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Chinook Salmon Passage in the Kenai River at River Mile 13.7 Using Adaptive Resolution Imaging Sonar, 2017–2019

by

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April 2023

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

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Weights and measures (metric)

centimeter	cm
deciliter	dL
gram	g
hectare	ha
kilogram	kg
kilometer	km
liter	L
meter	m
milliliter	mL
millimeter	mm

Weights and measures (English)

cubic feet per second	ft^3/s
foot	ft
gallon	gal
inch	in
mile	mi
nautical mile	nmi
ounce	oz
pound	lb
quart	qt
yard	yd

Time and temperature

day	d
degrees Celsius	°C
degrees Fahrenheit	°F
degrees kelvin	K
hour	h
minute	min
second	s

Physics and chemistry

all atomic symbols	
alternating current	AC
ampere	A
calorie	cal
direct current	DC
hertz	Hz
horsepower	hp
hydrogen ion activity (negative log of)	pH
parts per million	ppm
parts per thousand	ppt, ‰
volts	V
watts	W

General

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

Mathematics, statistics

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

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CHINOOK SALMON PASSAGE IN THE KENAI RIVER AT RIVER MILE 13.7 USING ADAPTIVE RESOLUTION IMAGING SONAR, 2017–2019

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ABSTRACT

Chinook salmon (*Oncorhynchus tshawytscha*) passage in the Kenai River was estimated from 2017 to 2019 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 each year by ARIS was estimated to be 7,238 (SE = 250), 3,000 (SE = 154), and 4,186 (SE = 160), respectively, during the 2017–2019 early runs (16 May–30 June); and 22,133 (SE = 452), 16,957 (SE = 410), and 11,870 (SE = 310), respectively, during the 2017–2019 late runs (1 July–20 August). Net upstream passage of all Chinook salmon regardless of size was estimated to be 9,696 (SE = 371), 5,390 (SE = 318), and 6,033 (SE = 285), respectively, during the 2017–2019 early runs; and 24,436 (SE = 423), 25,143 (SE = 654), and 18,093 (SE = 547), respectively, during the 2017–2019 late runs.

Keywords: 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 56.070 (*Kenai River and Kasilof River Early-Run King Salmon Conservation Management Plan*) and 5 AAC 21.359 (*Kenai River Late-Run King Salmon Management Plan*) and are intended to ensure sustainable Chinook salmon stocks. 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 river mile (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.[1] However, the RM 8.6 site had 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). One of the main advantages of the RM 13.7 site is the potential to achieve bank-to-bank coverage of the river with sonar, which was not possible at the RM 8.6 site (Figure 2). ADF&G operated a full-scale experimental project at the RM 13.7 site using ARIS during 17 May–17 August 2013 (Miller et al. 2016a) and again during 16 May–15 August 2014 while also continuing to operate the DIDSON at the RM 8.6 site (Miller et al. 2016b; Key et al. 2016b).

Estimates of Chinook salmon abundance require information on Chinook salmon size, which has been obtained historically from an inriver gillnetting program operated at RM 8.6 (Perschbacher 2012a, 2012b, 2012c, 2012d, 2014, 2015, 2018a; Perschbacher and Eskelin 2016). Historically, netting at RM 8.6 was restricted to a midriver corridor that approximately matched the cross-sectional area insonified by the DIDSON. In 2012, Chinook salmon sampled at the RM 8.6 netting project and at upstream tributary weirs differed in size, raising the possibility that Chinook salmon sampled midriver at RM 8.6 were not representative of the entire run. Auxiliary nearshore sonar deployments at RM 8.6 in 2011 and 2012 confirmed that some Chinook salmon were migrating between the DIDSON transducers and shore (Miller et al. 2014, 2015). In response, the netting program at RM 8.6 was expanded in 2013 to include experimental nearshore drifts (Perschbacher 2015).

In addition, following the 2012 season, a state space model (SSM) was fitted to sonar, netting, catch rate, and capture–recapture data; historical abundance was reconstructed; and sustainable escapement goals (3,800–8,500 fish for the early run[2]; and 15,000–30,000 fish for the late run) were recommended in preparation for the 2013 season (Fleischman and McKinley 2013; McKinley and Fleischman 2013). This modeling exercise, which synthesized information from all applicable data, estimated that the proportion of Chinook salmon migrating midriver (pMR) and detected by sonar and nets at RM 8.6 was 0.65 during the early run and 0.78 during the late run. In 2013 and 2014, to account for incomplete detection at RM 8.6 due to large tidal fluctuations, DIDSON estimates of inriver abundance were expanded by 1.55 (1/0.65) during the early run and 1.28 (1/0.78) during the late run and used inseason to assess achievement of the new escapement goals. Sonar operations were discontinued at the RM 8.6 site following the 2014 season in favor

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[1] See Key et al. (2016a) for a comprehensive history of sonar research and development at the Kenai River RM 8.6 site.

[2] For the early run, an optimal escapement goal of 5,300–9,000 was later adopted by the Alaska Board of Fisheries, superseding the sustainable escapement goal.

of abundance estimates produced at the RM 13.7 site where near bank-to-bank coverage eliminates uncertainty resulting from spatial expansions of passage estimates.

Estimates of small Chinook salmon are produced by mixture model analysis that requires fish size data from nets drifted at the RM 8.6 site, and such estimates can be sensitive to details of how the netting data are used (Miller et al. 2016b). In 2015, inseason estimates used for managing the fishery required substantial postseason revisions, largely because inseason procedures adopted to accommodate sparse netting data proved biased under some circumstances (Key et al. 2017).

Beginning in 2017, Chinook salmon stock assessment and management were based on direct sonar counts of fish 75 cm or longer as measured by ARIS length (AL) at the RM 13.7 site. Fish 75 cm AL or longer (equivalent to 75 cm or longer mid eye to tail fork [METF]) are composed almost entirely of Chinook salmon. Based on a spawner–recruit analysis conducted by Fleischman and Reimer (2017), ADF&G recommended sustainable escapement goals (SEGs) of 2,800–5,600 Kenai River early-run Chinook salmon and 13,500–27,000 Kenai River late-run Chinook salmon 75 cm METF and longer. In 2017, the early run SEG was superseded by an optimal escapement goal of 3,900–6,600 Chinook salmon 75 cm METF and longer, as established by the BOF. From 2017 to 2019, the RM 13.7 project operated from 16 May through 20 August. Abundance estimates of all Chinook salmon (regardless of size) were generated postseason using mixture model analyses that combined RM 13.7 sonar data and RM 8.6 netting data. This report documents data collection methods, analyses, and results from sonar operations at RM 13.7 from 2017 to 2019.

OBJECTIVES

PRIMARY OBJECTIVE

Produce daily inseason net upstream passage estimates of fish 75 cm or longer (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 will be based solely on ARIS fish-length measurements.

SECONDARY OBJECTIVE

Produce postseason net upstream passage estimates of Chinook salmon, regardless of size, at RM 13.7 of the Kenai River such that early- and late-run estimates are within 15% of the true value 95% of the time. These estimates will be based on fitting a mixture model to ARIS fish-length measurements and RM 8.6 netting data (midriver and nearshore drifts; see Wood and Eskelin *In prep*).

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.[3]

SITE DESCRIPTION

The sonar site is located 22 km (13.7 RM) 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) ARIS systems. Daily abundance estimates were generated from 16 May through 20 August of each year. 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 levels were low, 1 sonar on each bank was sufficient to insonify most of the 60–70 m river cross-section in the main channel (Tables 2–4), 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 between 21 May (2019) and 29 May (2018) on the left bank and between 27 May (2019) and 6 June (2017) on the right bank (Tables 2–4) and were subsequently 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 each year when the project began in mid-May but had sufficient water for fish passage by the time the sonar was deployed the second or third week of June (Tables 2–4). This channel was approximately 30 m

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

wide at high water and was covered by a single sonar combined with a fixed weir, both deployed on the left bank[4] 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; this sonar model is more advantageous for covering close-range targets and nearshore areas because it operates at a higher frequency and uses 96 beams, 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 as 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 software interface "ARIScope." At the start of each season, 2 sonars were deployed on the mainstem, each sampling 3 strata. Tables 2–4 summarize the range coverage by each range stratum along with the changes in range parameters throughout the respective seasons as the water level rose and aims were refined. When all 5 sonars were deployed, a total of 11 strata were sampled (8 on the main channel and 3 on the minor channel), each with a unique set of data

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

collection parameters (Table 5 and Figure 9). A systematic sampling design (Cochran 1977) was used to sample each stratum for 10 minutes each hour following the time schedule presented in Table 5. Backup sets collected in case of malfunction, were used only when the primary set was unavailable. Only 1 sample was processed per stratum per hour. This routine was followed 24 hours per day 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).

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 5 and 6, Appendix A1). 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 5).

Frame Rate

The maximum allowable frame rate was used for each stratum (Table 5). 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) to begin each season. Two factors typically necessitated sampling the last stratum of the right bank offshore sonar using low frequency. First, colder water temperatures (as low as 7°C) early in the season 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 when periodic transmission loss occurred. This usually happened in years with exceptional levels of visible pollen. 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 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 µs, 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 decibels (dB).

MANUAL ARIS FISH LENGTH MEASUREMENTS

Measurements of fish length were obtained using ARISFish software supplied by SMC (V2.5.7 in 2017, V2.6.2 in 2018, and V2.6.3 in 2019). Detailed instructions for taking manual measurements and the software settings and parameters that were used for this project are explained in

Appendices B1–B3. 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.

For 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." AL measurements are taken from what appear to be the head and tail ends of the image (e.g., Appendix A10). Miller et al. (2016) found AL measurements to be approximately equivalent to mid eye to tail fork (METF) measurements.

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* (usually 5 fish) 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 (Wood and Eskelin *In prep*) 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 of criteria **X** 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

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

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.

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:

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

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[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).

where

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

ϕ_{ij} = 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 (Wood and Eskelin *In prep*) as described in Appendices C1–C6.

The variance estimate followed Goodman (1960):

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

For the first few days of each season (16–23 May in 2017; 16–26 May in 2018; and 16–24 May in 2019), a pooled estimate of π_C was calculated because daily sample sizes from the netting were too small to produce reliable estimates.

For consistency with the inriver gillnetting data, most of which come from drift nets that presumably capture only upstream-bound fish, only ARIS upstream data were used along with the midriver and nearshore netting data from RM 8.6 to estimate Chinook salmon passage.

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[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 to estimate z_i and N_i but have no biological interpretation themselves. Estimates of z_i and N_i remain valid.

Daily net upstream Chinook salmon passage was approximated as

$$\widehat{N}_i \approx \hat{z}_i \frac{u_i - d_i}{u_i} \tag{10}$$

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

DATA COLLECTION

Data collection began each year on 16 May in the main channel offshore strata. The start of data collection in the main channel left-bank nearshore stratum varied from as early as 21 May in 2019 to as late as 29 May in 2018. The main channel right bank nearshore stratum start date varied from 27 May in 2019 to 6 June in 2017, and the start date in the minor channel stratum varied from 8 June in 2019 to 17 June in 2018 (Tables 2–4). All sampling ended after 20 August each year as scheduled.

Size Distribution and Species Composition

Small fish (presumably sockeye salmon) predominated in both early and late runs during each year, as evidenced by large left-hand modes in the ARIS length (AL) frequency distributions (Figures 12–14, top panels). The modes of the AL distributions line up well[7] with METF length distributions from salmon measured by the inriver netting project (Figures 12–14, 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).

Non-Chinook salmon captured in the inriver gillnets rarely exceeded 65–70 cm METF (Figures 12–14, bottom panels). From inspection of AL frequency distributions (Figures 12–14, 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 (Figures 12–14, top panels) that is more prominent on the right bank and in the offshore strata during both runs (Figures 12–14, middle panels). This mode was also observed during the 2013–2016 early runs and was attributed to resident fish (e.g., rainbow trout [*O. mykiss*] and Dolly Varden [*Salvelinus malma*], both of which are regularly caught in the netting program; Eric Wood, Fishery Biologist for RM 8.6 netting, ADF&G, Soldotna, personal communication) rather than sockeye salmon.

Spatial and Temporal Distribution of Upstream Migration

Figures showing spatial and temporal patterns of migration for medium (75 cm ≤ AL < 90 cm) and large (AL ≥90 cm) fish were produced for upstream-bound fish for all 3 years (Appendices D1–D9). Small (40 cm ≤ AL < 75 cm) fish that were measured are also displayed, although they are underrepresented, especially during the late run.

During both the early and late runs for all 3 years, greater percentages of upstream-bound medium and large (AL ≥75 cm) fish migrated past the sonar site on the right bank of the main channel, and

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[7] 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.

especially in the right bank versus the left bank nearshore strata (Tables 7–9, Figures 15–17). Small percentages of early- and late-run upstream-bound medium and large (AL ≥75 cm) fish (0–5% during the early run, 2–10% during the late run) were found migrating in the minor channel. Year-to-year variation in the percentage of medium and large fish that migrate upriver through the minor channel is probably related to the annual variation in water level, with higher water levels making the shallow minor channel more conducive to fish passage.

When upstream-bound medium and large fish were classified as day (sunrise to sunset) versus night (sunset to sunrise) migrators, percentages of fish passing at night were lower than day for all 3 years (Tables 7–9). The relative ratio of day to night early-run migrators ranged from 81:19 in 2017 to 89:11 in 2019; and for late run migrators, the relative ratio ranged from 75:25 in 2018 to 82:18 in 2019 (Tables 7–9). Furthermore, when the relatively shorter length of night versus day was considered, the proportion migrating at night was still disproportionately small compared to the relative length of night (Figures 18–20) throughout most of the early and late runs.

Direction of Travel by Size Category

The percentage of downstream traveling fish in each size category (small, medium, and large) was determined for run and spatial location. In general, a greater percentage of early-run medium and large fish traveled downstream than small fish, although this could not be determined for the late run (Tables 10–12). For the medium and large fish (AL ≥75 cm) category, a greater fraction traveled downstream each year (2017–2019) during the late run (11%, 15%, and 11%, respectively) than during the early run (9%, 12%, and 3%; Tables 10–12). Each year during the late run, relatively more medium and large fish migrated downstream in the minor channel (32%, 24%, 17%, respectively) than in the left (10%, 16%, and 6%) or right (11%, 14%, and 11%) banks of the main channel.

Daily percentages of medium and large fish (AL ≥75 cm) that were traveling upstream versus downstream were also tabulated (Appendices E1–E6).

CHINOOK SALMON PASSAGE

Daily proportions of upstream-bound fish that were Chinook salmon (regardless of size) were estimated for each year 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 for 2017–2019: 9,696 (SE = 371), 5,390 (SE = 318), and 6,033 (SE = 285), respectively, during the early run (16 May–30 June; Table 13) and 24,436 (SE = 423), 25,143 (SE = 654), and 18,093 (SE = 547), respectively, during the late run (1 July–20 August; Table 14).

The AL mixture model also produced daily estimates of early and late run Chinook salmon age group composition for each year (Tables 15–16) and daily net passage estimates by year (Figures 21–23). These estimates incorporate length information from ARIS as well as from inriver gillnet catches.

Median early-run Chinook salmon passage (fish of all sizes) occurred on 10 June in 2017, 12 June in 2018, and 11 June in 2019 (Table 17, Figures 21–23). The average all-size early-run median passage date for 2013–2019 is 11 June. Median late-run passage for Chinook salmon of all sizes occurred on 26 July in 2017, 25 July in 2018, and 20 July in 2019 (Table 17 and Figures 21–23).

MEDIUM AND LARGE FISH PASSAGE

Daily net upstream passage of medium (75 cm ≤ AL < 90 cm) and large (AL ≥90 cm) fish was estimated directly by the ARIS sonar. Estimated early-run (16 May–30 June) passage of fish ≥75 cm AL was 7,238 (SE = 250), 3,000 (SE = 154), and 4,186 (SE = 160) for 2017–2019, respectively (Table 18). Over the 3 years of this study, estimates of medium fish passage were between 1,796 (2018) and 3,825 (2017) and estimates of large fish passage were between 993 (2019) and 3,413 (2017) for the early runs (Table 18). Estimated late-run (1 July–20 August) passage of fish ≥75 cm AL was 22,133 (SE = 452), 16,957 (SE = 410), and 11,870 (SE = 310) for 2017–2019, respectively (Table 19). Over the 3 years of the study, estimates of medium fish passage were between 5,926 (2018) and 8,589 (2017) and estimates of large fish passage were between 5,100 (2019) and 13,544 (2017) for the late runs (Table 19).

Assuming all medium and large fish (≥75 cm AL) are Chinook salmon, median passage of Chinook salmon ≥75 cm AL during the early run occurred on 10 June for each year in 2017–2019 (Table 17; Figures 21–23). Median passage of Chinook salmon ≥75 cm AL during the late run occurred on 26, 28, and 21 July for each year during 2017–2019, respectively.

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. Early run (16 May–30 June) passage of Chinook salmon <75 cm AL was 2,458 (SE = 447), 2,390 (SE = 354), and 1,847 (SE = 327) for 2017–2019, respectively (Table 13). Late run (1 July–20 August) passage of Chinook salmon <75 cm AL was 2,303 (SE = 619), 8,186 (SE = 772), and 6,223 (SE = 629), respectively (Table 14).

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

The 2017 early-run net upstream passage estimate of medium and large Chinook salmon (≥75 cm; 7,238) was the highest recorded since data collection began at the RM 13.7 site in 2013 and was substantially larger than the 2013–2019 average of 4,164 fish (Table 20). When considered for all Chinook salmon regardless of size, the 2017 early-run estimate (9,696 fish) was the second highest recorded at the RM 13.7 site and was well above the 2013–2019 average of 6,702 fish (Table 20). The small Chinook salmon (AL ≤75 cm) passage estimate for 2017 (2,458 fish) was similar to the 2013–2019 average (2,538 fish).

The 2017 late-run net upstream passage estimate of medium and large Chinook salmon (22,133) was also the highest recorded since 2013 and was much larger than the 2013–2019 average of 15,647 (Table 20). However, this estimate for all Chinook salmon regardless of size (24,436) was not one of the highest on record, although it was above average (22,196). The 2017 late-run small Chinook salmon passage estimate (2,303 fish) was far below the 2013–2019 average of 6,536 fish and was the lowest late-run small Chinook salmon estimate observed since operations began at the RM 13.7 site in 2013.

The 2018 early-run passage estimates of medium and large Chinook salmon (3,000) and all Chinook salmon (5,390) were both less than their respective 2013–2019 averages by over 1,000 fish (Table 20). However, the small Chinook salmon (AL ≤75 cm) passage estimate from the 2018 early run (2,390) was quite close to the 2013–2019 average of 2,538 fish. The 2018 late-run passage estimates for medium and large Chinook salmon (16,957), all Chinook salmon (25,143), and small Chinook salmon (8,186) were all above their respective 2013–2019 averages (Table 20).

The 2019 early-run passage estimates for medium and large Chinook salmon (4,186) and all Chinook salmon (6,033) were both close to their respective 2013–2019 averages of 4,164 and 6,702 (Table 20). However, the small Chinook salmon (AL ≤75 cm) passage estimate the 2019 early run (1,847) was below the 2,538 fish average (Table 20). The 2019 late-run passage estimates for medium and large Chinook salmon (11,870) and all Chinook salmon (18,093) were both well below average and each was the second lowest passage observed since 2013 (Table 20). However, the 2019 estimate of late-run small Chinook salmon (6,223) was close to the average of 6,536 fish (Table 20).

Median early-run passage dates for medium and large Chinook salmon occurred on 10 June for each year in 2017–2019, which coincides exactly with the 2013–2019 average, and differs by only 1 day for the all-size Chinook salmon average (11 June) for the early run (Table 17). Median late-run passage dates for medium and large Chinook salmon occurred on 26, 28, and 21 July for each year during 2017–2019, respectively, encompassing the 2013–2019 late run mean of 26 July. The average late-run median passage date of medium and large Chinook salmon was 3 days later than the average date of median passage of all Chinook salmon regardless of size (23 July; Table 17).

Ratios of day to night migrators were fairly consistent across years from 2017 to 2019, ranging from about 4–8 times as many day migrators in the early run and about 3–5 times as many in the late run. These ratios are similar to those observed during past years (Miller et al. 2015; Miller et al. 2016a; Miller et al. 2016b; Key et al. 2017; Key et al. 2019).

Based on plots of daily net upstream Chinook salmon passage for ALMM estimates versus AL estimates of Chinook salmon ≥75 cm, the late run was made up of much smaller proportions of small Chinook salmon than the early run in 2017 (ALMM estimates nearly equal to AL ≥75 cm estimates; Figure 24), but in 2018 and 2019, both runs had substantial proportions of small fish (ALMM estimates larger than AL ≥75 estimates; Figures 25–26).

The daily ALMM RM 13.7 passage estimates of all-size Chinook salmon for 2017–2019 did not track closely with daily river conditions (discharge and visibility) or other measures of abundance (i.e., inriver gillnetting at RM 8.6 and sport fishery CPUE), although sockeye salmon abundance often tracked ALMM estimates in the late run, indicating their overlap in run timing (Figures 24–26).

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TABLES

Table 1.–On-site components of the ARIS systems used during 2017–2019.

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, 2017.

Sonar location	Range stratum	Time (min)[a]	Coverage range (m) by date								
			16 May	24 May	6 June	13 June	14 Jun[b]	27 Jun[b]	11 Jul[b]	3 Aug[b]	19 Aug[b]
Left nearshore	1	:00 / :30	[c]	2.5–9.0	2.5–9.0	2.5–9.0	3.5–13.0	3.5–14.0	3.5–15.5	3.5–15.5	3.5–14.5
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	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	8.0–22.0
	3	:20 / :50	22.0–33.0	22.0–33.0	22.0–33.0	22.0–33.0	22.0–33.0	22.0–33.0	22.0–33.0	22.0–33.0	22.0–33.0
Right offshore	1	:00 / :30	3.5–8.0	3.5–8.0	[d]	[d]	[d]	[d]	[d]	[d]	[d]
	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	6.0–22.0	6.0–22.0
	3	:20	22.0–33.0	22.0–33.0	22.0–33.0	22.0–33.0	22.0–33.0	22.0–33.0	22.0–33.0	22.0–33.0	22.0–33.0
Right nearshore	1	:40	[e]	[e]	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	:50	[e]	[e]	8.0–14.5	8.0–14.5	8.0–17.0	8.0–18.0	8.0–21.0	8.0–21.0	8.0–20.0
Minor channel	1	:00	[f]	[f]	[f]	2.8–6.0	2.8–6.0	2.8–6.0	2.8–6.0	2.8–6.0	2.8–6.0
	2	:10	[f]	[f]	[f]	6.0–12.0	6.0–12.0	6.0–12.0	6.0–12.0	6.0–12.0	6.0–12.0
	3	:30	[f]	[f]	[f]	12.0–20.0	12.0–20.0	12.0–20.0	12.0–20.0	12.0–20.0	12.0–20.0

[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] Nearshore sonars were moved to accommodate fluctuating water levels, resulting in changes to range.

[c] Sonar was not deployed in this stratum until 24 May.

[d] Beginning 6 June, right offshore Stratum 1 was covered by right nearshore Stratum 2.

[e] Sonar was not deployed in this stratum until 6 June.

[f] Sonar was not deployed in this stratum until 13 June.

Table 3.–Summary of sonar stratum range changes by date at RM 13.7 Kenai River, 2018.

Sonar location	Range stratum	Time (min)[a]	Coverage range (m) by date							
			16 May	29 May	31 May	5 Jun	12 Jun[b]	17 Jun	19 Jun[b]	10 Jul[b]
Left nearshore	1	:00 / :30	[c]	3.5–9.5	3.5–9.5	3.5–9.5	3.5–11.5	3.5–11.5	3.5–15.5	3.5–15.5
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	22.0–33.0	22.0–33.0	22.0–33.0	22.0–33.0	22.0–33.0	22.0–33.0	22.0–33.0	22.0–33.0
Right offshore	1	:00 / :30	3.8–8.0	3.8–8.0	3.5-8.0	[d]	[d]	[d]	[d]	[d]
	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	6.0–22.0
	3	:20	22.0–33.0	22.0–33.0	22.0–33.0	22.0–33.0	22.0–33.0	22.0–33.0	22.0–33.0	22.0–33.0
Right nearshore	1	:40	[e]	[e]	[e]	3.8–8.0	3.5–8.0	3.5–8.0	3.5–8.0	3.5–8.0
	2	:50	[e]	[e]	[e]	8.0–14.4	8.0–16.0	8.0–16.0	8.0–21.5	8.0–22.8
Minor channel	1	:00	[f]	[f]	[f]	[f]	[f]	2.5–6.0	2.5–6.0	2.8–6.0
	2	:10	[f]	[f]	[f]	[f]	[f]	6.0–12.0	6.0–12.0	6.0–12.0
	3	:30	[f]	[f]	[f]	[f]	[f]	12.0–20.0	12.0–20.0	12.0–20.0

[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] Nearshore sonars were moved to accommodate fluctuating water levels, resulting in changes to range.

[c] Sonar was not deployed in this stratum until 29 May.

[d] Beginning 5 June, right offshore Stratum 1 was covered by right nearshore Stratum 2.

[e] Sonar was not deployed in this stratum until 5 June.

[f] Sonar was not deployed in this stratum until 17 June.

Table 4.–Summary of sonar stratum range changes by date at RM 13.7 Kenai River, 2019.

Sonar location	Range stratum	Time (min)[a]	Coverage range (m) by date										
			16 May	21 May	27 May	3 June[b]	6 Jun[b]	8 Jun	12 Jun[b]	25 Jun[b]	2 Jul[b]	9 Jul[b]	29 Jul[b]
Left nearshore	1	:00 / :30	[c]	2.5–9.2	2.5–9.2	2.5–11.1	2.5–11.1	2.5–11.1	2.5–12.8	2.5–14.5	2.5–14.5	2.5–16.0	2.5–15.0
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	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	8.0–22.0	8.0–22.0	8.0–22.0
	3	:20 / :50	22.0–33.0	22.0–33.0	22.0–33.0	22.0–33.0	22.0–33.0	22.0–33.0	22.0–33.0	22.0–33.0	22.0–33.0	22.0–33.0	22.0–33.0
Right offshore	1	:00 / :30	3.8–8.0	3.8–8.0	[e]	[e]	[e]	[e]	[e]	[d]	[d]	[d]	[d]
	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	8.0–22.0	8.0–22.0	8.0–22.0
	3	:20	22.0–33.0	22.0–33.0	22.0–33.0	22.0–33.0	22.0–33.0	22.0–33.0	22.0–33.0	22.0–33.0	22.0–33.0	22.0–33.0	22.0–33.0
Right nearshore	1	:40	[d]	[d]	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	3.5–8.0
	2	:50	[d]	[d]	8.0-15.0	8.0–15.0	8.0–18.0	8.0–18.0	8.0–18.0	8.0–21.5	8.0–24.5	8.0–24.5	8.0–24.5
Minor channel	1	:00	[f]	[f]	[f]	[f]	[f]	2.8–6.0	2.8–6.0	2.8–6.0	2.8–6.0	2.8–6.0	2.8–6.0
	2	:10	[f]	[f]	[f]	[f]	[f]	6.0–12.0	6.0–12.0	6.0–12.0	6.0–12.0	6.0–12.0	6.0–12.0
	3	:30	[f]	[f]	[f]	[f]	[f]	12.0–20.0	12.0–20.0	12.0–20.0	12.0–20.0	12.0–20.0	12.0–20.0

[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] Nearshore sonars were moved to accommodate fluctuating water levels, resulting in changes to range.

[c] Sonar was not deployed in this stratum until 21 May.

[d] Sonar was not deployed in this stratum until 27 May.

[e] Beginning 27 May, right offshore Stratum 1 was covered by right nearshore Stratum 2.

[f] Sonar was not deployed in this stratum until 8 June.

Table 5.–Example of a sampling schedule and parameter values (taken from 1 August 2017) for each range stratum sampled by 5 ARIS systems.

Sonar location	ARIS serial	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) [c]	Samples per beam	Pitch (°)	Heading (°)
Left nearshore	1096	1	:00 / :30	8.0	3.5	15.5	High (1.8)	Max	16	22	4,850	10	1,645	–6.2	181
Left offshore	1064	1	:00 / :30	9.0	3.5	8	High (1.2)	Max	2	13	4,834	10	621	–7.0	62
		2	:10 / :40	9.0	8	22	High (1.2)	Max	10	22	11,051	10	1,934	–4.4	62
		3	:20 / :50	7.0	22	33	High (1.2)	Max	16	33	30,390	10	1,522	–1.2	62
Right offshore	1063	1	[d]	[d]	[d]	[d]	[d]	[d]	[d]	[d]	[d]	[d]	[d]	[d]	[d]
		2	:00/:20	8.0	8	22	High (1.2)	Max	12	21	10,920	10	1,911	–1.2	20
		3	:10/:30	6.8	22	33	High (1.2)	Max	12	33	30,031	10	1,502	–0.8	20
Right nearshore	1098	1	:40	9.0	3.5	8	High (1.2)	Max	2	13	4,810	10	619	–4.2	223
		2	:50	9.0	8	21	High (1.2)	Max	9	22	10,996	10	1,787	–4.0	223
Minor channel	1095	1	:00	8.0	2.8	6	High (1.2)	Max	9	13	3,431	10	479	–8.2	10
		2	:10	8.0	6	12	High (1.2)	Max	12	13	8,247	10	825	–2.7	10
		3	:30	8.0	12	20	High (1.2)	Max	12	19	16,494	10	1,100	2.8	10

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

[d] Normal data collection in right-bank offshore Stratum 1 occurred until the third or fourth week of May, after which increased water level allowed the right bank inshore sonar to be deployed 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).

Table 6.–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 7.–Spatial and temporal distribution (percent of total upstream bound) of medium and large fish (ARIS length ≥75 cm) by riverbank, transducer, and time (day or night) at RM 13.7 for the Kenai River early and late runs, 2017.

		Transducer location				Channel location			All strata (%)
		Main channel left bank		Main channel right bank		Main channel		Minor channel (%)	
Run	Time	Nearshore (%)	Offshore (%)	Offshore (%)	Nearshore (%)	Left bank (%)	Right bank (%)		
Early									
	Day	3	34	33	12	37	45	0	81
	Night	1	6	10	2	6	12	0	19
	Both	4	39	43	14	43	57	0	100
Late									
	Day	3	22	21	30	25	50	2	77
	Night	2	6	6	9	8	15	1	23
	Both	5	28	27	39	33	65	2	100

Note: Columns may not sum due to rounding.

Table 8.–Spatial and temporal distribution (percent of total upstream bound) of medium and large fish (ARIS length ≥75 cm) by riverbank, transducer, and time (day or night) at RM 13.7 for the Kenai River early and late runs, 2018.

		Transducer location				Channel location			All strata (%)
		Main channel left bank		Main channel right bank		Main channel		Minor channel (%)	
Run	Time	Nearshore (%)	Offshore (%)	Offshore (%)	Nearshore (%)	Left bank (%)	Right bank (%)		
Early									
	Day	4	34	25	15	38	40	4	82
	Night	1	6	8	3	7	11	0	18
	Both	5	40	32	18	45	50	5	100
Late									
	Day	2	28	20	24	29	43	2	75
	Night	1	7	6	8	8	15	2	25
	Both	3	35	26	32	38	58	4	100

Note: Columns may not sum due to rounding

Table 9.–Spatial and temporal distribution (percent of total upstream bound) of medium and large fish (ARIS length ≥75 cm) by riverbank, transducer, and time (day or night) at RM 13.7 for the Kenai River early and late runs, 2019.

		Transducer location				Channel location			All strata (%)
		Main channel left bank		Main channel right bank		Main channel		Minor channel (%)	
Run	Time	Nearshore (%)	Offshore (%)	Offshore (%)	Nearshore (%)	Left bank (%)	Right bank (%)		
Early									
	Day	9	17	23	37	26	60	3	89
	Night	1	2	4	5	3	9	0	11
	Both	10	19	26	42	29	68	3	100
Late									
	Day	4	13	14	43	17	57	8	82
	Night	1	2	4	10	3	13	2	19
	Both	5	15	18	52	20	70	10	100

Note: Columns may not sum due to rounding

Table 10.–Percentage of all fish (upstream and downstream) of a particular size category migrating downstream by riverbank and transducer at RM 13.7 for the 2017 Kenai River early and late runs.

		Transducer location				Channel location			All strata (%)
		Main channel left bank		Main channel right bank		Main channel		Minor channel (%)	
Run	Fish size[a]	Nearshore (%)	Offshore (%)	Offshore (%)	Nearshore (%)	Left bank (%)	Right bank (%)		
Early									
	Small	2	2	4	1	2	2	9	2
	Medium	6	9	10	6	8	9	0	9
	Large	11	11	10	3	11	9	0	10
	Med and large	8	10	10	5	10	9	0	9
Late									
	Small	[b]	[b]	[b]	[b]	[b]	[b]	[b]	[b]
	Medium	14	10	13	10	10	11	28	12
	Large	16	8	11	10	10	10	38	11
	Med and large	15	9	12	10	10	11	32	11

[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 were not tabulated for the late run.

Table 11.–Percentage of all fish (upstream and downstream) of a particular size category migrating downstream by riverbank and transducer at RM 13.7 for the 2018 Kenai River early and late runs.

		Transducer location				Channel location			
		Main channel left bank		Main channel right bank		Main channel			All strata (%)
Run	Fish size[a]	Nearshore (%)	Offshore (%)	Offshore (%)	Nearshore (%)	Left bank (%)	Right bank (%)	Minor channel (%)	
Early									
	Small	1	8	6	1	3	3	4	3
	Medium	8	12	11	0	11	8	14	10
	Large	13	21	9	8	21	8	18	15
	Med and large	9	17	10	4	16	8	16	12
Late									
	Small	[b]	[b]	[b]	[b]	[b]	[b]	[b]	[b]
	Medium	21	11	20	11	12	15	26	14
	Large	26	17	17	11	18	14	23	16
	Med and large	24	15	18	11	16	14	24	15

[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 were not tabulated for the late run.

Table 12.–Percentage of all fish (upstream and downstream) of a particular size category migrating downstream by riverbank and transducer at RM 13.7 for the 2019 Kenai River early and late runs.

		Transducer location				Channel location			
		Main channel left bank		Main channel right bank		Main channel			All strata (%)
Run	Fish size[a]	Nearshore (%)	Offshore (%)	Offshore (%)	Nearshore (%)	Left bank (%)	Right bank (%)	Minor channel (%)	
Early									
	Small	1	5	3	1	2	1	5	2
	Medium	2	0	3	0	1	1	15	2
	Large	0	12	5	0	10	3	33	6
	Med and large	1	4	4	0	3	2	17	3
Late									
	Small	[b]	[b]	[b]	[b]	[b]	[b]	[b]	[b]
	Medium	10	7	19	11	8	13	14	12
	Large	2	5	12	7	4	9	27	9
	Med and large	7	6	15	10	6	11	17	11

[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 were not tabulated for the late run.

Table 13.–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 2017–2019.

	2017						2018						2019					
	ALMM all sizes			ALMM <75 cm AL			ALMM all sizes			ALMM <75 cm AL			ALMM all sizes			ALMM <75 cm AL		
Date	Psg.	SE	CV	Psg.	SE	CV	Psg.	SE	CV	Psg.	SE	CV	Psg.	SE	CV	Psg.	SE	CV
16 May	28	6	0.22	22	7	0.34	12	4	0.32	12	4	0.32	2	1	0.47	2	1	0.47
17 May	30	6	0.22	0	13	NA	28	10	0.35	28	10	0.35	1	1	0.70	1	1	0.70
18 May	28	5	0.19	–2	14	7.20	13	5	0.42	–5	11	2.27	3	1	0.44	3	1	0.44
19 May	27	5	0.20	–15	19	1.25	11	4	0.34	–13	16	1.21	4	2	0.40	–2	6	3.10
20 May	33	8	0.25	–3	16	5.26	7	2	0.35	1	6	6.49	0	0	NA	6	4	0.67
21 May	15	4	0.25	9	16	1.75	8	3	0.34	–10	9	0.94	14	4	0.32	–4	11	2.74
22 May	35	12	0.35	17	16	0.93	18	5	0.28	–12	14	1.16	17	5	0.31	11	8	0.72
23 May	75	18	0.24	–16	29	18.00	20	7	0.33	–22	23	18.00	28	8	0.30	4	14	18.00
24 May	85	29	0.34	25	32	1.28	41	12	0.30	5	22	4.37	29	8	0.28	–7	16	-2.35
25 May	144	43	0.30	41	51	1.25	45	13	0.29	33	15	0.46	50	21	0.43	14	30	2.14
26 May	180	45	0.25	50	67	1.33	30	8	0.27	24	15	0.62	43	20	0.47	7	28	3.96
27 May	122	35	0.29	24	53	2.20	45	26	0.58	–4	41	10.20	58	25	0.44	11	29	2.68
28 May	120	34	0.29	29	47	1.63	59	17	0.29	10	34	3.35	100	36	0.36	20	43	2.13
29 May	183	43	0.24	32	60	1.88	83	27	0.32	35	49	1.39	86	35	0.41	26	41	1.60
30 May	248	69	0.28	49	85	1.73	120	37	0.30	41	47	1.15	84	28	0.33	18	35	1.94
31 May	199	51	0.26	30	82	2.73	90	29	0.33	29	37	1.28	61	26	0.42	13	30	2.33
1 Jun	268	74	0.28	33	84	2.50	168	49	0.29	59	58	1.00	187	57	0.31	60	66	1.10
2 Jun	332	66	0.20	60	78	1.30	173	47	0.27	58	58	1.00	141	44	0.31	26	49	1.88
3 Jun	447	79	0.18	79	99	1.26	162	48	0.30	59	54	0.92	260	57	0.22	61	67	1.10
4 Jun	258	67	0.26	58	77	1.32	209	58	0.28	82	63	0.76	242	58	0.24	66	66	1.00
5 Jun	372	75	0.20	87	87	1.00	232	78	0.34	123	82	0.67	320	67	0.21	90	74	0.83
6 Jun	346	69	0.20	145	79	0.54	172	48	0.28	52	56	1.09	283	57	0.20	63	67	1.06
7 Jun	350	80	0.23	143	86	0.60	190	51	0.27	69	64	0.93	174	43	0.25	37	47	1.27
8 Jun	355	64	0.18	84	80	0.95	145	39	0.27	42	45	1.08	191	45	0.23	34	53	1.57
9 Jun	217	49	0.23	42	60	1.43	164	42	0.26	61	52	0.86	219	50	0.23	56	56	0.99
10 Jun	348	64	0.18	95	85	0.89	172	46	0.27	51	53	1.04	197	45	0.23	52	49	0.94
11 Jun	388	79	0.20	104	88	0.84	173	43	0.25	40	50	1.24	289	65	0.22	83	74	0.89
12 Jun	396	79	0.20	124	93	0.75	125	44	0.35	47	48	1.02	180	56	0.31	59	60	1.02
13 Jun	465	95	0.20	158	106	0.67	130	47	0.36	58	54	0.92	364	76	0.21	146	92	0.63

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Table 13.–Page 2 of 2.

	2017						2018						2019					
	ALMM all sizes			ALMM <75 cm AL			ALMM all sizes			ALMM <75 cm AL			ALMM all sizes			ALMM <75 cm AL		
Date	Psg.	SE	CV	Psg.	SE	CV	Psg.	SE	CV	Psg.	SE	CV	Psg.	SE	CV	Psg.	SE	CV
14 Jun	529	108	0.21	155	117	0.75	200	58	0.29	79	64	0.81	150	42	0.28	47	47	1.01
15 Jun	479	90	0.19	165	111	0.67	174	57	0.33	89	60	0.68	217	67	0.31	90	71	0.79
16 Jun	321	74	0.23	128	91	0.71	37	17	0.45	19	22	1.18	63	28	0.45	20	33	1.65
17 Jun	315	72	0.23	122	78	0.64	135	52	0.39	69	54	0.79	106	42	0.39	39	45	1.16
18 Jun	325	60	0.18	66	70	1.06	171	64	0.38	110	67	0.61	117	39	0.33	43	43	0.99
19 Jun	153	38	0.25	32	55	1.72	141	102	0.72	117	103	0.88	145	45	0.31	54	52	0.97
20 Jun	106	42	0.40	40	49	1.24	197	87	0.44	138	90	0.65	205	54	0.26	58	62	1.06
21 Jun	235	67	0.29	102	73	0.72	102	33	0.33	41	41	0.99	95	35	0.37	28	38	1.37
22 Jun	116	33	0.28	26	41	1.58	113	42	0.37	53	47	0.89	122	45	0.37	49	50	1.03
23 Jun	115	29	0.25	24	49	2.05	321	114	0.35	274	115	0.42	135	43	0.32	44	49	1.11
24 Jun	104	30	0.29	20	39	1.93	102	43	0.43	54	47	0.86	166	51	0.31	63	57	0.90
25 Jun	126	34	0.27	12	40	3.32	181	74	0.41	109	76	0.70	201	58	0.29	83	68	0.82
26 Jun	188	39	0.21	19	46	2.44	97	39	0.40	43	43	1.00	155	40	0.26	52	48	0.93
27 Jun	129	33	0.26	2	44	21.88	116	38	0.32	50	43	0.87	161	44	0.27	64	48	0.76
28 Jun	96	28	0.29	12	32	2.68	175	45	0.26	54	52	0.96	88	35	0.40	39	42	1.08
29 Jun	144	35	0.24	17	46	2.72	87	32	0.37	39	37	0.96	173	47	0.27	78	53	0.68
30 Jun	121	28	0.23	12	38	3.14	196	57	0.29	99	64	0.65	107	34	0.32	40	43	1.08
Total	9,696	371	0.04	2,458	447	0.18	5,390	318	0.06	2,390	354	0.15	6,033	285	0.05	1,847	327	0.18

Note: NA = not applicable. Coefficient of variation (CV) not defined when passage equals zero. Psg. = passage.

Table 14.–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, 2017–2019.

	2017						2018						2019					
	ALMM all sizes			ALMM <75 cm AL			ALMM all sizes			ALMM <75 cm AL			ALMM all sizes			ALMM <75 cm AL		
Date	Psg.	SE	CV	Psg.	SE	CV	Psg.	SE	CV	Psg.	SE	CV	Psg.	SE	CV	Psg.	SE	CV
1 Jul	197	41	0.21	16	52	3.28	226	62	0.28	111	67	0.61	185	54	0.29	88	57	0.65
2 Jul	296	52	0.17	40	75	1.89	484	152	0.31	321	154	0.48	203	49	0.24	65	58	0.90
3 Jul	193	40	0.21	21	52	2.46	437	109	0.25	316	113	0.36	193	60	0.31	114	64	0.56
4 Jul	232	44	0.19	21	61	2.92	411	99	0.24	212	107	0.50	411	84	0.20	252	91	0.36
5 Jul	224	43	0.19	13	59	4.52	427	139	0.32	227	142	0.62	355	79	0.22	198	85	0.43
6 Jul	181	37	0.20	18	58	3.23	510	116	0.23	257	121	0.47	489	90	0.19	229	105	0.46
7 Jul	330	48	0.15	40	62	1.54	691	139	0.20	329	148	0.45	288	66	0.23	125	73	0.58
8 Jul	412	57	0.14	44	71	1.62	364	93	0.26	140	103	0.74	363	79	0.22	164	88	0.54
9 Jul	504	59	0.12	33	71	2.14	459	104	0.23	211	111	0.53	443	91	0.21	240	99	0.41
10 Jul	437	56	0.13	45	105	2.34	165	55	0.33	72	58	0.81	440	85	0.19	161	97	0.60
11 Jul	426	56	0.13	22	90	4.09	302	80	0.27	180	84	0.47	452	78	0.17	119	89	0.75
12 Jul	452	61	0.13	31	93	3.01	703	133	0.19	407	136	0.33	456	73	0.16	126	91	0.72
13 Jul	442	57	0.13	44	92	2.09	499	111	0.22	276	116	0.42	453	85	0.19	193	95	0.49
14 Jul	429	59	0.14	37	76	2.06	354	85	0.24	203	89	0.44	513	81	0.16	149	97	0.65
15 Jul	519	64	0.12	79	84	1.06	331	109	0.33	203	112	0.55	580	130	0.22	258	143	0.55
16 Jul	785	89	0.11	170	114	0.67	495	102	0.21	223	108	0.48	562	100	0.18	258	106	0.41
17 Jul	782	89	0.11	143	101	0.71	522	102	0.2	253	106	0.42	688	96	0.14	203	113	0.56
18 Jul	848	91	0.11	166	115	0.69	740	149	0.2	381	155	0.41	667	98	0.15	248	111	0.45
19 Jul	619	80	0.13	119	90	0.76	805	133	0.17	292	145	0.50	608	96	0.16	238	108	0.45
20 Jul	436	63	0.14	86	86	1.00	824	125	0.15	257	136	0.53	922	148	0.16	419	165	0.39
21 Jul	619	75	0.12	134	91	0.68	592	119	0.2	212	125	0.59	886	134	0.15	340	150	0.44
22 Jul	459	62	0.13	61	101	1.66	569	102	0.18	152	119	0.78	759	139	0.18	256	149	0.58
23 Jul	407	55	0.13	18	84	4.66	725	112	0.16	224	132	0.59	548	92	0.17	172	98	0.57
24 Jul	1007	82	0.08	22	107	4.86	569	83	0.15	170	103	0.61	522	85	0.16	158	102	0.65
25 Jul	584	59	0.10	23	90	3.93	905	109	0.12	258	150	0.58	437	68	0.16	107	88	0.83
26 Jul	699	67	0.10	23	94	4.10	657	89	0.13	204	98	0.48	436	69	0.16	103	90	0.88
27 Jul	422	50	0.12	24	76	3.19	574	80	0.14	148	97	0.66	317	61	0.19	75	74	0.99
28 Jul	646	64	0.10	24	101	4.23	619	87	0.14	202	106	0.53	355	67	0.19	100	75	0.75
29 Jul	569	57	0.10	26	89	3.41	611	84	0.14	160	96	0.60	305	53	0.17	63	67	1.06

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Table 14.–Page 2 of 2.

	2017						2018						2019					
	ALMM all sizes			ALMM <75 cm AL			ALMM all sizes			ALMM <75 cm AL			ALMM all sizes			ALMM <75 cm AL		
Date	Psg.	SE	CV	Psg.	SE	CV	Psg.	SE	CV	Psg.	SE	CV	Psg.	SE	CV	Psg.	SE	CV
30 Jul	416	49	0.12	36	73	2.04	537	92	0.17	115	108	0.94	403	71	0.18	112	80	0.72
31 Jul	996	85	0.09	73	117	1.61	685	88	0.13	197	114	0.58	273	54	0.20	61	67	1.11
1 Aug	471	50	0.11	37	82	2.23	758	103	0.14	203	122	0.6	157	30	0.19	17	43	2.51
2 Aug	637	58	0.09	35	87	2.49	542	70	0.13	121	87	0.72	208	42	0.20	32	59	1.86
3 Aug	524	56	0.11	47	84	1.79	649	75	0.12	93	90	0.97	196	42	0.21	44	52	1.18
4 Aug	810	72	0.09	73	99	1.36	538	67	0.13	101	85	0.84	449	107	0.24	144	113	0.79
5 Aug	822	72	0.09	68	125	1.84	711	85	0.12	119	109	0.92	257	78	0.30	87	90	1.04
6 Aug	728	68	0.09	61	92	1.51	468	58	0.12	55	96	1.75	177	51	0.29	38	67	1.77
7 Aug	550	62	0.11	25	119	4.75	830	93	0.11	131	143	1.09	280	66	0.23	68	81	1.19
8 Aug	629	65	0.10	37	117	3.17	330	48	0.15	52	68	1.31	170	41	0.24	42	59	1.40
9 Aug	427	46	0.11	29	79	2.73	315	45	0.14	44	76	1.73	132	42	0.32	41	47	1.14
10 Aug	217	28	0.13	12	67	5.59	380	55	0.15	66	82	1.24	170	44	0.26	46	55	1.19
11 Aug	362	46	0.13	35	98	2.79	338	46	0.14	31	72	2.31	139	36	0.26	–6	48	–7.92
12 Aug	306	63	0.21	23	88	3.81	471	63	0.13	60	108	1.79	118	41	0.35	3	52	17.17
13 Aug	394	52	0.13	39	64	1.64	191	28	0.15	28	72	2.55	85	32	0.37	24	45	1.86
14 Aug	198	30	0.15	18	59	3.25	236	36	0.15	7	92	13.09	292	75	0.26	68	89	1.3
15 Aug	267	48	0.18	32	72	2.23	357	56	0.16	43	108	2.52	162	57	0.35	47	67	1.42
16 Aug	247	32	0.13	12	63	5.28	240	35	0.15	17	92	5.39	224	58	0.26	66	71	1.07
17 Aug	189	33	0.18	14	55	3.93	170	28	0.17	19	71	3.73	181	84	0.46	65	90	1.38
18 Aug	369	49	0.13	26	79	3.04	266	52	0.2	49	86	1.76	43	18	0.41	7	49	6.97
19 Aug	410	56	0.14	6	84	14.05	254	34	0.13	12	75	6.28	22	16	0.73	–2	26	–12.8
20 Aug	311	41	0.13	22	66	3.02	307	41	0.14	22	66	3.02	119	41	0.35	–2	65	–32.74
Total	24,436	423	0.02	2,303	619	0.27	25,143	654	0.03	8,186	772	0.09	18,093	547	0.03	6,223	629	0.1

Note: Project operations concluded 20 August as scheduled in all 3 years. Psg. = passage. CV = coefficient of variation.

Table 15.–Daily estimates of Chinook salmon age composition (proportions) 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, 2017–2019.

	2017						2018						2019					
	Age 3 and 4		Age 5		Age 6 and 7		Age 3 and 4		Age 5		Age 6 and 7		Age 3 and 4		Age 5		Age 6 and 7	
Date	Prp.	SE	Prp.	SE	Prop	SE	Prp.	SE	Prp.	SE	Prp.	SE	Prp.	SE	Prp.	SE	Prp.	SE
16 May	0.08	0.07	0.21	0.14	0.71	0.14	0.17	0.13	0.40	0.14	0.43	0.13	0.12	0.13	0.50	0.15	0.37	0.13
17 May	0.08	0.07	0.21	0.14	0.71	0.14	0.17	0.13	0.40	0.14	0.43	0.13	0.12	0.13	0.50	0.15	0.37	0.13
18 May	0.08	0.07	0.21	0.14	0.71	0.14	0.17	0.13	0.40	0.14	0.43	0.13	0.12	0.13	0.50	0.15	0.37	0.13
19 May	0.08	0.07	0.21	0.14	0.71	0.14	0.17	0.13	0.40	0.14	0.43	0.13	0.12	0.13	0.50	0.15	0.37	0.13
20 May	0.08	0.07	0.21	0.14	0.71	0.14	0.17	0.13	0.40	0.14	0.43	0.13	0.12	0.13	0.50	0.15	0.37	0.13
21 May	0.08	0.07	0.21	0.14	0.71	0.14	0.17	0.13	0.40	0.14	0.43	0.13	0.12	0.13	0.50	0.15	0.37	0.13
22 May	0.08	0.07	0.21	0.14	0.71	0.14	0.17	0.13	0.40	0.14	0.43	0.13	0.12	0.13	0.50	0.15	0.37	0.13
23 May	0.08	0.07	0.21	0.14	0.71	0.14	0.17	0.13	0.40	0.14	0.43	0.13	0.12	0.13	0.50	0.15	0.37	0.13
24 May	0.19	0.12	0.53	0.24	0.28	0.22	0.17	0.13	0.40	0.14	0.43	0.13	0.12	0.13	0.50	0.15	0.37	0.13
25 May	0.27	0.11	0.30	0.15	0.43	0.14	0.17	0.13	0.40	0.14	0.43	0.13	0.20	0.19	0.49	0.19	0.31	0.14
26 May	0.22	0.10	0.49	0.25	0.30	0.24	0.17	0.13	0.40	0.14	0.43	0.13	0.11	0.14	0.61	0.23	0.28	0.21
27 May	0.20	0.09	0.55	0.21	0.25	0.19	0.08	0.10	0.40	0.23	0.51	0.23	0.15	0.16	0.57	0.19	0.28	0.16
28 May	0.18	0.09	0.67	0.15	0.14	0.14	0.08	0.09	0.32	0.14	0.61	0.14	0.13	0.15	0.63	0.17	0.24	0.13
29 May	0.17	0.08	0.57	0.15	0.26	0.14	0.07	0.09	0.58	0.16	0.35	0.15	0.16	0.17	0.79	0.17	0.05	0.07
30 May	0.18	0.08	0.59	0.19	0.23	0.18	0.32	0.12	0.52	0.13	0.16	0.09	0.11	0.12	0.80	0.14	0.09	0.09
31 May	0.14	0.09	0.45	0.10	0.40	0.09	0.31	0.12	0.39	0.15	0.30	0.14	0.11	0.13	0.82	0.15	0.08	0.09
1 Jun	0.12	0.07	0.53	0.17	0.35	0.17	0.36	0.11	0.33	0.12	0.31	0.11	0.29	0.14	0.66	0.14	0.06	0.07
2 Jun	0.15	0.09	0.46	0.27	0.39	0.27	0.32	0.11	0.58	0.12	0.10	0.07	0.23	0.12	0.59	0.13	0.19	0.10
3 Jun	0.13	0.09	0.69	0.17	0.17	0.16	0.40	0.11	0.53	0.13	0.07	0.08	0.21	0.10	0.68	0.11	0.11	0.07
4 Jun	0.18	0.10	0.69	0.13	0.14	0.10	0.44	0.11	0.51	0.11	0.04	0.05	0.22	0.10	0.63	0.11	0.15	0.07
5 Jun	0.19	0.09	0.78	0.09	0.03	0.04	0.45	0.12	0.51	0.12	0.04	0.04	0.21	0.10	0.71	0.10	0.08	0.05
6 Jun	0.19	0.10	0.75	0.11	0.06	0.07	0.30	0.12	0.66	0.12	0.04	0.04	0.16	0.08	0.72	0.09	0.12	0.06
7 Jun	0.26	0.13	0.55	0.12	0.19	0.09	0.33	0.11	0.52	0.12	0.15	0.08	0.13	0.07	0.76	0.08	0.11	0.06
8 Jun	0.16	0.09	0.78	0.10	0.06	0.06	0.24	0.10	0.69	0.11	0.07	0.06	0.11	0.07	0.75	0.09	0.14	0.07
9 Jun	0.16	0.09	0.77	0.10	0.07	0.06	0.32	0.11	0.56	0.11	0.12	0.07	0.19	0.09	0.77	0.10	0.04	0.03
10 Jun	0.23	0.10	0.72	0.10	0.05	0.04	0.27	0.12	0.46	0.12	0.27	0.09	0.15	0.08	0.81	0.09	0.04	0.03

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Table 15.–Page 2 of 2.

	2017						2018						2019					
	Age 3 and 4		Age 5		Age 6, 7		Age 3 and 4		Age 5		Age 6 and 7		Ages 3 and 4		Age 5		Age 6 and 7	
Date	Prp.	SE	Prp.	SE	Prop	SE	Prp.	SE	Prp.	SE	Prp.	SE	Prp.	SE	Prp.	SE	Prp.	SE
11 Jun	0.23	0.10	0.75	0.10	0.02	0.03	0.19	0.10	0.57	0.13	0.24	0.11	0.22	0.10	0.74	0.11	0.04	0.03
12 Jun	0.31	0.10	0.60	0.12	0.09	0.08	0.30	0.14	0.51	0.14	0.18	0.10	0.23	0.11	0.75	0.11	0.02	0.02
13 Jun	0.34	0.10	0.58	0.11	0.08	0.07	0.37	0.14	0.47	0.14	0.16	0.08	0.32	0.12	0.67	0.12	0.01	0.02
14 Jun	0.28	0.10	0.67	0.10	0.05	0.06	0.42	0.12	0.41	0.13	0.18	0.10	0.30	0.12	0.66	0.12	0.05	0.04
15 Jun	0.31	0.10	0.63	0.11	0.06	0.05	0.53	0.12	0.39	0.12	0.08	0.06	0.32	0.14	0.66	0.14	0.02	0.02
16 Jun	0.35	0.12	0.54	0.12	0.11	0.07	0.53	0.13	0.43	0.14	0.05	0.06	0.23	0.13	0.73	0.13	0.03	0.04
17 Jun	0.35	0.11	0.60	0.12	0.05	0.05	0.52	0.13	0.45	0.13	0.04	0.05	0.25	0.13	0.73	0.13	0.02	0.03
18 Jun	0.23	0.09	0.69	0.12	0.08	0.08	0.59	0.14	0.37	0.14	0.03	0.04	0.23	0.11	0.74	0.12	0.02	0.03
19 Jun	0.19	0.12	0.75	0.13	0.06	0.06	0.68	0.15	0.26	0.15	0.06	0.06	0.30	0.12	0.68	0.12	0.02	0.02
20 Jun	0.26	0.18	0.61	0.17	0.13	0.08	0.65	0.15	0.26	0.15	0.09	0.07	0.28	0.11	0.70	0.11	0.02	0.03
21 Jun	0.31	0.18	0.52	0.16	0.17	0.07	0.35	0.15	0.56	0.16	0.09	0.09	0.32	0.12	0.66	0.12	0.02	0.03
22 Jun	0.16	0.11	0.80	0.12	0.04	0.05	0.48	0.16	0.39	0.17	0.13	0.10	0.36	0.13	0.62	0.13	0.02	0.02
23 Jun	0.14	0.11	0.67	0.12	0.19	0.08	0.84	0.10	0.09	0.09	0.07	0.04	0.34	0.12	0.64	0.12	0.02	0.02
24 Jun	0.07	0.08	0.65	0.13	0.28	0.12	0.50	0.15	0.31	0.16	0.19	0.12	0.32	0.12	0.65	0.13	0.03	0.04
25 Jun	0.07	0.08	0.65	0.16	0.28	0.14	0.51	0.15	0.29	0.13	0.19	0.09	0.33	0.12	0.56	0.12	0.11	0.06
26 Jun	0.06	0.07	0.58	0.15	0.36	0.14	0.39	0.12	0.48	0.13	0.13	0.08	0.30	0.10	0.65	0.10	0.05	0.04
27 Jun	0.05	0.07	0.57	0.17	0.38	0.16	0.40	0.11	0.38	0.13	0.22	0.11	0.33	0.11	0.61	0.11	0.06	0.04
28 Jun	0.05	0.07	0.56	0.15	0.39	0.14	0.35	0.09	0.46	0.14	0.19	0.12	0.35	0.11	0.60	0.11	0.06	0.04
29 Jun	0.05	0.06	0.63	0.11	0.33	0.10	0.45	0.10	0.42	0.10	0.13	0.07	0.30	0.10	0.64	0.10	0.05	0.04
30 Jun	0.05	0.06	0.62	0.17	0.33	0.17	0.48	0.10	0.19	0.09	0.33	0.09	0.33	0.10	0.58	0.11	0.08	0.05
Mean[a]	0.21	0.02	0.62	0.04	0.17	0.02	0.42	0.04	0.42	0.04	0.16	0.02	0.24	0.03	0.68	0.05	0.08	0.01

Note: Prp. = proportion. SE = standard error.

[a] Mean proportions are weighted by daily ALMM estimates in Table 13.

Table 16.–Daily estimates of Chinook salmon age composition (proportions) 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, 2017–2019.

	2017						2018						2019					
	Age 3 and 4		Age 5		Age 6 and 7		Age 3 and 4		Age 5		Age 6 and 7		Age 3 and 4		Age 5		Age 6 and 7	
Date	Prp.	SE	Prp.	SE	Prp.	SE	Prp.	SE	Prp.	SE	Prp.	SE	Prp.	SE	Prp.	SE	Prp.	SE
1 Jul	0.09	0.07	0.50	0.21	0.41	0.20	0.49	0.09	0.34	0.09	0.17	0.07	0.34	0.10	0.54	0.11	0.12	0.06
2 Jul	0.08	0.07	0.65	0.17	0.27	0.17	0.63	0.10	0.18	0.09	0.19	0.08	0.38	0.09	0.55	0.10	0.07	0.07
3 Jul	0.11	0.06	0.68	0.21	0.21	0.21	0.67	0.09	0.21	0.08	0.12	0.04	0.48	0.09	0.37	0.10	0.15	0.07
4 Jul	0.11	0.06	0.65	0.21	0.24	0.21	0.51	0.10	0.13	0.07	0.35	0.08	0.48	0.09	0.43	0.08	0.09	0.04
5 Jul	0.09	0.05	0.55	0.16	0.36	0.16	0.51	0.11	0.10	0.07	0.39	0.09	0.50	0.09	0.45	0.09	0.05	0.04
6 Jul	0.08	0.05	0.37	0.15	0.54	0.15	0.50	0.10	0.19	0.08	0.32	0.08	0.40	0.08	0.49	0.08	0.11	0.04
7 Jul	0.09	0.05	0.60	0.16	0.31	0.16	0.49	0.10	0.16	0.07	0.34	0.07	0.43	0.09	0.50	0.09	0.07	0.05
8 Jul	0.07	0.04	0.47	0.17	0.46	0.18	0.47	0.10	0.11	0.08	0.41	0.09	0.44	0.09	0.48	0.09	0.08	0.04
9 Jul	0.07	0.04	0.67	0.19	0.27	0.19	0.49	0.08	0.10	0.07	0.40	0.08	0.41	0.10	0.53	0.10	0.06	0.04
10 Jul	0.06	0.04	0.47	0.18	0.47	0.18	0.55	0.08	0.03	0.04	0.41	0.08	0.30	0.12	0.58	0.11	0.12	0.05
11 Jul	0.06	0.04	0.40	0.17	0.54	0.18	0.57	0.07	0.05	0.05	0.38	0.08	0.26	0.11	0.63	0.10	0.11	0.05
12 Jul	0.08	0.04	0.32	0.19	0.59	0.19	0.61	0.06	0.05	0.05	0.34	0.07	0.27	0.09	0.62	0.10	0.11	0.08
13 Jul	0.09	0.04	0.25	0.19	0.67	0.19	0.58	0.07	0.02	0.03	0.40	0.07	0.34	0.11	0.52	0.10	0.15	0.05
14 Jul	0.07	0.04	0.16	0.12	0.77	0.12	0.61	0.07	0.06	0.06	0.33	0.07	0.29	0.09	0.56	0.09	0.15	0.06
15 Jul	0.13	0.05	0.35	0.23	0.53	0.23	0.64	0.07	0.03	0.04	0.33	0.07	0.43	0.13	0.41	0.11	0.16	0.06
16 Jul	0.18	0.06	0.28	0.13	0.54	0.13	0.56	0.08	0.11	0.07	0.34	0.07	0.43	0.09	0.36	0.08	0.21	0.07
17 Jul	0.17	0.06	0.28	0.14	0.55	0.15	0.51	0.08	0.07	0.06	0.41	0.08	0.32	0.07	0.61	0.09	0.06	0.07
18 Jul	0.19	0.06	0.14	0.09	0.67	0.09	0.52	0.08	0.02	0.03	0.45	0.08	0.38	0.07	0.50	0.08	0.12	0.05
19 Jul	0.18	0.06	0.19	0.13	0.62	0.13	0.38	0.09	0.13	0.09	0.49	0.10	0.38	0.08	0.49	0.08	0.13	0.05
20 Jul	0.19	0.06	0.13	0.10	0.68	0.10	0.34	0.09	0.10	0.08	0.56	0.10	0.41	0.08	0.41	0.08	0.18	0.06
21 Jul	0.16	0.05	0.20	0.18	0.63	0.18	0.36	0.10	0.13	0.10	0.51	0.12	0.42	0.08	0.43	0.10	0.16	0.09
22 Jul	0.11	0.05	0.24	0.14	0.65	0.14	0.33	0.08	0.08	0.08	0.58	0.10	0.38	0.09	0.44	0.11	0.18	0.08
23 Jul	0.06	0.03	0.14	0.14	0.80	0.14	0.35	0.08	0.19	0.09	0.47	0.10	0.29	0.10	0.44	0.10	0.27	0.08
24 Jul	0.03	0.02	0.22	0.24	0.75	0.24	0.31	0.07	0.08	0.07	0.61	0.09	0.29	0.09	0.43	0.10	0.28	0.08
25 Jul	0.02	0.02	0.14	0.12	0.84	0.11	0.29	0.06	0.11	0.08	0.61	0.09	0.27	0.08	0.51	0.10	0.23	0.09
26 Jul	0.04	0.02	0.03	0.04	0.93	0.04	0.31	0.06	0.27	0.09	0.42	0.09	0.24	0.09	0.52	0.11	0.24	0.10
27 Jul	0.03	0.02	0.47	0.21	0.50	0.21	0.31	0.06	0.08	0.07	0.61	0.09	0.19	0.09	0.65	0.12	0.16	0.09
28 Jul	0.03	0.02	0.09	0.07	0.88	0.07	0.34	0.07	0.14	0.07	0.52	0.08	0.22	0.10	0.63	0.12	0.15	0.09
29 Jul	0.03	0.03	0.06	0.08	0.90	0.08	0.30	0.06	0.08	0.05	0.62	0.07	0.17	0.08	0.62	0.10	0.21	0.08

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	2017						2018						2019					
	Age 3 and 4		Age 5		Age 6 and 7		Age 3 and 4		Age 5		Age 6 and 7		Age 3 and 4		Age 5		Age 6 and 7	
Date	Prp.	SE	Prp.	SE	Prp.	SE	Prp.	SE	Prp.	SE	Prp.	SE	Prp.	SE	Prp.	SE	Prp.	SE
30 Jul	0.06	0.03	0.07	0.07	0.87	0.07	0.31	0.07	0.09	0.07	0.59	0.09	0.21	0.10	0.57	0.11	0.21	0.09
31 Jul	0.07	0.03	0.12	0.10	0.82	0.10	0.29	0.07	0.06	0.05	0.66	0.07	0.21	0.11	0.55	0.11	0.25	0.08
1 Aug	0.07	0.03	0.06	0.11	0.86	0.11	0.27	0.07	0.04	0.04	0.68	0.07	0.06	0.08	0.63	0.11	0.31	0.10
2 Aug	0.06	0.03	0.20	0.16	0.74	0.16	0.22	0.07	0.06	0.05	0.72	0.07	0.11	0.10	0.61	0.13	0.28	0.11
3 Aug	0.09	0.03	0.06	0.08	0.86	0.08	0.13	0.06	0.14	0.07	0.73	0.08	0.18	0.12	0.50	0.13	0.32	0.11
4 Aug	0.09	0.03	0.04	0.06	0.87	0.06	0.11	0.05	0.03	0.03	0.87	0.06	0.26	0.17	0.52	0.15	0.22	0.08
5 Aug	0.09	0.03	0.05	0.06	0.86	0.06	0.16	0.07	0.18	0.08	0.66	0.08	0.33	0.18	0.44	0.17	0.23	0.11
6 Aug	0.07	0.04	0.12	0.15	0.81	0.15	0.14	0.06	0.08	0.05	0.78	0.07	0.31	0.15	0.39	0.19	0.30	0.15
7 Aug	0.07	0.04	0.06	0.07	0.88	0.08	0.15	0.06	0.09	0.05	0.76	0.07	0.28	0.14	0.46	0.15	0.26	0.11
8 Aug	0.05	0.04	0.05	0.06	0.89	0.06	0.12	0.06	0.17	0.08	0.70	0.09	0.27	0.14	0.55	0.14	0.18	0.09
9 Aug	0.06	0.04	0.07	0.07	0.87	0.07	0.12	0.07	0.26	0.08	0.62	0.08	0.31	0.15	0.32	0.21	0.37	0.18
10 Aug	0.03	0.03	0.09	0.08	0.89	0.09	0.15	0.07	0.12	0.08	0.73	0.09	0.18	0.13	0.61	0.15	0.21	0.11
11 Aug	0.04	0.05	0.15	0.12	0.81	0.12	0.11	0.06	0.25	0.08	0.64	0.08	0.17	0.12	0.39	0.19	0.44	0.18
12 Aug	0.07	0.10	0.55	0.33	0.38	0.32	0.11	0.08	0.16	0.09	0.73	0.09	0.25	0.16	0.49	0.21	0.26	0.17
13 Aug	0.09	0.07	0.24	0.15	0.66	0.15	0.11	0.09	0.15	0.11	0.75	0.12	0.28	0.16	0.31	0.21	0.41	0.20
14 Aug	0.06	0.07	0.23	0.13	0.71	0.13	0.09	0.08	0.14	0.11	0.77	0.12	0.24	0.15	0.51	0.16	0.25	0.12
15 Aug	0.09	0.10	0.17	0.12	0.74	0.13	0.11	0.09	0.29	0.12	0.60	0.12	0.29	0.19	0.36	0.18	0.34	0.14
16 Aug	0.04	0.05	0.48	0.20	0.48	0.19	0.10	0.08	0.04	0.05	0.86	0.08	0.25	0.16	0.52	0.16	0.23	0.10
17 Aug	0.06	0.08	0.26	0.15	0.67	0.16	0.12	0.10	0.10	0.08	0.78	0.11	0.44	0.22	0.28	0.20	0.28	0.15
18 Aug	0.05	0.06	0.14	0.13	0.81	0.14	0.16	0.12	0.04	0.05	0.80	0.12	0.23	0.23	0.55	0.26	0.22	0.17
19 Aug	0.05	0.06	0.06	0.08	0.89	0.10	0.05	0.06	0.07	0.06	0.88	0.08	0.24	0.24	0.39	0.25	0.36	0.22
20 Aug	0.04	0.05	0.53	0.29	0.43	0.29	0.04	0.06	0.13	0.09	0.82	0.10	0.15	0.17	0.49	0.25	0.36	0.23
Mean[a]	0.08	0.01	0.22	0.02	0.69	0.03	0.34	0.02	0.12	0.01	0.55	0.02	0.33	0.02	0.50	0.03	0.18	0.01

Note: Prp. = proportion. SE = standard error.

[a] Mean proportions are weighted by daily ALMM estimates in Table 14.

Table 17.–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, 2013–2019.

	Early run		Late run	
Year	AL ≥75 cm[a]	All Chinook[b]	AL ≥75 cm[a]	All Chinook[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
2016	11 Jun	10 Jun	23 Jul	20 Jul
2017	10 Jun	10 Jun	26 Jul	26 Jul
2018	10 Jun	12 Jun	28 Jul	25 Jul
2019	10 Jun	11 Jun	21 Jul	20 Jul
Average[c] 2013–2019	10 Jun	11 Jun	26 Jul	23 Jul

Source: 2013–2016: Miller et al. 2016a; Miller et al. 2016b; Key et al. 2017; Key et al. 2019.

[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] Determined by the average of the median passage dates.

Table 18.–Estimates of net upstream daily passage of medium (75 cm ≤ AL < 90 cm), large (AL ≥90 cm), and both medium and large (AL ≥75 cm) fish at RM 13.7 Kenai River early run, 2017–2019.

	2017						2018						2019					
	Medium		Large		Both		Medium		Large		Both		Medium		Large		Both	
Date	Psg	SE	Psg	SE	Psg	SE	Psg	SE	Psg	SE	Psg	SE	Psg	SE	Psg	SE	Psg	SE
16 May	0	0	6	4	6	4	0	0	0	0	0	0	0	0	0	0	0	0
17 May	0	0	30	11	30	11	0	0	0	0	0	0	0	0	0	0	0	0
18 May	12	7	18	12	30	13	6	6	12	8	18	10	0	0	0	0	0	0
19 May	6	6	36	17	42	18	18	9	6	10	24	15	0	0	6	6	6	6
20 May	12	7	24	14	36	13	6	6	0	0	6	6	0	0	-6	4	-6	4
21 May	-6	10	12	11	6	15	6	6	12	7	18	9	0	0	18	10	18	10
22 May	0	0	18	10	18	10	12	6	18	10	30	13	6	6	0	0	6	6
23 May	54	23	36	15	91	23	24	18	18	13	42	22	24	8	0	8	24	12
24 May	18	10	42	13	60	14	12	8	24	11	36	18	24	9	12	14	36	14
25 May	30	26	72	21	103	29	6	6	6	6	12	8	30	15	6	17	36	21
26 May	42	24	89	34	130	49	6	6	0	8	6	13	12	8	24	14	36	19
27 May	28	16	69	37	98	40	30	21	18	16	49	31	18	10	29	12	47	15
28 May	48	21	42	20	91	33	12	12	36	23	49	29	44	14	37	16	80	23
29 May	72	30	79	27	151	42	24	29	24	16	48	41	48	17	12	8	60	22
30 May	85	24	115	34	199	49	72	19	6	18	79	30	48	15	18	13	66	21
31 May	79	37	91	40	169	64	30	15	30	17	61	23	30	11	18	9	48	16
1 Jun	102	24	133	32	235	40	54	24	54	27	109	31	91	26	36	11	127	32
2 Jun	91	37	181	44	272	42	54	24	60	21	115	34	79	18	36	14	115	22
3 Jun	193	40	175	35	368	61	42	14	60	17	103	25	133	35	66	23	199	35
4 Jun	139	31	61	27	200	38	78	18	48	19	127	23	115	20	61	19	176	32
5 Jun	194	41	91	27	285	44	84	17	24	13	109	23	188	29	42	16	230	33
6 Jun	105	30	97	23	201	38	101	23	18	13	120	30	178	30	43	17	220	35
7 Jun	104	25	103	29	207	31	78	32	42	20	121	39	111	20	26	11	137	19
8 Jun	163	28	109	25	271	48	66	22	36	8	103	23	109	24	48	17	157	29
9 Jun	91	24	84	23	175	35	85	23	18	17	103	31	121	18	42	17	163	24
10 Jun	193	42	60	24	253	55	62	25	59	24	121	26	115	20	30	13	145	20

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	2017						2018						2019					
	Medium		Large		Both		Medium		Large		Both		Medium		Large		Both	
Date	Psg	SE	Psg	SE	Psg	SE	Psg	SE	Psg	SE	Psg	SE	Psg	SE	Psg	SE	Psg	SE
11 Jun	133	29	151	27	284	38	74	21	60	17	133	26	169	31	36	12	206	35
12 Jun	133	34	139	31	272	49	42	14	36	13	78	20	97	18	24	10	121	23
13 Jun	196	29	111	30	307	48	42	13	30	19	72	25	164	44	55	19	218	52
14 Jun	217	28	157	26	374	43	66	21	54	15	121	27	91	22	12	10	103	22
15 Jun	211	46	102	36	314	66	55	19	30	14	85	19	115	23	12	8	127	23
16 Jun	121	39	72	20	193	53	12	13	6	10	18	15	43	17	0	0	43	17
17 Jun	127	28	66	14	193	31	54	15	12	7	66	15	67	18	0	0	67	18
18 Jun	121	28	139	24	259	36	43	19	18	9	61	19	61	17	12	8	74	18
19 Jun	85	28	36	20	121	40	12	9	12	8	24	11	85	24	6	10	91	26
20 Jun	30	19	36	12	66	26	47	17	12	16	59	22	102	26	45	22	147	30
21 Jun	78	21	54	25	133	29	54	18	6	13	61	23	61	13	6	9	67	15
22 Jun	60	21	30	10	90	25	42	19	18	10	60	23	67	24	6	6	73	23
23 Jun	54	30	36	18	91	40	25	13	22	10	47	16	79	21	12	8	91	23
24 Jun	42	15	42	17	84	24	24	11	24	14	48	17	67	21	36	13	103	25
25 Jun	60	22	54	18	114	21	42	15	30	10	72	18	81	27	37	14	118	35
26 Jun	78	20	91	19	169	24	48	18	6	6	54	18	91	23	12	7	103	26
27 Jun	60	23	66	18	127	29	30	15	36	13	66	22	79	18	18	8	97	21
28 Jun	36	14	48	18	84	15	54	14	66	21	121	26	43	20	6	6	49	24
29 Jun	78	21	48	19	127	31	36	17	12	4	48	19	71	26	24	11	95	25
30 Jun	48	15	60	17	109	25	18	14	79	21	97	29	36	16	30	15	67	26
Total	3,825	175	3,413	163	7,238	250	1,796	114	1,204	97	3,000	154	3,193	135	993	82	4,186	160

Note: Psg = passage. SE = standard error.

Table 19.–Estimates of net upstream daily passage of medium (75 cm ≤ AL < 90 cm), large (AL ≥90 cm), and both medium and large (AL ≥75 cm) fish at RM 13.7 Kenai River late run, 2017–2019.

	2017						2018						2019					
	Medium		Large		Both		Medium		Large		Both		Medium		Large		Both	
Date	Psg	SE	Psg	SE	Psg	SE	Psg	SE	Psg	SE	Psg	SE	Psg	SE	Psg	SE	Psg	SE
1 Jul	90	25	90	20	181	33	54	15	60	19	115	25	67	17	30	11	97	19
2 Jul	154	33	102	30	256	55	72	12	91	21	163	23	63	25	75	23	138	32
3 Jul	61	20	111	21	172	33	72	22	49	20	121	31	36	18	42	12	79	22
4 Jul	81	20	130	32	211	43	48	13	151	36	199	39	110	27	49	15	159	34
5 Jul	88	24	124	38	211	40	59	18	141	24	200	29	109	22	48	15	157	30
6 Jul	42	17	121	31	163	45	97	23	157	27	253	35	181	41	79	20	260	54
7 Jul	133	25	157	30	290	39	121	23	242	36	362	49	103	23	61	13	163	30
8 Jul	109	27	259	39	368	43	91	30	133	22	224	44	94	27	104	27	199	39
9 Jul	175	28	296	34	471	39	121	30	127	26	248	40	142	23	62	25	203	37
10 Jul	156	38	236	59	392	89	50	14	43	11	93	19	182	40	97	26	279	46
11 Jul	157	37	247	42	404	70	60	15	62	21	122	24	212	30	121	31	333	43
12 Jul	123	33	298	45	421	71	109	24	187	27	296	28	162	29	169	39	330	54
13 Jul	133	50	265	37	398	72	54	17	169	26	223	35	173	34	87	23	260	44
14 Jul	121	30	272	41	392	48	91	22	61	13	151	27	212	41	152	27	364	54
15 Jul	181	28	259	44	440	54	37	14	92	18	128	23	200	40	121	30	322	60
16 Jul	289	45	326	44	615	70	114	20	158	29	272	35	170	22	134	25	304	34
17 Jul	284	50	356	50	639	48	98	14	171	21	269	27	248	45	236	29	485	61
18 Jul	278	36	404	57	682	70	106	20	253	36	359	44	255	45	164	25	419	53
19 Jul	175	25	326	31	500	40	187	29	326	36	513	59	255	39	115	28	370	49
20 Jul	121	21	229	50	350	59	205	33	362	36	567	53	321	49	182	43	503	73
21 Jul	171	39	314	29	485	52	151	23	229	36	380	39	297	41	248	44	546	67
22 Jul	136	37	262	55	398	80	145	29	272	49	417	62	242	36	260	34	503	54
23 Jul	175	30	214	53	389	64	199	40	302	50	501	69	188	29	188	23	376	35
24 Jul	337	36	648	74	985	69	85	38	314	41	399	62	170	36	194	41	364	56
25 Jul	193	38	368	50	561	68	224	42	423	78	647	103	185	36	146	44	330	57
26 Jul	175	22	501	61	676	66	199	22	253	32	453	42	164	41	170	31	333	58
27 Jul	187	41	211	43	398	58	165	30	261	40	426	56	158	28	85	31	242	42
28 Jul	217	35	404	65	622	79	151	29	266	56	417	61	152	31	103	31	255	34

-continued-

Table 19.–Page 2 of 2.

	2017						2018						2019					
	Medium		Large		Both		Medium		Large		Both		Medium		Large		Both	
Date	Psg	SE	Psg	SE	Psg	SE	Psg	SE	Psg	SE	Psg	SE	Psg	SE	Psg	SE	Psg	SE
29 Jul	229	35	314	55	543	68	103	22	348	39	451	48	139	28	103	20	242	40
30 Jul	169	35	211	38	380	55	153	24	269	47	422	56	176	31	115	20	291	38
31 Jul	416	47	507	61	923	81	181	39	307	59	488	72	103	23	109	31	212	40
1 Aug	181	32	254	59	434	65	145	35	410	48	555	66	67	22	73	20	140	30
2 Aug	273	44	330	45	602	65	163	38	259	37	421	51	85	28	91	30	176	42
3 Aug	174	38	302	47	477	63	188	31	368	51	556	51	85	24	67	22	152	31
4 Aug	272	53	465	44	737	68	127	23	310	54	437	52	183	36	123	34	305	38
5 Aug	229	31	525	110	754	102	217	36	374	58	592	69	98	30	73	25	170	45
6 Aug	278	45	389	45	667	62	56	29	357	71	413	76	79	35	61	20	139	44
7 Aug	205	38	320	85	525	101	181	45	519	81	699	109	133	32	79	25	212	48
8 Aug	266	67	326	68	592	98	109	21	169	45	278	48	79	29	49	24	128	42
9 Aug	133	32	265	62	398	64	103	27	169	54	271	61	36	16	55	16	91	21
10 Aug	78	38	127	52	205	61	97	27	217	48	314	60	75	25	49	21	124	33
11 Aug	109	48	218	61	327	86	125	28	182	52	307	54	61	27	85	22	145	31
12 Aug	133	43	151	35	283	61	127	37	284	65	411	87	97	21	18	19	115	31
13 Aug	133	32	223	26	355	38	91	38	73	59	163	66	18	25	43	20	61	31
14 Aug	54	34	126	35	180	50	108	49	120	55	229	84	133	31	91	26	224	48
15 Aug	67	37	169	50	235	53	157	47	157	70	314	93	61	21	55	31	115	35
16 Aug	121	33	114	43	235	54	103	42	120	55	223	85	98	31	59	22	158	41
17 Aug	67	27	108	38	175	44	25	37	127	55	151	65	61	22	55	18	116	31
18 Aug	85	34	259	41	343	62	69	35	147	51	217	68	-12	39	48	17	36	45
19 Aug	221	61	183	45	404	63	36	35	205	59	242	67	19	18	6	18	24	20
20 Aug	157	34	133	39	289	52	98	30	187	45	285	52	48	38	73	23	121	51
Total	8,589	263	13,544	353	22,133	452	5,926	213	11,031	323	16,957	410	6,770	224	5,100	189	11,870	310

Note: Psg = passage.

Table 20.–Total estimated net upstream passage of Chinook salmon ≥75 cm, all Chinook salmon (regardless of size), and Chinook salmon <75 cm, by year and run (early and late), RM 13.7 Kenai River, 2013–2019.

	Chinook salmon ≥75 cm		All Chinook salmon		Chinook salmon <75 cm	
Year	Early run	Late run	Early run	Late run	Early run	Late run
2013	1,724	12,656	2,845	19,373	1,121	6,717
2014	2,397	10,871	5,768	16,871	3,371	6,000
2015	4,212	17,687	7,332	28,918	3,120	11,231
2016	6,391	17,447	9,851	22,537	3,460	5,090
2017	7,238	22,133	9,696	24,436	2,458	2,303
2018	3,000	16,957	5,390	25,143	2,390	8,186
2019	4,186	11,870	6,033	18,093	1,847	6,223
Average						
2013–2019	4,164	15,647	6,702	22,196	2,538	6,536

Source: 2013–2016: Miller et al. 2016a; Miller et al. 2016b; Key et al. 2017; Key et al. 2019.

FIGURES

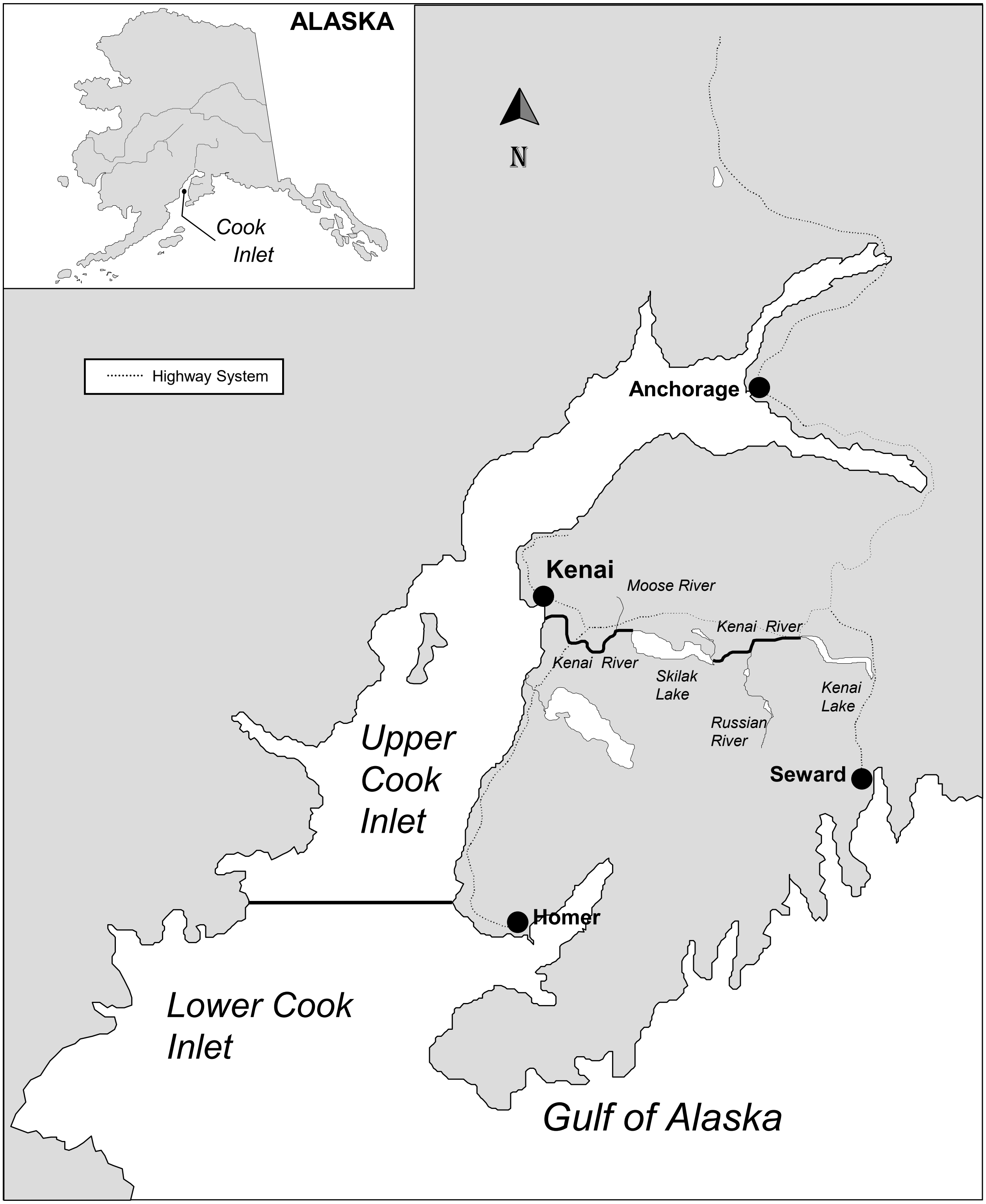


Figure 1.–Cook Inlet showing the location of the Kenai River.

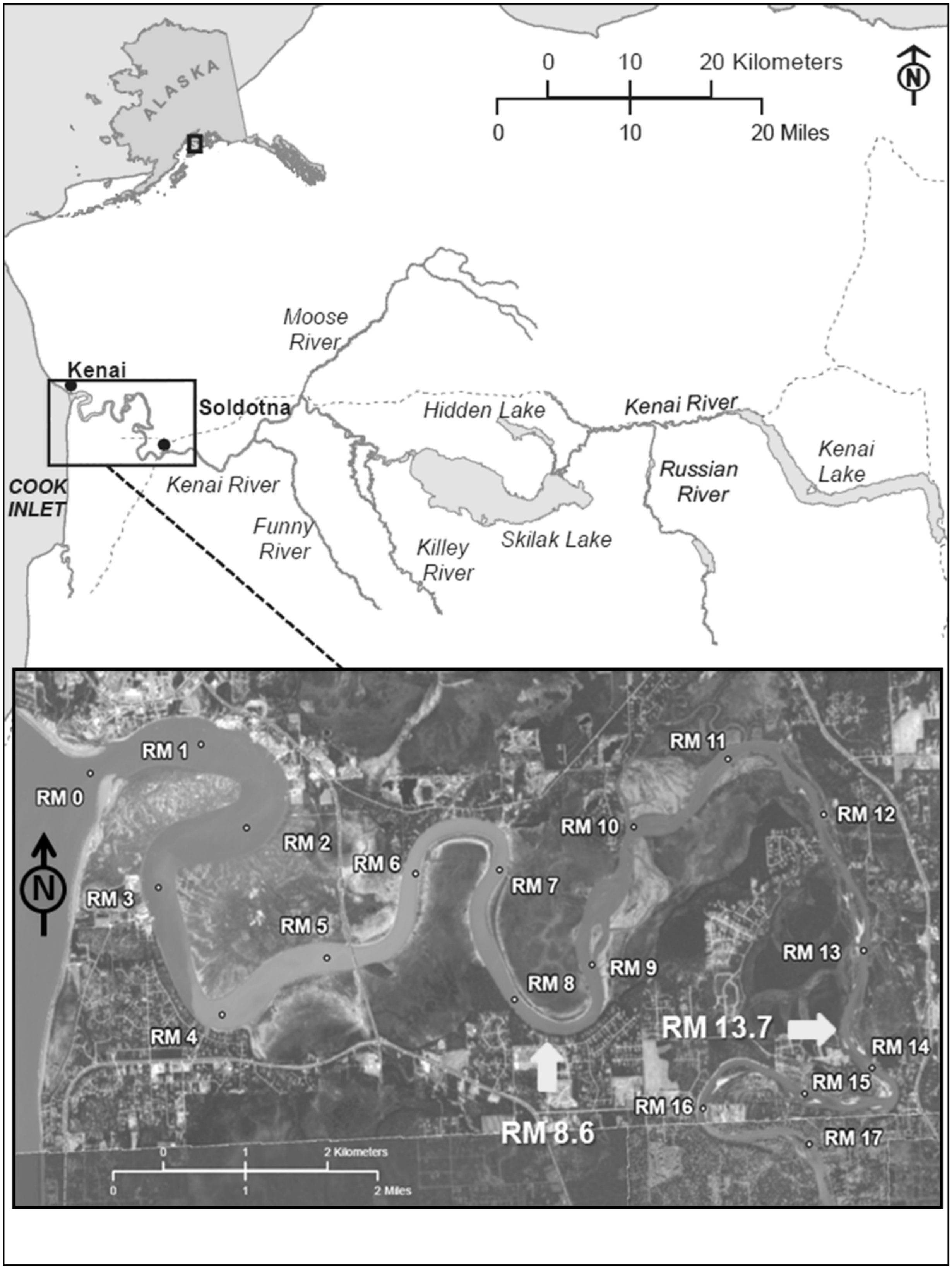


Figure 2.–Map of Kenai River showing location of river mile (RM) 8.6 netting project and RM 13.7 Chinook salmon sonar site.

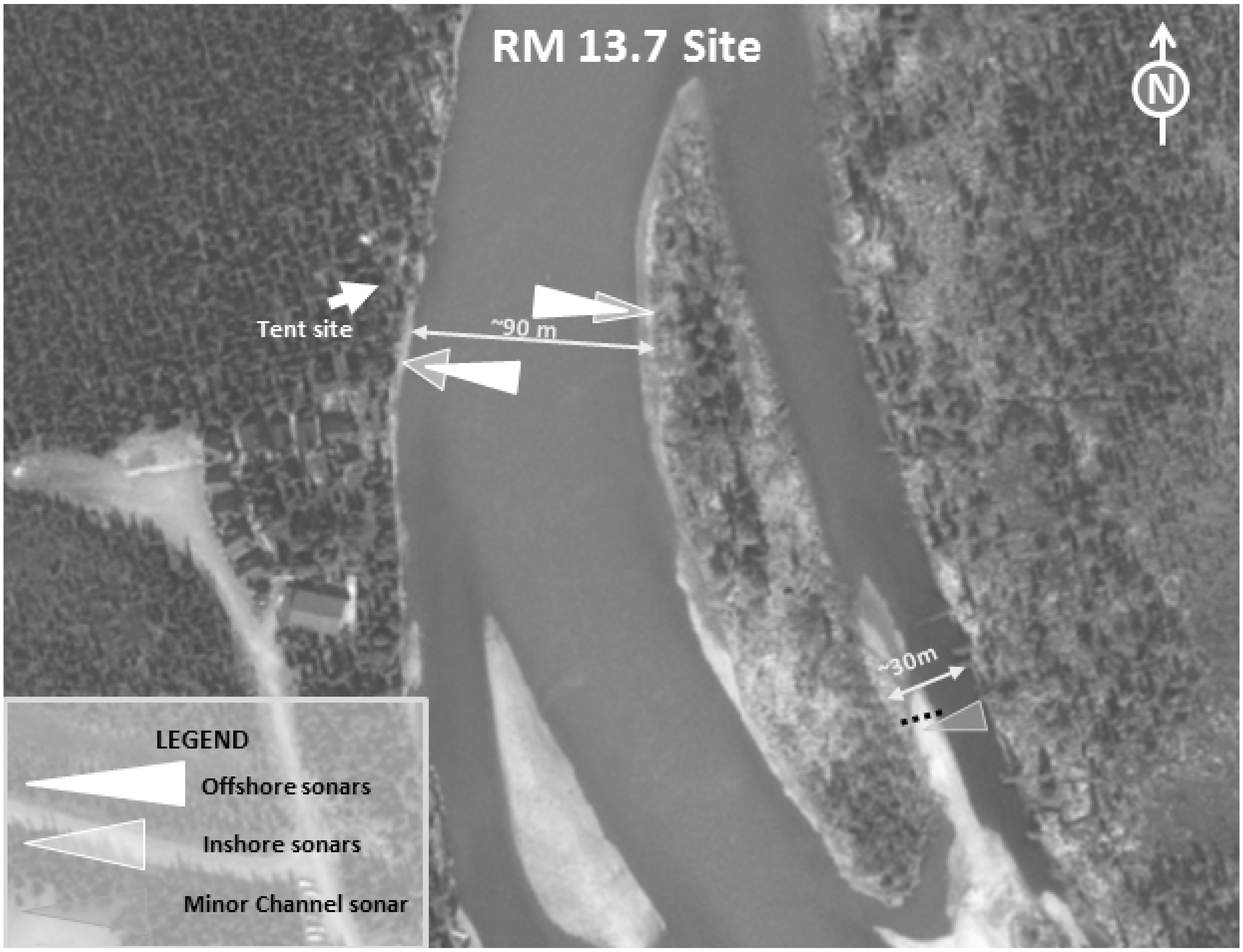


Figure 3.–Kenai River sonar site at river mile (RM) 13.7 showing approximate beam coverage.

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

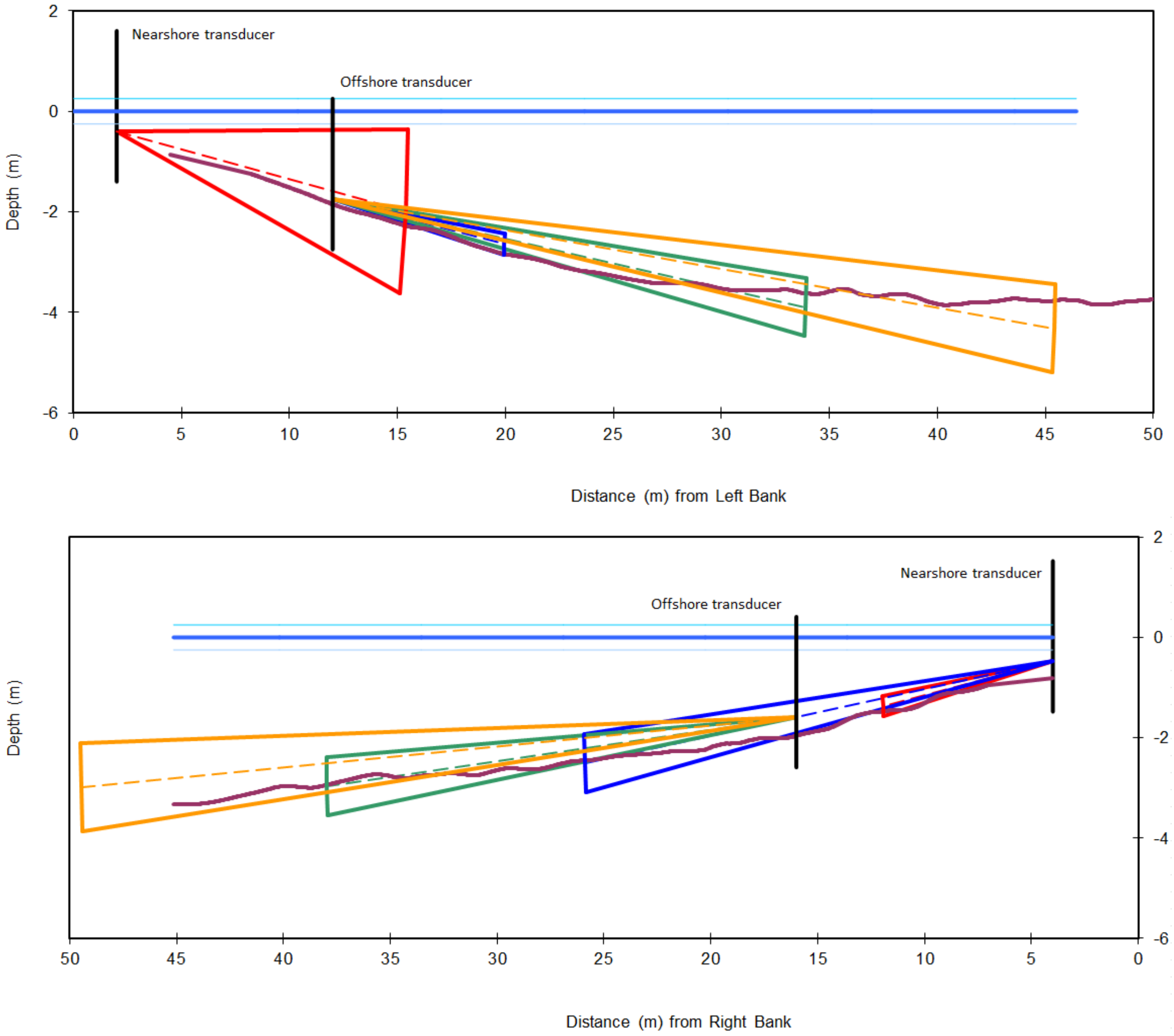


Figure 4.–Kenai River at river mile (RM) 13.7 showing main channel left and right bank bottom profiles collected on 8 July 2015 with nearshore and offshore sonar beams superimposed.

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 river mile (RM) 13.7 sonar site was achieved using an ARIS 1200 deployed on a tripod mount combined with a fixed weir.

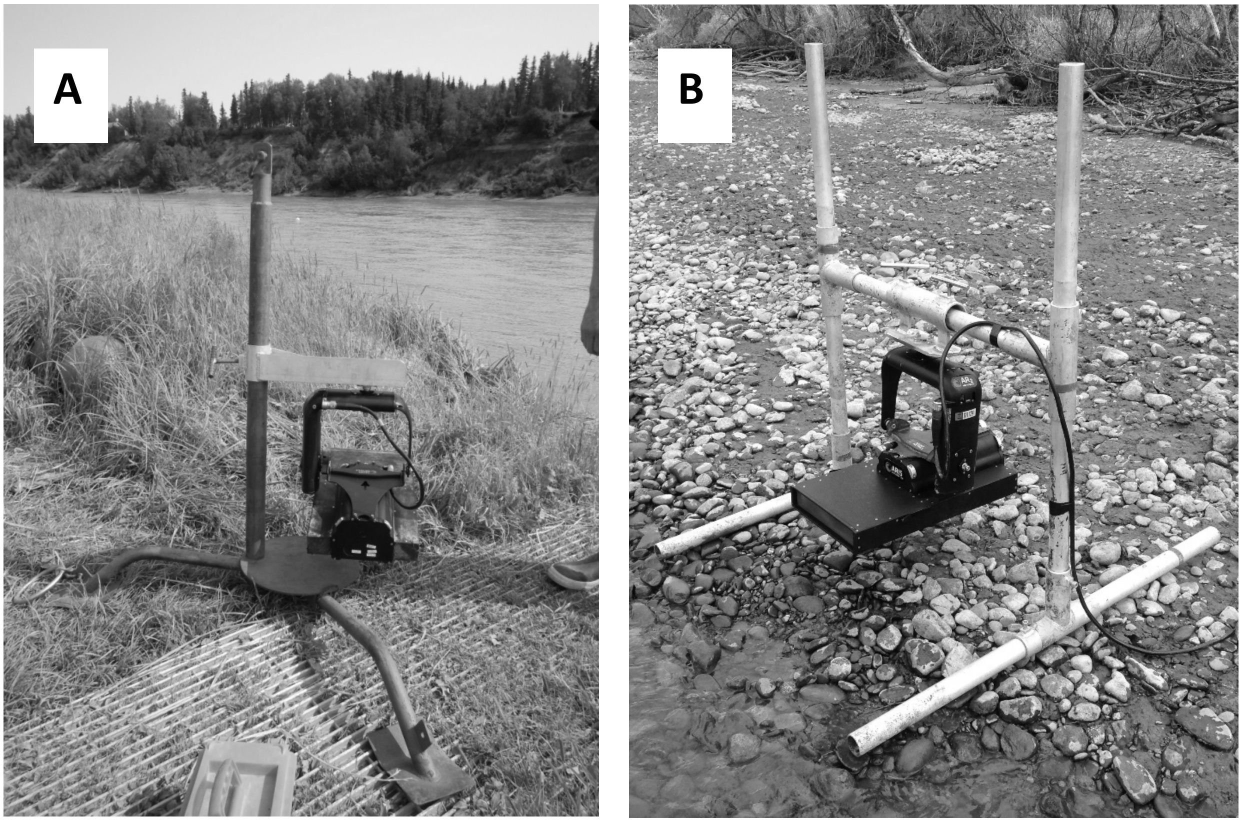


Figure 6.–An ARIS 1200 with a high-resolution lens mounted on a steel tripod for offshore deployment (A) and on an aluminum H-mount for nearshore deployment (B).

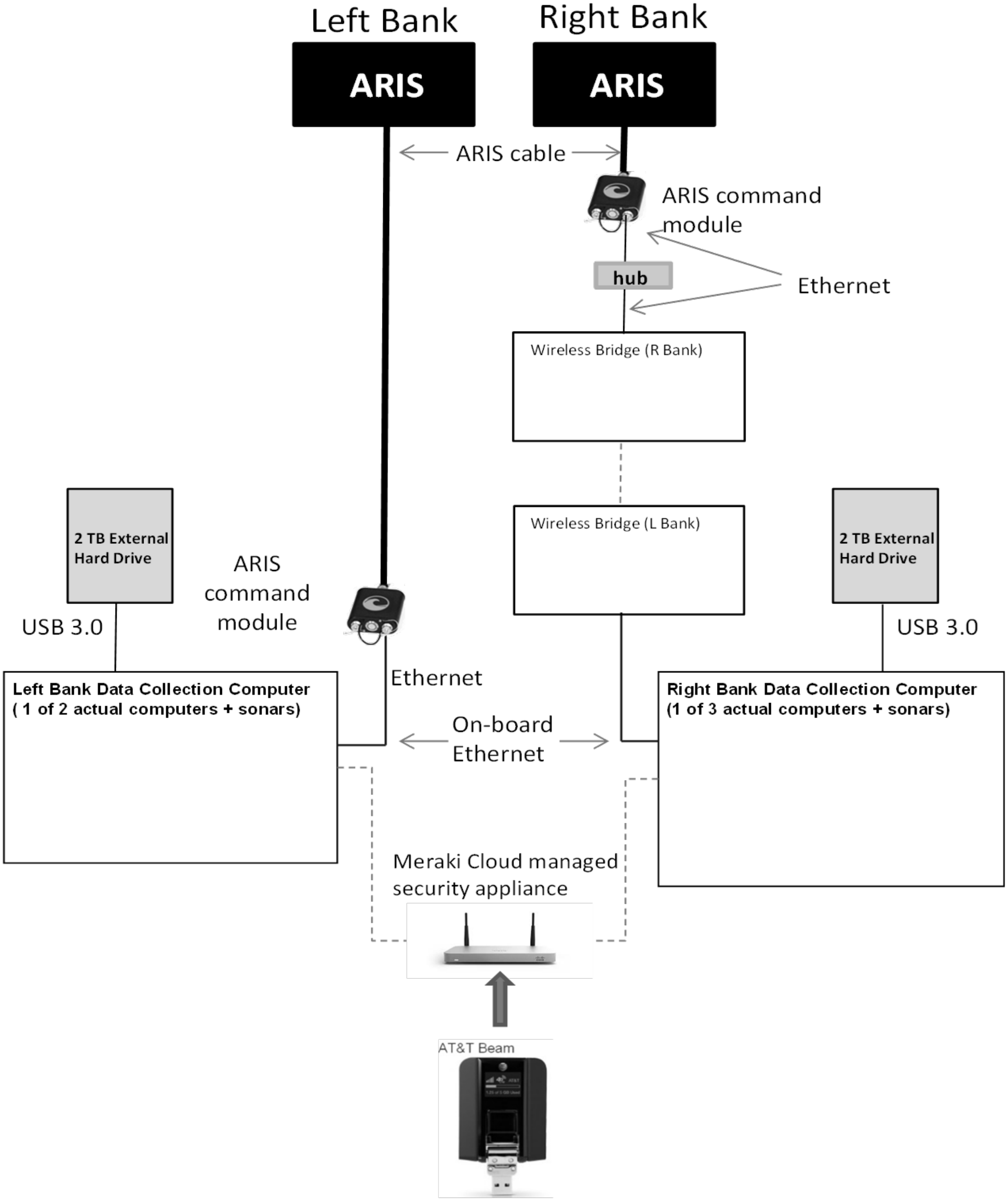
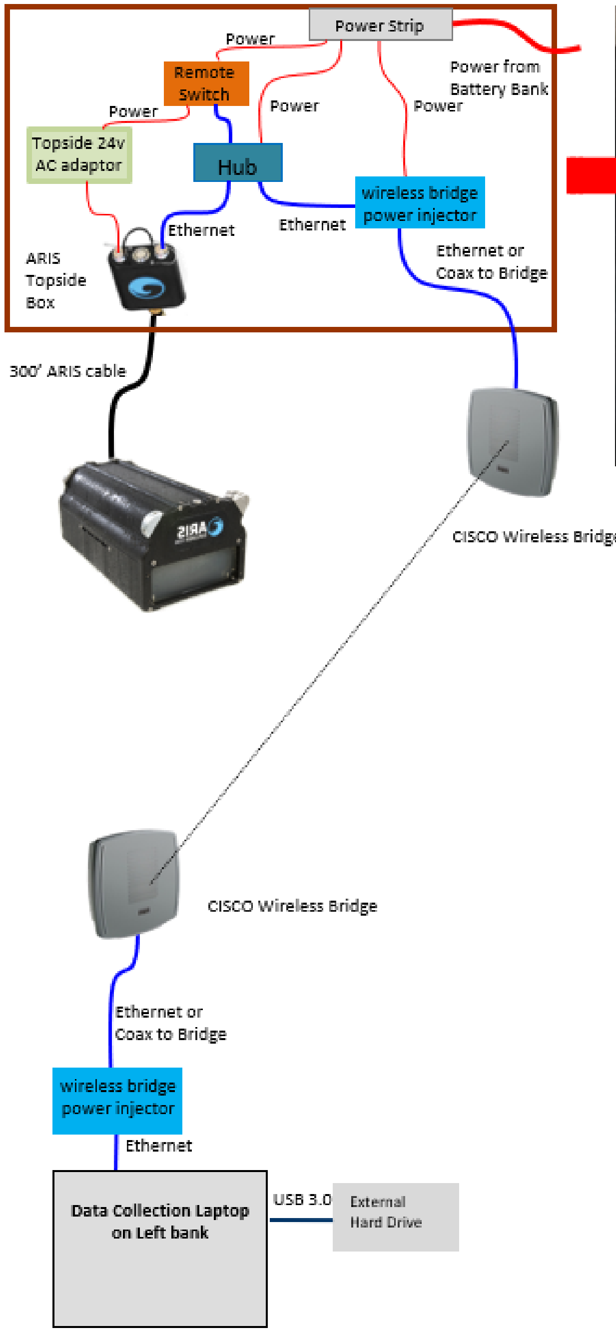
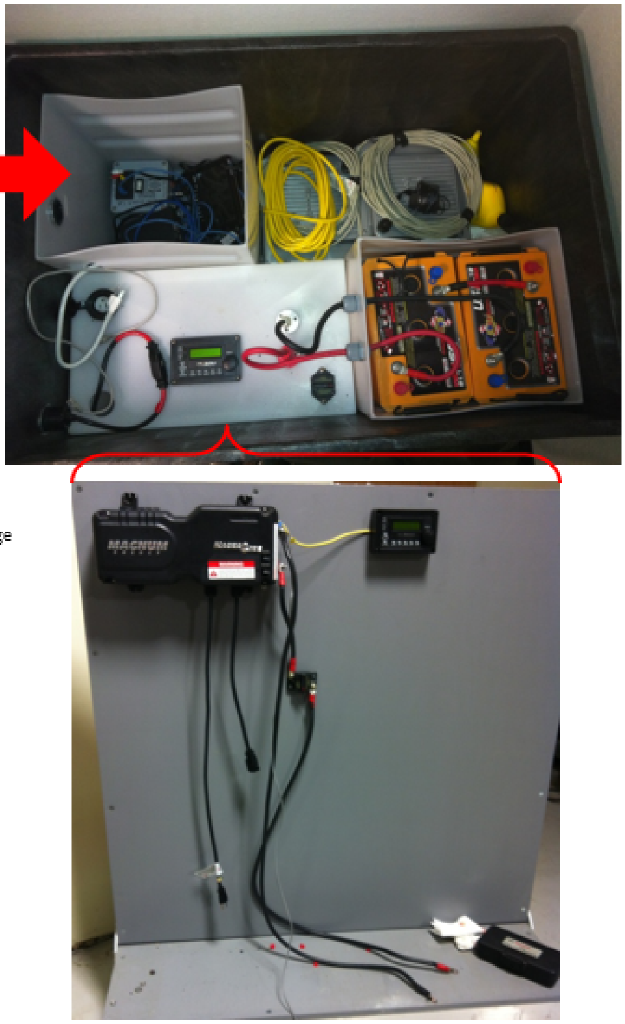


Figure 7.–ARIS data collection schematic for the river mile 13.7 site on the Kenai River.

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 can be accessed remotely using GoToMyPC via an AT&T Beam (providing 4G LTE service) and a Meraki wireless router.

The components shown in the diagram below are housed in the small white container in the upper left corner of the fish tote (42"x29"x28"). The batteries are stored in a separate container in the lower right corner of the fish tote. The combined charger/inverter are mounted in the third container in the lower left corner.





The Magnum Pure Sine Inverter kit (MMS1012-G1000 W/12V) combines the inverter and charger which are stored/mounted in the white container at the lower left corner of the fish tote. The controller (ME-RC50) is mounted on the top of the container. The system is powered by two AGM L16 6V batteries that are charged daily by 1000W Honda generator. Additional batteries can be added as required.

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

Note: The minor channel requires 2 batteries to run a single ARIS system whereas the right-bank requires 4 batteries to run 2 separate ARIS systems.

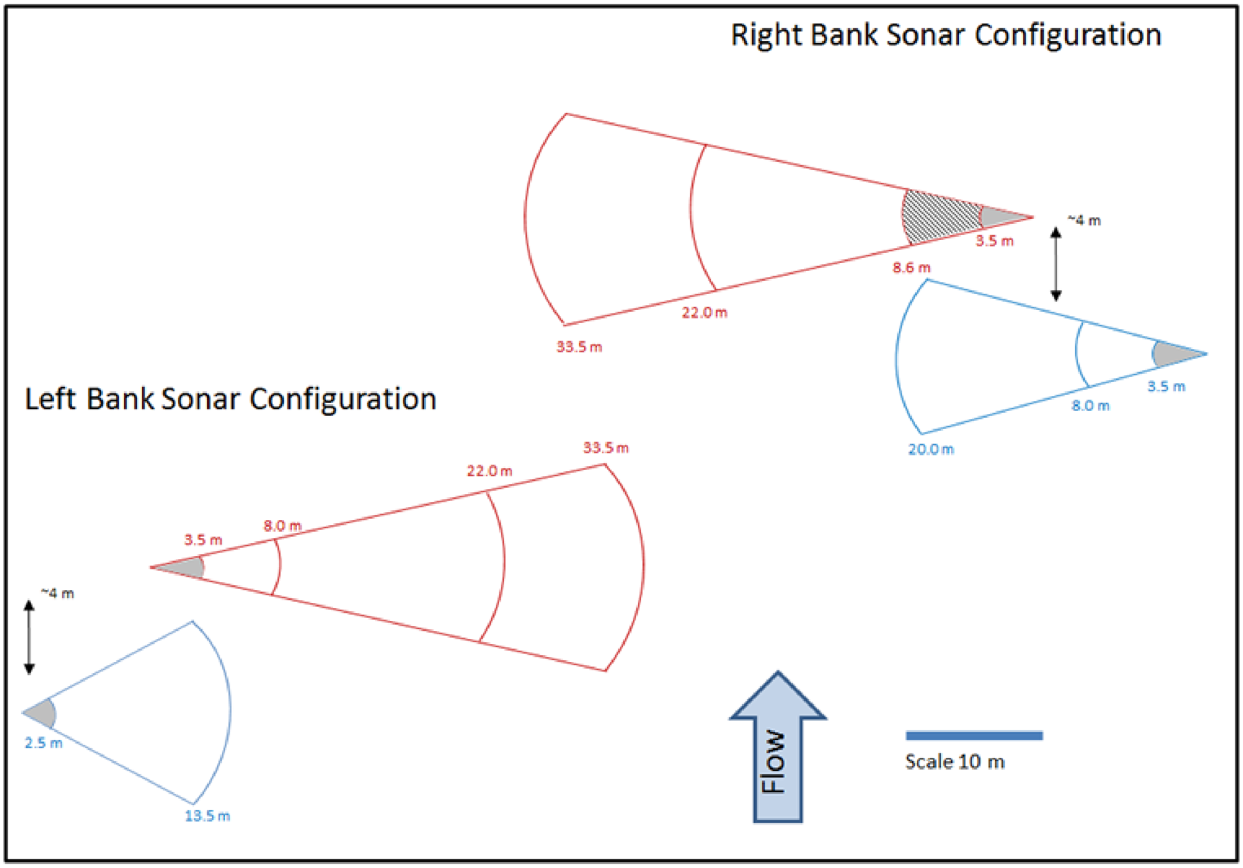
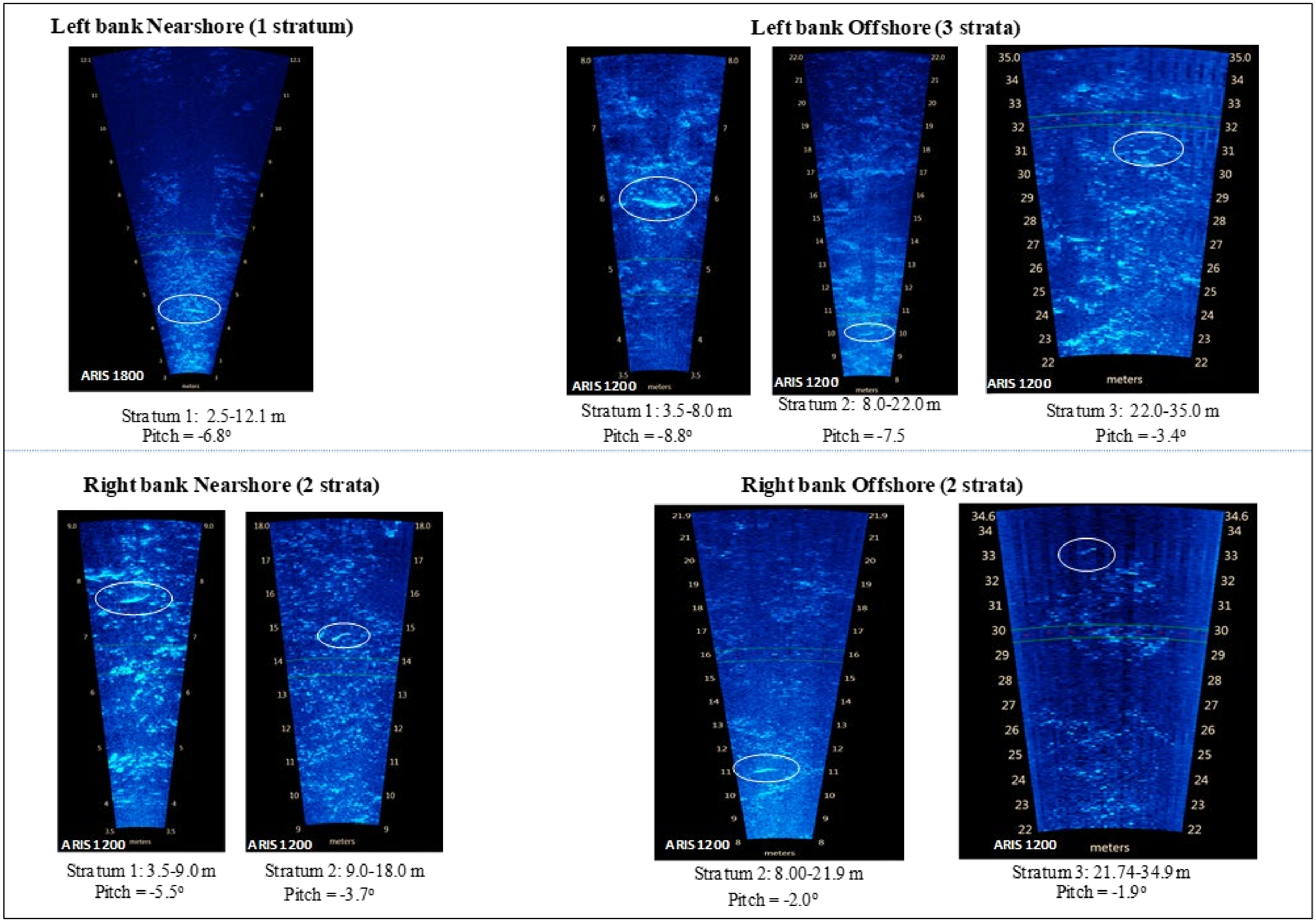


Figure 9.–Schematic for 4 range strata on the left-bank (1 nearshore range [blue], 3 offshore ranges [red]) and 4 range strata on the right-bank (2 nearshore ranges [blue], 2 offshore ranges [red]) of the main channel of the Kenai River at river mile 13.7.

Note: No data are collected (grey area) between the face of the transducer and the start of the first range stratum 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 (grey area with stripes) begins 16 May and continues to about 24 May or when increased water levels allow the right bank inshore sonar to be deployed. The right bank inshore sonar is used from that date forward, covering the area formerly covered by the right bank offshore 3.5–8.6 m stratum with the right bank inshore 8.0–20.0 m stratum.



Left bank Nearshore (1 stratum)

Stratum 1: 2.5-12.1 m
Pitch = -6.8°

Left bank Offshore (3 strata)

Stratum 1: 3.5-8.0 m
Pitch = -8.8°

Stratum 2: 8.0-22.0 m
Pitch = -7.5

Stratum 3: 22.0-35.0 m
Pitch = -3.4°

Right bank Nearshore (2 strata)

Stratum 1: 3.5-9.0 m
Pitch = -5.5°

Stratum 2: 9.0-18.0 m
Pitch = -3.7°

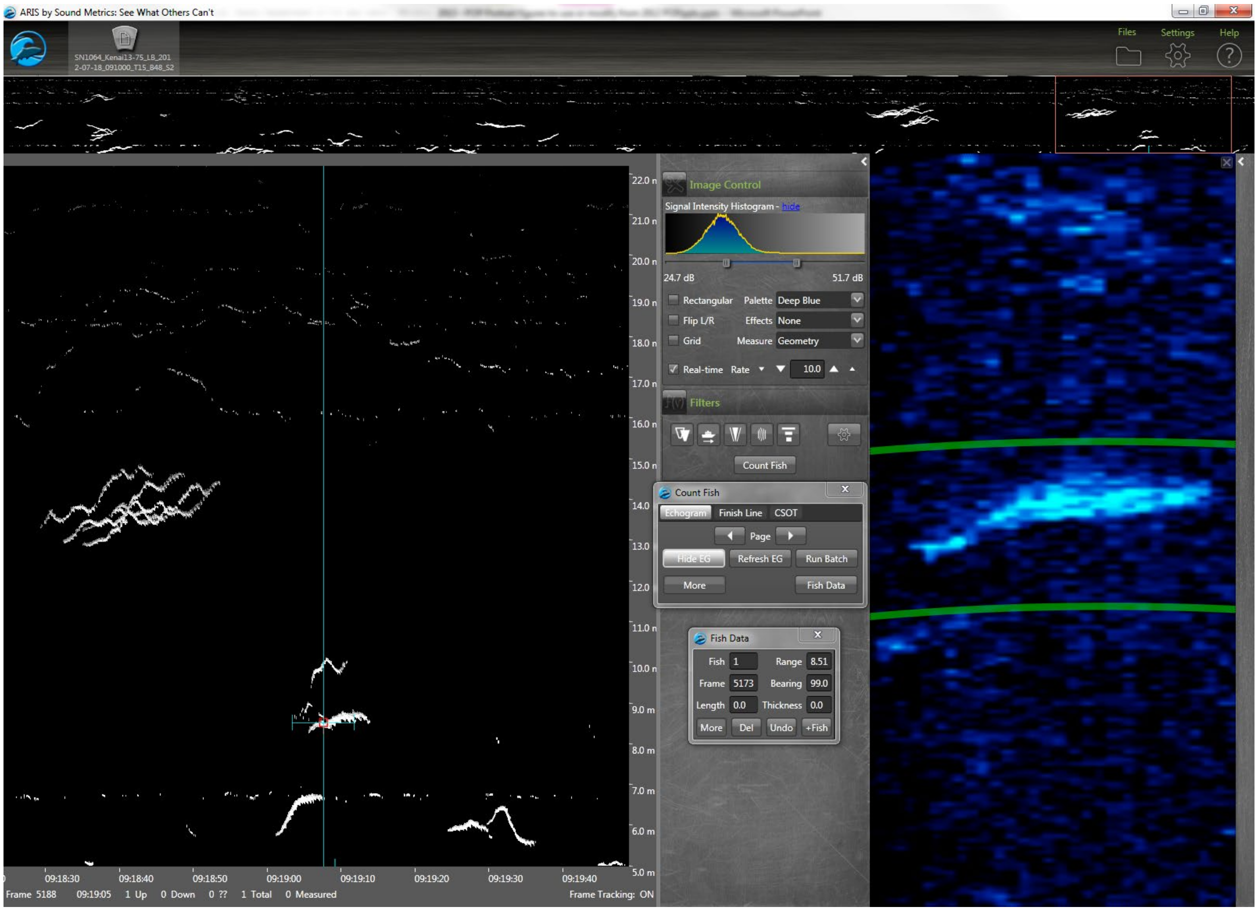
Right bank Offshore (2 strata)

Stratum 2: 8.00-21.9 m
Pitch = -2.0°

Stratum 3: 21.74-34.9 m
Pitch = -1.9°

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

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



SN1064_Kenai13-75_LB_2012-07-18_091000_T15_B48_S2

24.7 dB 51.7 dB

☐ Rectangular Palette Deep Blue

☐ Flip L/R Effects None

☐ Grid Measure Geometry

☑ Real-time Rate 10.0

Fish 1 Range 8.51

Frame 5173 Bearing 99.0

Length 0.0 Thickness 0.0

Frame 5188 09:19:05 1 Up 0 Down 0 ?? 1 Total 0 Measured

Frame Tracking: ON

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.

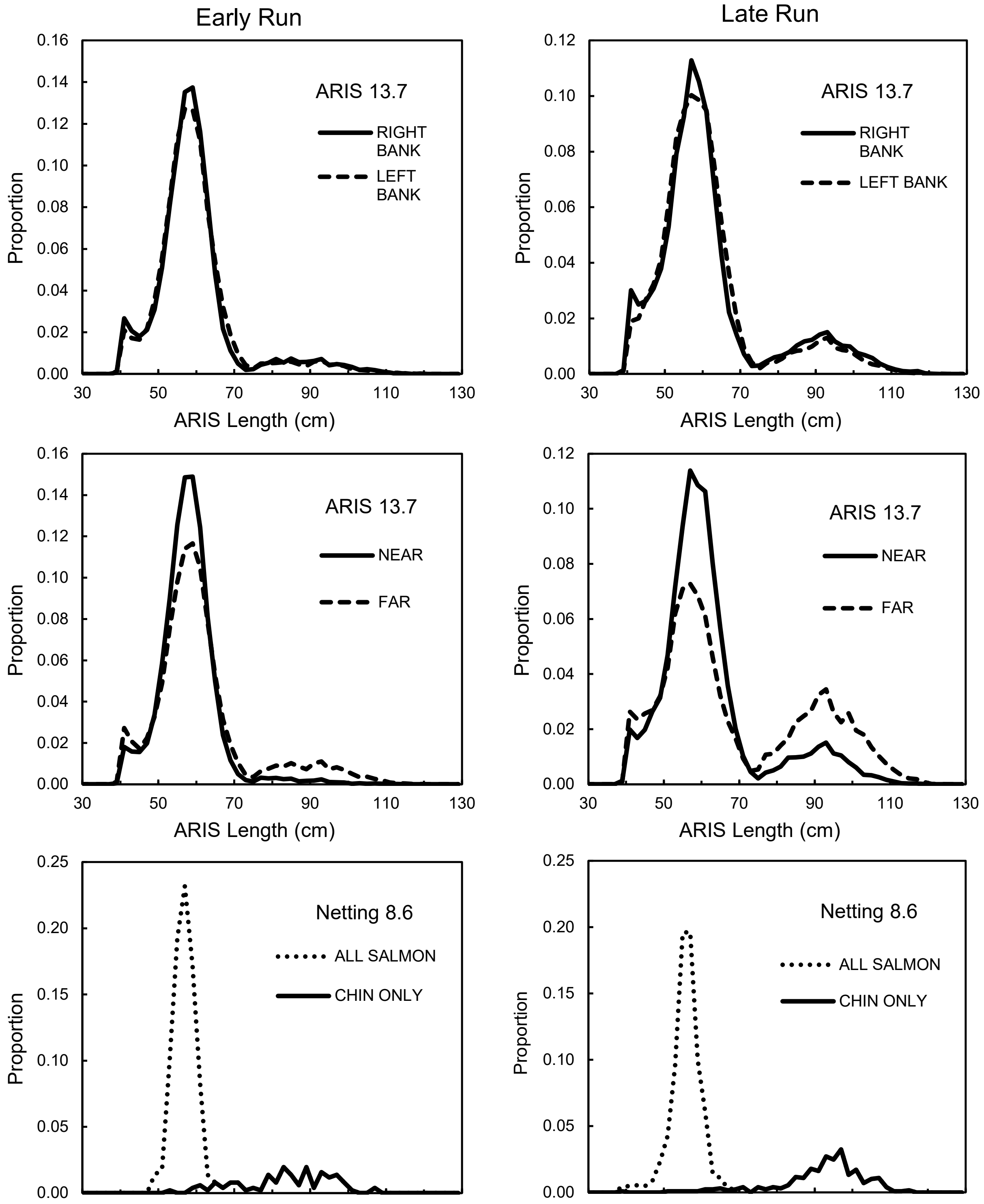


Figure 12.–Frequency distributions of ARIS lengths by bank at river mile (RM) 13.7 (top), ARIS lengths by near and far transducers (middle), and mid eye to tail fork (METF) lengths by species (all salmon vs. Chinook salmon only) from an inriver netting project at RM 8.6 (bottom), Kenai River early and late runs, 2017.

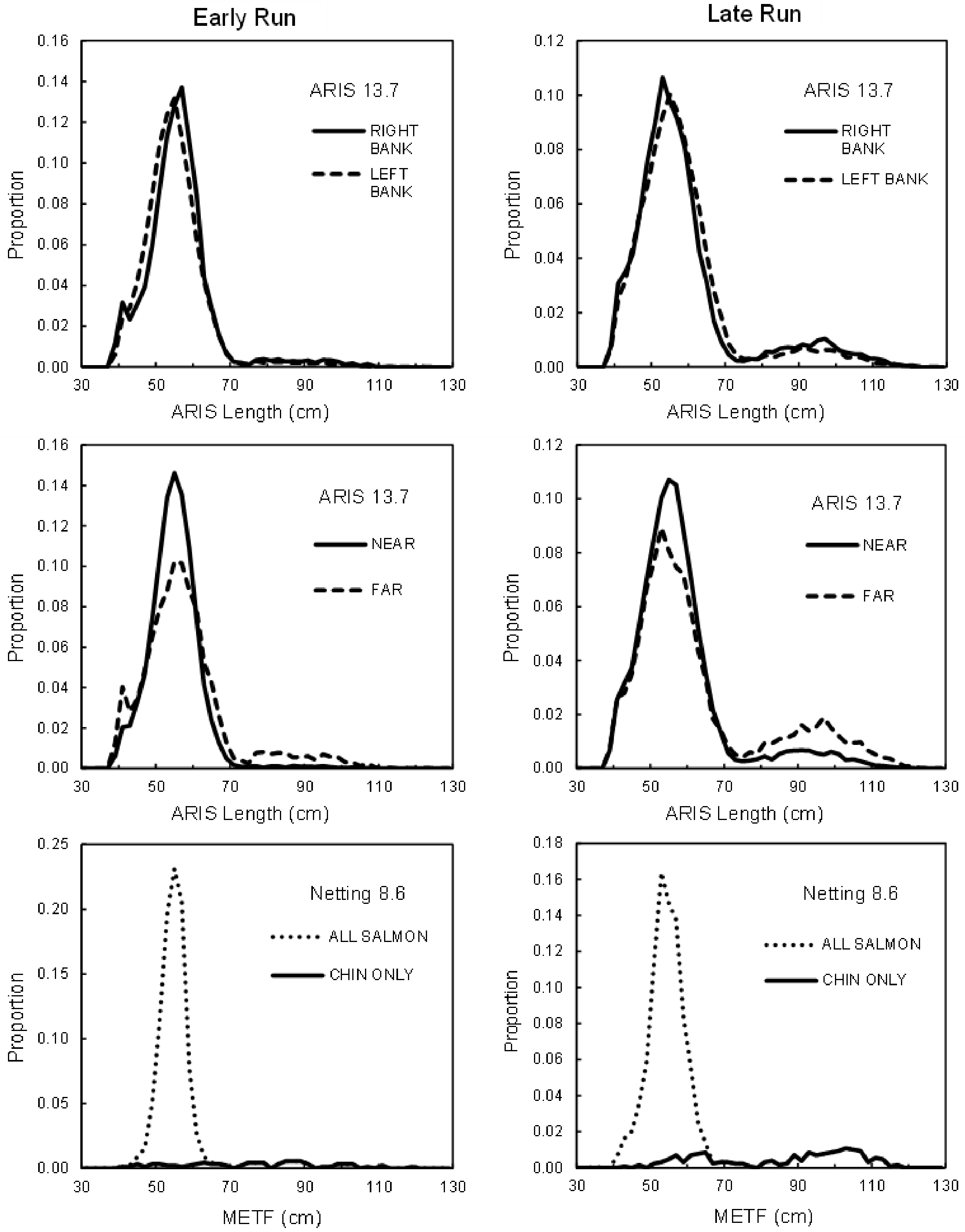


Figure 13.–Frequency distributions of ARIS lengths by bank at river mile (RM) 13.7 (top), ARIS lengths by near and far transducers (middle), and mid eye to tail fork (METF) lengths by species (all salmon vs. Chinook salmon only) from an inriver netting project at RM 8.6 (bottom), Kenai River early and late runs, 2018.

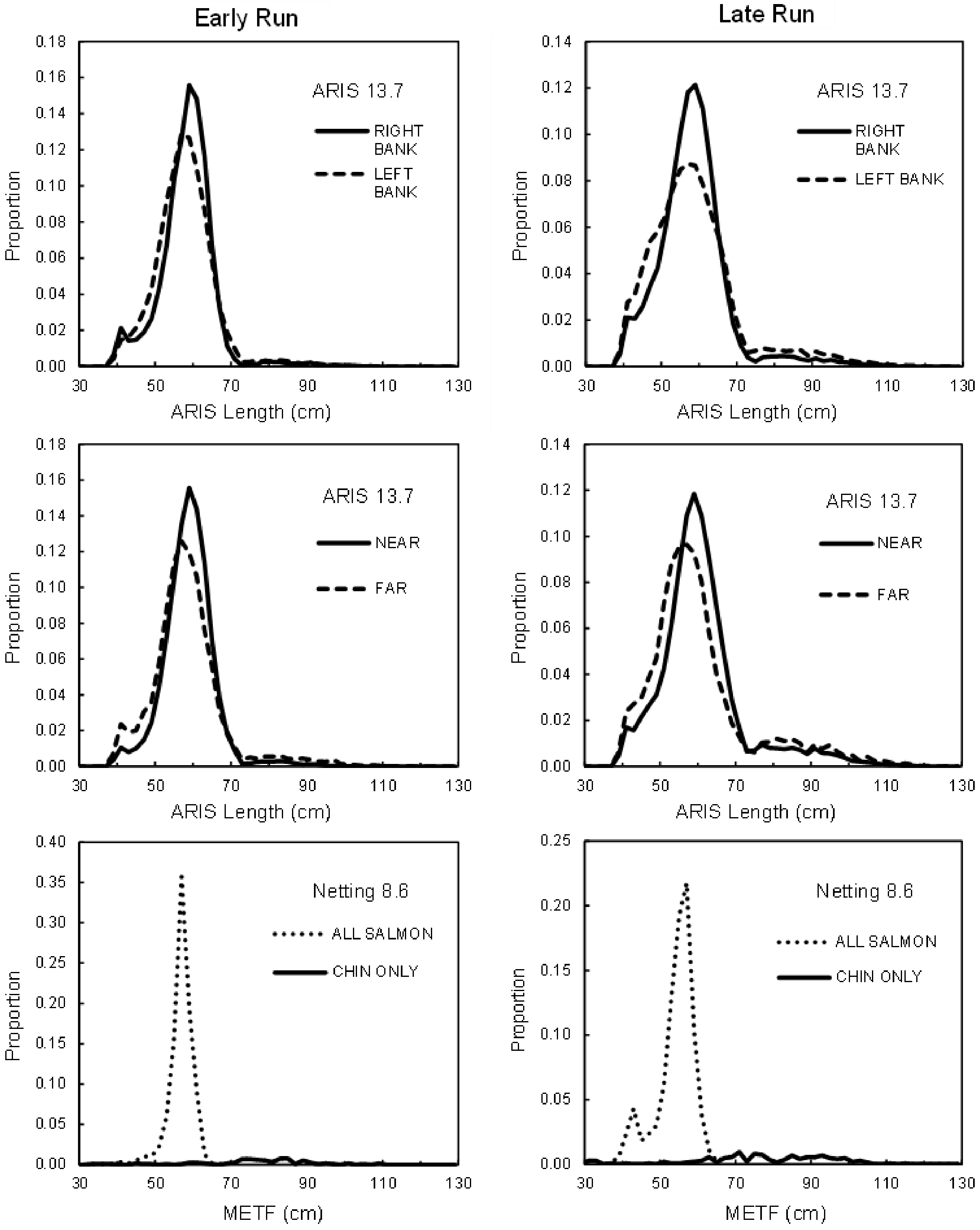
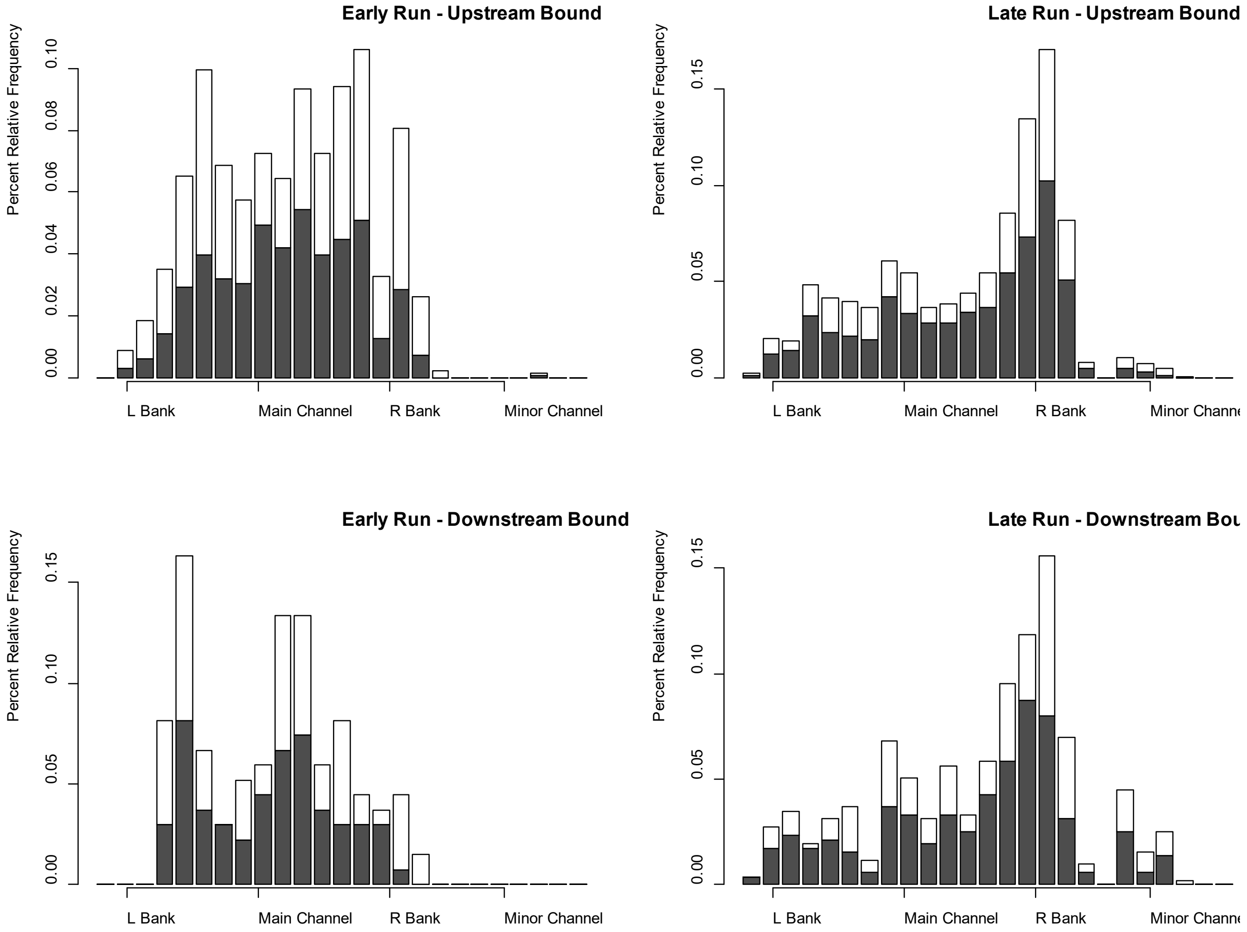


Figure 14.–Frequency distributions of ARIS lengths by bank at river mile (RM) 13.7 (top), ARIS lengths by near and far transducers (middle), and mid eye to tail fork (METF) lengths by species (all salmon vs. Chinook salmon only) from an inriver netting project at RM 8.6 (bottom), Kenai River early and late runs, 2019



Early Run - Upstream Bound

Late Run - Upstream Bound

Early Run - Downstream Bound

Late Run - Downstream Bou

Figure 15.–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, river mile 13.7, Kenai River, 2017.

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

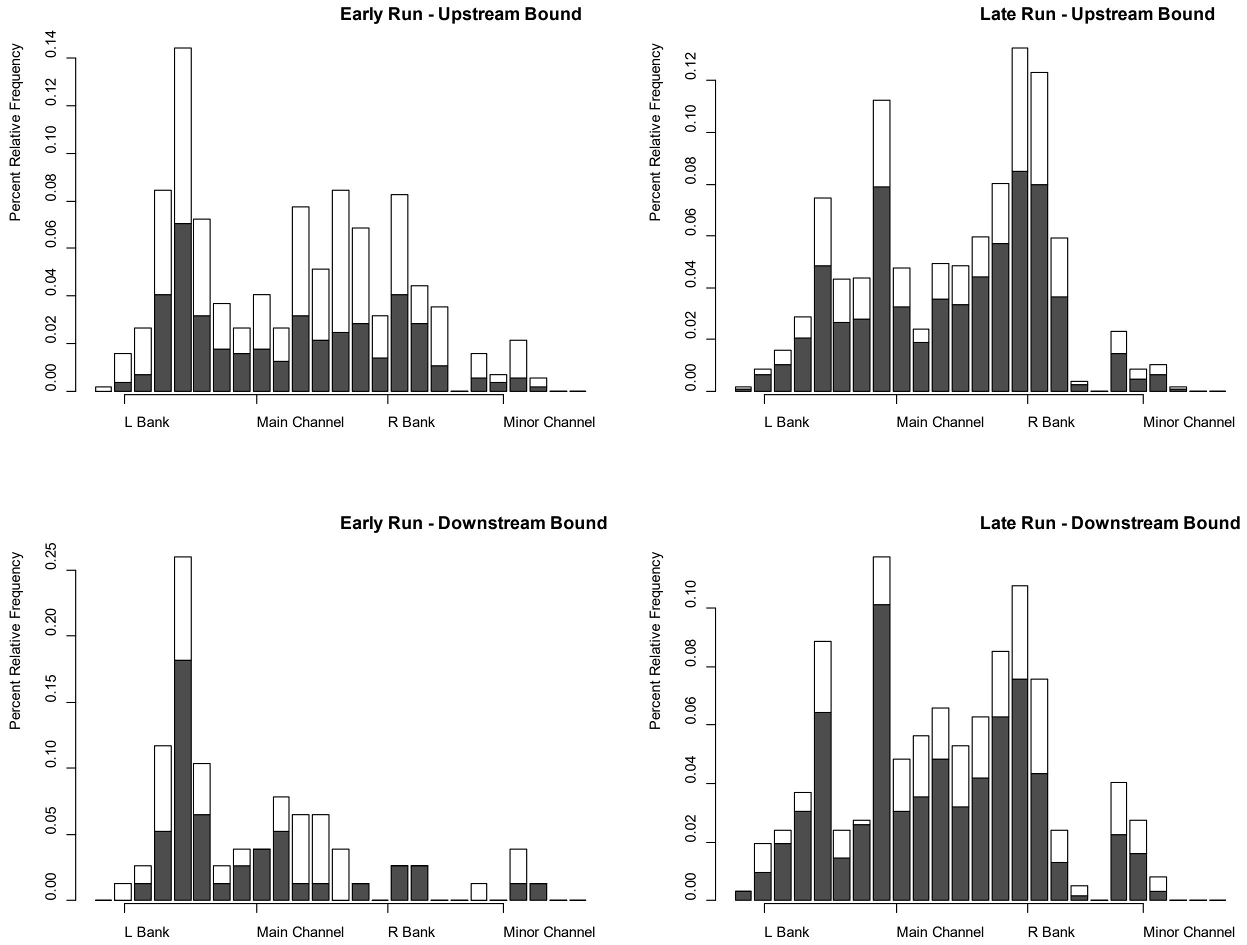


Figure 16.–Horizontal distribution, in 5 m increments from the left-bank main channel shore to the right-bank minor channel shore, of medium (75 cm ≤ AL < 90 cm, open bars) and large (AL ≥90 cm, solid bars) early- and late-run fish measured from ARIS at river mile 13.7, Kenai River, 2018.

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

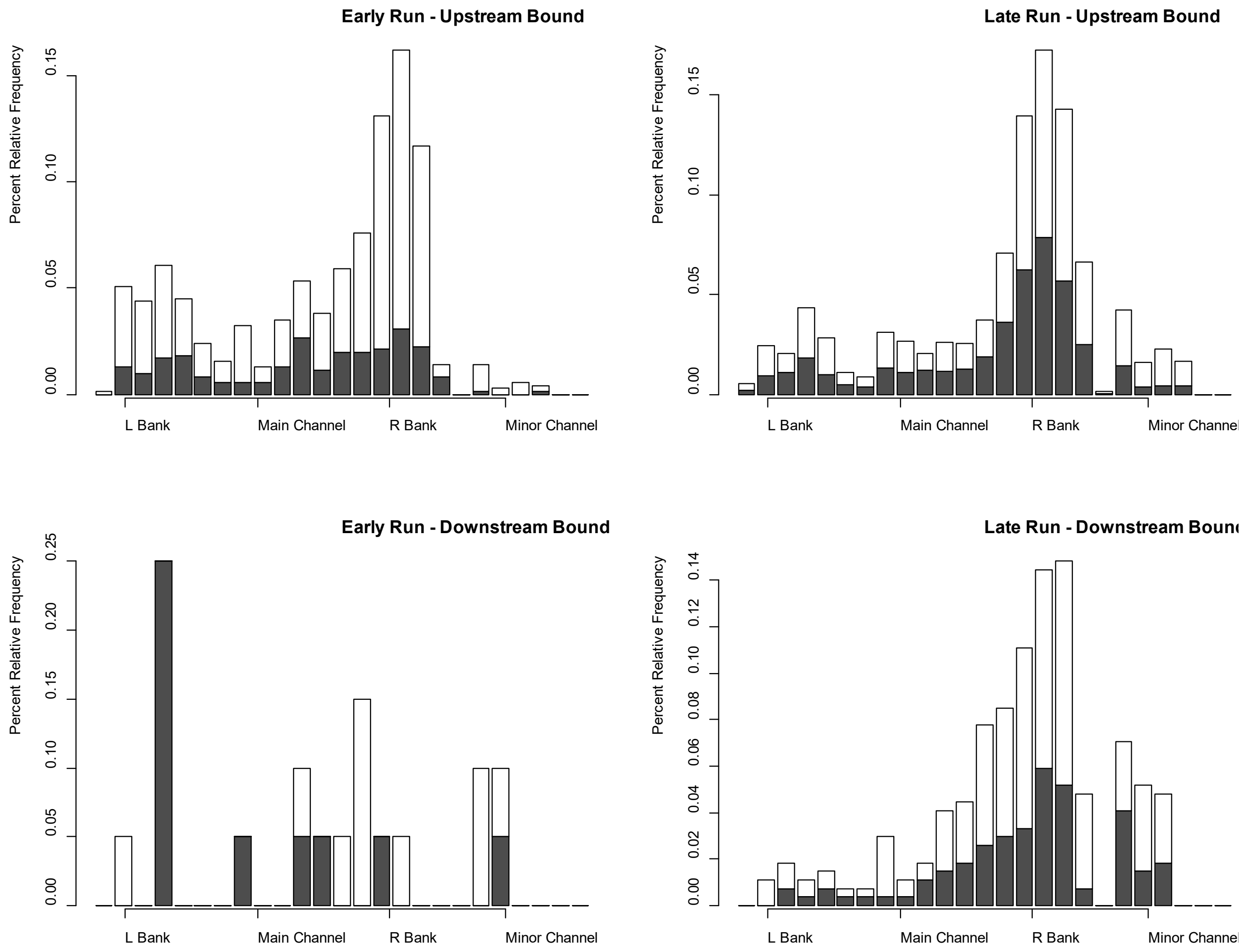


Figure 17.–Horizontal distribution, in 5 m increments from the left-bank main channel shore to the right-bank minor channel shore, of medium (75 cm ≤ AL < 90 cm, open bars) and large (AL ≥90 cm, solid bars) early- and late-run fish measured from ARIS at river mile 13.7, Kenai River, 2019.

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

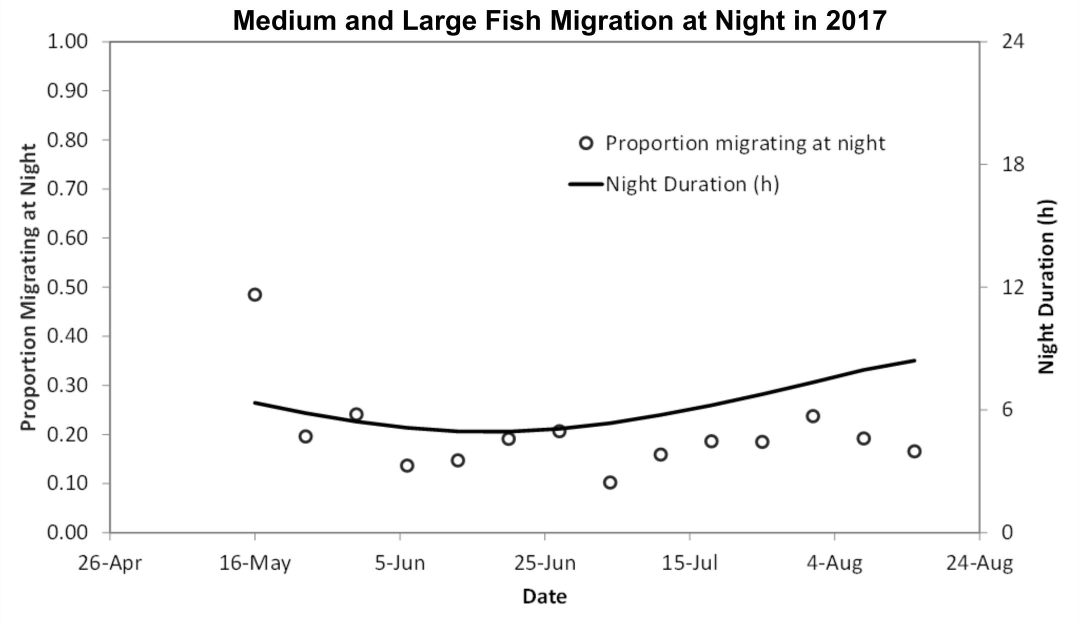


Figure 18.–Weekly proportions of fish greater than 75 cm AL migrating upstream at night (between sunset and sunrise; circles) compared to night duration (solid line) in Kenai, Alaska, 2017.

Note: 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. AL = ARIS length.

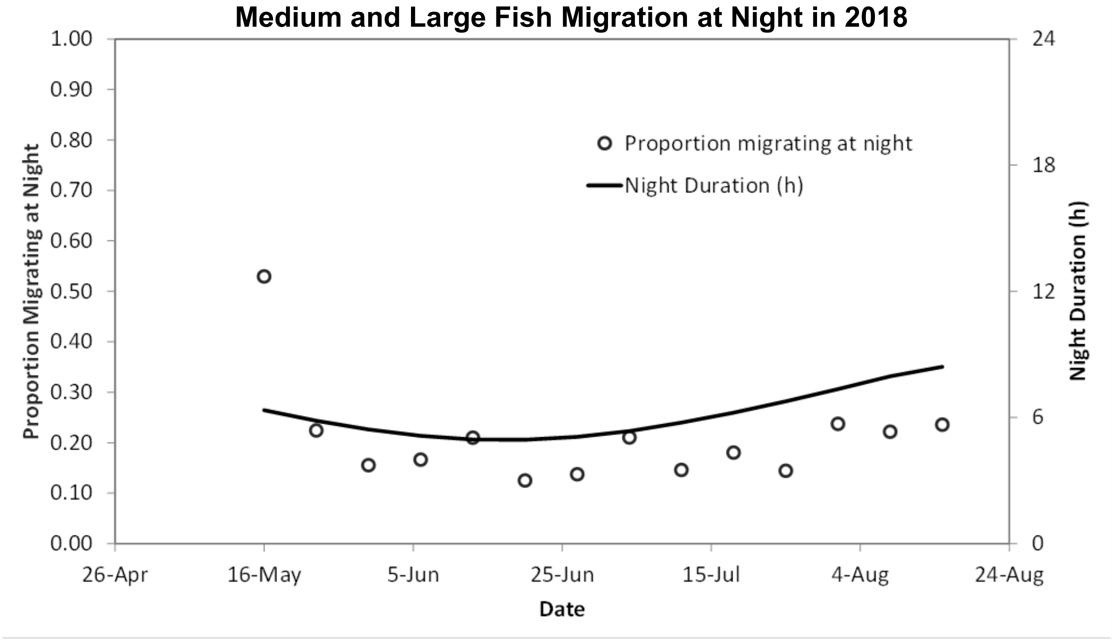


Figure 19.–Weekly proportions of fish greater than 75 cm AL migrating upstream at night (between sunset and sunrise; circles) compared to night duration (solid line) in Kenai, Alaska, 2018.

Note: 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. AL = ARIS length.

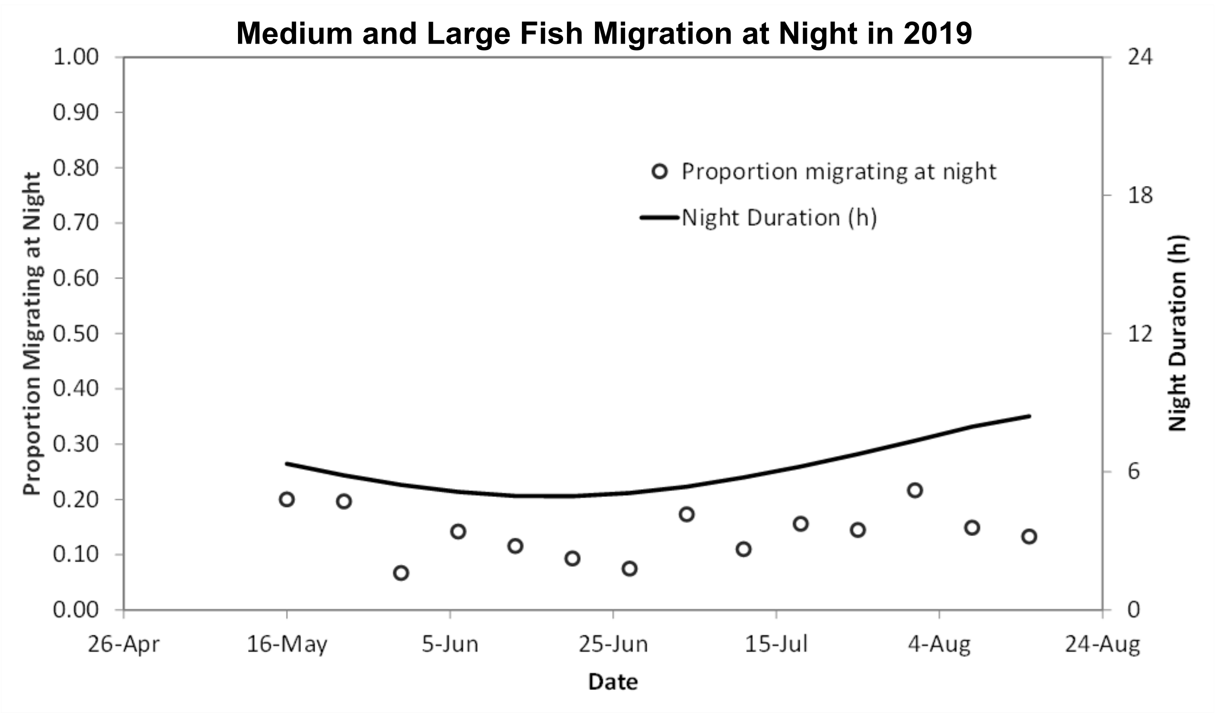


Figure 20.–Weekly proportions of fish greater than 75 cm AL migrating upstream at night (between sunset and sunrise; circles) compared to night duration (solid line) in Kenai, Alaska, 2019.

Note: 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. AL = ARIS length.

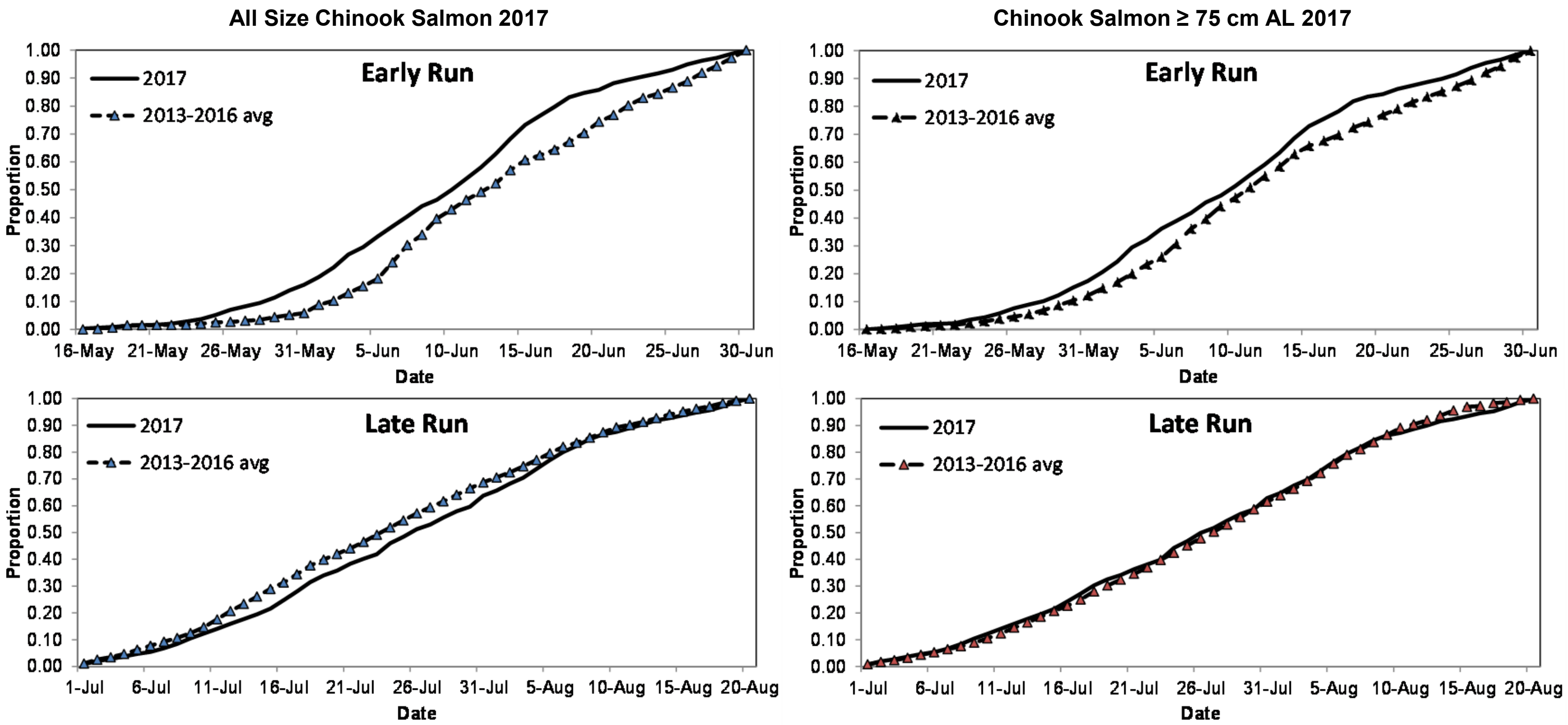
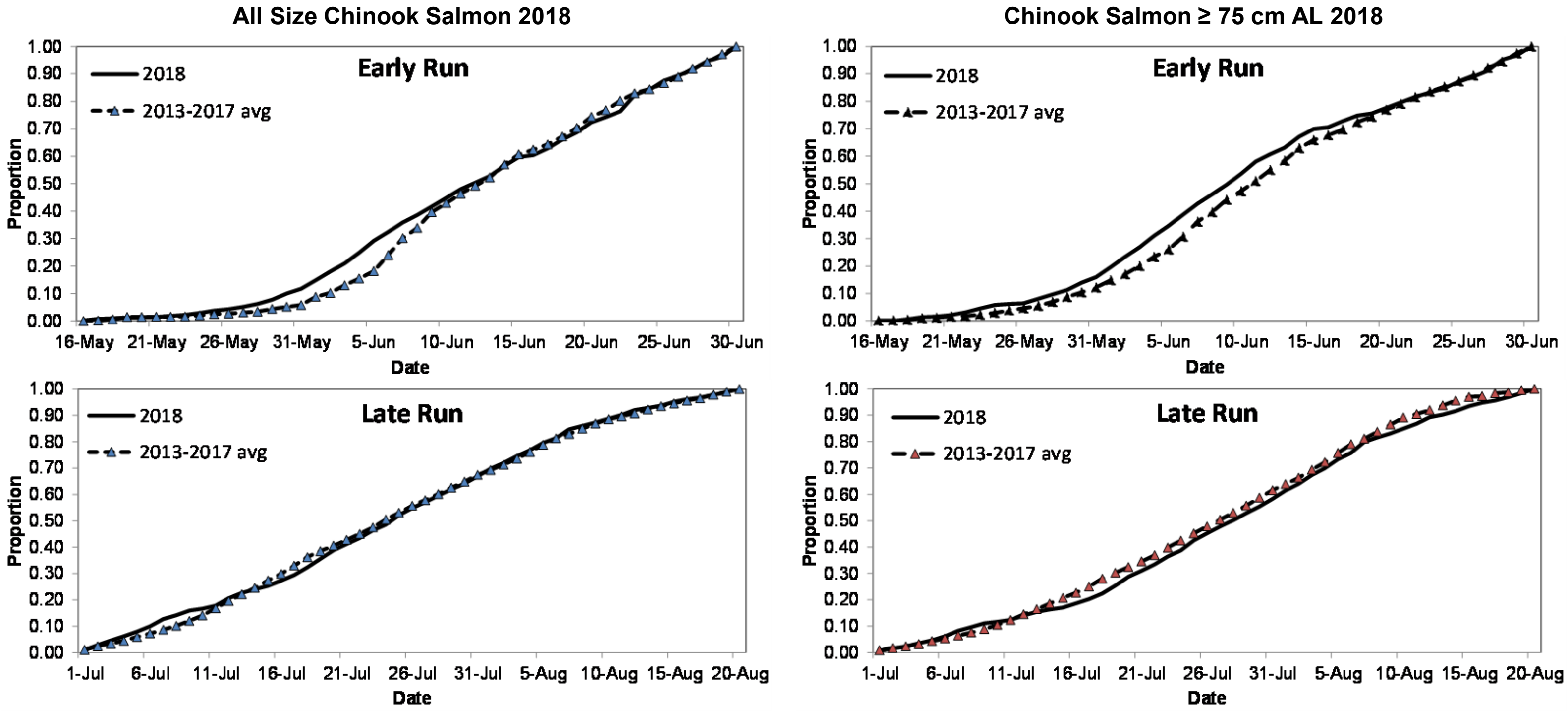


Figure 21.–Cumulative proportion of passage by day for early-run all-size Chinook salmon (top left) and medium and large (≥75 cm AL) Chinook salmon only (top right), as well as late-run all-size (bottom left) and late-run medium and large only (bottom right), Kenai River at river mile 13.7, 2017 and the 2013–2016 average.

Note: AL = ARIS length. Proportions of Chinook salmon are based on AL mixture model.


All Size Chinook Salmon 2018

Chinook Salmon ≥ 75 cm AL 2018

Figure 22.–Cumulative proportion of passage by day for early-run all-size Chinook salmon (top left) and medium and large (≥75 cm AL) Chinook salmon only (top right), as well as late-run all-size (bottom left) and late-run medium and large only (bottom right), Kenai River at river mile 13.7, 2018 and the 2013–2016 average.

Note: AL = ARIS length. Proportions of Chinook salmon are based on AL mixture model.

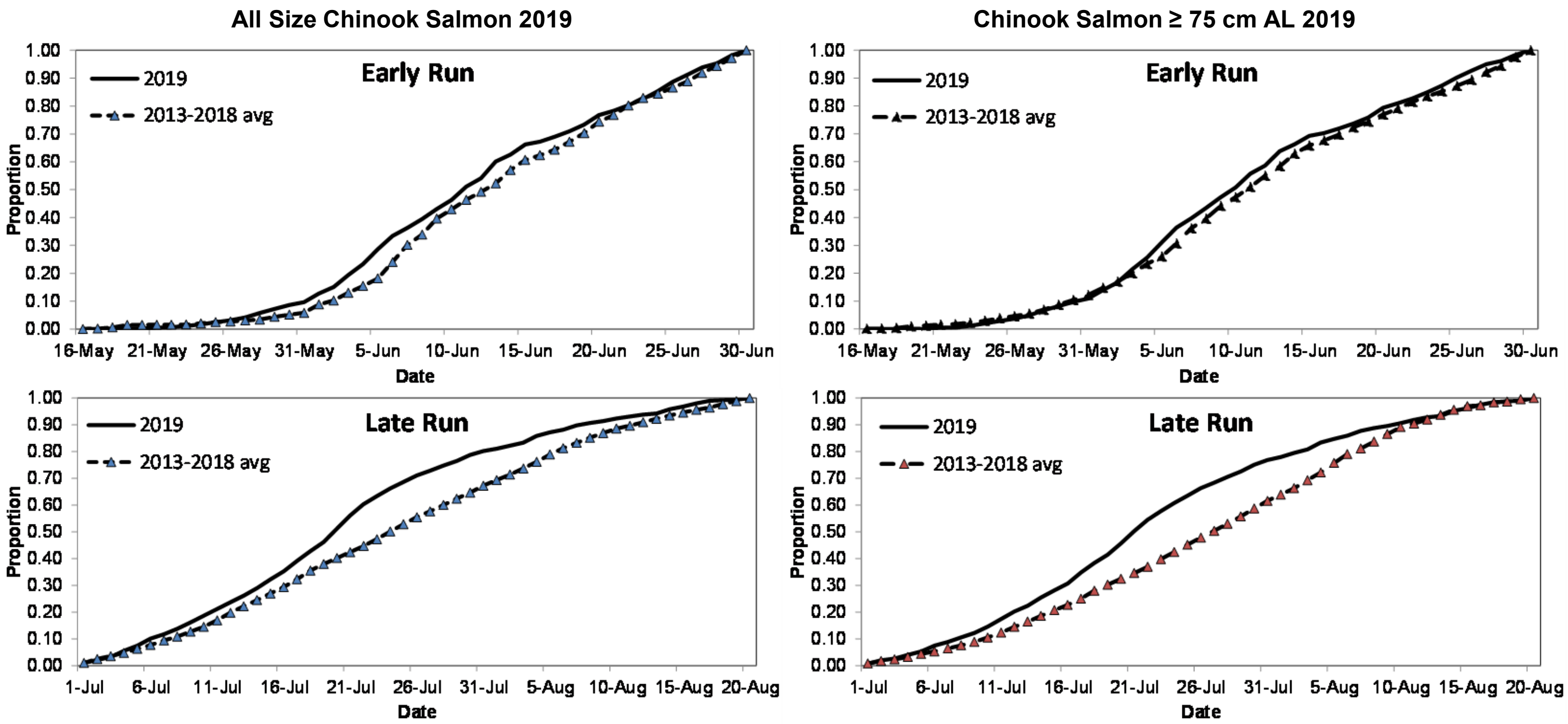


Figure 23.–Cumulative proportion of passage by day for early-run all-size Chinook salmon (top left) and medium and large (≥75 cm AL) Chinook salmon only (top right), as well as late-run all-size (bottom left) and late-run medium and large only (bottom right), Kenai River at river mile 13.7, 2019 and the 2013–2016 average.

Note: AL = ARIS length. Proportions of Chinook salmon are based on AL mixture model.

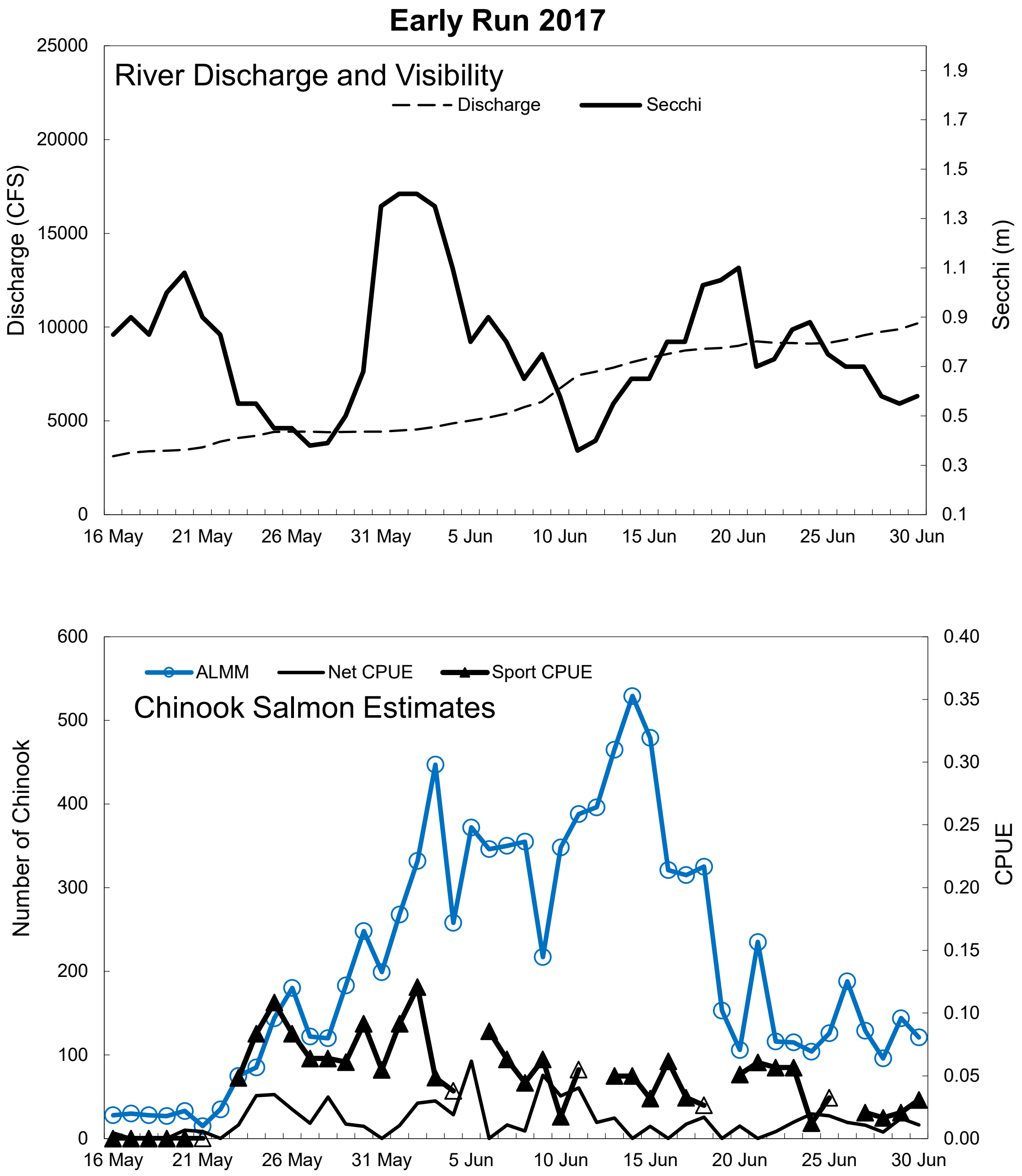


Figure 24.–Daily discharge rates collected at the Soldotna Bridge and Secchi disk readings taken at the river mile (RM) 8.6 netting site (top); and ARIS-length mixture model (ALMM) estimates of net upstream Chinook salmon passage at RM 13.7, inriver gillnet Chinook salmon CPUE at RM 8.6, and Chinook salmon sport fishery CPUE (bottom), during the Kenai River Chinook salmon early run, 2017.

Note: River discharge taken from USGS Water resource data, Alaska, water year 2017 (Website: Daily Streamflow for Alaska, Soldotna gauging station, site #15266300, accessed November 2020 at https://waterdata.usgs.gov/usa/nwis/uv?site_no=15266300). Net CPUE from Wood and Eskelin (*In prep*). Open triangles represent days on which only unguided anglers were allowed to fish.

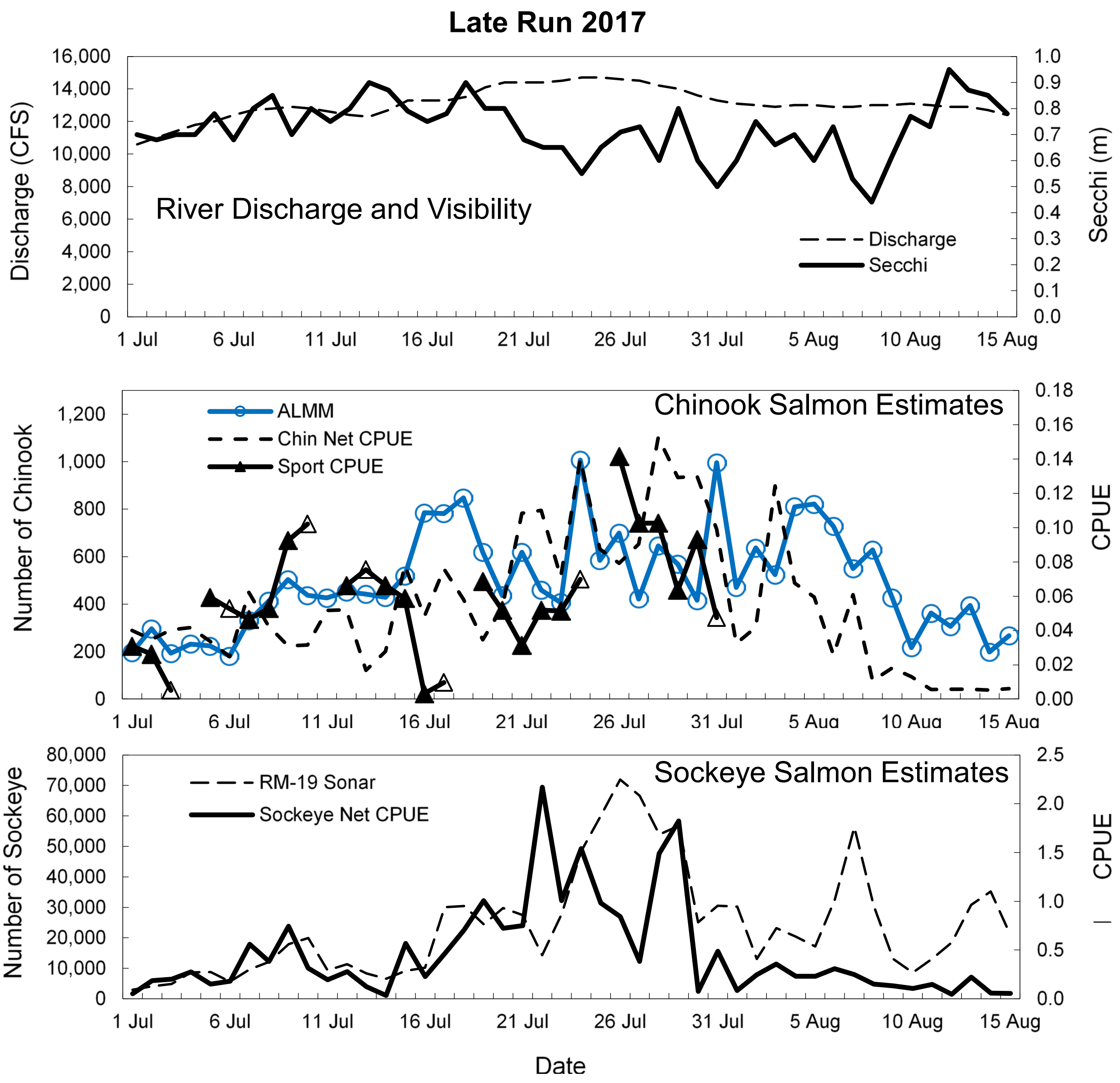


Figure 25.–Daily discharge rates collected at the Soldotna Bridge and Secchi disk readings taken at the river mile (RM) 8.6 netting site (top); ARIS-length mixture model (ALMM) estimates of net upstream Chinook salmon passage at RM 13.7, inriver gillnet Chinook salmon CPUE at RM 8.6 (middle); RM 19 sockeye salmon sonar passage and inriver gillnet sockeye salmon CPUE at RM 8.6 (bottom) during the Kenai River Chinook salmon late run, 2017.

Note: River discharge taken from USGS Water resource data, Alaska, water year 2017 (Website: Daily Streamflow for Alaska, Soldotna gauging station, site #15266300, accessed November 2020 at http://water.usgs.gov/ak/nwis/discharge). Net CPUE from Wood and Eskelin (*In prep*). RM 19 sonar estimates are unpublished data from W. J. Glick, Division of Commercial Fisheries, ADF&G, Soldotna. Open triangles represent days on which only unguided anglers were allowed to fish. The late-run sport fishery closed by regulation July 31.

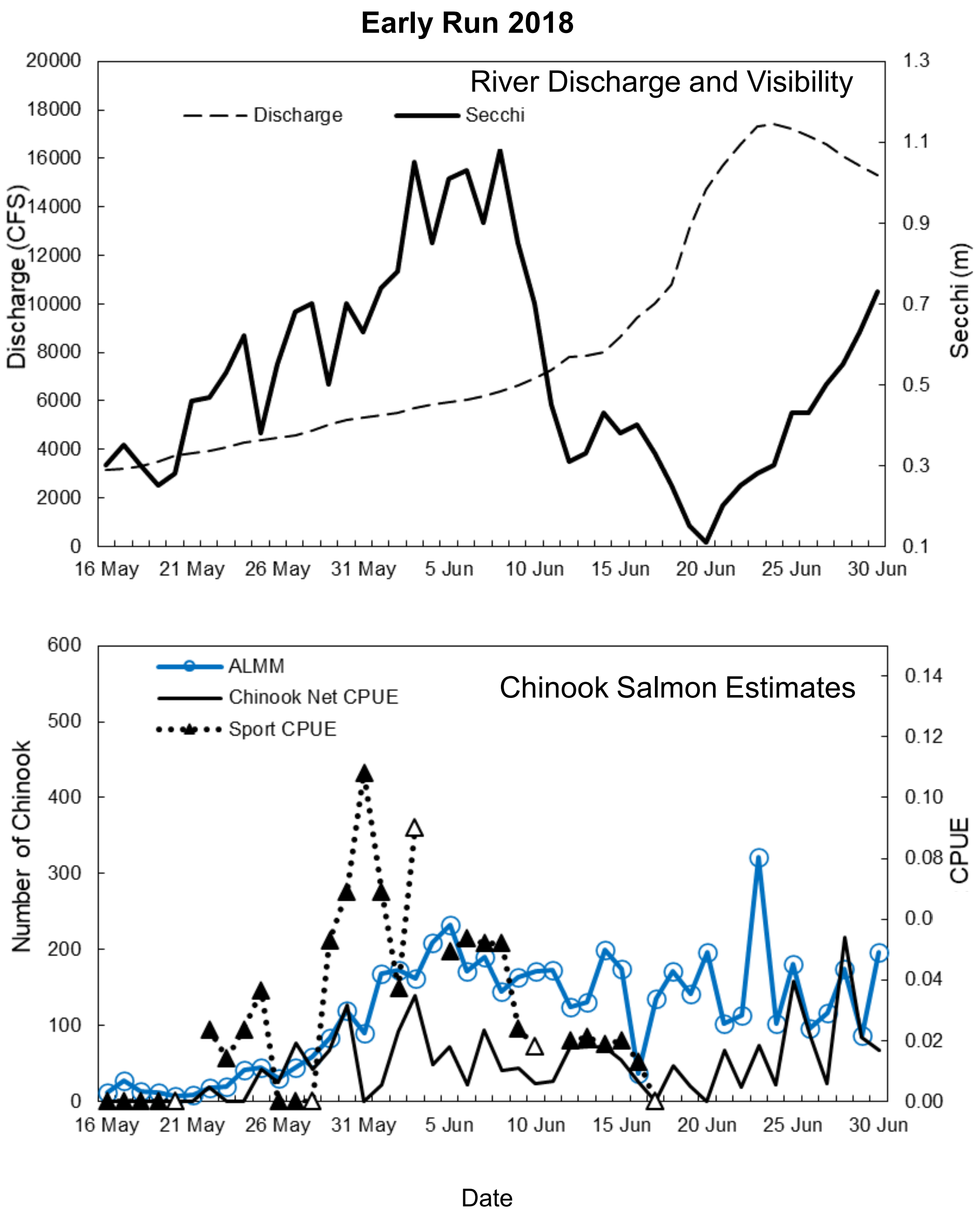


Figure 26.–Daily discharge rates collected at the Soldotna Bridge and Secchi disk readings taken at the river mile (RM) 8.6 netting site (top); and ARIS-length mixture model (ALMM) estimates of net upstream Chinook salmon passage at RM 13.7, inriver gillnet Chinook salmon CPUE at RM 8.6 (bottom) during the Kenai River Chinook salmon early run, 2018.

Note: River discharge taken from USGS Water resource data, Alaska, water year 2018 (Website: Daily Streamflow for Alaska, Soldotna gauging station, site #15266300, accessed November 2020 at https://waterdata.usgs.gov/usa/nwis/uv?site_no=15266300. Net CPUE from Wood and Eskelin (*In prep*). Open triangles represent days on which only unguided anglers were allowed to fish.

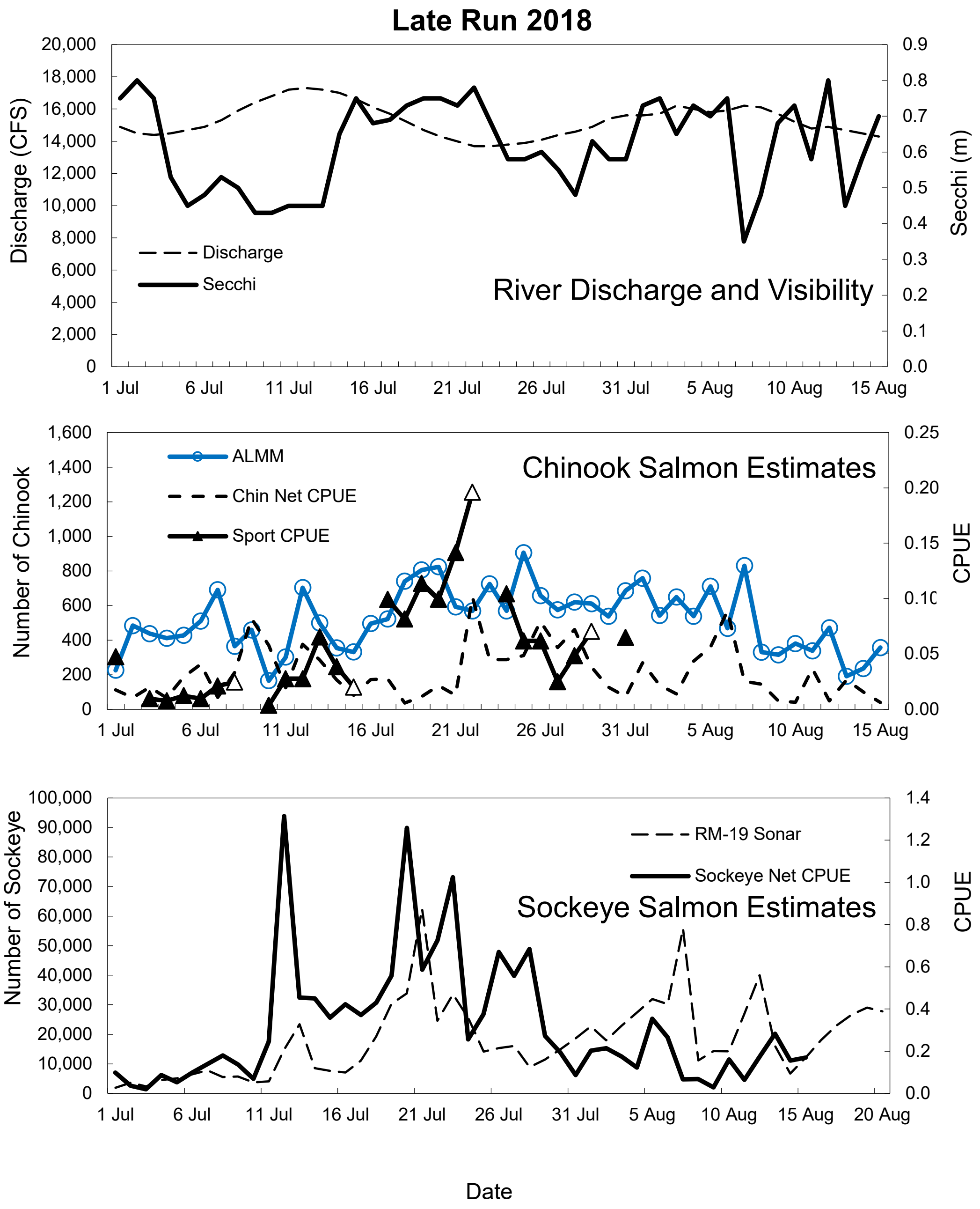


Figure 27.–Daily discharge rates collected at the Soldotna Bridge and Secchi disk readings taken at the river mile (RM) 8.6 netting site (top); ARIS-length mixture model (ALMM) estimates of net upstream Chinook salmon passage at RM 13.7, inriver gillnet Chinook salmon CPUE at RM 8.6 (middle); RM 19 sockeye salmon sonar passage and inriver gillnet sockeye salmon CPUE at RM 8.6 (bottom) during the Kenai River Chinook salmon late run, 2018.

Note: River discharge taken from USGS Water resource data, Alaska, water year 2018 (Website: Daily Streamflow for Alaska, Soldotna gauging station, site #15266300, accessed November 2020 at http://water.usgs.gov/ak/nwis/discharge). Net CPUE from Wood and Eskelin (*In prep*). RM 19 sonar estimates are unpublished data from W.J. Glick, Division of Commercial Fisheries, ADF&G, Soldotna. Open triangles represent days on which only unguided anglers were allowed to fish. The late-run sport fishery prohibited the use of bait 1 July and went to no retention 18 July until closure.

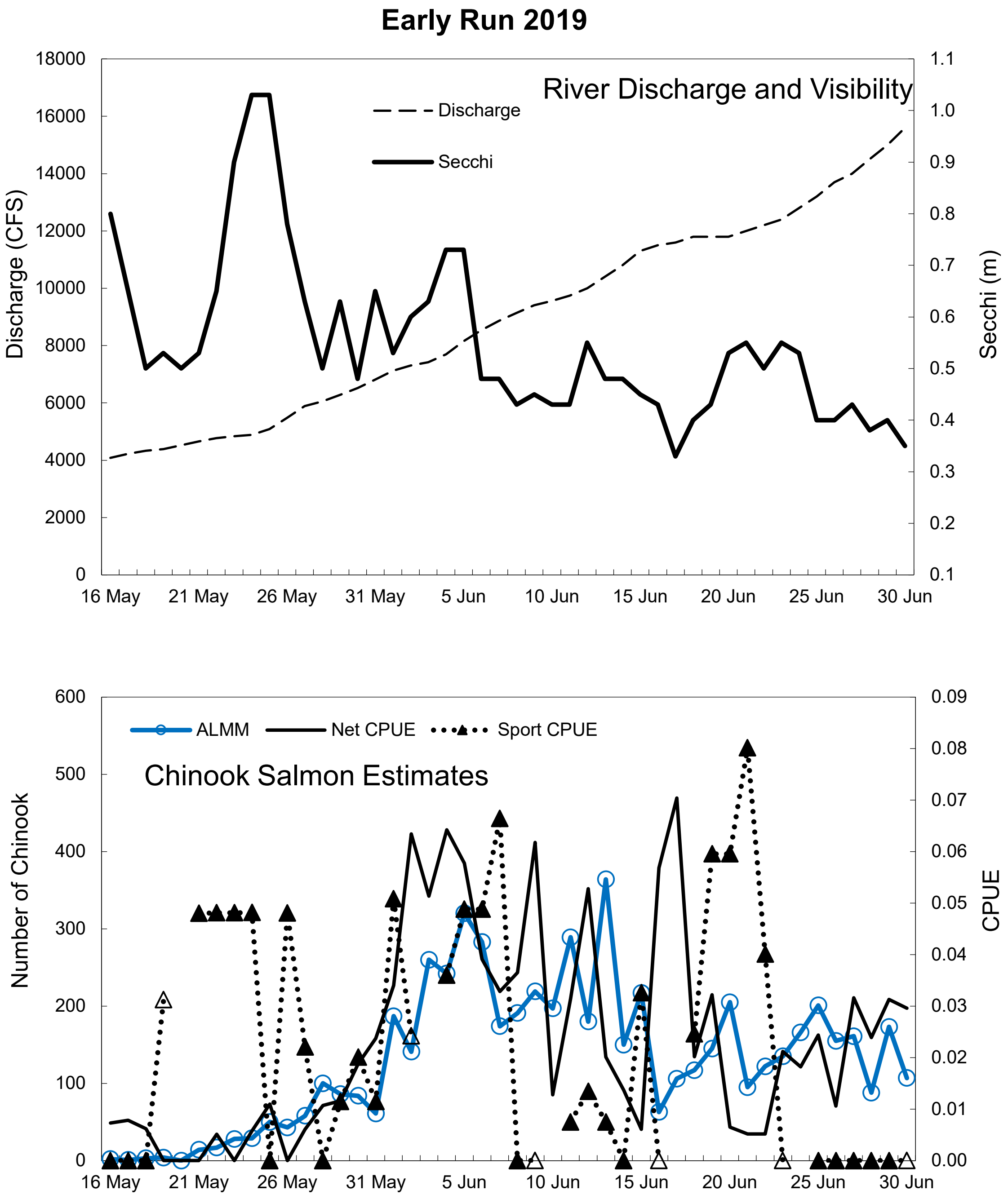


Figure 28.–Daily discharge rates collected at the Soldotna Bridge and Secchi disk readings taken at the river mile (RM) 8.6 netting site (top); and ARIS-length mixture model (ALMM) estimates of net upstream Chinook salmon passage at RM 13.7, inriver gillnet Chinook salmon CPUE at RM 8.6 (bottom) during the Kenai River Chinook salmon early run, 2019.

Note: River discharge taken from USGS Water resource data, Alaska, water year 2018 (Website: Daily Streamflow for Alaska, Soldotna gauging station, site #15266300, accessed November 2020 at https://waterdata.usgs.gov/usa/nwis/uv?site_no=15266300). Net CPUE from Wood and Eskelin (*In prep*). Open triangles represent only unguided CPUE.

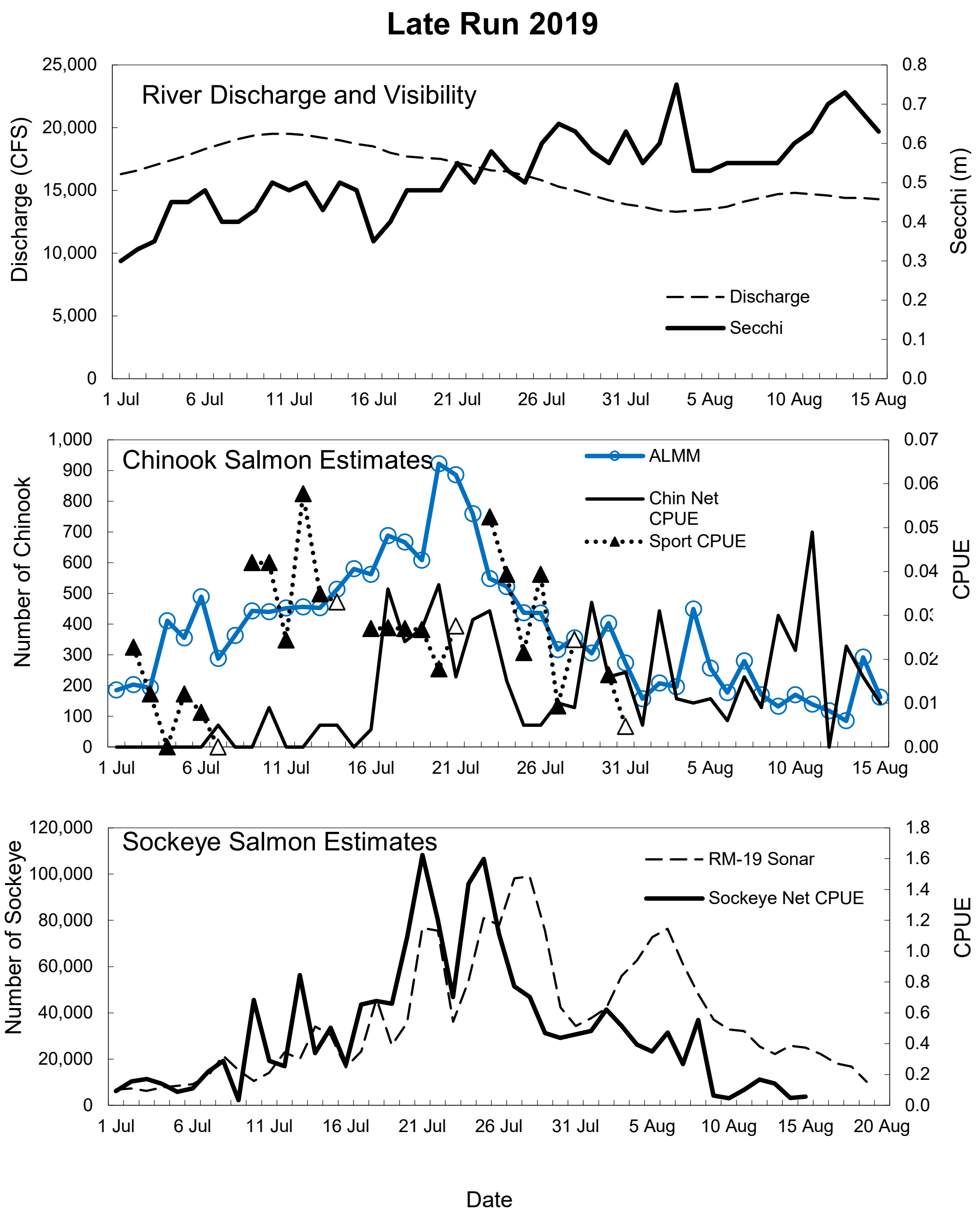


Figure 29.–Daily discharge rates collected at the Soldotna Bridge and Secchi disk readings taken at the river mile (RM) 8.6 netting site (top); ARIS-length mixture model (ALMM) estimates of net upstream Chinook salmon passage at RM 13.7, inriver gillnet Chinook salmon CPUE at RM 8.6 (middle); RM 19 sockeye salmon sonar passage and inriver gillnet sockeye salmon CPUE at RM 8.6 (bottom) during the Kenai River Chinook salmon late run, 2019.

Note: River discharge taken from USGS Water resource data, Alaska, water year 2019 (Website: Daily Streamflow for Alaska, Soldotna gauging station, site #15266300, accessed November 2020 at http://water.usgs.gov/ak/nwis/discharge). Net CPUE from Wood and Eskelin (*In prep*). RM 19 sonar estimates are unpublished data from W. J. Glick, Division of Commercial Fisheries, ADF&G, Soldotna. Open triangles represent days on which only unguided anglers were allowed to fish. The late-run sport fishery prohibited the use of bait 1 July and closed by regulation 31 July.

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 2 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.

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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.

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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 w/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

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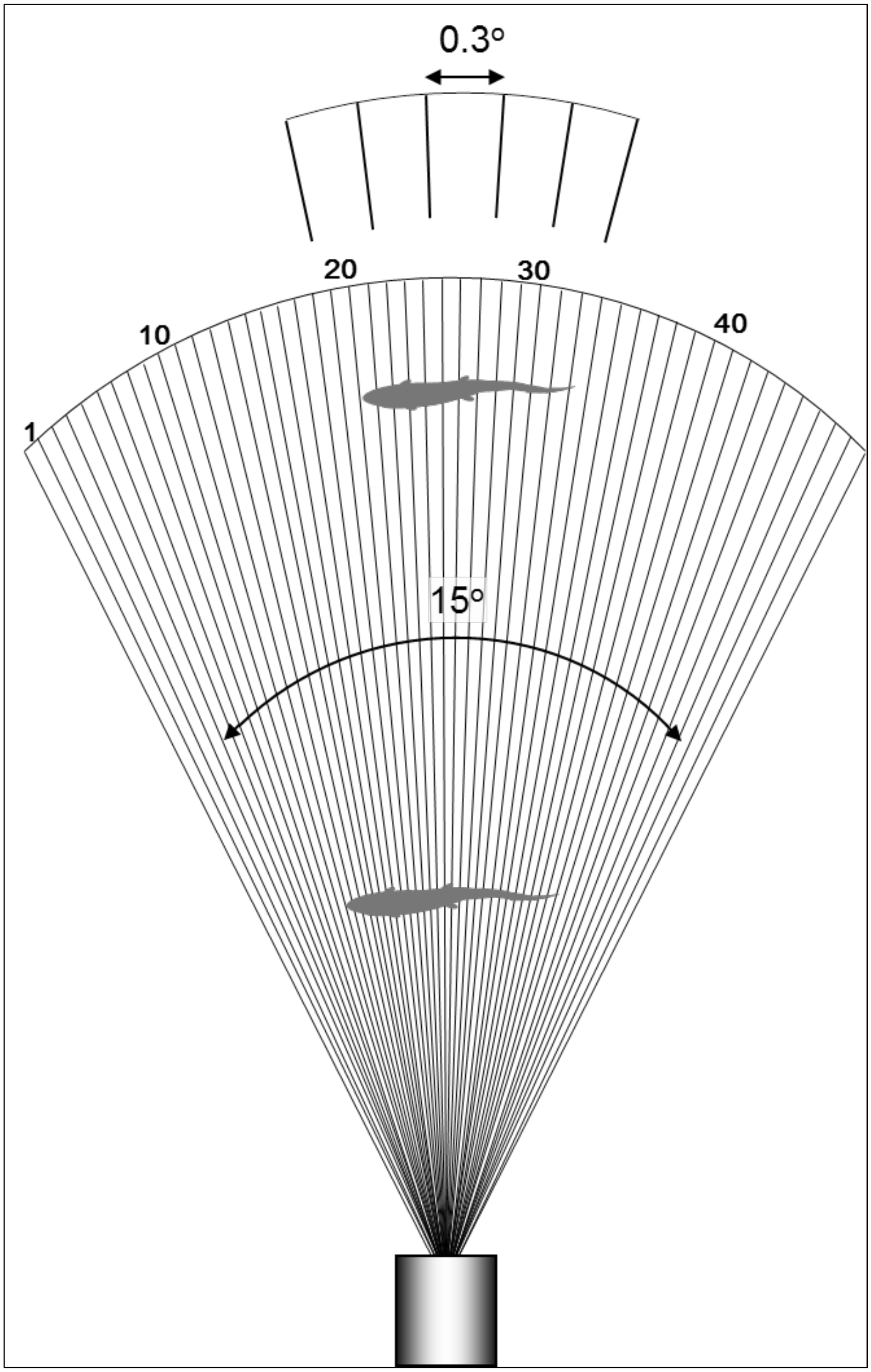
ARIS 1200 Specifications (continued)

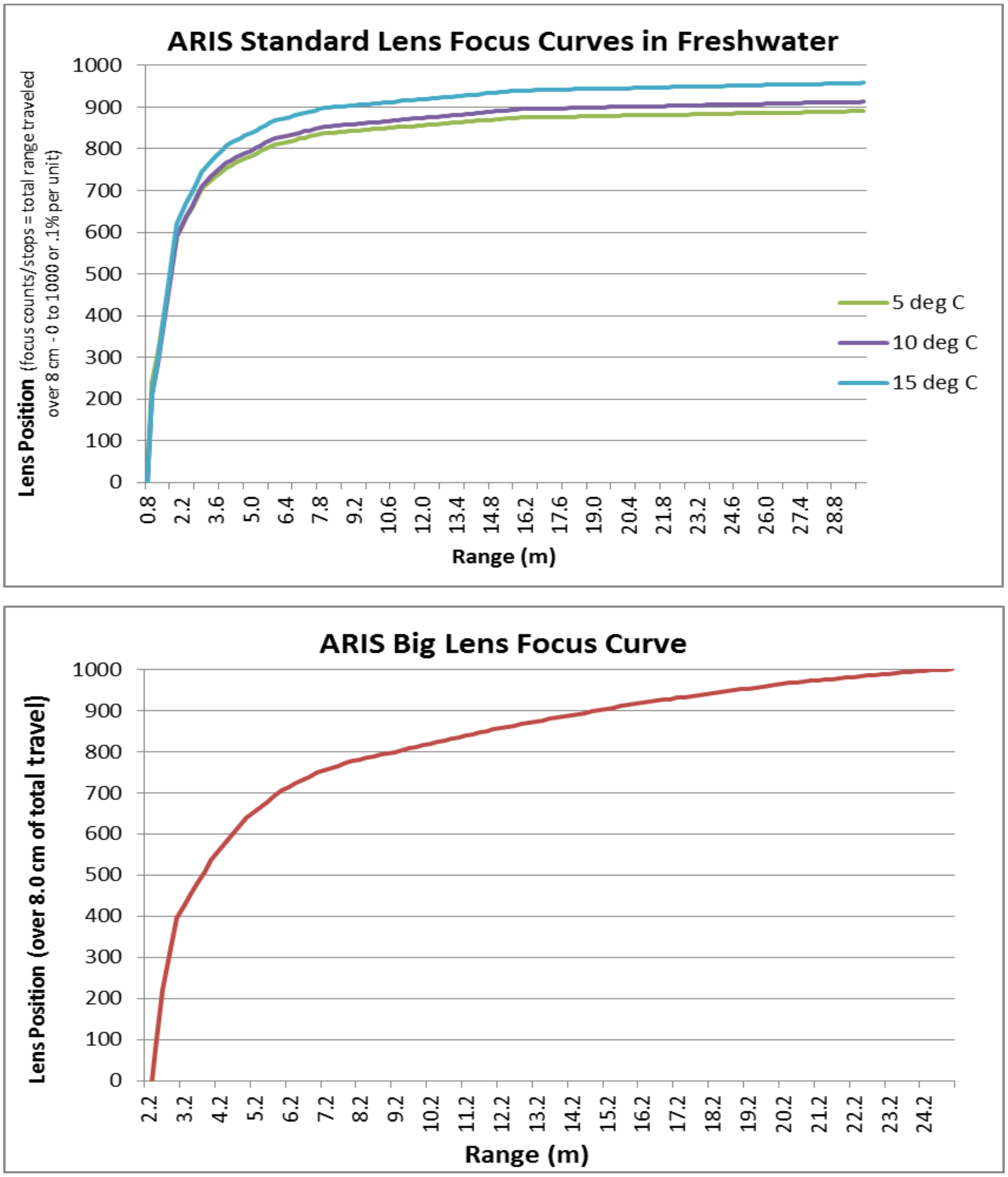
Both Modes
Number of beams 48
Beam Spacing 0.6° nominal
Horizontal Field-of-View 28°
Max frame rate (range dependent) 2.5–15 frames/s
Minimum Range Start 0.7 m
Downrange Resolution 3 mm to 10 cm
Transmit Pulse Length 4 μs to 100 μs
Remote Focus 0.7 m to max range
Power Consumption 18 Watts typical
Weight 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.



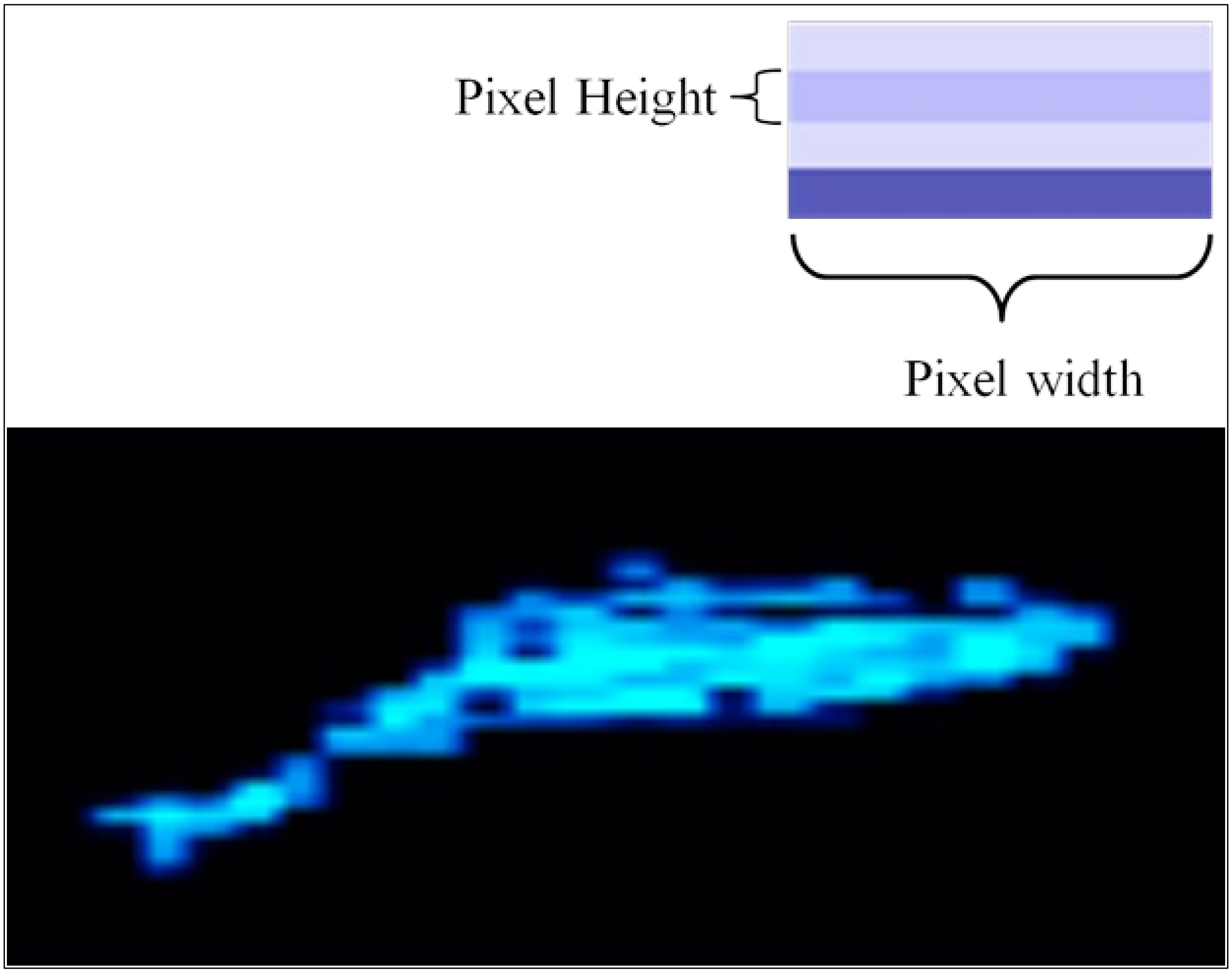
Note: The overall horizontal beam width of 15° is composed of 48 sub-beams with approximately 0.3° beam widths. Because sub-beams grow wider with range, fish at close range are better resolved than fish at far range (adapted from Burwen et al. [2007]).

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

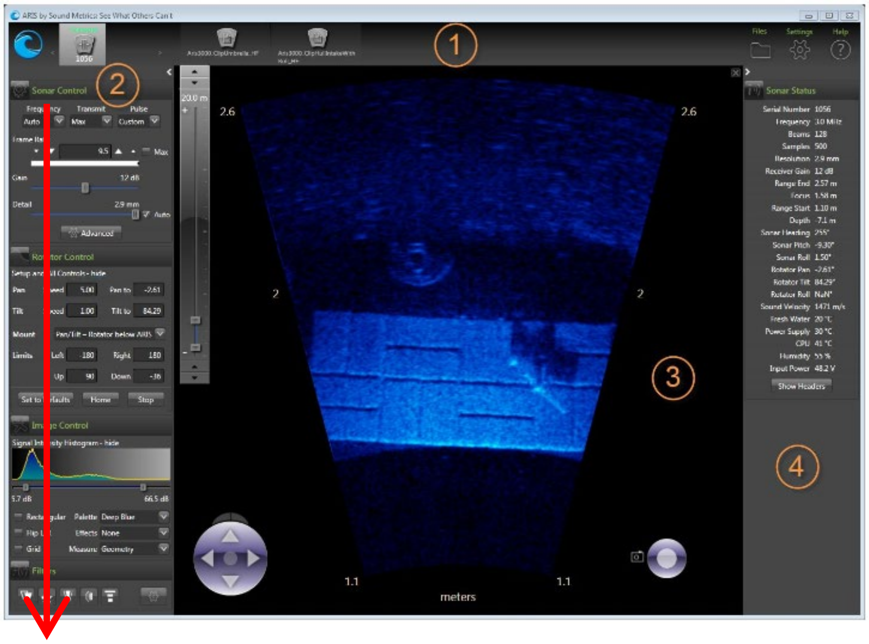


Note: "Big Lens" refers to the high-resolution lens.

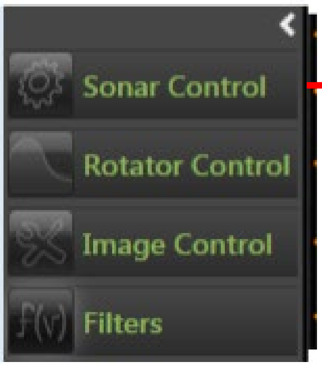
Appendix A6.–An enlargement showing individual pixels that compose an image (top) and an ARIS image of a free-swimming Chinook salmon (bottom).



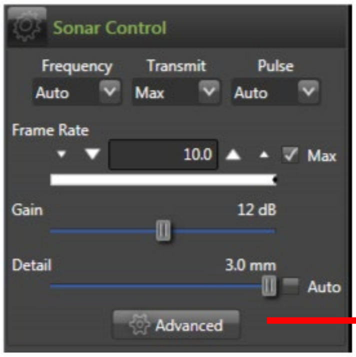
Appendix A7.–Downrange resolution for ARIS images is set using the “Detail” slider under the expanded “Sonar Control” dialog window or by setting the “Sample Period” under the “Advanced Sonar Settings” dialog window.



Control Panel Menu

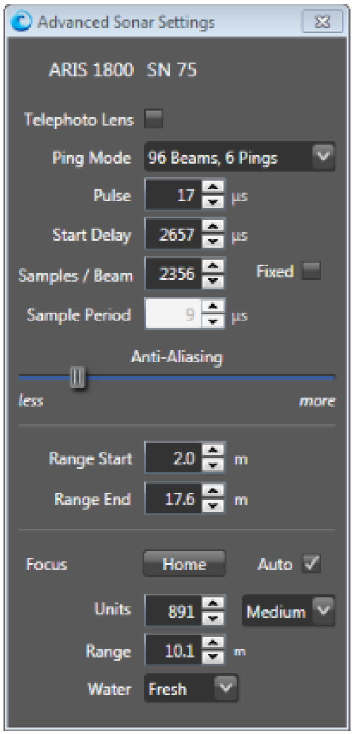


Expanded Sonar Control Window



Frequency: Auto
Transmit: Max
Pulse: Auto
Frame Rate: 10.0 ☑ Max
Gain: 12 dB
Detail: 3.0 mm ☐ Auto

Advanced Settings dialog



ARIS 1800 SN 75
Telephoto Lens ☐
Ping Mode: 96 Beams, 6 Pings
Pulse: 17 µs
Start Delay: 2657 µs
Samples / Beam: 2356
Fixed ☐
Sample Period: 9 µs
Range Start: 2.0 m
Range End: 17.6 m
Focus: Auto ☑
Units: 891 Medium
Range: 10.1 m
Water: Fresh

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).

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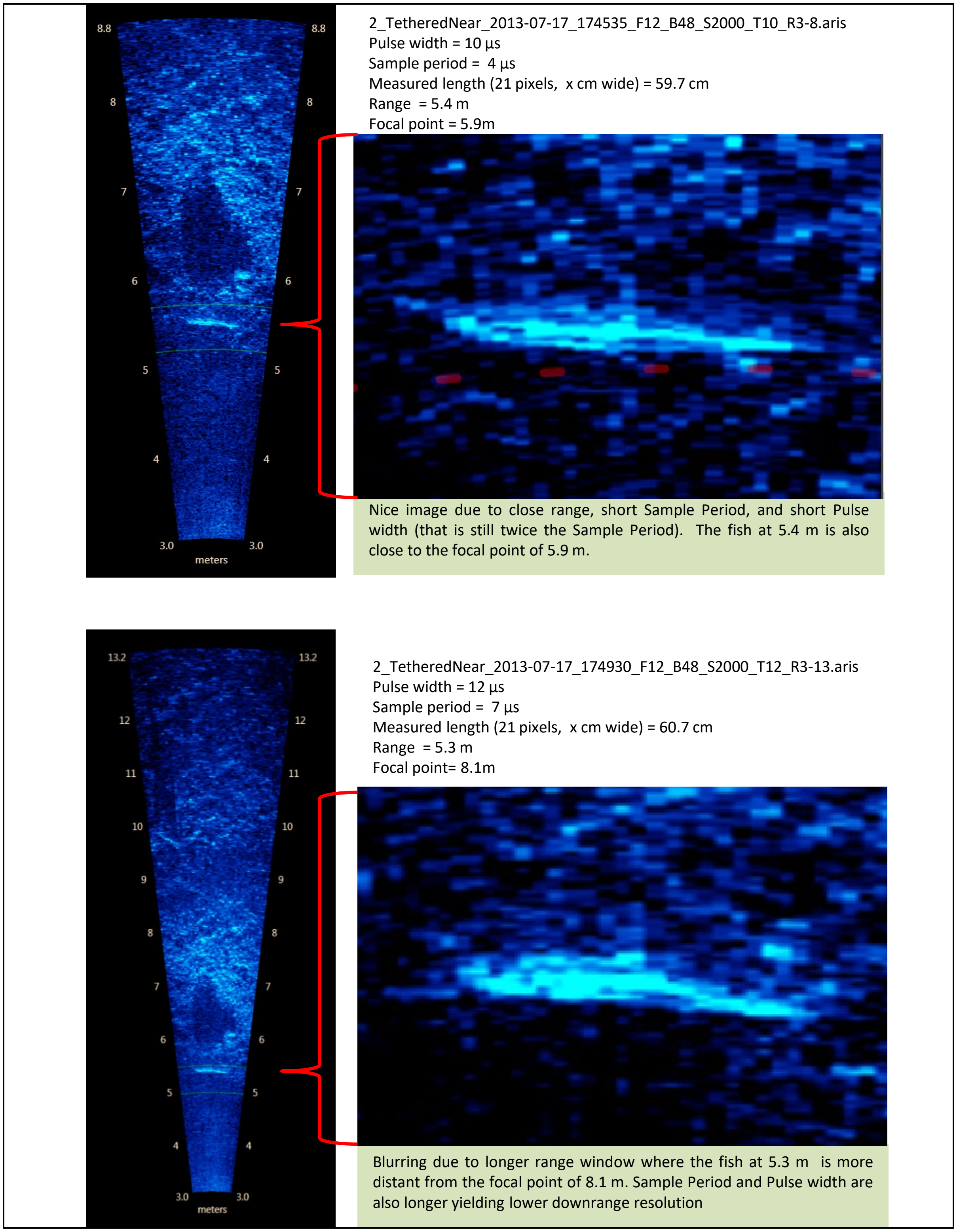
Appendix A8.–Page 2 of 2.

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.



2_TetheredNear_2013-07-17_174535_F12_B48_S2000_T10_R3-8.aris
Pulse width = 10 µs
Sample period = 4 µs
Measured length (21 pixels, x cm wide) = 59.7 cm
Range = 5.4 m
Focal point = 5.9m

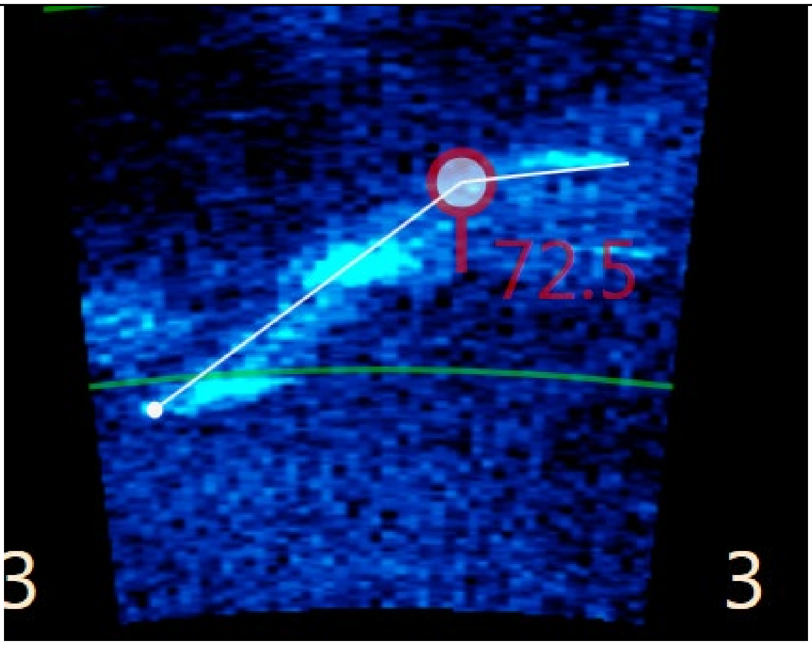
Nice image due to close range, short Sample Period, and short Pulse width (that is still twice the Sample Period). The fish at 5.4 m is also close to the focal point of 5.9 m.

2_TetheredNear_2013-07-17_174930_F12_B48_S2000_T12_R3-13.aris
Pulse width = 12 µs
Sample period = 7 µs
Measured length (21 pixels, x cm wide) = 60.7 cm
Range = 5.3 m
Focal point= 8.1m

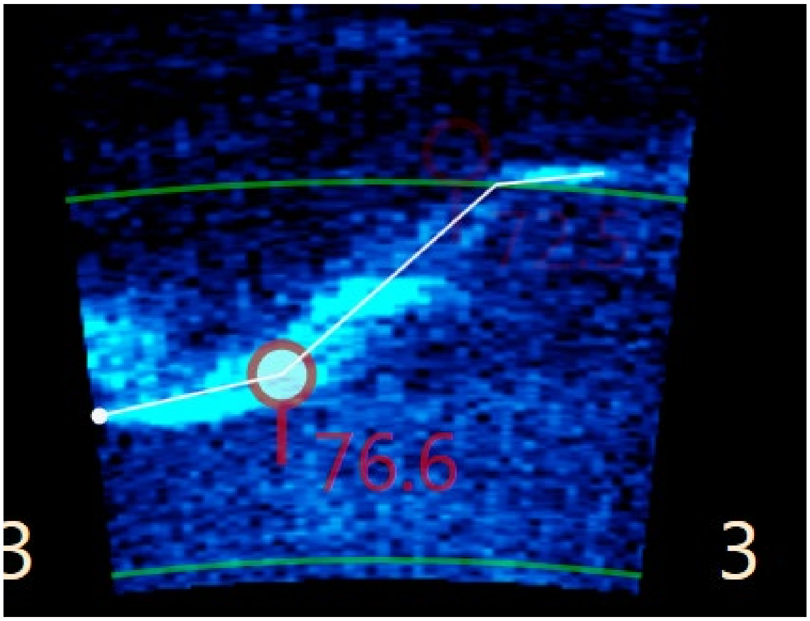
Blurring due to longer range window where the fish at 5.3 m is more distant from the focal point of 8.1 m. Sample Period and Pulse width are also longer yielding lower downrange resolution

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.

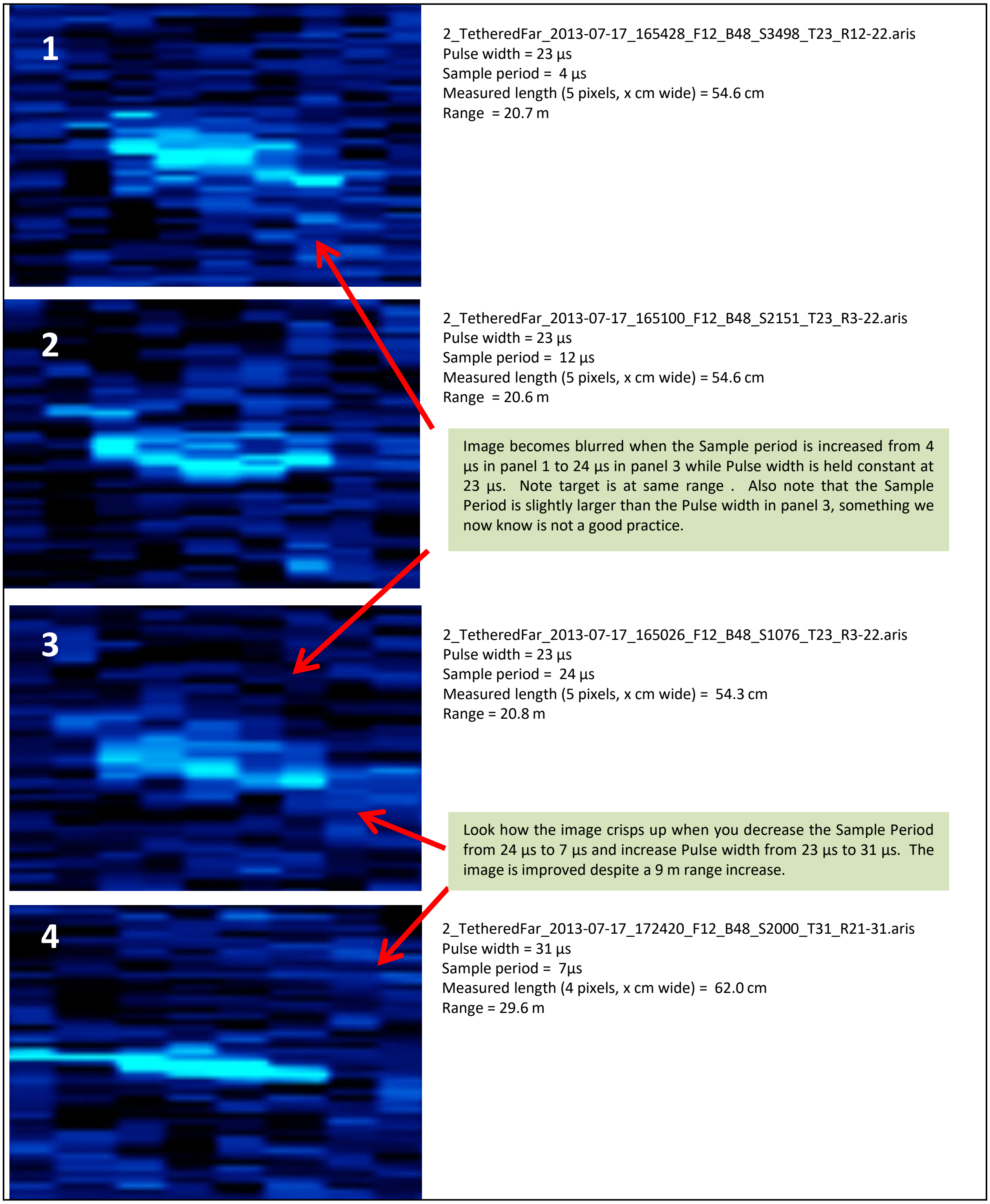


3_TetheredNear_2013-07-17_182746_F12_B48_S1724_T08_R3-8.aris
Fish Range: 3.35 m
Frame 2498
Fish size 72.5 cm



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.



2_TetheredFar_2013-07-17_165428_F12_B48_S3498_T23_R12-22.aris
Pulse width = 23 µs
Sample period = 4 µs
Measured length (5 pixels, x cm wide) = 54.6 cm
Range = 20.7 m

2_TetheredFar_2013-07-17_165100_F12_B48_S2151_T23_R3-22.aris
Pulse width = 23 µs
Sample period = 12 µs
Measured length (5 pixels, x cm wide) = 54.6 cm
Range = 20.6 m

Image becomes blurred when the Sample period is increased from 4 µs in panel 1 to 24 µs in panel 3 while Pulse width is held constant at 23 µs. Note target is at same range . Also note that the Sample Period is slightly larger than the Pulse width in panel 3, something we now know is not a good practice.

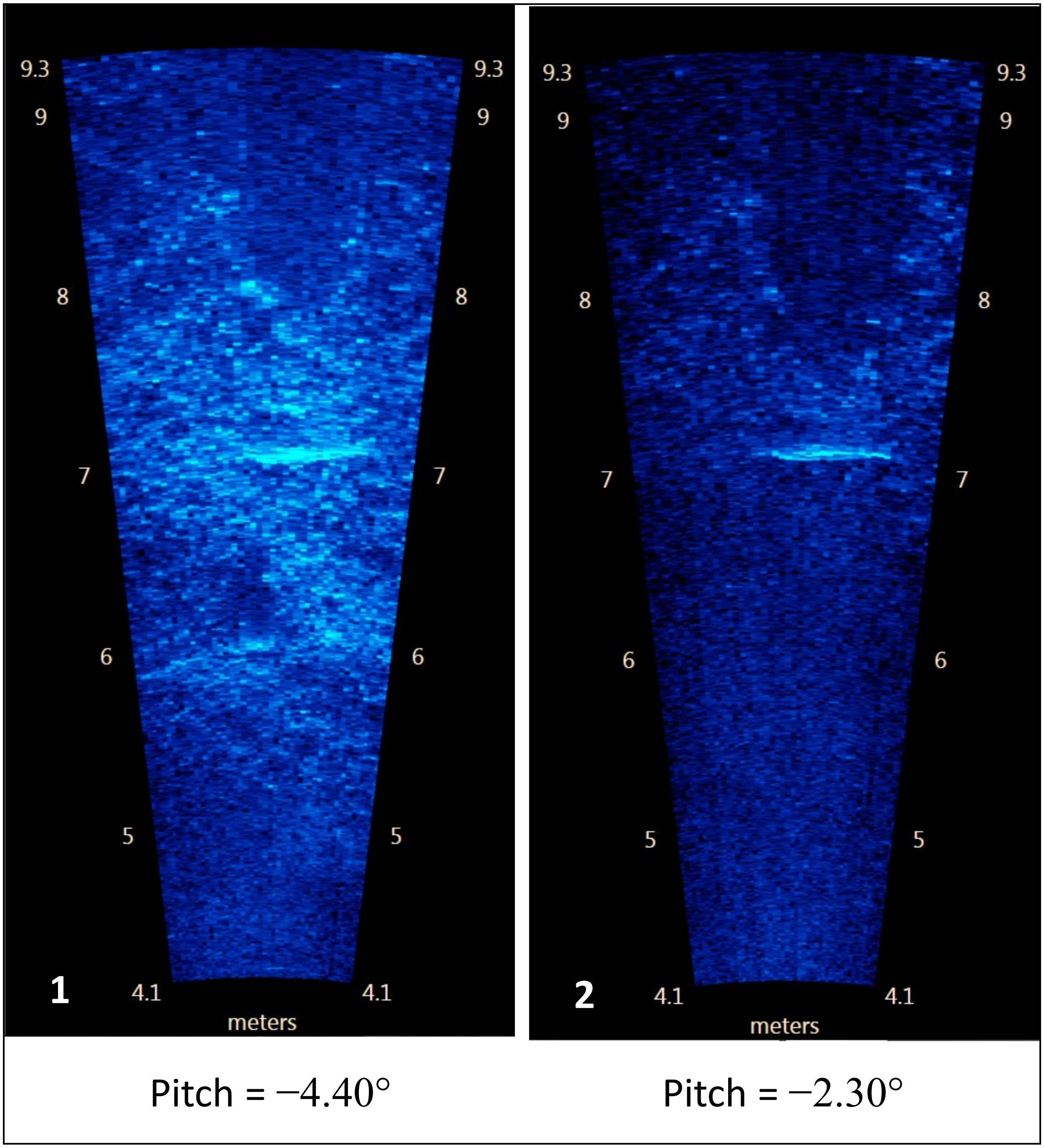
2_TetheredFar_2013-07-17_165026_F12_B48_S1076_T23_R3-22.aris
Pulse width = 23 µs
Sample period = 24 µs
Measured length (5 pixels, x cm wide) = 54.3 cm
Range = 20.8 m

Look how the image crisps up when you decrease the Sample Period from 24 µs to 7 µs and increase Pulse width from 23 µs to 31 µs. The image is improved despite a 9 m range increase.

2_TetheredFar_2013-07-17_172420_F12_B48_S2000_T31_R21-31.aris
Pulse width = 31 µs
Sample period = 7µs
Measured length (4 pixels, x cm wide) = 62.0 cm
Range = 29.6 m

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.



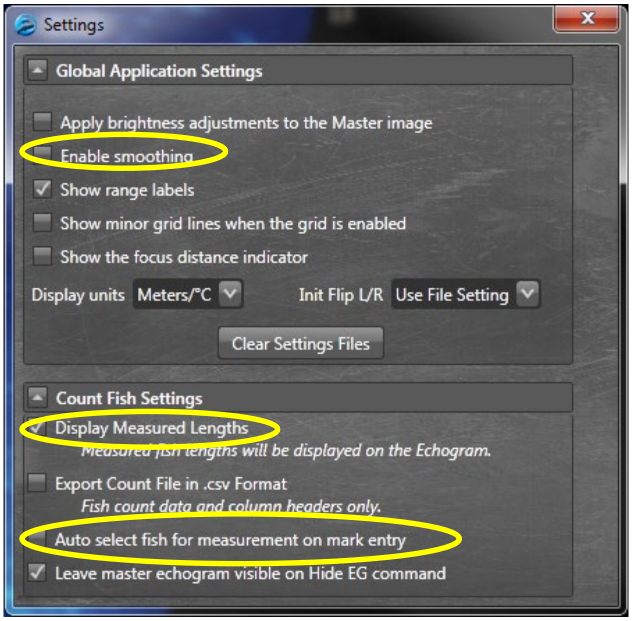
Note: Aiming the sonar farther into the bottom than required to cover the near-bottom region can cause unnecessary loss of vertical beam width and water column coverage and degrade the fish image.

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 hand corner) and use the following settings:



Global Application Settings

☐ Apply brightness adjustments to the Master image
☐ Enable smoothing
☑ Show range labels
☐ Show minor grid lines when the grid is enabled
☐ Show the focus distance indicator

Display units Meters/°C
Init Flip L/R Use File Setting

Count Fish Settings

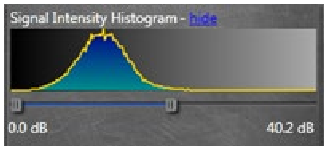
☑ Display Measured Lengths
Measured fish lengths will be displayed on the Echogram.
☐ Export Count File in .csv Format
Fish count data and column headers only.
☐ Auto select fish for measurement on mark entry
☑ Leave master echogram visible on Hide EG command

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>**.

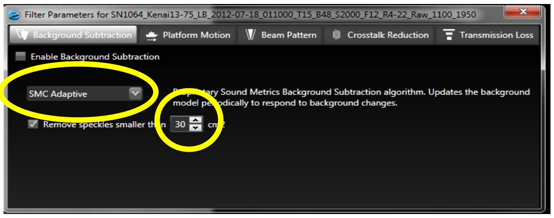
2. Navigate to the appropriate directory and open file (or simply **<double click>** on the file).
3. Set **<Signal Intensity Histogram>** sliders to 0.0 and 40.2 dB (or other recommended values for a specific stratum).



-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.


Filter Parameters for SN1064_Kenai13-75_LB_2012-07-18_011000_T15_B48_S2000_F12_R4-22_Raw_1100_1950

☐ Enable Background Subtraction

SMC Adaptive

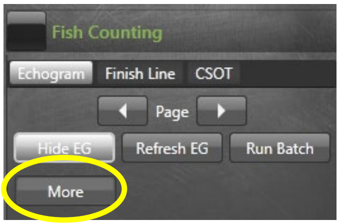
Proprietary Sound Metrics Background Subtraction algorithm. Updates the background model periodically to respond to background changes.

☑ Remove speckles smaller than 30 cm2

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

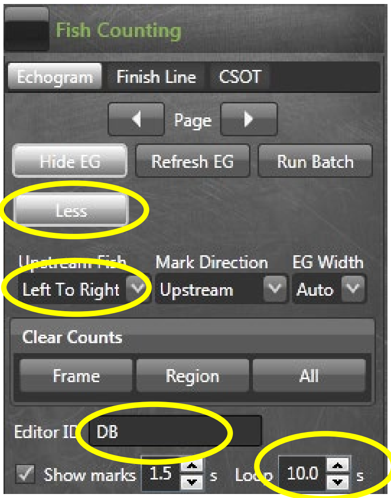
7. Select **<Echogram**> **<Show EG>** from the **<Fish Counting>** menu to display the echogram.

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.



Upstream Fish Left To Right
Mark Direction Upstream
EG Width Auto
Editor ID DB
☑ Show marks 1.5 s
Loop 10.0 s

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.[1]

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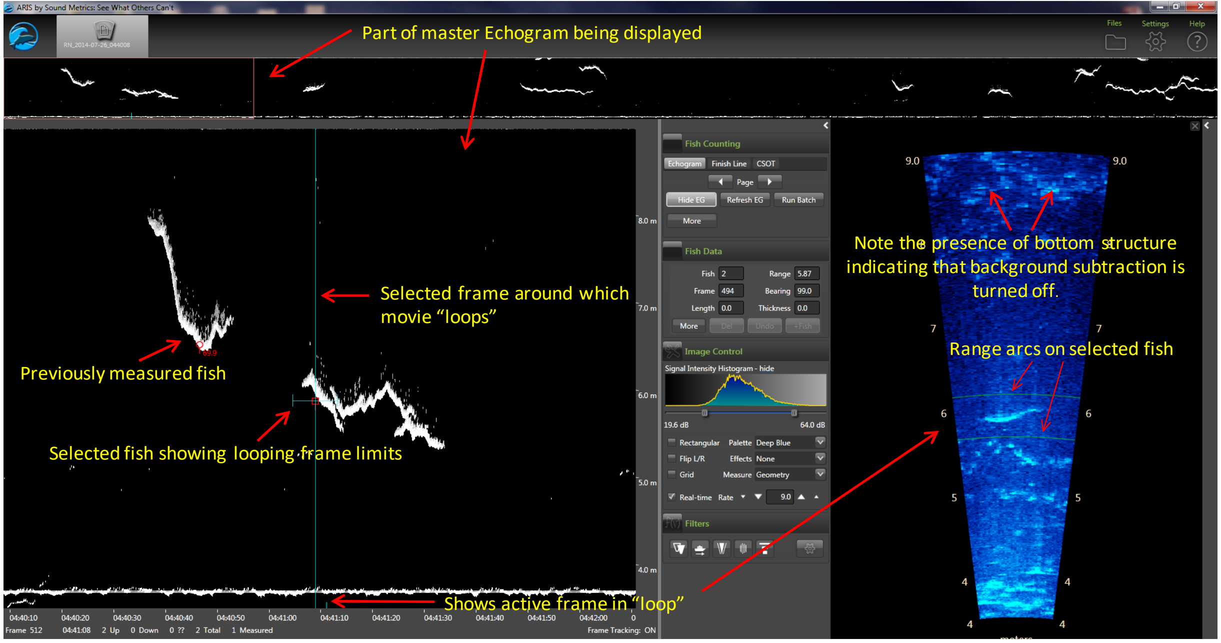
[1] Unlike with DIDSON data, we do not usually use the background subtraction (BS) option while measuring ARIS fish image lengths. The new SMC ARISFish BS algorithm is more aggressive than the DIDSON algorithm and unless one is very careful in selecting a frame, it is easy to underestimate fish length. 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:



Part of master Echogram being displayed

Selected frame around which movie "loops"

Previously measured fish

Selected fish showing looping frame limits

Shows active frame in "loop"

Note the presence of bottom structure indicating that background subtraction is turned off.

Range arcs on selected fish

Fish 2 Range 5.87
Frame 494 Bearing 99.0
Length 0.0 Thickness 0.0

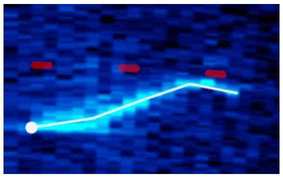
☐ Rectangular Palette Deep Blue
☐ Flip L/R Effects None
☐ Grid Measure Geometry
☑ Real-time Rate 9.0

Frame 512 04:41:08 2 Up 0 Down 0 ?? 2 Total 1 Measured Frame Tracking: ON

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” the 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).

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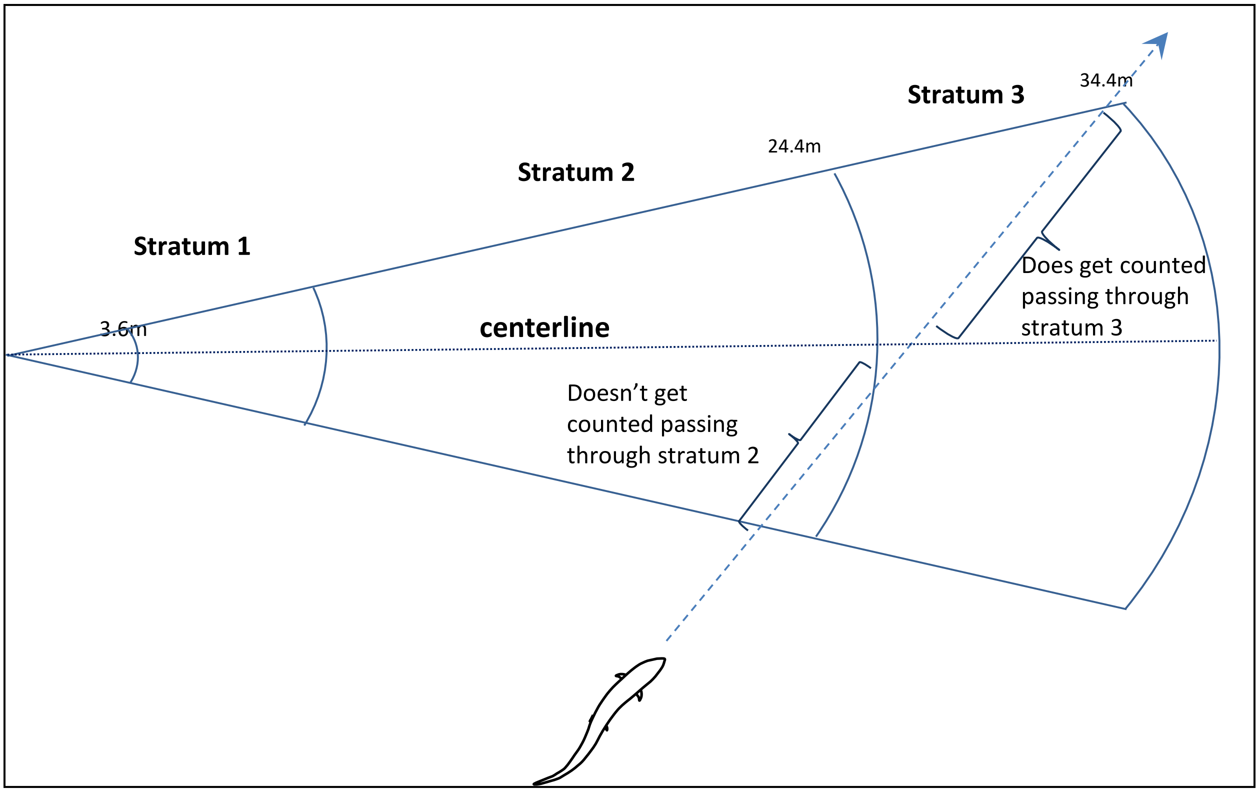
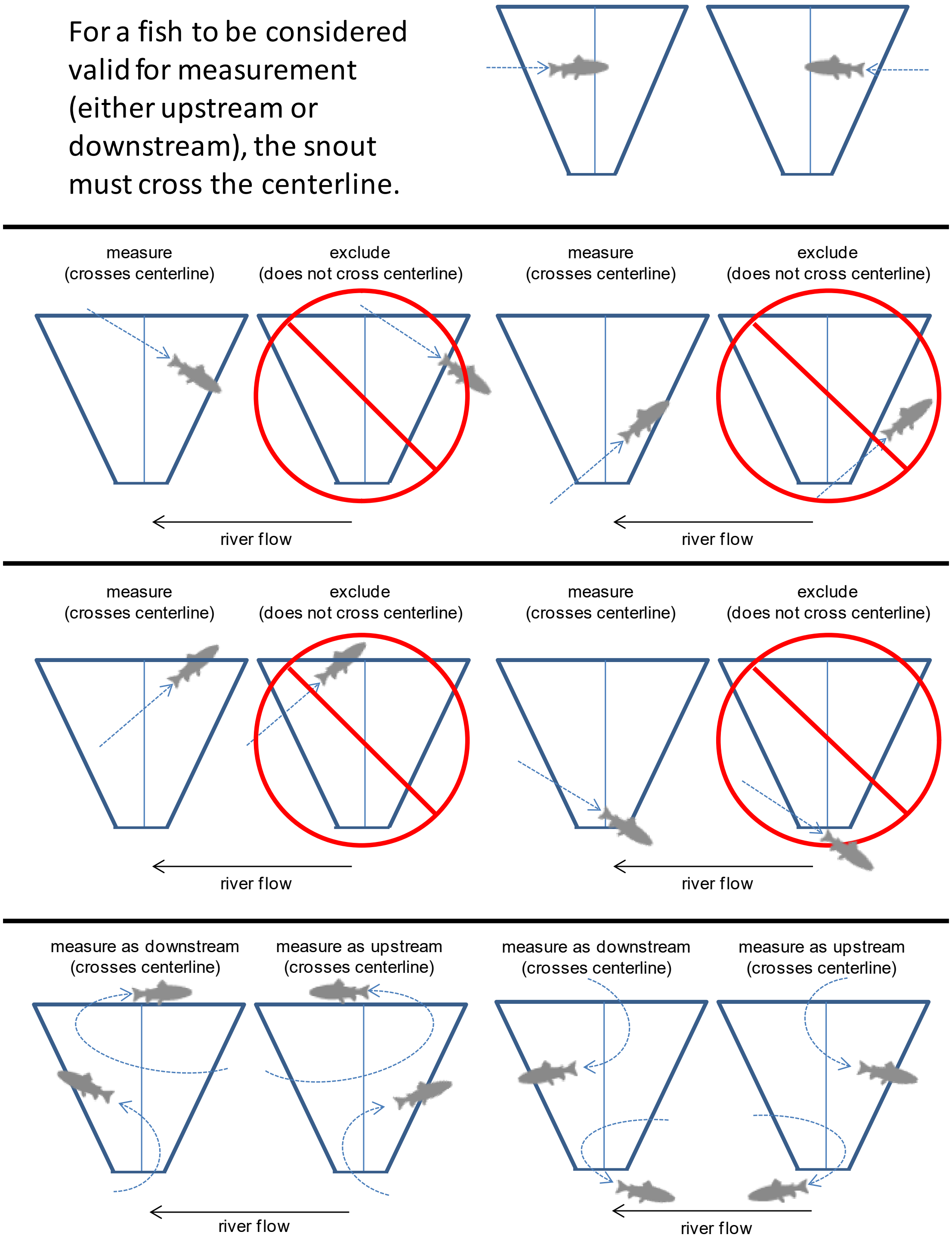
5. Exclude fish that enter the beam from downstream and then exit the beam downstream (do not measure even if they cross the centerline).
6. Exclude fish that enter the beam from either upstream or downstream and then disappear from the image (unless there is evidence to suggest direction of travel).
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.



For a fish to be considered valid for measurement (either upstream or downstream), the snout must cross the centerline.

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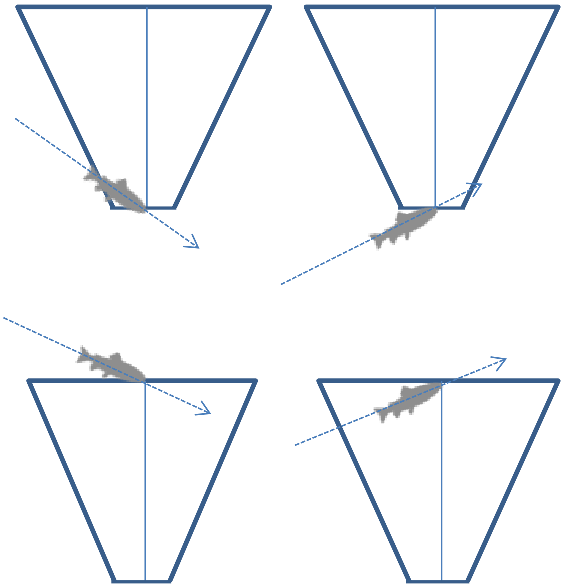
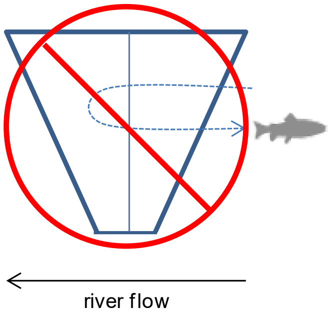
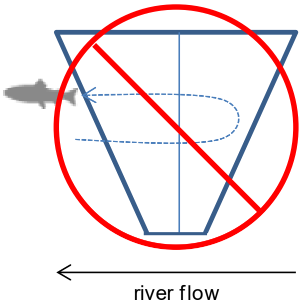
If the snout of the fish enters the near- or far-range boundary right on the centerline, the fish should be considered valid for measurement.



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

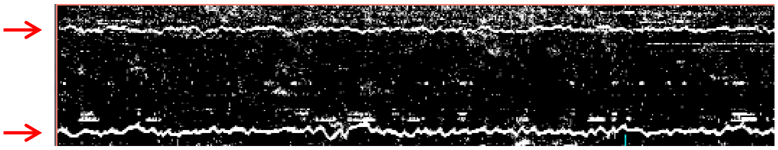


Exclude fish that enter the beam from downstream, then exit the beam downstream (do not measure even if they cross the centerline).



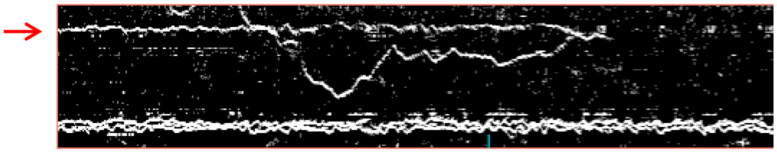
-continued-

Exclude fish that hold throughout the length of the sample.

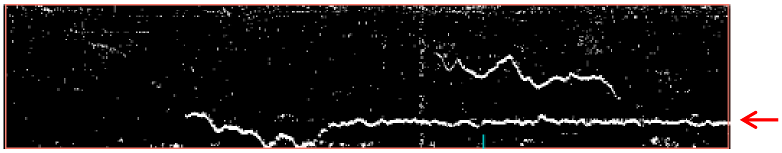


Two fish hold throughout the entire file.
Exclude both fish.

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



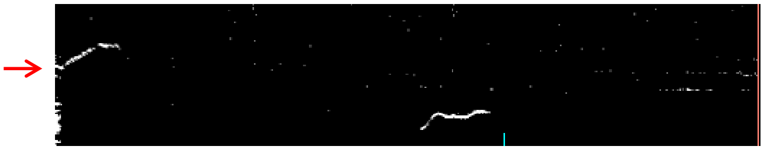
Fish holding as sample begins, then exits the beam about ¾ of the way through the sample. Exclude this fish.



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.

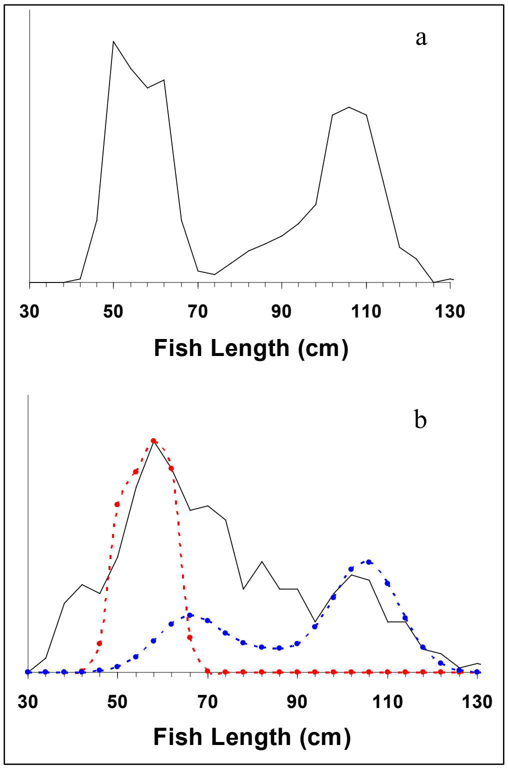


Fish is actively migrating through the beam as the sample starts. It crosses the center line and exits upstream so should be measured.

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:

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

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

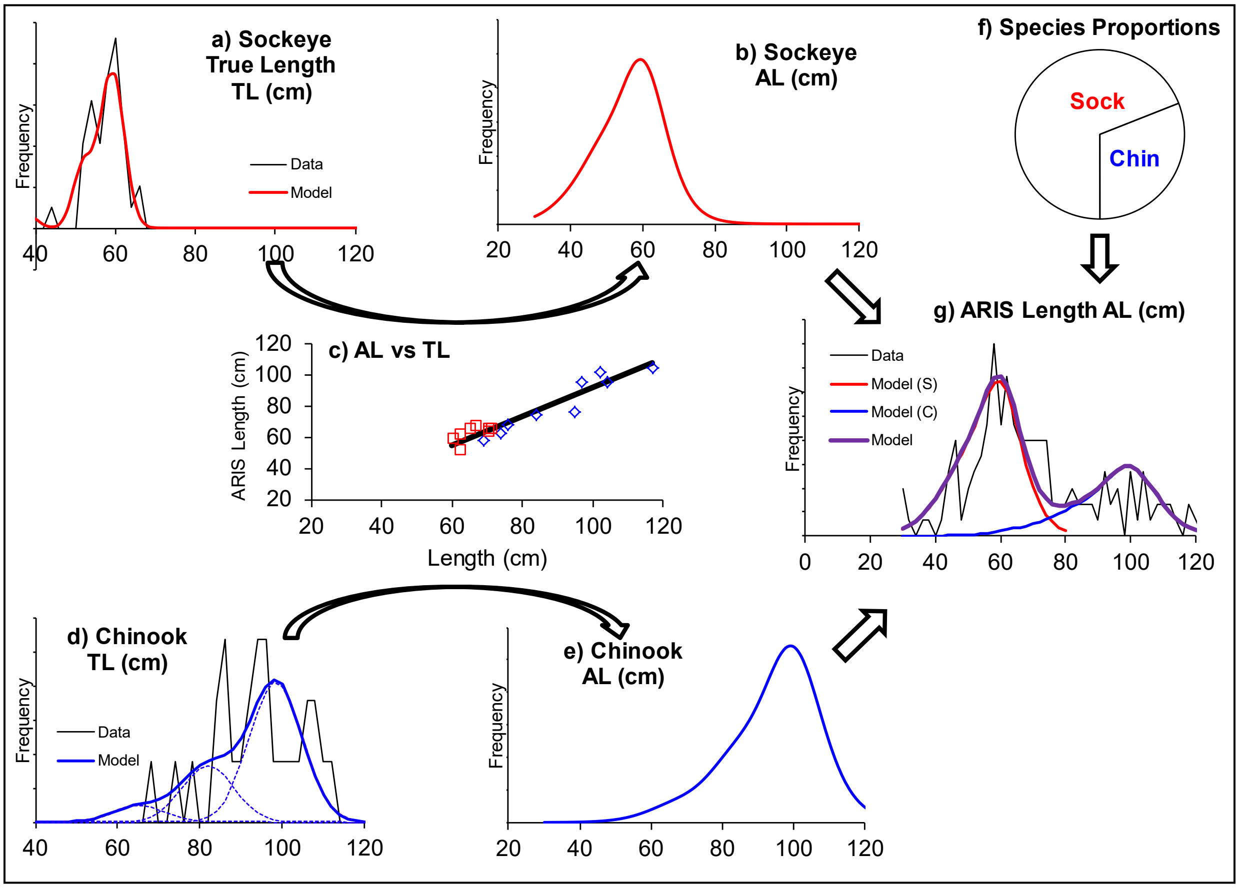
where θ_{Ca} and θ_{Sa} are the proportions of Chinook and sockeye salmon belonging to age component a and the distributions

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

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

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 (panel c). The weights (species proportions, panel f) are the parameters of interest.

Appendix C3.–Methodology used for fitting the mixture model.

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) was 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[1] 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.

---

[1] 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.

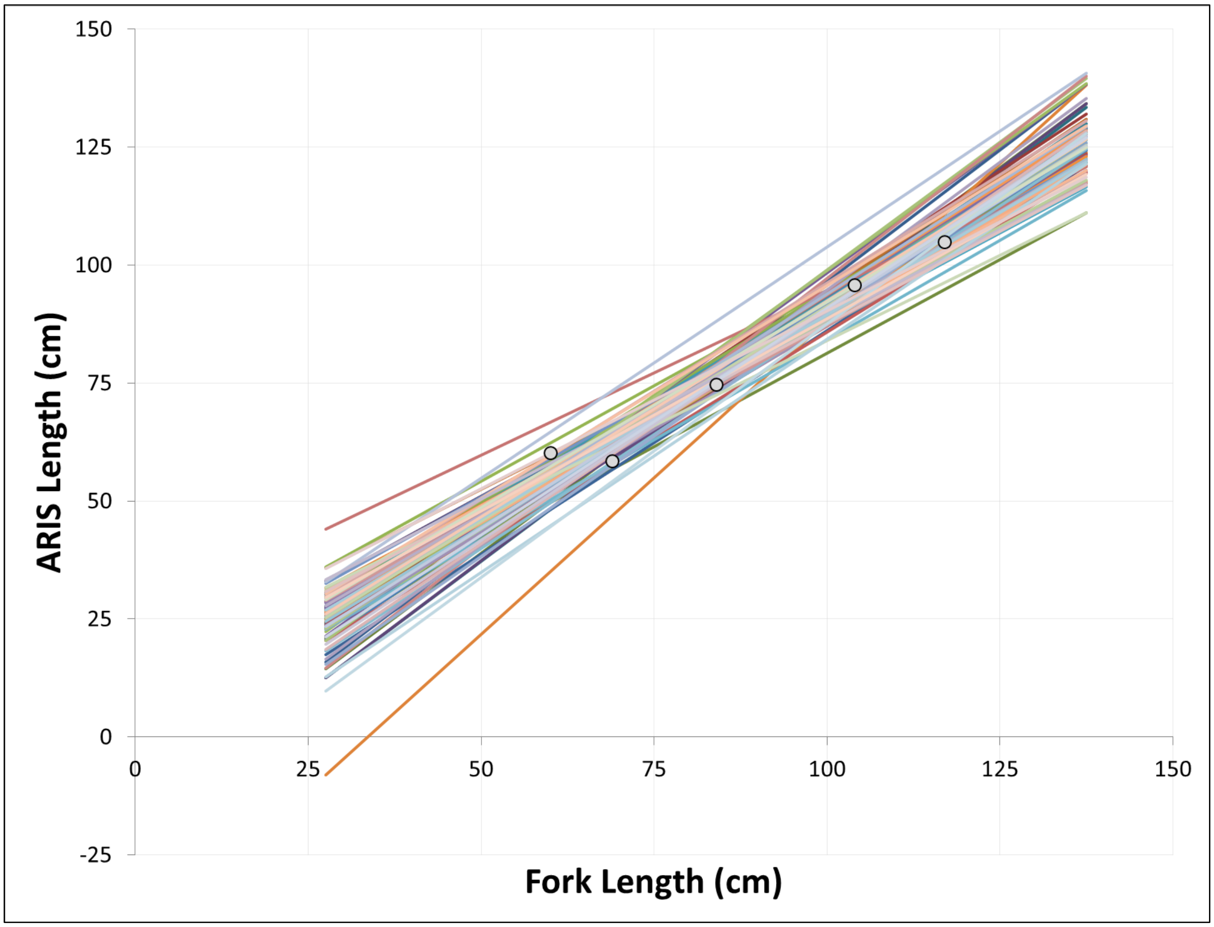
```
model{
 beta0 ~ dnorm(75,0.0025)
 beta1 ~ dnorm(1,25)I(0,)
 sigma.AL ~ dunif(0,20)
 tau.AL  <- 1 / sigma.AL / sigma.AL
 ps[1:2] ~ ddirch(D.species[])
 pa[1,1] ~ dbeta(0.5,0.5)
 theta1 ~ dbeta(0.5,0.5)
 pa[1,2] <- theta1 * (1 - pa[1,1])
 pa[1,3] <- 1 - pa[1,1] - pa[1,2]
 pa[2,1] ~ dbeta(0.5,0.5)
 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 estimates, contrasted with 2015 inseason methods.

In 2013–2015, the methods used to produce ARIS-length (AL) mixture model 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 AL mixture model estimates (Miller et al. 2013–2016b: Appendices C6 and C7; Key et al. 2017: Appendix C6).

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

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

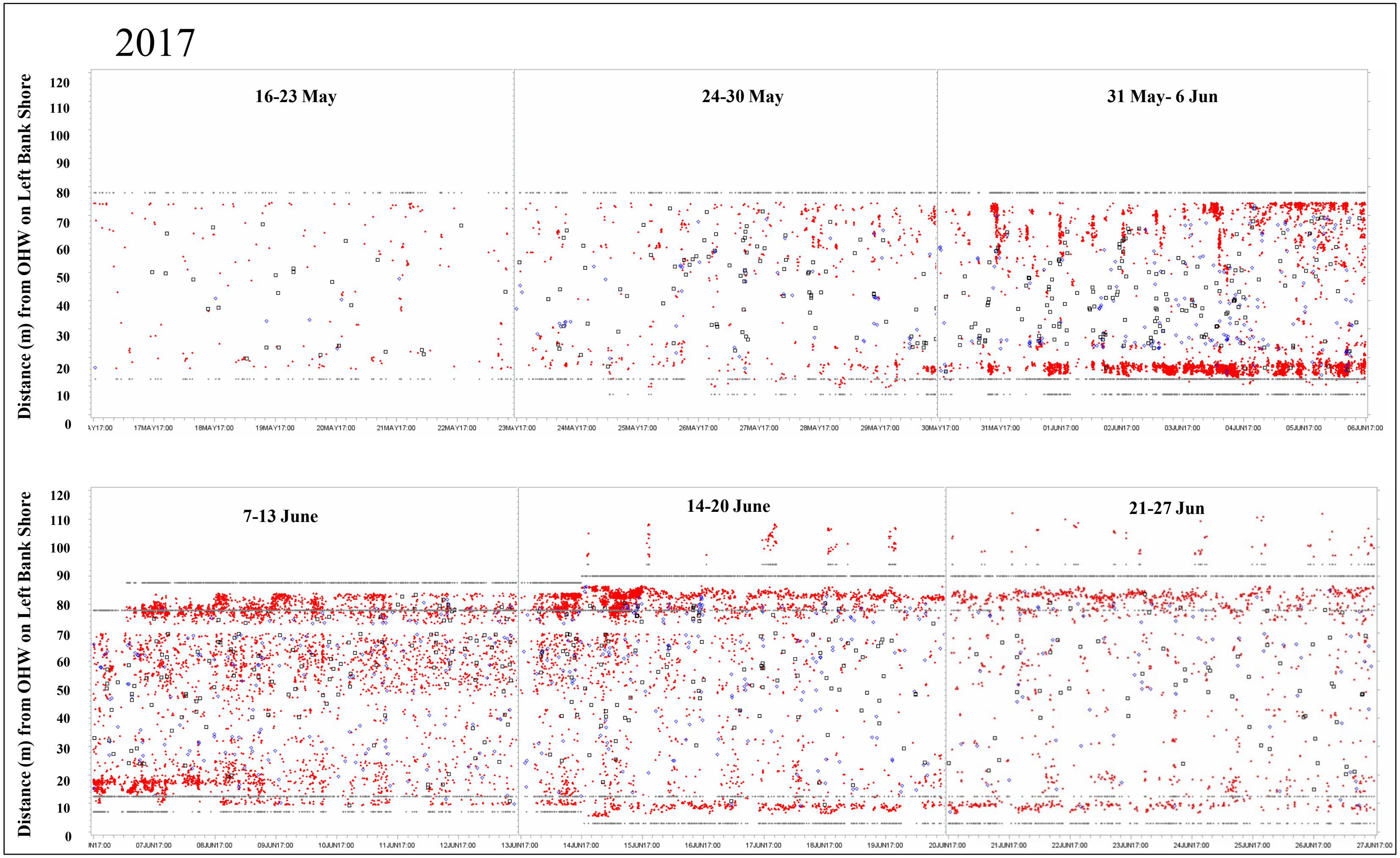
Methodological detail	Inseason 2015	Inseason and final 2016[a]
Age composition prior	Informative[b]	Noninformative
Species composition prior	Dirichlet(0.5,0.5)	Dirichlet(0.1,0.9)
Netting data	Midriver only	Midriver and nearshore
Chinook salmon size selectivity by age class	0.61, 0.57, 0.41	1, 1, 1

[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)

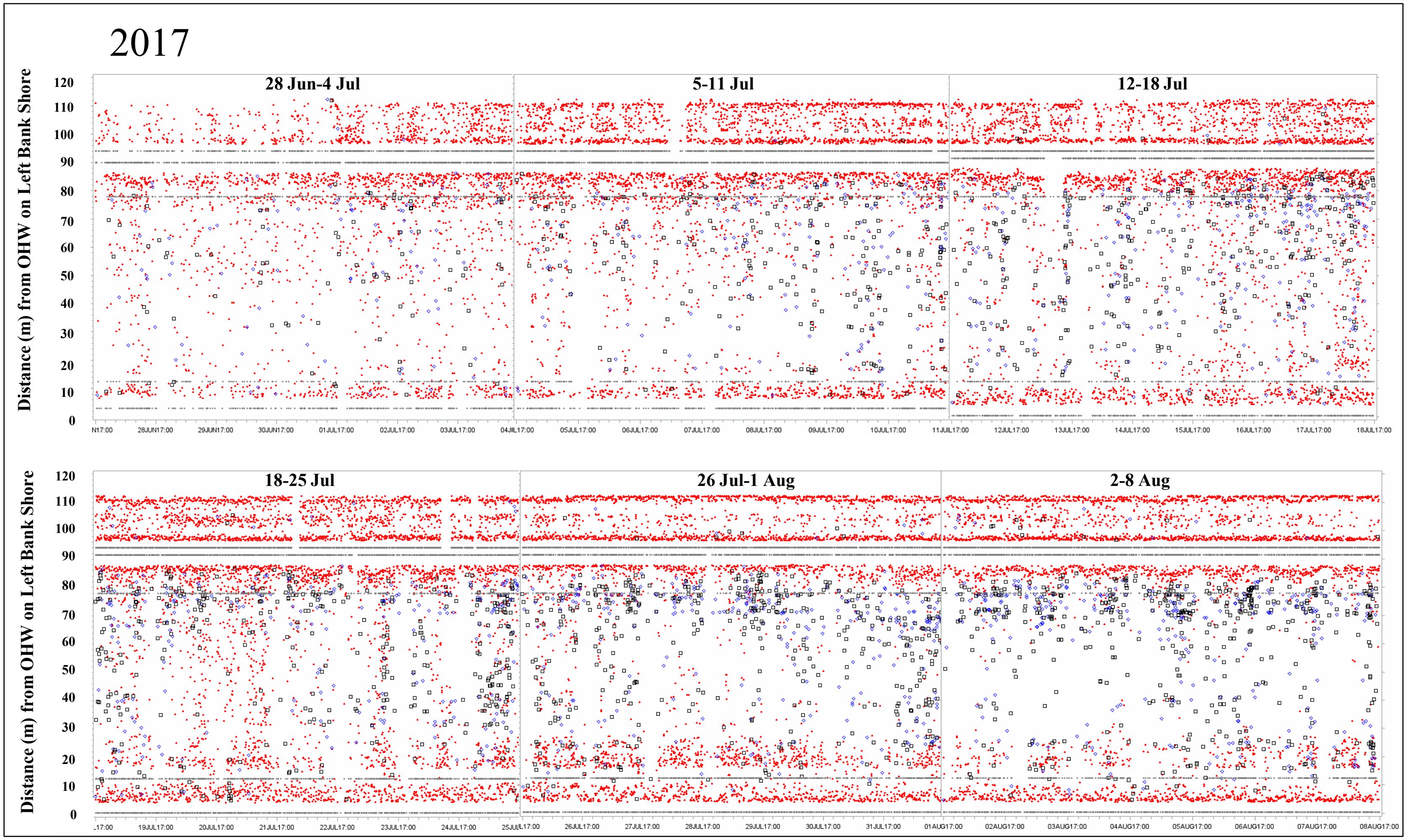
APPENDIX D: SPATIAL AND TEMPORAL DISTRIBUTION OF UPSTREAM-BOUND FISH BY SIZE AS MEASURED BY ARIS, RM 13.7 KENAI RIVER, 2017–2019

Appendix D1.–Spatial and temporal distribution of upstream migrating 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 May–27 June 2017.



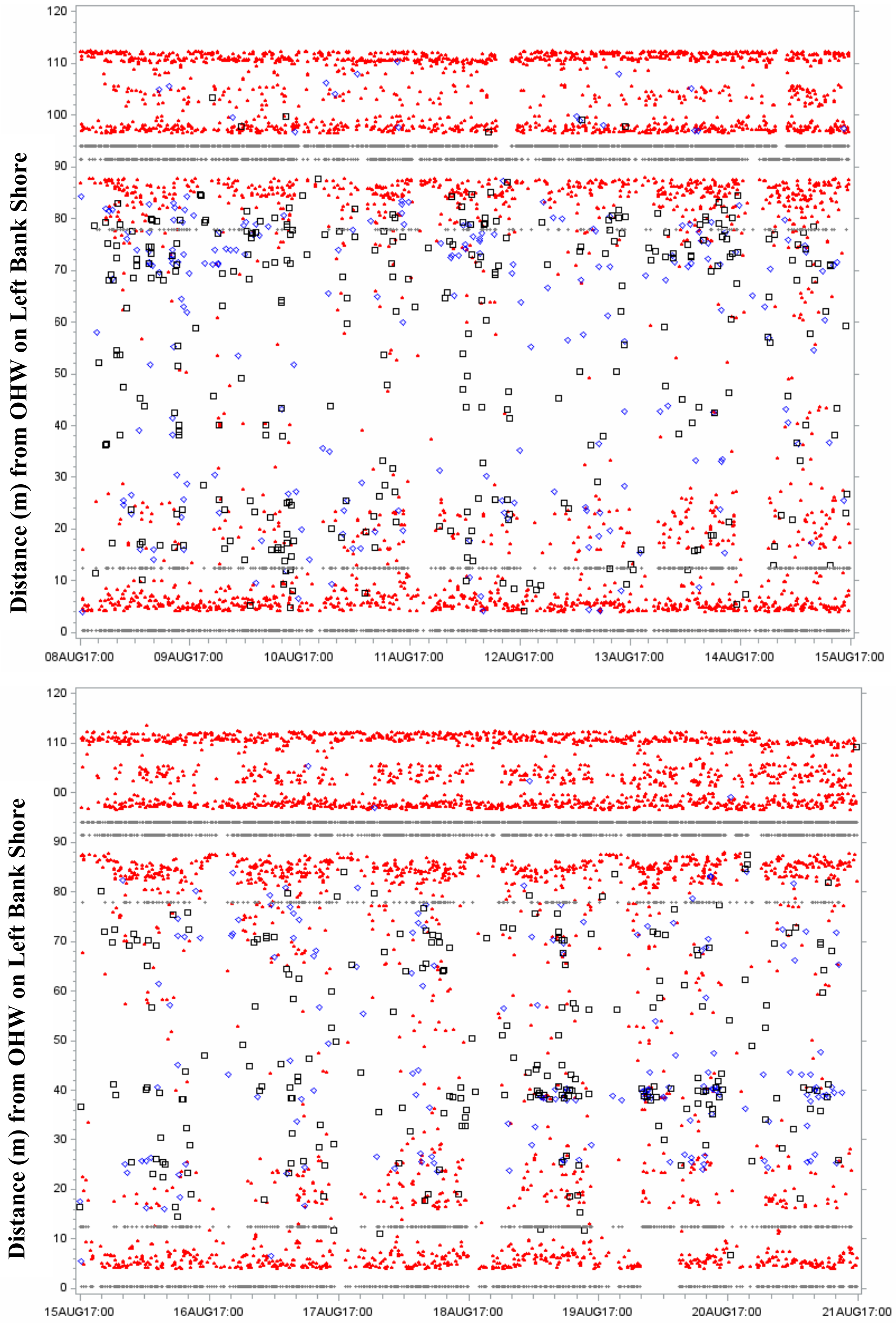
Note: Small fish can be underrepresented in the sample. Transducer locations are plotted as small grey crosses, one per fish. For the main channel, the vertical axis is the distance from a reference point near the ordinary high water level (OHW) on the left bank. The side channel transducer was arbitrarily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

Appendix D2.–Spatial and temporal distribution of upstream migrating 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, 28 June–8 August 2017.



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 from a reference point near the ordinary high water level on the left bank. The side channel transducer was arbitrarily set to 95 m for graphical convenience.

Appendix D3.–Spatial and temporal distribution of upstream migrating 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, 8–21 August 2017.

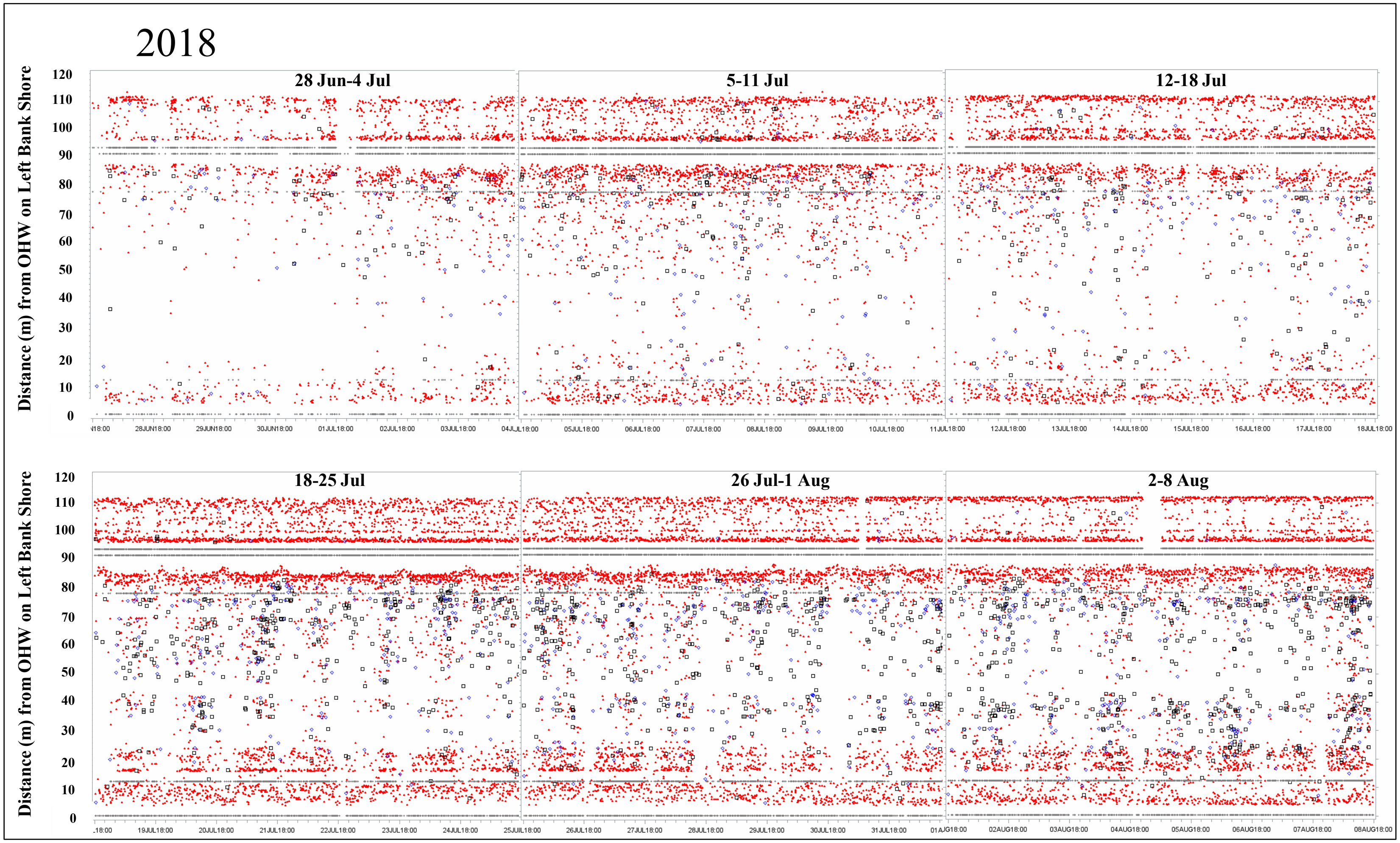


Note: Small fish can be underrepresented in the sample. Transducer locations are plotted as small grey crosses, one per fish. For the main channel, the vertical axis is distance from a reference point near the ordinary high water level on the left bank. The side channel transducer was arbitrarily set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

Appendix D4.–Spatial and temporal distribution of upstream migrating 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 May–27 June 2018.

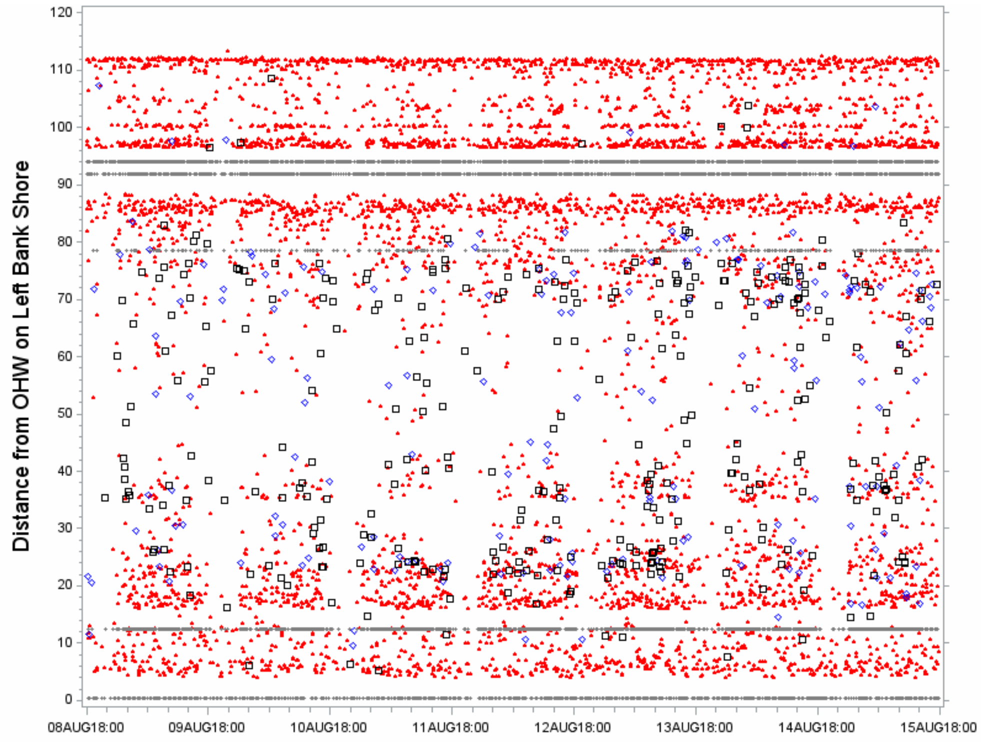
Note: Small fish can be underrepresented in the sample. Transducer locations are plotted as small grey crosses, one per fish. For the main channel, the vertical axis is the distance from a reference point near the ordinary high water level (OHW) on the left bank. The side channel transducer was arbitrarily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

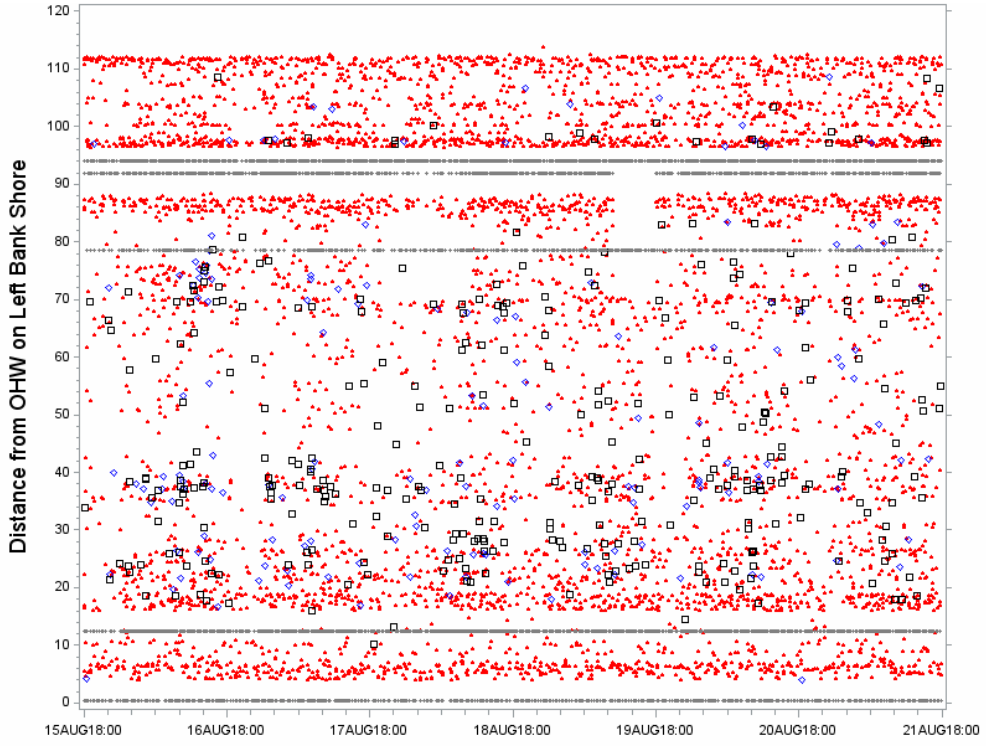
Appendix D5.–Spatial and temporal distribution of upstream migrating small (ARIS length [AL] <75 cm; small red dots), medium (75 cm ≤ AL < 90 cm; larger blue diamonds), and large fish (AL ≥90 cm; large black squares), RM 13.7 Kenai River, 27 June–8 August 2018.



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 from a reference point near the ordinary high water level on the left bank. The side channel transducer was arbitrarily set to 95 m for graphical convenience.

Appendix D6.–Spatial and temporal distribution of upstream migrating 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, 8–21 August 2018.



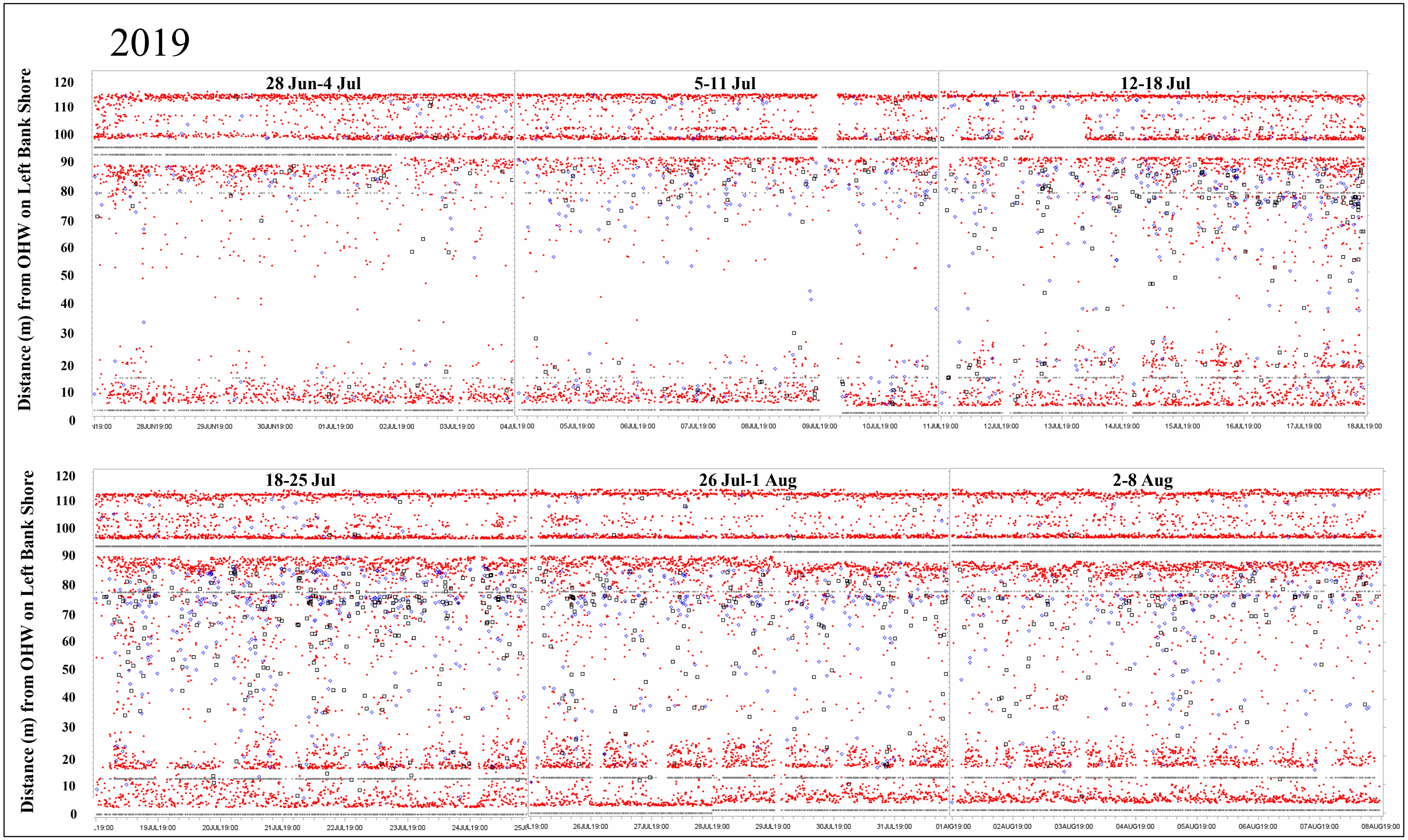


Note: Small fish can be underrepresented in the sample. Transducer locations are plotted as small grey crosses, one per fish. For the main channel, the vertical axis is distance from a reference point near the ordinary high water level on the left bank. The side channel transducer was arbitrarily set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

Appendix D7.–Spatial and temporal distribution of upstream migrating 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 May–27 June 2019.

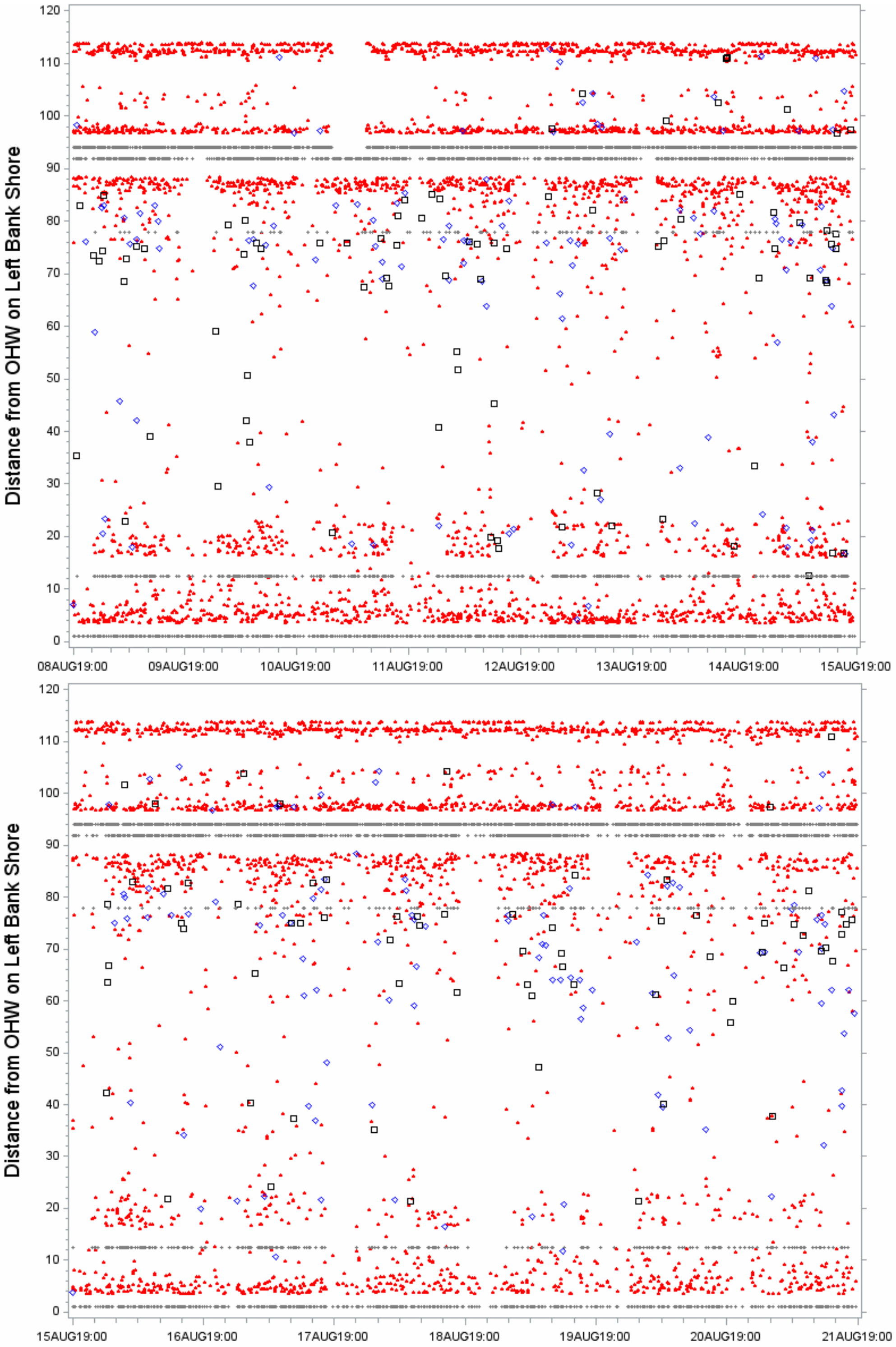
Note: Small fish can be underrepresented in the sample. Transducer locations are plotted as small grey crosses, one per fish. For the main channel, the vertical axis is the distance from a reference point near the ordinary high water level (OHW) on the left bank. The side channel transducer was arbitrarily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

Appendix D8.–Spatial and temporal distribution of upstream migrating 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, 27 June–8 August 2019.



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 from a reference point near the ordinary high water level on the left bank. The side channel transducer was arbitrarily set to 95 m for graphical convenience.

Appendix D9.–Spatial and temporal distribution of upstream migrating 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, 8–21 August 2019.



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 from a reference point near the ordinary high water level 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, 2017–2019

Appendix E1.–Daily count and percentages of fish ≥75 cm ARIS length moving upstream and downstream (and daily total) for the early run, RM 13.7 Kenai River, 2017.

Early run 16 May–7 June						Early run 8–30 June					
	Downstream		Upstream				Downstream		Upstream		
Date	Num.	%	Num.	%	Total	Date	Num.	%	Num.	%	Total
16 May	0	0	1	100	1	8 Jun	2	4	47	96	49
17 May	0	0	5	100	5	9 Jun	2	6	31	94	33
18 May	1	14	6	86	7	10 Jun	4	8	46	92	50
19 May	1	11	8	89	9	11 Jun	0	0	47	100	47
20 May	1	13	7	88	8	12 Jun	2	4	47	96	49
21 May	2	40	3	60	5	13 Jun	1	2	51	98	52
22 May	0	0	3	100	3	14 Jun	0	0	62	100	62
23 May	2	11	17	89	19	15 Jun	0	0	52	100	52
24 May	1	8	11	92	12	16 Jun	1	3	33	97	34
25 May	1	5	18	95	19	17 Jun	0	0	32	100	32
26 May	11	25	33	75	44	18 Jun	0	0	43	100	43
27 May	8	26	23	74	31	19 Jun	6	19	26	81	32
28 May	3	14	18	86	21	20 Jun	3	18	14	82	17
29 May	3	10	28	90	31	21 Jun	2	8	24	92	26
30 May	2	5	35	95	37	22 Jun	0	0	15	100	15
31 May	11	22	39	78	50	23 Jun	6	22	21	78	27
1 Jun	4	9	43	91	47	24 Jun	0	0	14	100	14
2 Jun	12	17	57	83	69	25 Jun	0	0	19	100	19
3 Jun	11	13	72	87	83	26 Jun	1	3	29	97	30
4 Jun	12	21	45	79	57	27 Jun	1	4	22	96	23
5 Jun	2	4	49	96	51	28 Jun	1	6	15	94	16
6 Jun	8	16	43	84	51	29 Jun	1	4	22	96	23
7 Jun	5	11	39	89	44	30 Jun	1	5	19	95	20
						Total	135	9	1,334	91	1,469

Appendix E2.–Daily count and percentages of fish ≥75 cm ARIS length moving upstream and downstream (and daily total) for the late run, RM 13.7 Kenai River, 2017.

Late run 1–26 Jul						Late run 27 Jul–20 Aug					
	Downstream		Upstream				Downstream		Upstream		
Date	Num.	%	Num.	%	Total	Date	Num.	%	Num.	%	Total
1 Jul	1	3	31	97	32	27 Jul	4	5	70	95	74
2 Jul	0	0	42	100	42	28 Jul	4	4	107	96	111
3 Jul	0	0	28	100	28	29 Jul	11	10	101	90	112
4 Jul	0	0	33	100	33	30 Jul	17	18	80	82	97
5 Jul	0	0	32	100	32	31 Jul	5	3	158	97	163
6 Jul	0	0	27	100	27	1 Aug	20	18	92	82	112
7 Jul	2	4	50	96	52	2 Aug	22	16	118	84	140
8 Jul	0	0	61	100	61	3 Aug	12	12	91	88	103
9 Jul	2	2	80	98	82	4 Aug	13	9	135	91	148
10 Jul	5	7	70	93	75	5 Aug	6	4	131	96	137
11 Jul	2	3	69	97	71	6 Aug	11	8	122	92	133
12 Jul	5	7	67	93	72	7 Aug	12	11	99	89	111
13 Jul	3	4	69	96	72	8 Aug	10	8	108	92	118
14 Jul	2	3	67	97	69	9 Aug	32	25	98	75	130
15 Jul	3	4	76	96	79	10 Aug	33	33	67	67	100
16 Jul	7	6	109	94	116	11 Aug	28	25	82	75	110
17 Jul	2	2	108	98	110	12 Aug	19	22	66	78	85
18 Jul	4	3	117	97	121	13 Aug	20	20	79	80	99
19 Jul	1	1	84	99	85	14 Aug	23	30	53	70	76
20 Jul	0	0	58	100	58	15 Aug	21	26	60	74	81
21 Jul	0	0	80	100	80	16 Aug	25	28	64	72	89
22 Jul	2	3	65	97	67	17 Aug	31	34	60	66	91
23 Jul	2	3	60	97	62	18 Aug	26	24	83	76	109
24 Jul	4	3	154	97	158	19 Aug	27	23	88	77	115
25 Jul	11	10	104	90	115	20 Aug	20	23	68	77	88
26 Jul	4	3	116	97	120	Total	514	11	4,137	89	4,651

Appendix E3.–Daily count and percentages of fish ≥75 cm ARIS length moving upstream and downstream (and daily total) for the early run, RM 13.7 Kenai River, 2018.

Early run 16 May–7 June					
	Downstream		Upstream		
Date	Num.	%	Num.	%	Total
16 May	0	0	0	0	0
17 May	0	0	0	0	0
18 May	0	0	3	100	3
19 May	1	17	5	83	6
20 May	0	0	1	100	1
21 May	0	0	3	100	3
22 May	0	0	5	100	5
23 May	0	0	7	100	7
24 May	0	0	6	100	6
25 May	0	0	2	100	2
26 May	1	33	2	67	3
27 May	6	30	14	70	20
28 May	6	30	14	70	20
29 May	5	28	13	72	18
30 May	5	22	18	78	23
31 May	5	25	15	75	20
1 Jun	2	9	20	91	22
2 Jun	4	15	23	85	27
3 Jun	0	0	17	100	17
4 Jun	1	4	22	96	23
5 Jun	2	9	20	91	22
6 Jun	4	15	23	85	27
7 Jun	5	17	25	83	30
Early run 7–30 June					
	Downstream		Upstream		
Date	Num.	%	Num.	%	Total
8 Jun	1	5	18	95	19
9 Jun	4	16	21	84	25
10 Jun	3	12	22	88	25
11 Jun	2	8	22	92	24
12 Jun	0	0	13	100	13
13 Jun	0	0	12	100	12
14 Jun	0	0	20	100	20
15 Jun	2	11	16	89	18
16 Jun	3	33	6	67	9
17 Jun	0	0	11	100	11
18 Jun	1	8	11	92	12
19 Jun	1	17	5	83	6
20 Jun	3	20	12	80	15
21 Jun	3	19	13	81	16
22 Jun	1	8	11	92	12
23 Jun	1	13	7	88	8
24 Jun	0	0	8	100	8
25 Jun	0	0	12	100	12
26 Jun	0	0	9	100	9
27 Jun	1	8	12	92	13
28 Jun	1	5	21	95	22
29 Jun	1	10	9	90	10
30 Jun	2	10	18	90	20
Total	77	12	567	88	644

Appendix E4.–Daily count and percentages of fish ≥75 cm ARIS length moving upstream and downstream (and daily total) for the late run, RM 13.7 Kenai River, 2018.

Late run 1–26 Jul					
	Downstream		Upstream		
Date	Num.	%	Num.	%	Total
1 Jul	0	0	19	100	19
2 Jul	1	3	28	97	29
3 Jul	4	14	24	86	28
4 Jul	1	3	34	97	35
5 Jul	1	3	35	97	36
6 Jul	1	2	43	98	44
7 Jul	2	3	62	97	64
8 Jul	2	5	39	95	41
9 Jul	1	2	42	98	43
10 Jul	1	6	16	94	17
11 Jul	2	8	22	92	24
12 Jul	0	0	49	100	49
13 Jul	1	3	38	97	39
14 Jul	1	4	26	96	27
15 Jul	1	4	22	96	23
16 Jul	1	3	38	97	39
17 Jul	1	2	45	98	46
18 Jul	0	0	58	100	58
19 Jul	2	2	87	98	89
20 Jul	6	6	100	94	106
21 Jul	2	3	65	97	67
22 Jul	3	4	72	96	75
23 Jul	2	2	85	98	87
24 Jul	10	12	76	88	86
25 Jul	9	7	116	93	125
26 Jul	4	5	79	95	83

Late run 27 Jul–20 Aug					
	Downstream		Upstream		
Date	Num.	%	Num.	%	Total
27 Jul	4	5	69	95	73
28 Jul	13	14	82	86	95
29 Jul	4	5	77	95	81
30 Jul	4	6	60	94	64
31 Jul	25	19	106	81	131
1 Aug	9	8	101	92	110
2 Aug	18	17	88	83	106
3 Aug	8	7	100	93	108
4 Aug	8	9	80	91	88
5 Aug	13	10	111	90	124
6 Aug	17	17	84	83	101
7 Aug	15	10	131	90	146
8 Aug	12	17	58	83	70
9 Aug	16	21	61	79	77
10 Aug	13	17	65	83	78
11 Aug	20	23	67	77	87
12 Aug	22	20	90	80	112
13 Aug	57	40	84	60	141
14 Aug	42	34	80	66	122
15 Aug	41	31	93	69	134
16 Aug	36	33	73	67	109
17 Aug	54	40	80	60	134
18 Aug	38	35	71	65	109
19 Aug	46	35	86	65	132
20 Aug	25	26	72	74	97
Total	619	15	3,389	85	4,008

Appendix E5.–Daily count and percentages of fish ≥75 cm ARIS length moving upstream and downstream (and daily total) for the early run, RM 13.7 Kenai River, 2019.

Early run 16 May–7 June						Early run 8–30 June					
	Downstream		Upstream				Downstream		Upstream		
Date	Num.	%	Num.	%	Total	Date	Num.	%	Num.	%	Total
16 May	0	0	0	0	0	8 Jun	0	0	26	100	26
17 May	0	0	0	0	0	9 Jun	0	0	27	100	27
18 May	0	0	0	0	0	10 Jun	0	0	24	100	24
19 May	0	0	1	100	1	11 Jun	0	0	34	100	34
20 May	1	100	0	0	1	12 Jun	1	5	21	95	22
21 May	0	0	3	100	3	13 Jun	0	0	36	100	36
22 May	0	0	1	100	1	14 Jun	1	5	18	95	19
23 May	1	17	5	83	6	15 Jun	0	0	21	100	21
24 May	1	13	7	88	8	16 Jun	0	0	7	100	7
25 May	2	20	8	80	10	17 Jun	0	0	11	100	11
26 May	0	0	6	100	6	18 Jun	0	0	12	100	12
27 May	0	0	7	100	7	19 Jun	1	6	16	94	17
28 May	0	0	13	100	13	20 Jun	0	0	23	100	23
29 May	0	0	10	100	10	21 Jun	2	13	13	87	15
30 May	0	0	11	100	11	22 Jun	0	0	12	100	12
31 May	0	0	8	100	8	23 Jun	1	6	16	94	17
1 Jun	0	0	21	100	21	24 Jun	1	5	18	95	19
2 Jun	0	0	19	100	19	25 Jun	0	0	19	100	19
3 Jun	3	8	36	92	39	26 Jun	0	0	17	100	17
4 Jun	2	6	31	94	33	27 Jun	0	0	16	100	16
5 Jun	0	0	38	100	38	28 Jun	0	0	8	100	8
6 Jun	0	0	36	100	36	29 Jun	1	6	16	94	17
7 Jun	0	0	22	100	22	30 Jun	1	8	12	92	13
						Total	19	3	706	97	725

Appendix E6.–Daily count and percentages of fish ≥75 cm ARIS length moving upstream and downstream (and daily total) for the late run, RM 13.7 Kenai River, 2019.

Late run 1–26 Jul						Late run 27 Jul–20 Aug					
	Downstream		Upstream				Downstream		Upstream		
Date	Num.	%	Num.	%	Total	Date	Num.	%	Num.	%	Total
1 Jul	0	0	16	100	16	27 Jul	5	10	45	90	50
2 Jul	3	11	25	89	28	28 Jul	3	6	45	94	48
3 Jul	1	7	14	93	15	29 Jul	3	7	43	93	46
4 Jul	3	9	29	91	32	30 Jul	7	11	55	89	62
5 Jul	0	0	26	100	26	31 Jul	6	13	41	87	47
6 Jul	0	0	43	100	43	1 Aug	9	22	32	78	41
7 Jul	0	0	27	100	27	2 Aug	3	9	32	91	35
8 Jul	1	3	32	97	33	3 Aug	7	18	32	82	39
9 Jul	1	4	27	96	28	4 Aug	8	12	58	88	66
10 Jul	1	2	47	98	48	5 Aug	17	27	45	73	62
11 Jul	3	5	58	95	61	6 Aug	9	22	32	78	41
12 Jul	0	0	52	100	52	7 Aug	2	5	37	95	39
13 Jul	8	14	49	86	57	8 Aug	8	22	29	78	37
14 Jul	2	3	62	97	64	9 Aug	4	17	19	83	23
15 Jul	1	2	54	98	55	10 Aug	3	12	23	88	26
16 Jul	2	4	52	96	54	11 Aug	9	21	33	79	42
17 Jul	2	2	82	98	84	12 Aug	10	26	29	74	39
18 Jul	6	7	75	93	81	13 Aug	9	32	19	68	28
19 Jul	4	6	65	94	69	14 Aug	6	12	43	88	49
20 Jul	1	1	84	99	85	15 Aug	8	23	27	77	35
21 Jul	5	5	95	95	100	16 Aug	10	22	35	78	45
22 Jul	2	2	85	98	87	17 Aug	6	19	25	81	31
23 Jul	2	3	64	97	66	18 Aug	23	44	29	56	52
24 Jul	5	7	65	93	70	19 Aug	15	44	19	56	34
25 Jul	4	6	58	94	62	20 Aug	18	32	38	68	56
26 Jul	3	5	58	95	61	Total	268	11	2,209	89	2,477