithm and unless one is very careful in selecting a frame, it is easy to underestimate fish length. Toggling between BS mode and the raw image can sometimes be helpful in determining the end of a tail or snout. If BS is used, we generally take BS off before finalizing a measurement. A well-selected frame will give the same length measurement with or without BS.

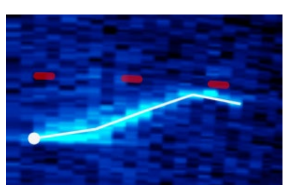
10. The overall display should look similar to the following image:



11. Select **<Alt><right arrow>** to advance to the next file when needed; all parameter settings and the display configuration should be preserved.
12. Individual fish may be measured at this point.
13. When switching banks, reset **<Upstream Fish>** direction of travel in Step 9.
14. When switching strata, use Windows Explorer to find the first file and **<double click>** it.

Instructions for manual fish length measurements using SMC ARISFish software version 1.5 in 2013.

1. Ensure **<Background Subtraction>** is toggled "off" as described in Step 10 above.
2. **<Left click>** on the echogram fish to be measured (puts red marker on fish).
3. **<Right click>** inside the red circle (a blue line with loop limits will appear).
4. Press **<space bar>** to start movie showing fish bounded by range arcs (see figure in Step 11 above).
5. **<Right click drag>** on the movie image to zoom in for measurement.
6. Press **<space bar>** to pause the movie.
7. Use **<right arrow>** and **<left arrow>** to step through movie 1 frame at a time to find a frame that displays the entire fish length well (e.g., Appendix B3).
8. **<Left click drag>** if necessary to center the movie window prior to measuring.
9. **<Left click>** on the fish snout and continue to **<left click>** along the midline of the fish to create a "segmented measurement." The segments should follow the midline of the body of the fish, ending with the tail.



-continued-

10. Select the **<f>** key to add the measurement to the .txt file ("fish it"). The measurement will appear in red (**<left click>** on echogram inside mark, to delete measurement and start over).
11. Select the **<v>** key to "unzoom" the movie window (this not necessary if there is another fish nearby to measure).
12. Repeat steps 1–8 for each fish, or **<left click>** on the master echogram to advance to a new echogram section, or **<alt><right arrow>** to advance to the next file.

Hot keys

<e> to "save" all echogram measurements to file

<f> to "fish it" (to accept the measurement and display it on the echogram)

<u> to "undo" the last segment

<d> to "delete" all segments

<v> to "unzoom" the movie window

<space bar> to pause in movie mode

<right arrow> forward direction when playing a movie or advances frame 1 at a time if the movie is paused.

<left arrow> opposite of above

<left click drag> to show movie over the selected time

<right click drag> zooms the selected area

Instructions for including or excluding fish to be counted and measured

In order to optimize the aim of the sonar beams relative to the river bottom, the insonified zone is often divided into individual range strata that are sampled separately. In order to avoid overcounting fish as they cross stratum boundaries, we apply the "centerline rule" where a fish is not counted unless it crosses the centerline of the sonar beam. Appendix B2 demonstrates the potential for overcounting without applying this criterion. Additional examples are given in Appendix B3.

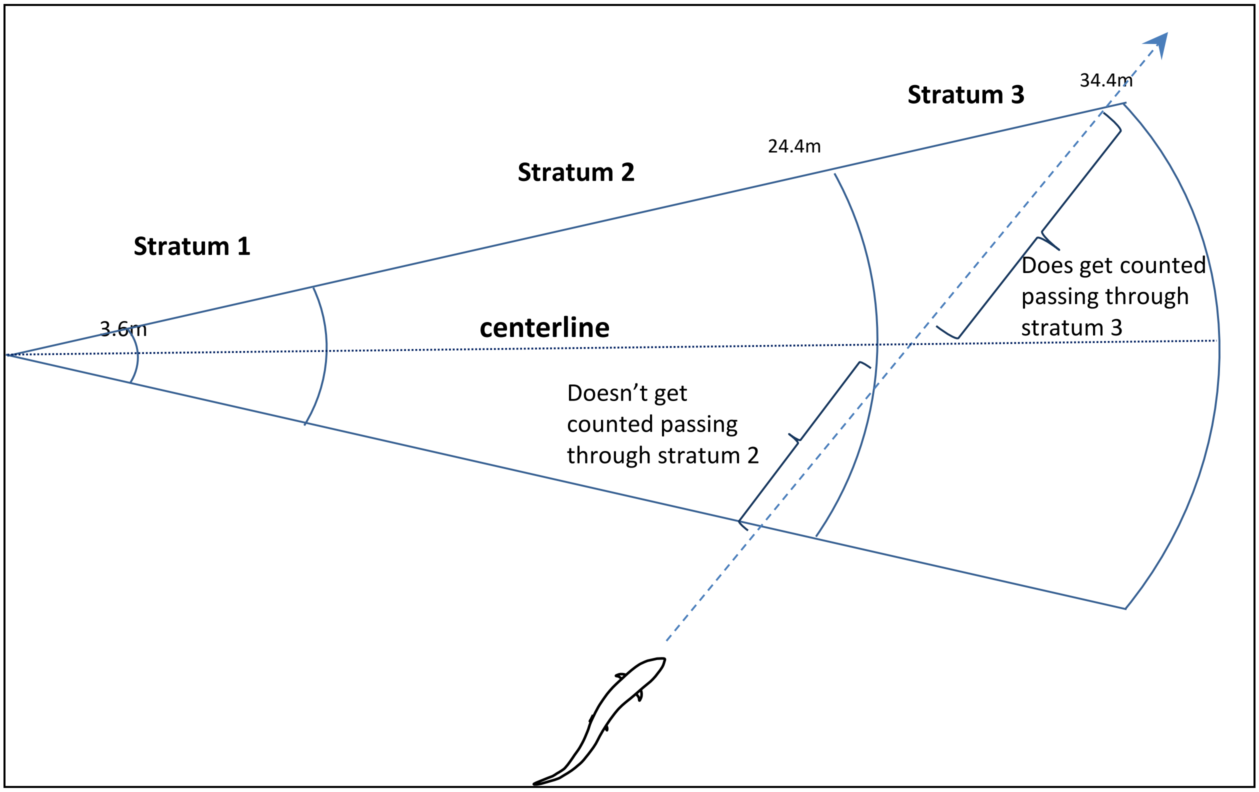
Summary of fish measurement rules

1. For a fish to be considered valid for measurement, it must cross the centerline.
    a) If a fish enters or exits the beam on the near- or far-range boundary (beginning or end range), the snout of the fish must cross the centerline before it can be considered a valid fish to measure.
    b) If the snout of the fish enters the near- or far-range boundary right on the centerline, the fish should be considered valid for measurement.
2. Exclude fish that "hold" throughout the length of the sample.
3. Exclude fish that are "holding" at either the beginning or the end of the sample. Fish that are actively migrating (not holding) as the sample begins or ends should be considered valid targets for measurement as long as they cross the centerline.
4. Exclude fish that enter the beam from upstream and then exit the beam upstream (do not measure even if they cross the centerline).

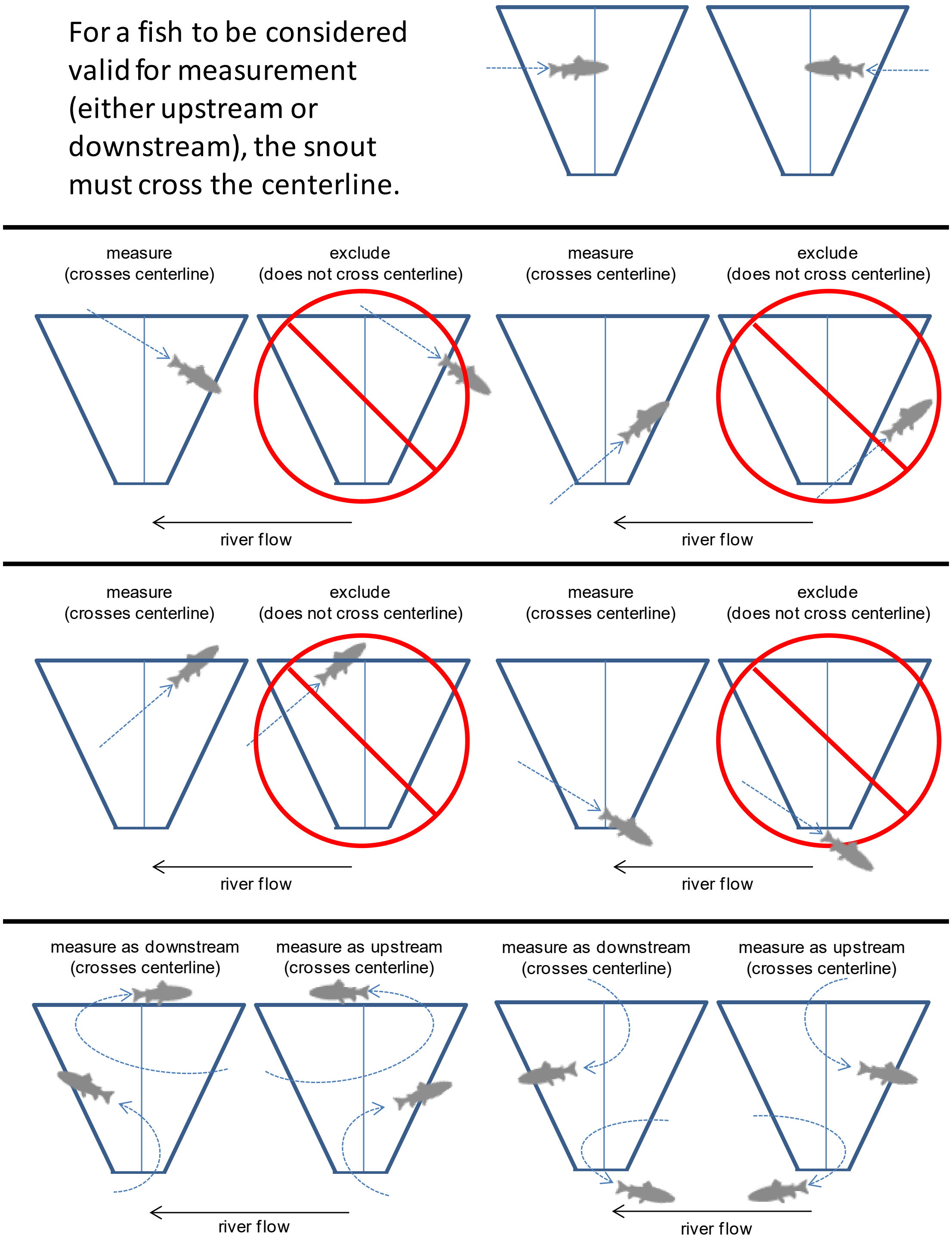
-continued-

5. Exclude fish that enter the beam from downstream and then exit the beam downstream (do not measure even if they cross the centerline).
6. Exclude fish that enter the beam from either upstream or downstream and then disappear from the image (unless there is evidence to suggest direction of travel).
7. Use the video image to identify actively migrating fish when several holding fish are present. If several fish are holding throughout the sample, use the video mode or run the cursor across the echogram while watching the ARIS image to observe fish that are actively transiting the image. Measure fish that are actively transiting the image and that meet all criteria listed above.
8. Consulting with others is recommended if there is a questionable trace or fish or if the rules listed above are unclear.

Appendix B2.–To avoid counting this fish in both Stratum 2 and Stratum 3, the fish will only be counted in Stratum 3 where it crosses the centerline of the beam.

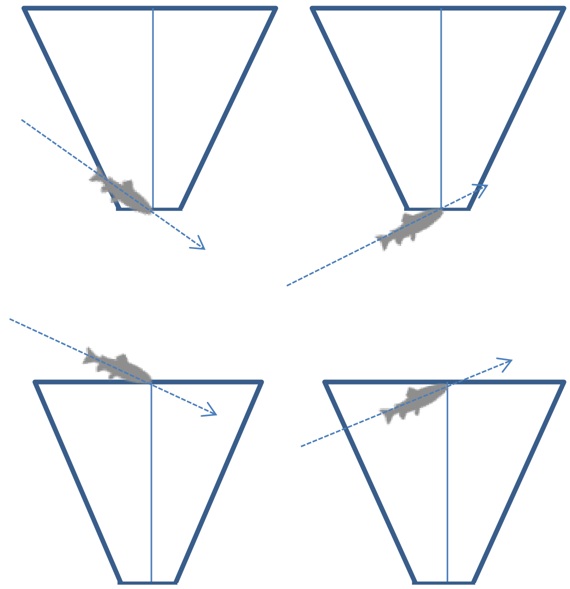


Appendix B3.–Specific examples for applying the "centerline" rule when selecting fish for counting and measurements.

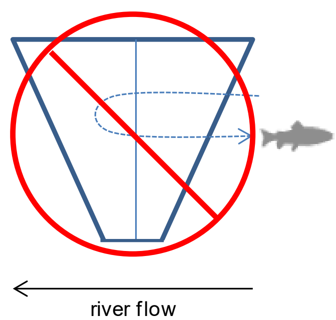


-continued-

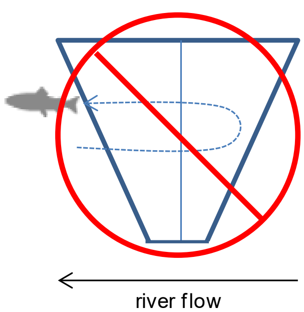
If the snout of the fish enters the near- or far-range boundary right on the centerline, the fish should be considered valid for measurement.



Exclude fish that enter the beam from upstream, then exit the beam upstream (do not measure even if they cross the centerline).

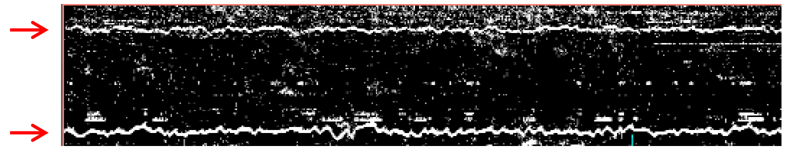


Exclude fish that enter the beam from downstream, then exit the beam downstream (do not measure even if they cross the centerline).



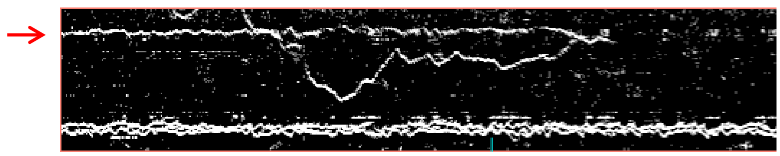
-continued-

Exclude fish that hold throughout the length of the sample.

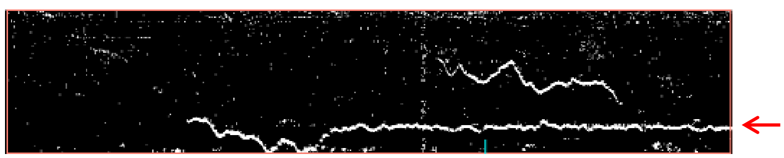


Two fish hold throughout the entire file.
Exclude both fish.

Exclude fish that hold at either the beginning or end of the sample.



Fish holding as sample begins, then exits the beam about ¾ of the way through the sample. Exclude this fish.



Fish enters the beam mid sample, then holds through the end of the sample. Exclude this fish

---

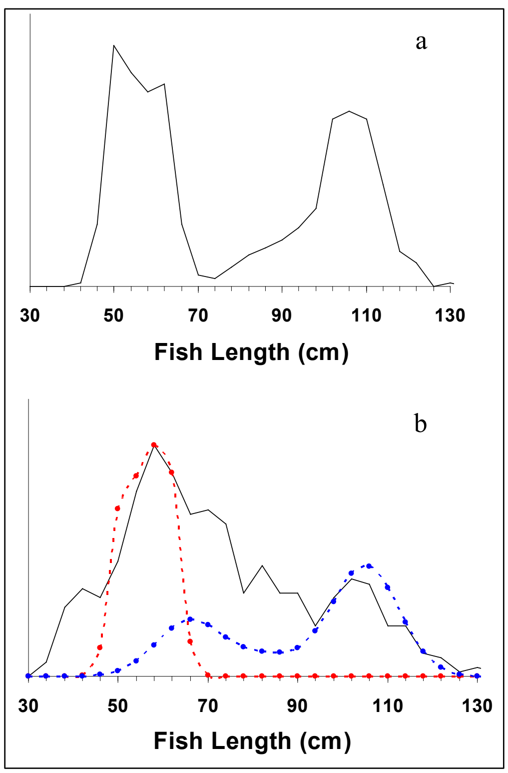
Fish that are actively migrating (not holding) as the sample begins or ends should be considered valid targets for measurement as long as they cross the centerline.

Fish is actively migrating through the beam as the sample starts. It crosses the center line and exits upstream so should be measured.

APPENDIX C: ARIS LENGTH MIXTURE MODEL AND ASSOCIATED WINBUGS PROGRAM CODE

Mixture models are useful for extracting information from the observed frequency distribution of a carefully selected measurement. For example, if the exact length, but not the species, of every fish passing the sonar were known, the distribution of such measurements might resemble graph “a” in the figure below. With auxiliary information about sockeye and Chinook salmon size, the shape of such a distribution can reveal much about the relative abundance of sockeye and Chinook salmon. For instance, if sockeye salmon were known not to exceed 70 cm, and small Chinook salmon were known to be rare, one could conclude that the left hand mode of the distribution is almost all sockeye salmon and that the species composition is perhaps 50:50 sockeye salmon to Chinook salmon. Mixture model analysis is a quantitative version of this assessment in which the shape of the overall frequency distribution is modeled and “fitted” until it best approximates the data. Uncertainty is assessed by providing a range of plausible species compositions that could have resulted in the observed frequency distribution.

The mixture model analysis is sensitive to and accounts for measurement error. For example, if many Chinook salmon are small and there is error in the length measurements, the effect of the measurement error is to cause the modes of the distribution to overlap, reducing the ability to detect detail in the length distribution and reducing the precision of the estimates (e.g., graph “b” of the figure below). Under this scenario, it is more difficult to interpret the data, but a mixture model approach can provide objective estimates with objective assessments of uncertainty.



Note: True length distributions of sockeye salmon (red dashed line) and Chinook salmon (blue dashed line) are shown along with hypothetical distributions of fish length measurements (black dashed line).

-continued-

The mixture model approach explicitly incorporates the expected variability in hydroacoustic measurements (known from tethered fish experiments), as well as current information about fish size distributions (from the RM 8.6 netting program).

The probability density function (PDF) of ARIS length measurements w was modeled as a weighted mixture of 2 component distributions arising from sockeye salmon and Chinook salmon:

$$f(w) = \pi_S f_S(w) + \pi_C f_C(w) \tag{C1}$$

where $f_S(w)$ and $f_C(w)$ are the PDFs of the sockeye salmon and Chinook salmon component distributions, and the weights π_S and π_C are the proportions of sockeye salmon and Chinook salmon in the population. See also the flow chart in Appendix C2.

Individual observations of w for fish i were modeled as normal random variables whose mean is a linear function of true fish length x:

$$w_i = \beta_0 + \beta_1 x_i + \varepsilon_i \tag{C2}$$

where β_0 is the intercept, β_1 is the slope, and the error ε_i is normally distributed with mean 0 and variance σ^2.

Thus, the component distributions $f_S(w)$ and $f_C(w)$ are functions of the length distributions $f_S(x)$ and $f_C(x)$ (see Equations C3–C4) and the linear model parameters β_0, β_1, and σ^2. The species proportions π_S and π_C are the parameters of interest.

Length measurements were obtained from fish captured by gillnets (e.g., Perschbacher 2015) immediately downstream of the RM 8.6 sonar site. Netting data from midriver and nearshore drifts were used. Multiple days of length data from the nets were paired with hydroacoustic data from a single day.

Sockeye and Chinook salmon return from the sea to spawn at several discrete ages. We modeled sockeye and Chinook salmon length distributions ($f_S(x)$ and $f_C(x)$, respectively) as 3-component normal age mixtures:

$$f_S(x) = \theta_{S1} f_{S1}(x) + \theta_{S2} f_{S2}(x) + \theta_{S3} f_{S3}(x) \text{ and} \tag{C3}$$

$$f_C(x) = \theta_{C1} f_{C1}(x) + \theta_{C2} f_{C2}(x) + \theta_{C3} f_{C3}(x) \tag{C4}$$

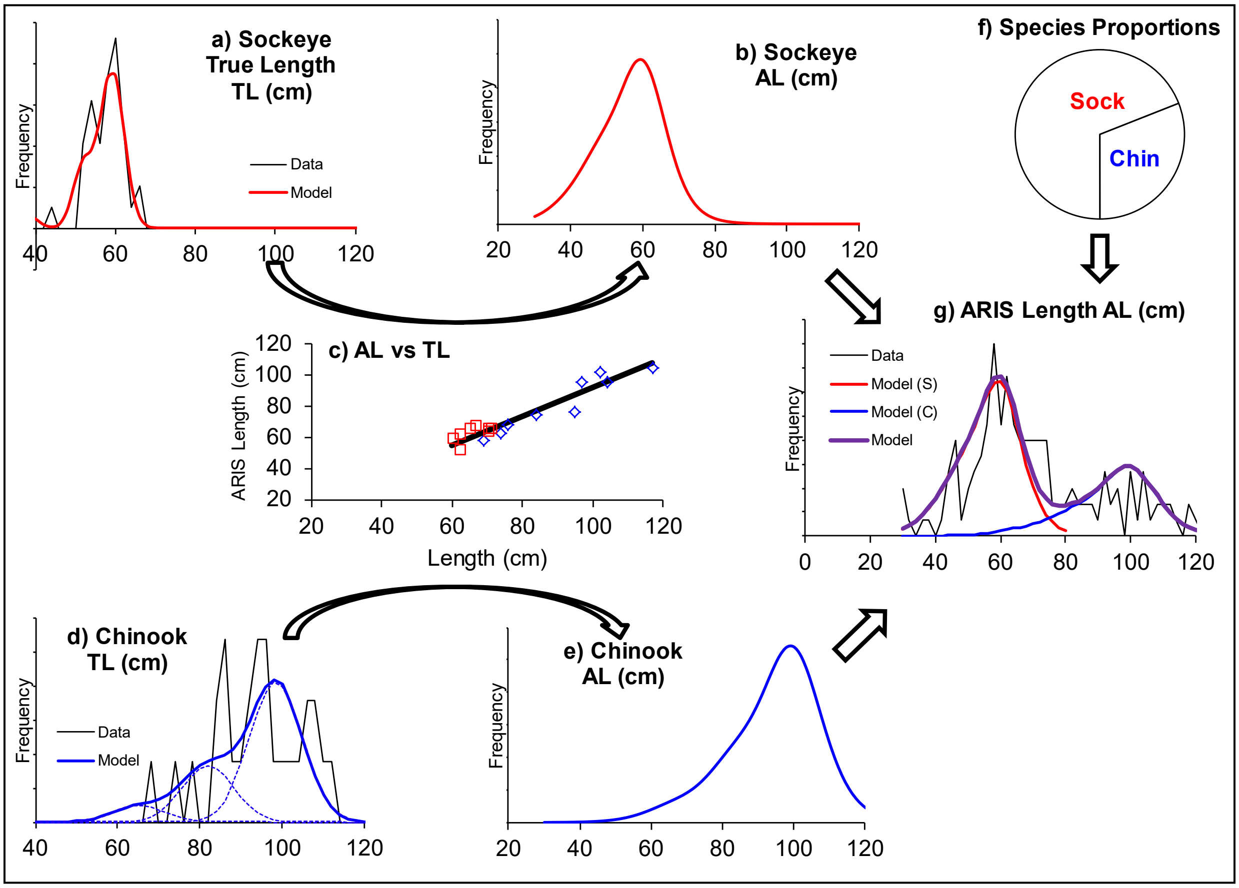
where θ_{Ca} and θ_{Sa} are the proportions of Chinook and sockeye salmon belonging to age component a and the distributions

$$f_{Sa}(x) \sim N(\mu_{Sa}, \tau^2_{Sa}) \text{, and} \tag{C5}$$

$$f_{Ca}(x) \sim N(\mu_{Ca}, \tau^2_{Ca}) \tag{C6}$$

where μ is mean length-at-age and τ is the standard deviation. The overall design is therefore a mixture of (transformed) mixtures. That is, the observed hydroacoustic data are modeled as a 2-component mixture (sockeye salmon and Chinook salmon) of ARIS length (w), each component of which is transformed from a 3-component normal age mixture of fish length (x).

Appendix C2.–Flow chart of a mixture model.



Note: The frequency distribution of ARIS length (AL, Panel g) is modeled as a weighted mixture of species-specific AL distributions (Panels b and e), which in turn are the products of species-specific size distributions (Panels a and d) and the relationship between AL and true fish length (TL) (Panel c). The weights (species proportions, Panel f) are the parameters of interest ("Sock" = sockeye, "Chin" = Chinook).

Bayesian statistical methods (Gelman et al. 2004) were employed to fit the mixture model to the data. Bayesian methods were chosen because they provide realistic estimates of uncertainty and the ability to incorporate diverse sources of auxiliary information. We implemented the Bayesian mixture model in WinBUGS (Bayes Using Gibbs Sampler; Gilks et al. 1994) (Appendix C4).

Bayesian methods require that prior probability distributions be formulated for all unknowns in the model. Informative normal priors based on historical data were used for the length-at-age means μ and standard deviations τ (Appendix C4). Species proportions π_C and π_S were assigned very mildly informative Dirichlet(0.1, 0.9) priors. Prior distributions for age proportions $\{\theta_{Ca}\}$ and $\{\theta_{Sa}\}$ were constructed from nested beta(0.5,0.5) distributions. Netting probability of capture was assumed to be equal for all 3 age classes. Netting length data (e.g., Perschbacher 2015) from days $d-6$ through d were paired with ARIS length data from day d. A linear statistical model (Appendix C5) of tethered fish data was integrated into the mixture model, and a subset of tethered fish data from Burwen et al. (2010) were used to provide a mildly informative prior for the β_0 and β_1 parameters (Equation C2).

The end product of a Bayesian analysis is the joint posterior probability distribution of all unknowns in the model. WinBUGS uses Markov chain Monte Carlo methods to sample from the posterior distribution. A single Markov chain[15] was initiated for each daily run of the ARIS length mixture model, samples were thinned 10 to 1, and history plots were monitored to confirm convergence and mixing. The first 5,000 or more "burn-in" samples were discarded, and at least 10,000 additional samples were drawn from the posterior distribution and used for inference. For point estimates, posterior means were used. Posterior standard deviations provide a measure of uncertainty analogous to the standard error from a classical (non-Bayesian) analysis.

[15] During initial development of the model, multiple chains were used to assess convergence (Gelman et al. 2004). This was not necessary during production of daily estimates.

Appendix C4.–WinBUGS code for ARIS length mixture model.

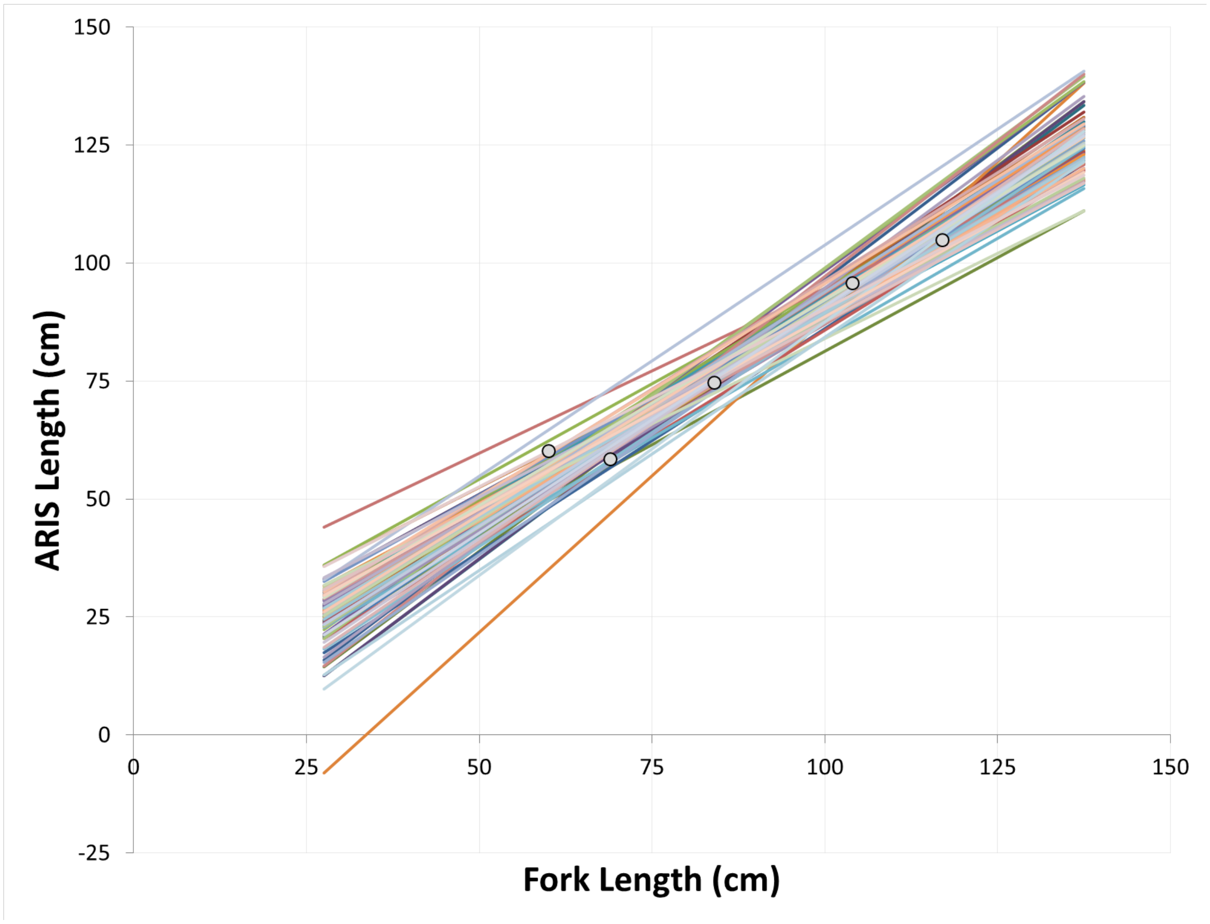
```
model{
 beta0 ~ dnorm(75,0.0025)
 beta1 ~ dnorm(1,25)I(0,)
 sigma.AL ~ dunif(0,20)
 tau.AL  <- 1 / sigma.AL / sigma.AL
 ps[1:2] ~ ddirch(D.species[])
 pa[1,1] ~ dbeta(0.5,0.5)
 theta1 ~ dbeta(0.5,0.5)
 pa[1,2] <- theta1 * (1 - pa[1,1])
 pa[1,3] <- 1 - pa[1,1] - pa[1,2]
 pa[2,1] ~ dbeta(0.5,0.5)
 theta2 ~ dbeta(0.5,0.5)
 pa[2,2] <- theta2 * (1 - pa[2,1])
 pa[2,3] <- 1 - pa[2,1] - pa[2,2]

 n.chin <- ps[1] * n_meas
 p.large <- ps[1] * (1 - pa[1,1] - pa[1,2])
 n.large <- p.large * n_meas

 Lsig[1,1] <- 78
 Lsig[1,2] <- 70
 Lsig[1,3] <- 74
 Lsig[2,1] <- 25
 Lsig[2,2] <- 25
 Lsig[2,3] <- 25
 for (s in 1:2)  {for (a in 1:3)  {Ltau[s,a] <- 1 / Lsig[s,a] / Lsig[s,a] } }
 mu[1,1] ~ dnorm(621,0.0076)
 mu[1,2] ~ dnorm(825,0.0021)
 mu[1,3] ~ dnorm(1020,0.0047)
 mu[2,1] ~ dnorm(380,0.0004)
 mu[2,2] ~ dnorm(500,0.0004)
 mu[2,3] ~ dnorm(580,0.0004)
 for (a in 1:3)  {
  pa.effective[1,a] <- pa[1,a] * q1.a[a] /  inprod(pa[1,],q1.a[])
  pa.effective[2,a] <- pa[2,a]
  }
 for (k in 1:5) {
  FL.cm.75[k] <- FL.cm[k] - 75
  mu.AL1[k] <- beta0 + beta1 * FL.cm.75[k]
  DL1[k] ~ dnorm(mu.AL1[k],tau.AL)
  }
 for (i in 1:n_fish) {
  age[i] ~ dcat(pa.effective[species[i],1:3])
  mefl.mm[i] ~ dnorm(mu[species[i],age[i]],Ltau[species[i],age[i]])
  }
 for (j in 1:n_meas) {
  species2[j] ~ dcat(ps[])
  age2[j] ~ dcat(pa[species2[j],1:3])
  mefl.mm.2[j] ~ dnorm(mu[species2[j],age2[j]],Ltau[species2[j],age2[j]])
  FL2.cm.75[j] <- 1.1 * mefl.mm.2[j] / 10 - 75
  mu.AL2[j] <- beta0 + beta1 * FL2.cm.75[j]
  AL2[j] ~ dnorm(mu.AL2[j],tau.AL)I(40,)
  }
 }
```

Note: Prior distributions are shown in green font, likelihoods in blue.

Appendix C5.–Abridged tethered fish data set (symbols) used to provide a mildly informative prior distribution for the relationship between fork length (FL) and ARIS length (AL). Plausible relationships (lines) are plotted using 100 random samples of the slope and intercept from the prior distribution.



Appendix C6.–Methodological details used for 2016 inseason and final ARIS-length mixture model (ALMM) estimates, contrasted with 2015 inseason methods.

In 2013–2015, the methods used to produce ALMM estimates of Chinook salmon passage during the fishing season to inform inseason management differed in several respects from those used to produce the final published estimates. Some of these differences were partially responsible for substantial postseason revisions to the ALMM estimates (Miller et al. 2013–2016b: Appendices C6 and C7; Key et al. 2017: Appendix C6).

In 2016, we standardized the methodology used to produce inseason versus postseason estimates, thereby reducing the potential for major postseason revisions.

The standardized methodology used in 2016 for both inseason and final estimates is summarized here, with 2015 inseason methods supplied for comparison.

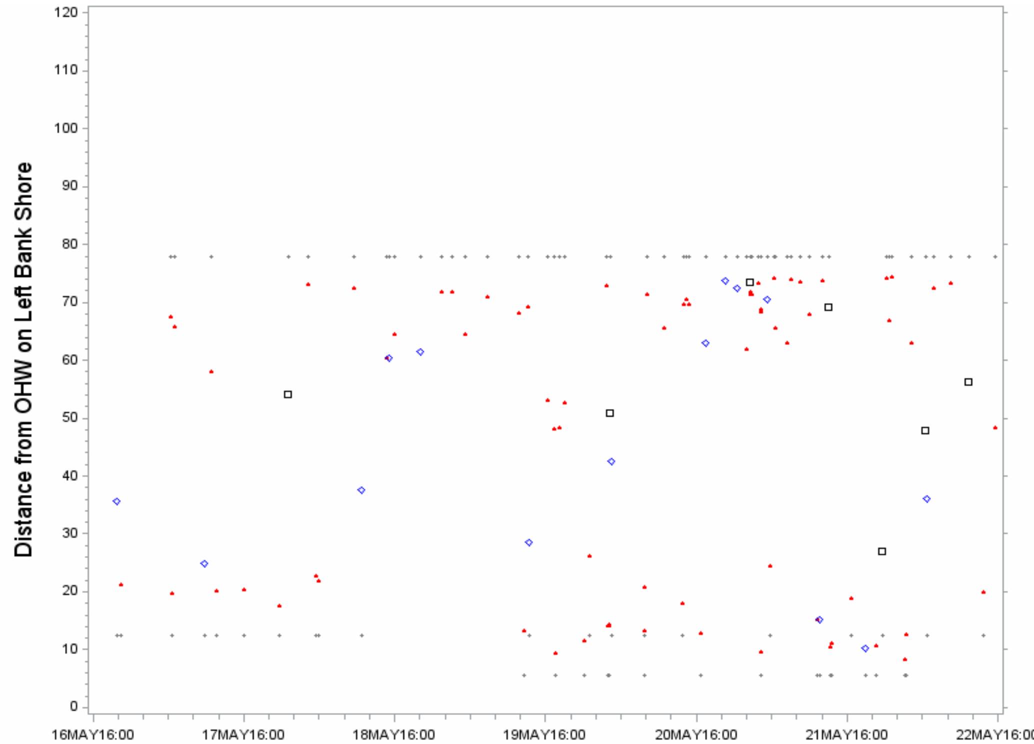
Methodological detail	2015 inseason	2016 inseason and final [a]
Age composition prior	Informative [b]	noninformative [b]
Species composition prior	Dirichlet(0.5,0.5)	Dirichlet(0.1,0.9)
Netting data	Midriver only	Midriver and nearshore
Chinook salmon size selectivity by age class	0.61, 0.57, 0.41	1, 1, 1

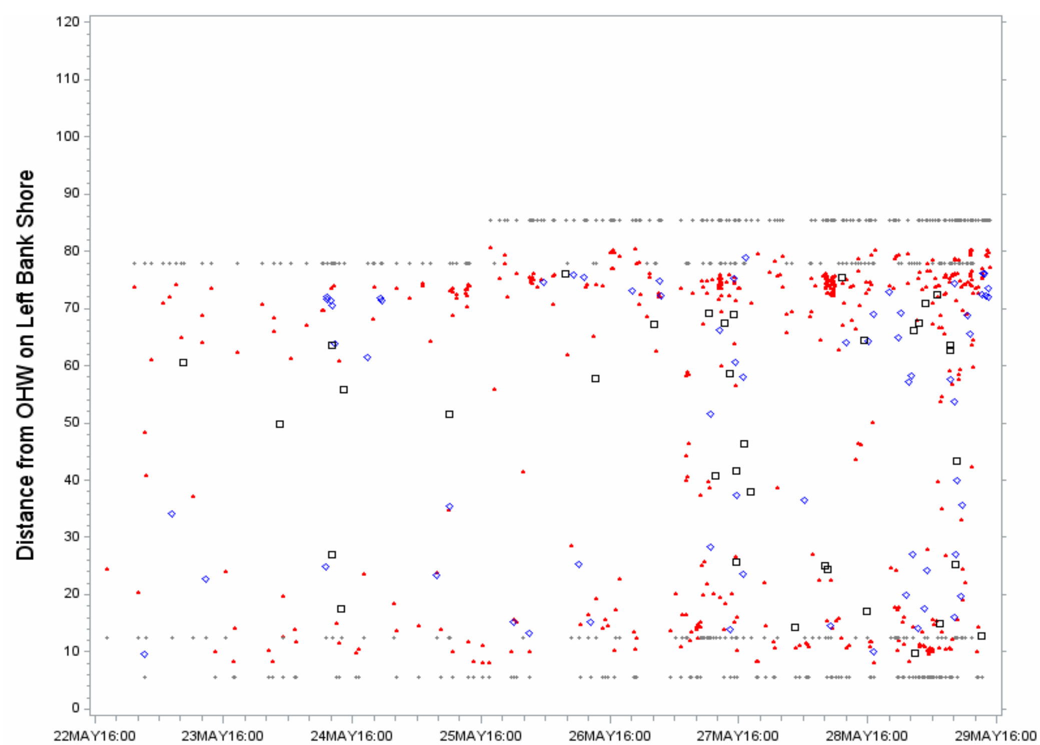
[a] Noninformative nested beta priors (see Appendix C4).

[b] Informative priors differed by week, as developed from a hierarchical age composition model (Key et al. 2016b: Appendix B4).

APPENDIX D: SPATIAL AND TEMPORAL DISTRIBUTION OF FISH BY SIZE AS MEASURED BY ARIS, RM 13.7 KENAI RIVER, 2016

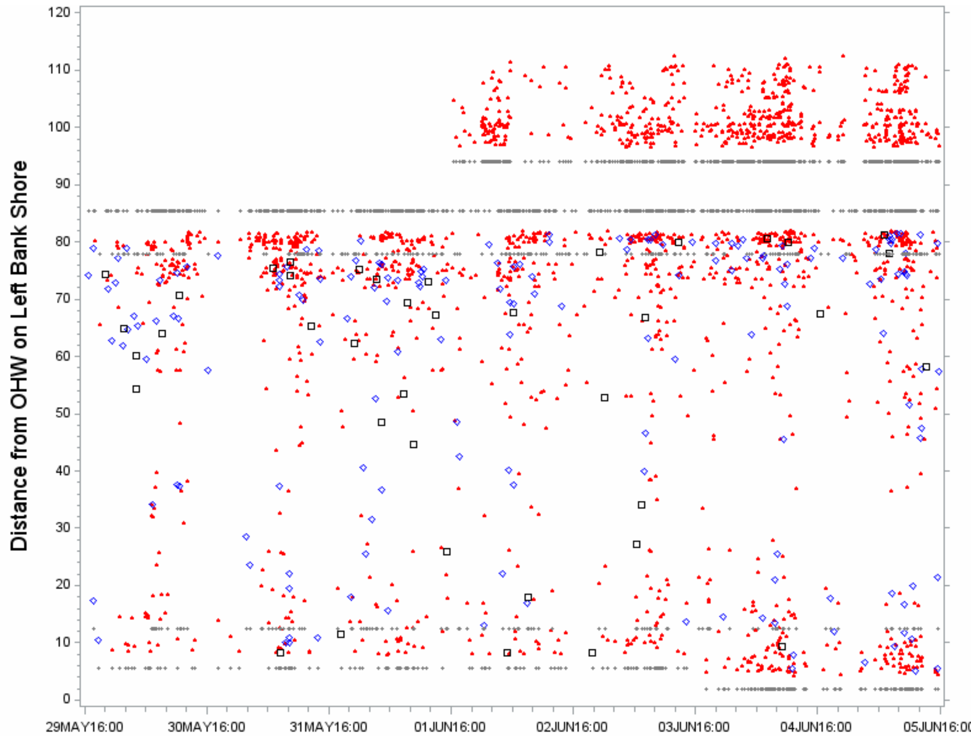
Appendix D1.–Spatial and temporal distribution of small (ARIS length [AL] < 75 cm; small red dots), medium (75 cm ≤ AL < 90 cm; larger blue diamonds), and large fish (AL ≥ 90 cm; large black squares), RM 13.7 Kenai River, 16–29 May 2016.

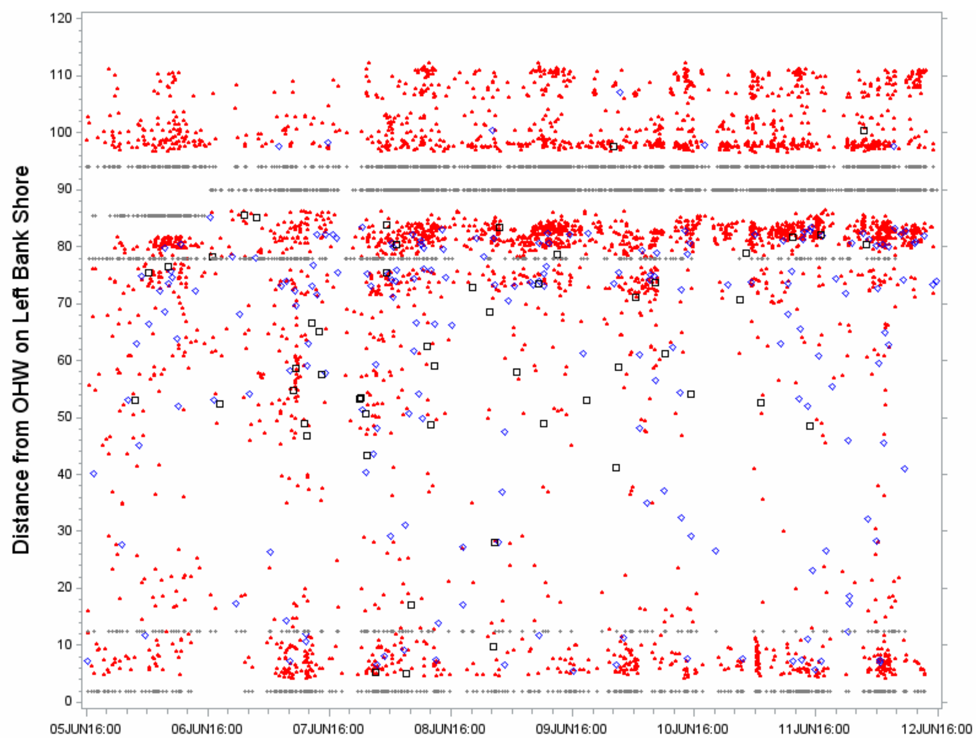




Note: Small fish can be underrepresented in the sample. Transducer locations are plotted as small grey crosses, one per fish. For the main channel, the vertical axis is the distance (meters) from a reference point near the ordinary high water level (OHW) on the left bank.

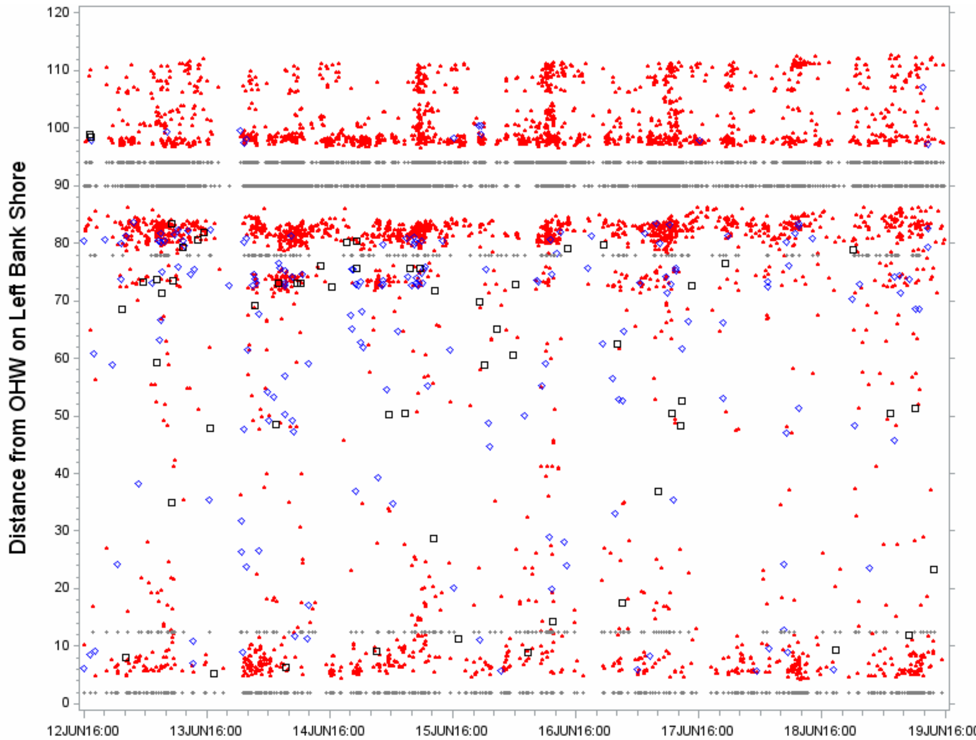
Appendix D2.–Spatial and temporal distribution of small (ARIS length [AL] < 75 cm; small red dots), medium (75 cm ≤ AL < 90 cm; larger blue diamonds), and large fish (AL ≥ 90 cm; large black squares), RM 13.7 Kenai River, 29 May–12 June 2016.

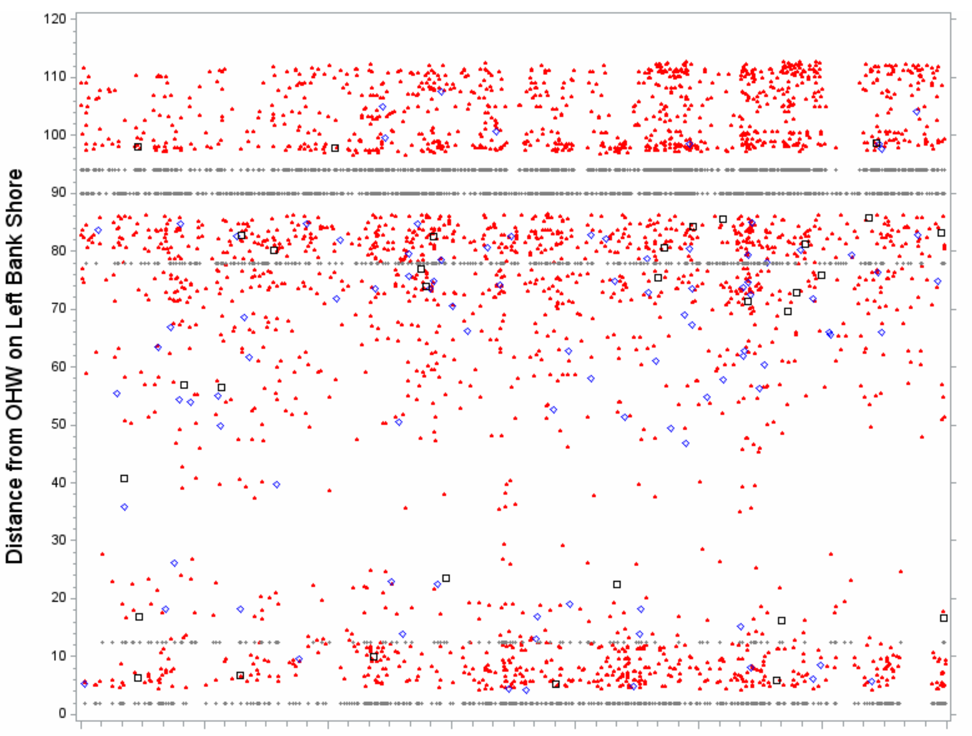




Note: Small fish can be underrepresented in the sample. Transducer locations are plotted as small grey crosses, one per fish. For the main channel, the vertical axis is the distance (meters) from a reference point near the ordinary high water level (OHW) on the left bank. The side channel transducer was arbitrarily set to 95 m for graphical convenience.

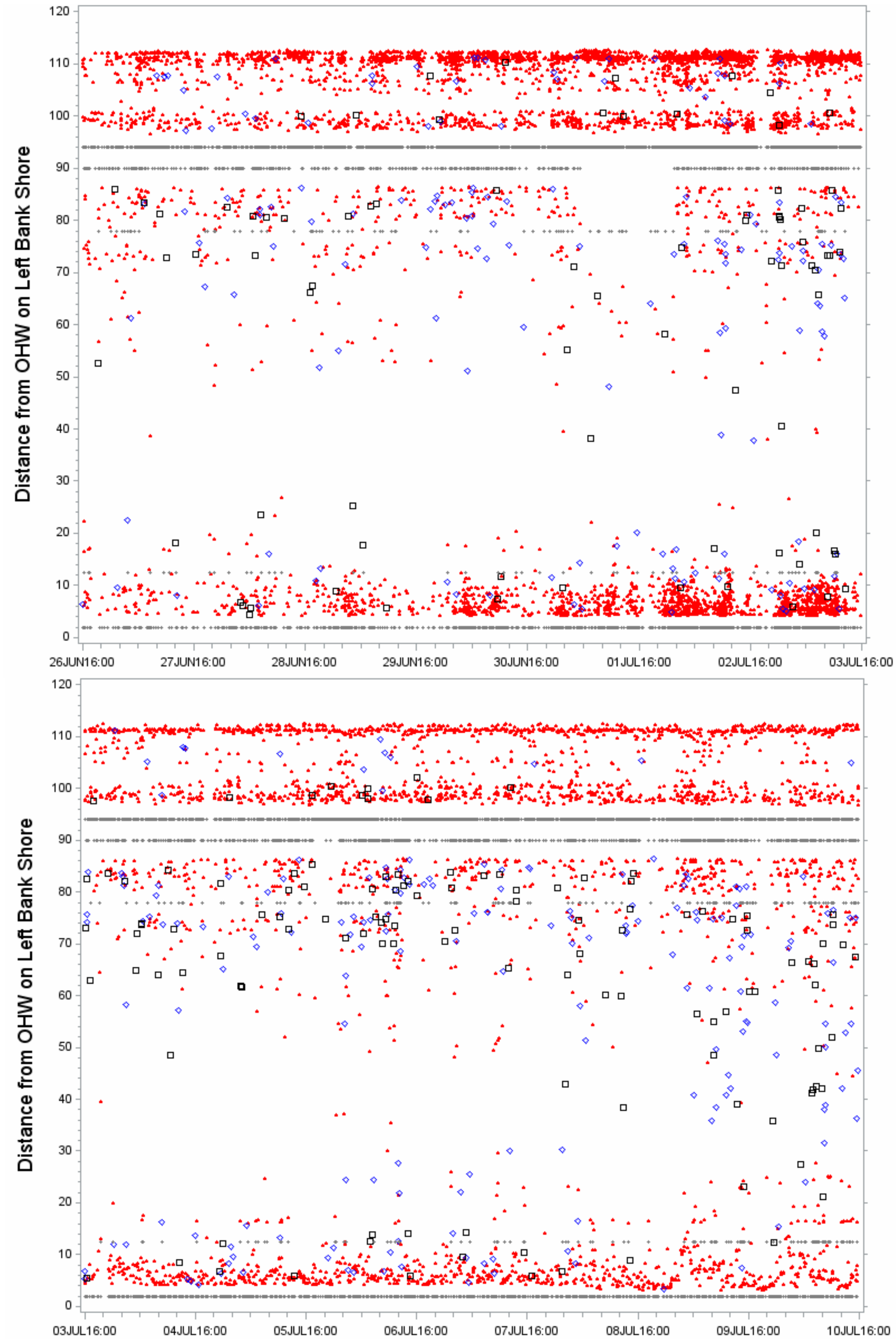
Appendix D3.–Spatial and temporal distribution of small (ARIS length [AL] < 75 cm; small red dots), medium (75 cm ≤ AL < 90 cm; larger blue triangles), and large fish (AL ≥ 90 cm; large black squares), RM 13.7 Kenai River, 12–26 June 2016.





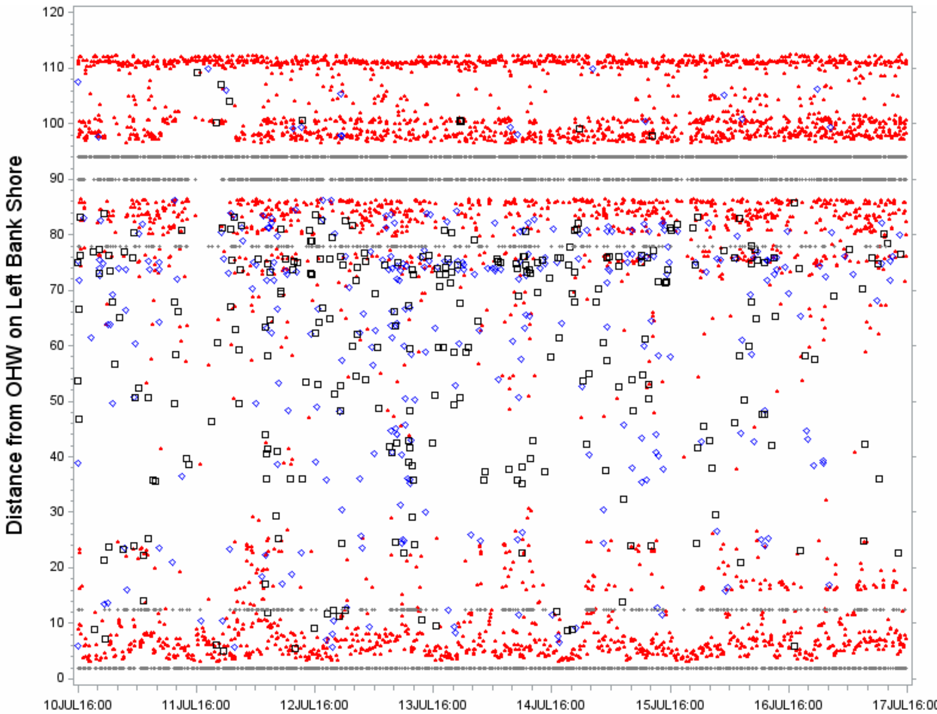
Note: Small fish can be underrepresented in the sample. Transducer locations are plotted as small grey crosses, one per fish. For the main channel, the vertical axis is the distance (meters) from a reference point near the ordinary high water level (OHW) on the left bank. The side channel transducer was arbitrarily set to 95 m for graphical convenience.

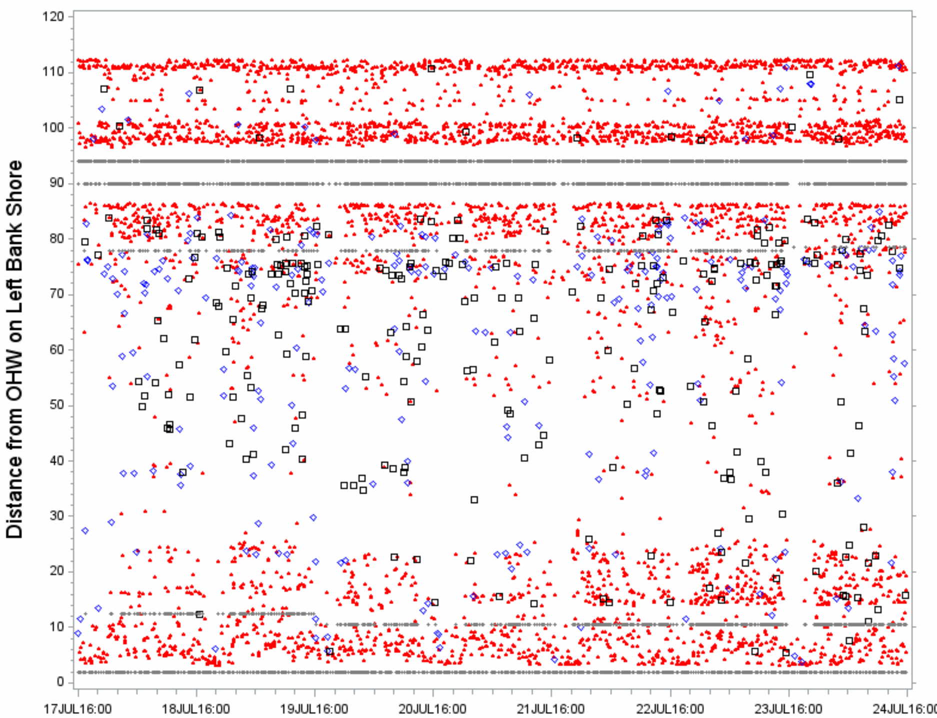
Appendix D4.–Spatial and temporal distribution of small (ARIS length [AL] < 75 cm; small red dots), medium (75 cm ≤ AL < 90 cm; larger blue diamonds), and large fish (AL ≥ 90 cm; large black squares), RM 13.7 Kenai River, 26 June–10 July 2016.



Note: Small fish can be underrepresented in the sample. Transducer locations are plotted as small grey crosses, one per fish. For the main channel, the vertical axis is the distance (meters) from a reference point near the ordinary high water level (OHW) on the left bank. The side channel transducer was arbitrarily set to 95 m for graphical convenience.

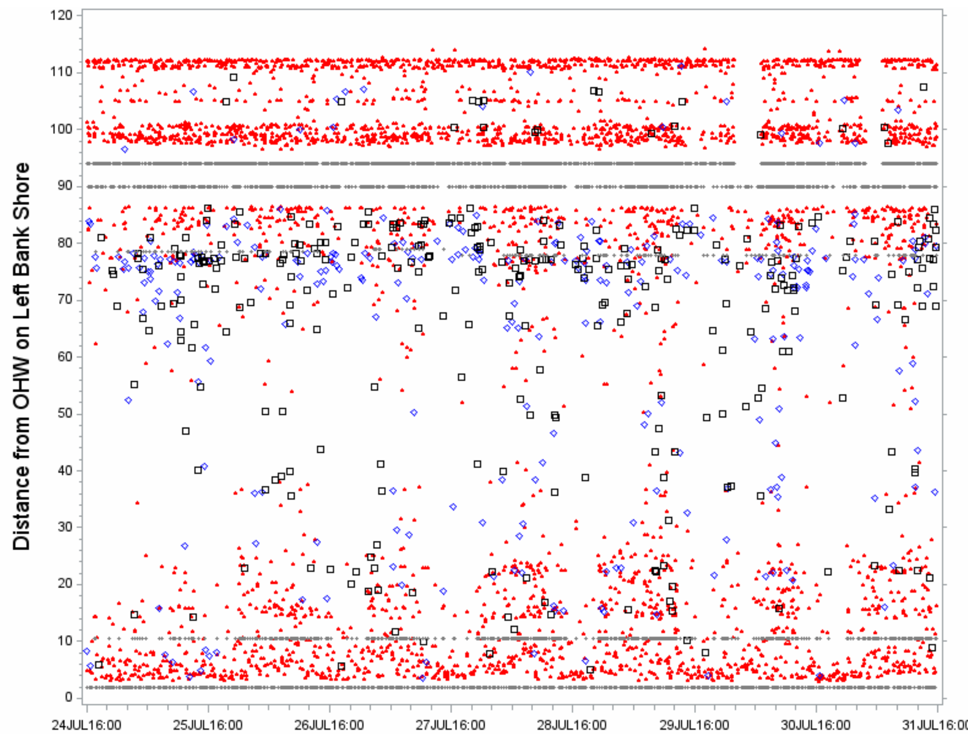
Appendix D5.–Spatial and temporal distribution of small (ARIS length [AL] < 75 cm; small red dots), medium (75 cm ≤ AL < 90 cm; larger blue diamonds), and large fish (AL ≥ 90 cm; large black squares), RM 13.7 Kenai River, 10–24 July 2016.

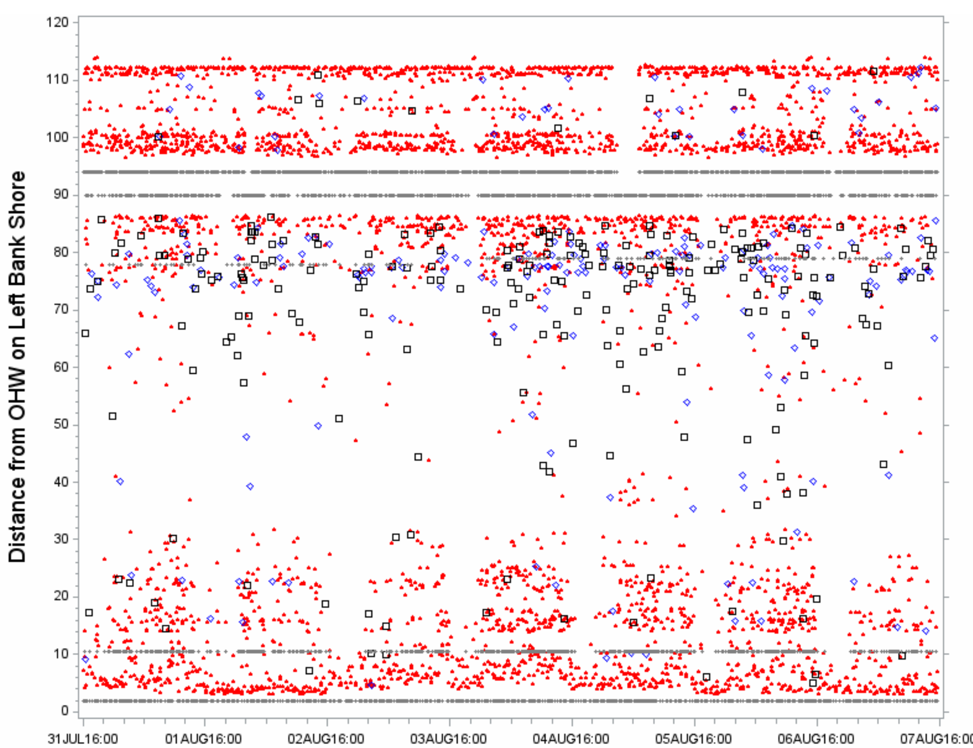




Note: Small fish can be underrepresented in the sample. Transducer locations are plotted as small grey crosses, one per fish. For the main channel, the vertical axis is distance (meters) from a reference point near the ordinary high water level (OHW) on the left bank. The side channel transducer was arbitrarily set to 95 m for graphical convenience.

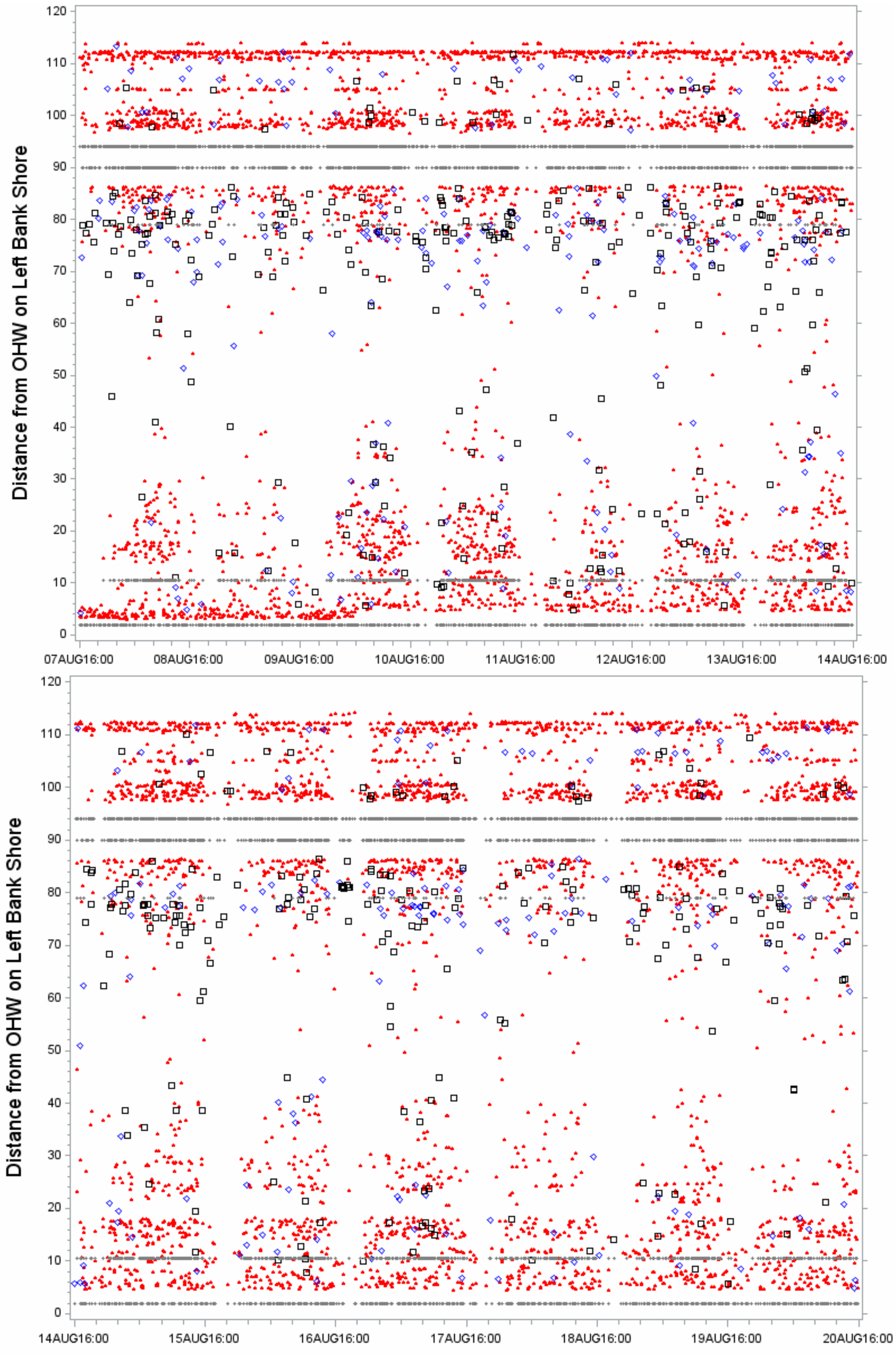
Appendix D6.–Spatial and temporal distribution of small (ARIS length [AL] < 75 cm; small red dots), medium (75 cm ≤ AL < 90 cm; larger blue diamonds), and large fish (AL ≥ 90 cm; large black squares), RM 13.7 Kenai River, 24 July–7 August 2016.





Note: Small fish can be underrepresented in the sample. Transducer locations are plotted as small grey crosses, one per fish. For the main channel, vertical axis is the distance (meters) from a reference point near the ordinary high water level (OHW) on the left bank. The side channel transducer was arbitrarily set to 95 m for graphical convenience

Appendix D7.–Spatial and temporal distribution of small (ARIS length [AL] < 75 cm; small red dots), medium (75 cm ≤ AL < 90 cm; larger blue diamonds), and large fish (AL ≥ 90 cm; large black squares), RM 13.7 Kenai River, 8–20 August 2015.



Note: Small fish can be underrepresented in the sample. Transducer locations are plotted as small grey crosses, one per fish. For the main channel, the vertical axis is distance (meters) from a reference point near the ordinary high water level (OHW) on the left bank. The side channel transducer was arbitrarily set to 95 m for graphical convenience.

APPENDIX E: DIRECTION OF TRAVEL OF MEDIUM AND LARGE FISH DETECTED BY ARIS, RM 13.7 KENAI RIVER, 2016

Appendix E1.–Daily count and proportion of fish greater than or equal to 75 cm ARIS length moving upstream and downstream for the early run, RM 13.7 Kenai River, 2016.

	Downstream		Upstream		Total number
Date	Number	Percent	Number	Percent	sampled
16 May	0	0%	2	100%	2
17 May	0	0%	3	100%	3
18 May	1	33%	2	67%	3
19 May	0	0%	2	100%	2
20 May	1	11%	8	89%	9
21 May	0	0%	5	100%	5
22 May	1	25%	3	75%	4
23 May	0	0%	11	100%	11
24 May	1	14%	6	86%	7
25 May	3	25%	9	75%	12
26 May	3	14%	18	86%	21
27 May	1	7%	14	93%	15
28 May	0	0%	40	100%	40
29 May	1	3%	28	97%	29
30 May	0	0%	26	100%	26
31 May	0	0%	36	100%	36
1 Jun	0	0%	23	100%	23
2 Jun	1	5%	21	95%	22
3 Jun	0	0%	30	100%	30
4 Jun	2	5%	39	95%	41
5 Jun	0	0%	21	100%	21
6 Jun	4	10%	38	90%	42
7 Jun	0	0%	54	100%	54
8 Jun	0	0%	35	100%	35
9 Jun	2	5%	35	95%	37
10 Jun	1	3%	29	97%	30
11 Jun	0	0%	40	100%	40
12 Jun	2	4%	47	96%	49
13 Jun	2	4%	49	96%	51
14 Jun	1	2%	47	98%	48
15 Jun	4	11%	32	89%	36
16 Jun	1	3%	31	97%	32
17 Jun	0	0%	20	100%	20
18 Jun	0	0%	22	100%	22
19 Jun	0	0%	15	100%	15
20 Jun	0	0%	13	100%	13
21 Jun	1	4%	22	96%	23
22 Jun	0	0%	14	100%	14
23 Jun	0	0%	22	100%	22
24 Jun	0	0%	26	100%	26
25 Jun	1	6%	16	94%	17
26 Jun	0	0%	17	100%	17
27 Jun	1	3%	28	97%	29
28 Jun	0	0%	21	100%	21
29 Jun	1	3%	36	97%	37
30 Jun	0	0%	22	100%	22
Total	36	3%	1,078	97%	1,114

Appendix E2.–Daily count and proportion of fish greater than or equal to 75 cm ARIS length moving upstream and downstream for the late run, RM 13.7 Kenai River, 2016.

	Downstream		Upstream		Total number
Date	Number	Percent	Number	Percent	sampled
1 Jul	0	0%	0	0%	0
2 Jul	0	0%	39	100%	39
3 Jul	2	3%	64	97%	66
4 Jul	4	9%	42	91%	46
5 Jul	1	3%	34	97%	35
6 Jul	9	13%	62	87%	71
7 Jul	2	5%	36	95%	38
8 Jul	1	3%	35	97%	36
9 Jul	2	4%	48	96%	50
10 Jul	3	6%	45	94%	48
11 Jul	3	4%	76	96%	79
12 Jul	8	8%	95	92%	103
13 Jul	9	6%	138	94%	147
14 Jul	9	8%	104	92%	113
15 Jul	5	5%	101	95%	106
16 Jul	1	1%	67	99%	68
17 Jul	1	2%	40	98%	41
18 Jul	7	9%	67	91%	74
19 Jul	13	12%	93	88%	106
20 Jul	10	12%	72	88%	82
21 Jul	12	17%	59	83%	71
22 Jul	11	14%	67	86%	78
23 Jul	2	2%	86	98%	88
24 Jul	4	5%	73	95%	77
25 Jul	13	13%	86	87%	99
26 Jul	6	7%	79	93%	85
27 Jul	20	20%	78	80%	98
28 Jul	11	10%	99	90%	110
29 Jul	5	5%	94	95%	99
30 Jul	7	7%	87	93%	94
31 Jul	6	7%	76	93%	82
1 Aug	10	17%	48	83%	58
2 Aug	12	17%	59	83%	71
3 Aug	14	25%	43	75%	57
4 Aug	18	21%	68	79%	86
5 Aug	14	15%	82	85%	96
6 Aug	19	18%	84	82%	103
7 Aug	11	17%	55	83%	66
8 Aug	17	18%	76	82%	93
9 Aug	15	20%	61	80%	76
10 Aug	24	26%	68	74%	92
11 Aug	23	21%	85	79%	108
12 Aug	47	42%	64	58%	111

-continued-

Appendix E2.–Page 2 of 2.

Date	Downstream		Upstream		Total number sampled
	Number	Percent	Number	Percent	
13 Aug	21	20%	84	80%	105
14 Aug	28	27%	76	73%	104
15 Aug	27	32%	57	68%	84
16 Aug	40	30%	92	70%	132
17 Aug	33	42%	46	58%	79
18 Aug	28	34%	55	66%	83
19 Aug	30	33%	62	67%	92
Total	636	15%	3,482	85%	4,118