Fishery Data Series No. 16-44

Chinook Salmon Passage in the Kenai River at River Mile 13.7 Using Adaptive Resolution Imaging Sonar, 2014

by

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

Symbols and Abbreviations

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Weights and measures (metric)

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

Weights and measures (English)

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

Time and temperature

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

Physics and chemistry

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

General

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

Mathematics, statistics

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

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TABLE OF CONTENTS

Page

TABLE OF CONTENTS (Continued)

Page

LIST OF TABLES

Table **Page**

LIST OF FIGURES

LIST OF FIGURES (Continued)

Figure **Page**

LIST OF APPENDICES

Appendix **Page**

LIST OF APPENDICES (Continued)

ABSTRACT

In 2014, Kenai River Chinook salmon (*Oncorhynchus tshawytscha*) passage was estimated using Adaptive Resolution Imaging Sonar (ARIS) at river mile 13.7. Net upstream passage of Chinook salmon greater than or equal to 75 cm as measured by ARIS was estimated to be 2,397 (SE 132) during the early run (16 May–30 June) and 10,871 (SE 291) during the late run (1 July–15 August). Net upstream passage of all Chinook salmon regardless of size was estimated to be 5,768 (SE 359) during the early run and 16,871 (SE 580) during the late run.

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

INTRODUCTION

Chinook salmon (*Oncorhynchus tshawytscha*) returning to the Kenai River (Figure 1) are managed as 2 distinct runs (Burger et al. 1985): early (mid-May–30 June) and late (1 July–mid-August). Early-run Chinook salmon are harvested primarily by sport anglers, and late-run Chinook salmon are harvested by commercial, sport, subsistence, and personal use fisheries. These fisheries may be restricted or liberalized if the projected escapement falls below or above goals adopted by the Alaska Board of Fisheries (BOF). These goals are defined by Alaska Administrative Codes 5 AAC 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. Escapement goals have evolved over the years as stock assessment and our understanding of stock dynamics have improved (McBride et al. 1989; Hammarstrom and Hasbrouck 1998-1999; Bosch and Burwen 1999). During the 2014 season, goals of 5,300–9,000 early-run and 15,000–30,000 late-run Chinook salmon were in effect, as assessed by DIDSON-based sonar estimates at river mile (RM) 8.6. Sonar estimates of inriver Chinook salmon passage provide the basis for estimating spawning escapement and implementing management plans that regulate harvest in the competing fisheries for this stock.

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

The RM 8.6 site was originally selected in 1985, based primarily on its suitability for operating a dual-beam (and subsequently a split-beam) sonar system, which required a near-perfect linear bottom profile over the entire insonified zone or, in this case, from the nearshore region to the thalweg. See Key et al (2016a) for a comprehensive history of sonar research and development at the Kenai River RM 8.6 site. However, the RM 8.6 site has many disadvantages, primarily related to its location within tidal influence: 1) incomplete coverage of the river during high tides that flood the region behind the transducers, 2) milling fish behavior related to tidal flux, 3) physical risk to gear by large debris carried by extreme tidal fluxes, and 4) lack of legal access to the property on one bank. It became evident that relocating the site farther upriver could improve the estimates of Chinook salmon passage by minimizing or eliminating these negative factors. In 1999, ADF&G evaluated a second sonar site at RM 13.2 for use of split-beam sonar to assess fish passage, but the bottom topography was less acoustically favorable and the 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 is not possible at the RM 8.6 site (Figure 3). 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. 2016) and again during 16 May–15 August 2014 while also continuing to operate the DIDSON at the RM 8.6 site.

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). Until recently, netting at RM 8.6 has been restricted to a midriver corridor in order to approximately match the cross-sectional area insonified by the sonar. In 2012, Chinook salmon sampled at the RM 8.6 netting project and at tributary weirs upstream 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[1]; 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, 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.

This report documents data collection methods, analyses, and results from sonar operations at RM 13.7 in 2014. Daily estimates are reported for net upstream Chinook salmon passage by size

[1] 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.

category. The estimates reported here represent only the second season of operation at RM 13.7 and constitute exploratory data (i.e., data not used for management decisions) that will be considered in plans for future assessments of Kenai River Chinook salmon. DIDSON-derived estimates (expanded) from the RM 8.6 site (Key et al. 2016b) were used to manage Kenai River fisheries in 2014. The current escapement goals were designed to be assessed by sonar counts at either RM 8.6 (expanded) or RM 13.7. The equivalence of these data during 2013 and 2014 is addressed. Other items discussed include run timing differences between RM 8.6 and RM 13.7, and difficulties associated with estimation of small Chinook salmon during the early run.

Findings of an expanded ARIS tethered fish study in 2014 are also presented. Designed to follow up on a limited study conducted in 2013 (Miller et al. 2016), objectives of the 2014 tethered fish study were as follows : 1) assess the relationship between ARIS length and true length, 2) test for effects of range, frequency, and observer on ARIS length measurements, and 3) confirm the adequacy of current settings that govern image resolution.

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[2].

SITE DESCRIPTION

The sonar site is located 22 km (13.7 miles) from the mouth of the Kenai River (Figure 2). This location was identified during bathymetric surveys conducted in 2012 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 90 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.

[2] WRCC (Western Region Climate Center). 2015. Kenai FAA Airport, Alaska. Website Western U.S. Climate Historical Summaries, Climatological Data Summaries, Alaska, accessed August 28, 2015. http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?ak4550.

ACOUSTIC SAMPLING

Acoustic sampling was conducted using Sound Metrics Corporation (SMC[3]) ARIS systems. Daily abundance estimates were generated from 16 May through 15 August 2014. Components of the ARIS systems are listed in Table 1. Appendices A1–A12 provide greater detail on ARIS technology and a comparison with DIDSON technology.

Sonar System Configuration and River Coverage

Site characteristics at RM 13.7 allow for near complete sonar coverage of the river cross-section. A bathymetric survey conducted in 2012 included 8 bottom profile transects that showed several promising areas for deploying sonars (Figures 4–5). Transects 5 and 6 in Figure 5 were chosen for the right- and left-bank main channel sonar deployments in 2014.

A total of 5 sonars were required to provide coverage: a nearshore and offshore sonar on each bank of the main channel (Figure 6) plus 1 sonar on the minor channel (Figure 7). During the early part of the season, when the water level was low, 1 sonar on each bank was sufficient to insonify most of the 60–70 m of river cross-section in the main channel (Table 2), but later in the season, as water levels rose, a second sonar was deployed on each bank to insonify the nearshore zone and the first 3–5 m in front of the offshore sonars (Figure 6). The nearshore sonars were first deployed on 28 May (left bank) and 2 June (right bank) (Table 2) and were moved closer to shore as the water level rose. At its highest water stage, the main channel increased to approximately 90 m in width. In the main channel, the original (now offshore) sonars were not moved closer to shore as water levels rose because they were already insonifying the maximum range recommended for operation in high-frequency mode (approximately 30 m; Appendix A2). The minor channel was dry when the project began in mid-May, but had sufficient water for fish passage by the time the sonar was deployed on 11 June (Table 2). This channel was approximately 30 m 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 7).

Two different ARIS models were used to provide optimal cross-river coverage of the main channel (Figures 3 and 6, 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 6) and on the minor channel due to the longer (~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 of the limited range that needed to be covered and the advantages of this sonar model for covering close-range targets. The ARIS 1800 is more advantageous for insonifying close-range targets and nearshore areas because it operates at a higher frequency, yielding higher resolution without the use of a large (high-resolution) lens. The standard lens has the advantage of better focusing capabilities at closer ranges (Appendix A5) and wider beam dimensions (14°×28° versus 3°×15°) to provide better coverage in both vertical and horizontal dimensions at short ranges. Finally, using sonars with different operating frequencies allowed nearshore and offshore strata to be sampled simultaneously without crosstalk interference.

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[3] Product names used in this publication are included for completeness but do not constitute product endorsement.
[4] The left bank is on the left-hand side of the river as one faces downstream.

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 8). 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 6). 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 9). 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 9 and 10). Two battery banks, charged daily using generators, provided power to the right-bank sonar electronics and wireless bridges.

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). The ARIS can be programmed to automatically sample each range stratum using the software interface "ARIScope." At the start of the season, 2 sonars were deployed on the mainstem, each sampling 3 strata. Table 2 summarizes the range coverage by each range stratum along with the changes in range parameters throughout the season as the water level rose and aims were refined. By 11 June, 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 collection parameters (Table 3, Figure 11). By 22 July, water levels were more or less stable and no significant changes were made to any parameters or to the positions of the sonars through the end of the season on 15 August. A systematic sample design (Cochran 1977) was used to sample each stratum for 10 minutes each hour following the schedule in Table 3. This routine was followed 24 hours per day and 7 days per week unless a transducer was inoperable.

A test of the systematic sample 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 3 and 4, Appendix A1). The downrange resolution capability of ARIS is particularly improved over its predecessor (DIDSON). ARIS can collect up to 4,000 samples per beam to define the downrange resolution compared to 512 samples per beam for DIDSON (Table 4). ARIS user-selectable parameters are described in Appendix A1 along with the corresponding fixed values in the DIDSON system.

A consultant from Sound Metrics Corporation was on site from 12 to 16 May 2014 to assist project personnel with selecting the initial sampling strata and optimizing the aim and data collection parameters for each stratum. Parameters that varied with each stratum were frame rate, frequency, window length, sample period (which controls samples per beam and "Detail"), and transmit pulse width (Table 3).

Frame Rate

The maximum allowable frame rate was used for each stratum (Table 3). In practice, frame rates for each stratum were arrived at empirically by first fixing the parameters for start and end ranges and sample period for each stratum and then finding the maximum achievable frame rate. Frame rate is dependent on the number of beams used (96 beams for ARIS 1800, 48 beams for ARIS 1200), the end range of each stratum, and the frame size. The farther the end range, the longer the return time for the number of pings that builds an individual 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

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 6 and 11). 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 12). 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 2 exceptions. The last stratum on the right bank offshore sonar was sampled at low frequency (0.7 MHz) from 16 to 21 May, and the last stratum on the left bank offshore sonar was sampled on low frequency (0.7 MHz) from 16 May to 4 June. Two factors combined to necessitate sampling the last strata of the offshore sonars using low frequency. First, transmission loss resulting from colder water temperatures (as low as 7° C on 20 May) required the use of low frequency mode to achieve the desired range of approximately 35 m when sampling the furthest stratum on each bank. Second, the right and left bank offshore sonars 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.

By 4 June, water temperatures had warmed enough (10° C) and background noise had declined enough that high frequency mode could be used to achieve the desired maximum range of about 35 m by both offshore sonars. Starting on 22 July, a Sound Metrics consultant began making hardware modifications to all ARIS units that significantly reduced background noise and should mitigate the issue in the future.

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. With DIDSON, the sample period was fixed at 27 µs with a transmit pulse width of 50 µs. All ARIS strata were collected at shorter sample periods that varied from 4 to 15 µs or at least twice the downrange resolution as DIDSON. Shorter sample periods were generally used with close-range strata and paired with shorter transmit pulse widths, providing exceptionally high resolution. For example, the sample periods for the first stratum of each ARIS 1200 varied from 4 to 6 µs. With increasing range, longer transmit pulse widths are generally required for sufficient power to achieve greater ranges. As a general rule, the manufacturer recommends setting the transmit pulse width long enough to get 2 samples within the transmit pulse. However at ranges less than about 10 m, a transmit pulse long enough for 1 sample will suffice (Bill Hanot, personal communication, Sound Metrics Corporation, Seattle, WA).

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. The transmit pulse width for each stratum was set to "Auto," which sets the pulse width to the end range in microseconds. "Transmit Level" was set to maximum for each stratum and "Gain" varied by stratum from 0 to 24 dB.

MANUAL ARIS FISH LENGTH MEASUREMENTS

Measurements of fish length were obtained using ARISFish V2.3 software supplied by SMC. Detailed instructions for taking manual measurements and the software settings and parameters that were used for this project are given in Appendix B1. Electronic echograms similar to those generated with the DIDSON software (Miller et al. 2015) provided a system to manually count, track, and size individual fish (Figure 13).

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

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

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

1) During samples without dense aggregations of fish, length and direction of travel were recorded for all salmon-shaped fish greater than or equal to 40 cm AL that met the centerline rule (Appendix B3).
2) During individual samples with dense aggregations of fish, length and direction of travel were recorded for all fish greater than or equal to 75 cm AL. However, length was recorded for only a subsample of fish with ARIS length greater than or equal to 40 cm and less than 75 cm. The first *F* fish in the sampled period were measured, where choice of *F* depended on daily staff time constraints. For the remainder of the sample (after the first *F* fish), only fish appearing to be greater than or equal to 75 cm AL 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 (Perschbacher 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). 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 the 2013 report (Miller et al. 2016), when only pilot 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. Unlike the DIDSON sonar estimates at RM 8.6, which estimate the number of fish migrating upstream in a midriver corridor (Miller et al. 2013-2015; Key et al. 2016a, 2016b), the RM 13.7 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 $\mathbf{X}$ of criteria under investigation (e.g., fish with ARIS length equal to or greater than 75 cm and that migrated in an upstream direction) during day i was estimated as follows:

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

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

$$\hat{y}_{iks} = \frac{24}{h_{iks}} \sum_{s=1}^{4} \hat{y}_{ijks} \,, \tag{2}$$

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:

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

where

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

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

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

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

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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).

Chinook Salmon Passage

Upstream Chinook salmon passage, regardless of size, was estimated by fitting a mixture model to upstream ARIS length and RM 8.6 netting data. Upstream Chinook salmon passage on day *i* was estimated as follows:

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

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 lengths from RM 13.7 and netting data from RM 8.6 (Perschbacher and Eskelin *In prep*) as described in Appendices C1–C7.

The variance estimate followed Goodman (1960):

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

During 16 May–2 June 2014, a pooled estimate of π_C was calculated because daily sample sizes were too small to produce reliable estimates during that period.

Upstream ARIS data were used to be consistent with the drift gillnetting data, which presumably capture only upstream bound fish. Midriver and nearshore netting data from RM 8.6 were used (see Discussion).

Daily net upstream Chinook salmon passage was approximated as

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

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.

Note that estimates of w_i and π_{Ci} are intermediate quantities only, in the sense that they are required in order to estimate z_i and N_i, but have no biological interpretation themselves because not all small fish (40–75 cm AL) were measured and counted. Estimates of z_i and N_i remain valid. A test conducted on 26 days of July 2014 data found good agreement between Chinook salmon abundance estimates obtained with complete sampling versus those obtained without complete sampling of small fish. The relationship had a slope of 0.96 and a coefficient of determination of 0.99.

Tethered Fish Data Collection

Tethered fish data were collected 21–24 July 2014 using an ARIS 1200 with a high-resolution lens deployed from the right bank of the Kenai River at RM 8.6. Data collection was conducted at RM 8.6 rather than RM 13.7 because of lower background noise, and because an inriver gillnetting project at RM 8.6 provided live salmon to tether.

A total of 25 fish, 16 sockeye salmon and 9 Chinook salmon, were captured and tethered following techniques described by Burwen et al. (2010) to each of 2 stations. The "near" and "far" stations were deployed such that a passive target would be located at approximately 15 m and 30 m from the transducer, respectively, but because the fish had some freedom of movement, they actually positioned themselves at an 8–21 m range for the "near" station, and a 20–34 m range for the "far" station. Samples (short "video" clips) of ARIS data were obtained using multiple parameter settings for each fish at each station. Parameters subject to change included frequency (high = 1.2 MHz or low = 0.7 MHz), window length (2–26 m), sample period (4–28 µs), and transmit pulse width (10–49 µs). A total of 224 individual samples representing unique combinations of fish, station, and equipment settings were measured, following procedures detailed in Appendix B1. For each sample, 3 ARIS length measurements were taken by each of 3 experienced observers, following a double-blind design. The means of the 3 measurements per observer yielded 672 individual ARIS length estimates for analysis from 2014.

For some analyses, data collected from 2 sockeye salmon and 1 Chinook salmon in a 2013 ARIS tethered fish pilot study were included. The 2013 data were collected at 2 ranges and 2 frequencies, although not all fish were measured at all range and frequency combinations. A total of 8 individual length estimates, each measured by a single observer, were available from 2013. See Miller et al. (2016) for details of the 2013 study.

For addressing Objectives 1 and 2 (assess the relationship between ARIS length and true length, and test for effects of range, frequency, and observer on ARIS length measurements), a filtered subset of the 2013–2014 tethered fish data (8 individual length estimates from 2013 plus 447 from 2014) was considered. This subset comprised the data collected using equipment settings (similar to those found in Table 3) commonly used at the upriver site (RM 13.7) and was designed to be germane to 2013–2014 free-swimming fish data collected at the RM 13.7 site.

For addressing Objective 3 (confirm the adequacy of current settings that govern image resolution), only data collected using sample periods of 5 µs, 10 µs, and 27 µs were considered (n = 552 individual estimates from 2014 only). This subset was designed to compare the sample period suggested by the manufacturer (10 µs; Bill Hanot, personal communication, Sound Metrics Corporation, Seattle, WA) to higher and lower sample period settings.

Regression parameters were estimated by fitting general linear models (Neter et al. 1990) to individual length estimates (Objectives 1 and 2) or to the average of those estimates across observers (Objective 3).

RESULTS

Data collection began on 16 May for the main channel offshore transducers, 28 May for the main channel left bank nearshore transducer, 2 June for the main channel right bank nearshore transducer, and 11 June for the minor channel transducer (Table 2). All sampling ended after 15 August.

SIZE DISTRIBUTION AND SPECIES COMPOSITION

Small fish (presumably sockeye salmon) predominated in both early and late runs, as evidenced by large left-hand modes in the ARIS length (AL) frequency distributions (Figure 14, top panels). The modes of the AL distributions line up well[6] with mid eye to tail fork (METF) length distributions from salmon measured by the inriver netting project (Figure 14, bottom panels). The AL distributions are broader than the corresponding METF distributions because there is greater error associated with measuring length from ARIS images.

Non-Chinook salmon captured in the RM-8.6 gillnets rarely exceeded 65–70 cm METF (Figure 14, bottom panels). From inspection of AL frequency distributions (Figure 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. From inspection of DIDSON length (DL) frequency distributions (Figure 14, middle panels), it is also evident that the right tail of the left-hand mode (presumably non-Chinook salmon) very rarely exceeded 75 cm DL. Thus, DIDSON and ARIS length measurements were very nearly equivalent, at least for fish approximately 65 cm to 75 cm METF.

The frequency distribution of early-run ARIS lengths was more complex than the early-run DIDSON length distribution, possessing a small separate mode near 45 cm (Figure 14, top left panel). This mode was observed during the 2013 early run as well and probably consists of resident fish (e.g., rainbow trout [*O. mykiss*] and Dolly Varden [*Salvelinus malma*]) rather than sockeye salmon[7]. No mode was present at 45 cm in the late run ARIS length frequency distribution (Figure 14, top right panel), when much larger numbers of sockeye salmon and pink salmon could have obscured any such resident fish.

SPATIAL AND TEMPORAL DISTRIBUTION

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

During both the early and late runs, a majority (52% early run, 68% late run) of upstream bound medium and large (AL ≥ 75 cm) fish migrated past the sonar site on the right bank of the main channel (Table 5, Figure 15). No early-run and only 2% of late-run upstream bound medium and large (AL ≥ 75 cm) fish were found migrating in the minor channel.

The same fraction (39%) of medium and large (AL ≥ 75 cm) fish migrated closer to shore in both the early and late run (nearshore values in Table 5 summed over left and right banks). Nearshore migrants comprised larger fractions of right bank fish than left bank fish, especially during the late run (Table 5, Figure 15, Appendices D1–D7).

In 2014, diurnal migration cycles were less consistent than in 2013. When upstream bound medium and large fish were classified as day (sunrise to sunset) versus night (sunset to sunrise) migrators, the number migrating at night in May 2014 was disproportionately large compared to the relative lengths of night and day (Figure 16); however, after early July, disproportionately fewer fish migrated at night. The relative ratio of day to night migrators was 75:25 in the early run and 78:22 in the late run (Table 5).

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[6] Lengths from the netting data are not representative across species because non-Chinook salmon were sampled (measured) at only one-half the rate of Chinook salmon. Chinook salmon are therefore disproportionately represented in the netting length data.

[7] No ocean age-1 sockeye salmon (which average approximately 40 cm METF) were sampled during the early run at the Russian River weir (the main component of early-run Kenai River sockeye salmon; Jason Pawluk, Sport Fish Biologist, ADF&G, Soldotna; personal communication).

DIRECTION OF TRAVEL

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

Among medium and large fish (AL ≥ 75 cm), a greater fraction traveled downstream in the late run (9.6%) than in the early run (1.8%) (Table 6). During the late run, relatively more medium and large fish migrated downstream in the minor channel (20.0%) than on the left (13.7%) or right (7.3%) banks of the main channel. Also, for both early and late runs, the downstream fraction of medium and large migrants was higher for fish detected by the nearshore transducers than for those detected by offshore transducers (Table 6).

Among small fish (AL < 75 cm) migrating during the early run, a greater fraction were observed traveling downstream on the left bank of the main channel (2.5%) than on the right bank (1.0%) (Table 6).

Daily percentages of medium and large fish (AL ≥ 75 cm) that were bound upstream and downstream are tabulated in Appendices E1–E2.

CHINOOK SALMON PASSAGE

Daily proportions of upstream bound fish that were Chinook salmon (regardless of size) were estimated using an ARIS–length mixture model (ALMM). These proportions were multiplied by ARIS estimates of upstream fish passage and corrected for downstream bound fish to produce ARIS estimates of net upstream Chinook salmon passage: 5,768 (SE 359) Chinook salmon during the early run (16 May–30 June; Table 7) and 16,871 (SE 580) during the late run (1 July–15 August; Table 8).

The AL mixture model also produced daily estimates of Chinook salmon age group composition (Tables 9 and 10). These estimates incorporated length information from ARIS as well as from inriver gillnet catches.

Daily estimates of net upstream Chinook salmon passage are plotted in Figure 17. Other measures of abundance are plotted for comparison in Figures 18 and 19, including expanded DIDSON-based estimates from RM 8.6.

MEDIUM AND LARGE FISH PASSAGE

Daily net upstream passage of medium (75 cm ≤ AL < 90 cm) and large (AL ≥ 90 cm) Chinook salmon were estimated directly by the ARIS sonar. During the 2014 early run (16 May–30 June), an estimated 2,397 (SE 132) fish greater than or equal to 75 cm AL passed RM 13.7, including 1,940 (SE 114) medium and 457 (SE 55) large fish (Table 11). During the 2014 late run (1 July–15 August), an estimated 10,871 (SE 291) fish greater than or equal to 75 cm AL passed RM 13.7, including 5,641 (SE 205) medium (75 cm ≤ AL < 90 cm) and 5,230 (SE 192) large (AL ≥ 90 cm) fish (Table 12).

SMALL FISH PASSAGE

Daily net upstream passage of small (AL ≤ 75 cm) Chinook salmon was estimated by subtracting the estimate of medium and large fish from the estimate of Chinook salmon regardless of size. During the 2014 early run (16 May–30 June), an estimated 3,371 (SE 383) Chinook salmon less than 75 cm AL passed RM 13.7 (Table 7). During the 2014 late run (1 July–15 August), an estimated 6,000 (SE 649) Chinook salmon less than 75 cm AL passed RM 13.7 (Table 8).

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.

TETHERED FISH MEASUREMENTS

Individual ARIS length estimates (n = 455) had a strong linear relationship with fork length (FL, measured from snout to fork of tail; R^2 = 0.91; Figure 20). Measurements of length were also significantly (P < 0.05) affected by range (distance from transducer), choice of high versus low frequency, and observer, after controlling for FL.

Individual observer effects differed (P < 0.001) by up to 2.5 cm, however variation in AL due to these effects was small relative to the effect of FL. For example, differences among observers increased the error associated with predicting the ARIS length of 2014 tethered fish by only 2.3%. When modeled as a random effect, the error standard deviation due to observer differences was approximately 1.4 cm. In subsequent analyses we ignored observer effect, considering it to be part of the overall error variance.

The effect due to sonar frequency was also small; measurements using low frequency averaged 1.5 cm (SE 0.7) longer (P = 0.03) than those using high frequency.

Finally, range from the transducer had a small positive effect on AL, controlling for FL (Figure 21). For every meter of range, the expected value of AL increased (P < 0.001) by 0.18 cm (SE 0.03). Fish tethered at the far-range station had longer and more variable AL measurements, controlling for FL (Figure 22). Controlling for tethering station, the range effect was less evident (P = 0.02) at the “far” station and nonexistent (P = 0.94) at the “near” station (Figure 22).

Sample period appeared to have minimal effect on the accuracy of AL measurements relative to FL measurements. There was no discernable improvement in precision when collecting data at higher resolution settings (i.e., lower sample period; Figure 23). Additional analyses that controlled for range (not shown) also failed to show meaningful improvement in precision.

DISCUSSION

TETHERED FISH MEASUREMENTS

The relationship between AL and FL was nearly identical to the relationship between DIDSON length (DL) and FL (Figure 24, Table 13; DIDSON data from Burwen et al. [2010] and Miller et al. [2012]). Regardless which data set and effects are included in the model, the intercept of the regression line between AL and FL was always positive and the slope (FL coefficient) less than 1 (Table 13). Thus ARIS (and DIDSON) length measurements are nearly unbiased for small (40–60 cm) salmon but they slightly underestimate the size of longer fish. For example, the expected ARIS or DIDSON length measurement from a tethered Chinook salmon with a fork length of 100 cm is 90 cm (Figure 20). Note that the relationships of AL to FL plotted in Figures 20 and 24 are conditional on fish being 21 m from the transducer (mean range of 2013–2014 tethered fish) and on the use of high frequency (1.2 MHz).

The amount of error associated with ARIS length measurements was also similar to the amount of error in DIDSON length estimates. The ARIS regression error standard deviations in Table 13

(RMSE = 4.7–4.9 cm) cannot be directly compared to the DIDSON value (3.9 cm) because the ARIS lengths were from individual observers whereas the DIDSON lengths were the means of 2 observers. When 2014 ARIS data were averaged across observers and re-analyzed, the resulting RMSE was 3.6 cm, similar to DIDSON (3.9 cm; Table 13).

The apparent increase in the variability of AL at long range may be due to increased pixel size and a corresponding reduction in resolution. However, the mean and variability of AL changed little with range within a given tethering station (Figure 22); thus, it is possible that the detected range effects could be an artifact of other differences between the near and far stations. Previous tethered-fish studies with DIDSON did not detect an effect of range on length measurements (Burwen et al. 2010; Miller et al. 2012).

The relationship between AL and FL was similar among data collected using varying sample periods (5 µs, 10 µs, and 27 µs), thus indicating the resolution setting used for data collection has minimal effect on the accuracy of AL measurements. We conclude that the resolution setting suggested by the manufacturer (10 µs) provides an adequate balance between the accuracy of AL measurements and the amount of storage space required for processing and archiving data.

Expected AL measurements from the ARIS tethered fish data were approximately 4 cm longer than corresponding estimates based on mixture models that were fit daily to free-swimming fish data collected at RM 13.7 during 2013–2014 (Figure 24). This can be partially explained by a 13 m difference in average range between the 2 data sets (21 m for tethered fish, 8 m for daily mixture model), accounting for approximately 2.6 cm of the difference in expected length.

Although ARIS length (AL) measurements are closely related to hand-measured fish size (FL), and are expressed in centimeters, AL measurements should not be interpreted as exact length measurements. For fish of a given size, individual ARIS measurements can vary by 10 cm or more (Figure 20). The FL:AL relationship developed from the 2013–2014 daily mixture model output (AL = 3.03 + 0.866 FL; Table 13) is arguably the most appropriate conversion between AL and FL because it is derived from free-swimming fish data collected at the RM 13.7 site. Using this relationship, the inverse predictions of fork length for fish measuring 40, 75, and 90 cm AL are 43, 83, and 100 cm FL. Equivalent mid eye to tail fork (METF) measurements would be 39, 75, and 91 cm METF. Total length (TL), measured in inches from snout to tip of tail as prescribed in Alaska sport fishing regulations (Alaska Administrative Code 5 AAC 75.995) would be 17, 33, and 40 inches TL. Inverse predictions of fish size as a function of AL are summarized in Table 14.

EQUIVALENCE OF ABUNDANCE ESTIMATES AT RM 8.6 AND RM 13.7

The current escapement goals were designed to be assessed using spatially expanded DIDSON-based estimates obtained at RM 8.6. Spatial expansion factors (1.55 for the early run, 1.28 for the late run) were derived by fitting statistical models to annual abundance, harvest, and age composition data from 1986 to 2012 (Fleischman and McKinley 2013; McKinley and Fleischman 2013). With the availability of riverwide ARIS-based estimates of Chinook salmon abundance in 2013 and 2014, we can now compare the spatially expanded estimates with empirical estimates of inriver abundance. See Table 15 for a summary of the differences between old (expanded RM 8.6) vs new (RM 13.7) sonar estimators of abundance.

An accurate comparison of the estimates requires accounting for harvest and spawning of fish between the lower and upper sonar sites. An inriver creel survey in 2014 estimated that 242

(45%; SE 2.1%) of 539 harvested Chinook salmon were taken between river miles 8.6 and 13.7 (Perschbacher and Eskelin *In prep*). Telemetry experiments found that 2.7% (2013) and 5.3% (2014) of radiotagged Chinook salmon spawned between the sonar sites (Eskelin and Reimer *In prep*). With this information, inriver run abundance at RM 8.6 can be reconstructed from the ARIS (RM 13.7) estimates (IR_{RA}; Table 16). Reconstructed values can then be compared with expanded DIDSON observations of abundance (IR_{XD}; Table 16) because both estimates are germane to the lower (RM 8.6) site. The comparison is a test of the model-derived expansion factors designed to correct for incomplete detection by sonars at RM 8.6. Ratios of IR_{RA} to IR_{XD} near 1.0 would confirm that the actual proportions pMR of Chinook salmon migrating between the RM 8.6 transducers are close to the values estimated by McKinley and Fleischman (2013; early run pMR = 0.65) and Fleischman and McKinley (2013; late run pMR = 0.78), thus validating the current expansion factors. Values of IR_{RA}:IR_{XD} different than 1.0 reflect deviations from the expected migratory behavior. A ratio greater than one means that more than the expected number of Chinook salmon were "missed" (not detected) at RM 8.6, and a ratio less than one means that fewer than expected were missed.

During the early run, the IR_{RA}:IR_{XD} ratio was 1.28 in 2013 and 0.77 in 2014; during the late run it was 1.06 in 2013 and 1.01 in 2014 (Table 16). Thus, during both early and late runs, the DIDSON at RM 8.6 missed a greater proportion of Chinook salmon in 2013 than in 2014. Findings from an experimental nearshore netting project at RM 8.6 were consistent with this result: there were relatively more Chinook salmon near shore (behind sonar) in 2013 (Perschbacher 2015) than in 2014 (Perschbacher and Eskelin *In prep*).

The mean 2013–2014 ratio was 1.02 for the early run and 1.04 during the late run (Table 16), suggesting that on average, migrating Chinook salmon behaved approximately as expected by the model and on average, the RM 8.6 estimates were expanded appropriately. On the other hand, the individual annual ratios differed substantially between years, especially during the early run (1.28 vs. 0.77; Table 16). Thus, in a given year, the spatially expanded estimates can be prone to error, producing management advice that can be either too restrictive or too lenient.

We conclude that ARIS estimates at RM 13.7 derived from midriver netting data are, on average, equivalent to expanded RM 8.6 DIDSON estimates. Consequently, they can be used to monitor the attainment of escapement goals currently in effect. See below for more discussion about netting data and its role in assessing Chinook salmon abundance[8].

Inseason assessment based on the RM 13.7 sonar, which insonifies nearly the entire cross-section of the river, eliminates the uncertainty introduced by the inconsistent detection rates at RM 8.6. This is the primary advantage of the RM 13.7 sonar site. Other benefits include reduced risk of losing the sonar gear (vulnerable during extreme tides at RM 8.6), and cost savings due to reduced staffing requirements.

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[8] Strictly speaking, the 2013 and 2014 ARIS estimates (IR_{14} in Table 16) are not perfectly comparable because the 2013 estimates were generated without nearshore netting data. However, when 2014 estimates derived from midriver netting data only were used in the comparison, the average ratios were even closer to 1.0 and the conclusions remained the same (Steve Fleischman, Fisheries Scientist, ADF&G, unpublished data).

REMAINING CHALLENGES

Run Timing at RM 13.7

Run timing differences between the 2 sonar sites are also relevant to management. Daily ALMM (ARIS–length mixture model) estimates of Chinook salmon net-upstream passage at RM 13.7 are plotted with daily spatially expanded DLMM (DIDSON-length mixture model) estimates of upstream-only passage at RM 8.6 in Figure 25. Daily passage estimates at the 2 sites generally tracked one another in 2013 and 2014, although there were periods when the estimates diverged substantially. Failure of the 2 estimates to align could be due to delayed migration between the 2 sites, changing detectability (pMR) at the lower site, or both.

The median date of early-run passage was 4 days earlier[9] at RM 13.7 than at RM 8.6 in 2013, but the same in 2014 (Figure 26). The median date of late-run passage was 3–4 days later at RM 13.7 than at RM 8.6 in both 2013 and 2014 (Figure 26). Radiotelemetry results were consistent with these findings: some Chinook salmon radiotagged at RM 8.6 began to exhibit delayed upstream migration in late July (Eskelin and Reimer *In prep*).

Run timing curves based on RM 8.6 DIDSON (n = 5 years[10]) and netting CPUE (n = 13 years[11]) indicate that 2013 and 2014 runs were not anomalously early or late; and 2013–2014 mean run timing was very similar to mean run timing obtained from those longer datasets (Figure 27). Thus, the 2 years of RM 13.7 sonar data, though limited, should provide reasonable point projections of end-of-season run size for the 2015 season.

While the primary advantage of the RM 13.7 site is increased accuracy of the final Chinook salmon escapement estimate, a disadvantage is that inseason projections used for management decisions will occur at a time when a smaller fraction of the run has passed the sonar, due to a delay as fish transit the 5 miles to the upper site. Projections based on smaller fractions require larger expansions and are more uncertain. The information loss due to delayed run timing will offset some of the gain due to monitoring nearly the entire run at RM 13.7, and the net effect on the ability to accurately assess the run inseason is unknown at this point.

Delayed run timing will be a more important consideration during the late run. In 2013 and 2014, it took up to 4 days longer for a given proportion of the late run to pass RM 13.7 compared to RM 8.6 (Figure 26). Decisions based on data through 21 July are currently based on the expectation that approximately 50% of the run has passed RM 8.6, whereas only 39% of the run had passed the RM 13.7 sonar by that date (on average) in 2013–2014 (Figure 27).

Note that daily sonar estimates that are relevant to questions about run timing exist only for years starting in 2010, when DIDSON estimates were first produced. A more complete understanding of run timing at RM 13.7 will be gained as more years of data accumulate.

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[9] Logically, fish cannot pass RM 13.7 before they pass RM 8.6. The median passage date was earlier at the RM 13.7 site because the RM 8.6 site missed many small fish during the first half of the early run, especially in 2013, thereby skewing the median date several days later.

[10] DIDSON-based estimates of Chinook salmon abundance were first produced at RM 8.6 in 2010 and provided less biased estimates than historic split-beam based abundance estimates (Miller et al. 2013).

[11] The standardized netting program at RM 8.6 has provided a consistent index of Chinook salmon abundance since 2002, when improvements to the existing netting program were implemented (Miller et al. 2004).

Early-run Abundance of Small Chinook Salmon

Direct estimates of medium and large fish passage from the ARIS at RM 13.7 (Tables 11–12) constitute the most accurate and reliable information to date about Kenai River Chinook salmon abundance. This is due to the nearly complete spatial coverage, and also because fish measuring 75 cm AL or longer do not overlap in length with sockeye salmon and other small salmon (Figure 14); thus, they can be directly assessed by the sonar. A Chinook salmon measuring 75 cm AL is approximately 75.4 cm METF or 33.3 in total length (TL; Table 14).

Obtaining accurate estimates of small Chinook salmon is more difficult. Chinook salmon less than 75 cm AL cannot be distinguished from other salmon with sonar (Figure 14); therefore, they cannot be directly counted. To assess the abundance of small Chinook salmon, we require supplementary information from the inriver netting program on the relative proportions of small (versus medium or large) Chinook salmon. An illustration of how sonar and netting data are combined to estimate small Chinook salmon abundance is as follows. If the sonar counts 100 Chinook salmon that are medium or large ($\geq$75 cm AL or METF), and the inriver nets catch 10 Chinook salmon, of which 2 (20% or 0.2 of total) are less than 75 cm and the remaining 8 (0.8 of total) are larger, then an estimate of total Chinook salmon abundance (regardless of size) is equal to 100 divided by 0.8, or 125. Of these, 100 are known to be medium or large via sonar, thus, approximately 25 Chinook salmon must be small (<75 cm)[12].

Because estimates of small Chinook salmon require this additional step, they are less precise than estimates of larger Chinook salmon. In 2014, early- and late-run estimates of small Chinook salmon were 2–4 times more uncertain than corresponding estimates of larger Chinook salmon (CV = 0.11–0.12 for small Chinook salmon [from Tables 7 and 8] versus CV = 0.03–0.06 for medium and large Chinook salmon [from Tables 11 and 12]).

2013 Early Run: Sensitivity to Migration Patterns at RM 8.6

During the 2013 early run, it became clear that ALMM estimates of small Chinook salmon are sensitive to migration patterns at the RM 8.6 inriver gillnetting study site. During that year, an estimated 2,095 small Chinook salmon were observed passing the Funny and Killey river weirs, yet the ALMM estimate of small Chinook salmon passage at RM 13.7 during the 2013 early run was only 1,121 (Miller et al. 2016). Furthermore, a simple capture–recapture model fitted to telemetry and weir data generated an estimate of 2,806 small Chinook salmon during the 2013 early run (Miller et al. 2016).

ALMM estimates of Chinook salmon abundance can depend heavily on netting results. Higher proportions of small Chinook salmon in the nets result in larger estimates of small (and all sizes) Chinook salmon abundance, and vice versa for lower proportions. For example, taking the earlier illustration, if the sonar count remained the same (100) but 4 (instead of 2) of the 10 netted fish were small, then the abundance estimate would be equal to 100 divided by 0.6 or 167 (instead of 125) Chinook salmon, composed of 100 medium and large fish and 67 (instead of 25) small fish.

Consequently, ALMM estimates of Chinook salmon abundance are sensitive to how the netting data are collected. Until recently, inriver gillnet sampling was restricted to a midriver corridor approximating the RM 8.6 insonified zone, but we now know that migrating Chinook salmon are

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[12] This is a simplified example to illustrate how the netting data affect the abundance estimates. The actual estimates are obtained by fitting a statistical mixture model in order to account for error in the ARIS length measurements and to provide an assessment of uncertainty. See Appendices C1–C7 for details about the ARIS length mixture model (ALMM).

sometimes stratified by size, with smaller fish migrating nearer to the river bank and larger fish farther offshore (Miller 2000; Hughes 2004; Perschbacher 2015). In May and June of 2013, this pattern occurred very strongly, causing the midriver netting program to produce a size-biased sample, with small fish under-represented and large fish over-represented. As a result, early-run ALMM estimates of small Chinook salmon were too low, as detailed above.

In 2014, the inriver netting program initiated a new sampling design that balanced the number of drifts in nearshore and midriver strata, thereby producing a more representative sample and greater ability to detect size-stratified migration patterns. As it happened, fewer fish migrated near shore in 2014, and size stratification was weaker (Perschbacher and Eskelin *In prep*). As a result, early-run ALMM estimates of small Chinook salmon were sufficient to explain the 1,840 small Chinook salmon passing the Killey and Funny river weirs (based on data described in Gates and Boersma [2014a, 2014b]), whether or not nearshore drifts were included. The final estimate, using midriver and nearshore data, of small Chinook salmon for the 2014 early run was 3,371 (5,768 minus 2,397; Table 7). However, even if midriver-only netting data were used, the estimate would have been only slightly smaller (2,967; S. Fleischman, Fisheries Scientist, ADF&G, unpublished data). Evidently, size-stratified migration was not a major factor during 2014.

We conclude that migratory behavior of small versus large Chinook salmon at RM 8.6 of the Kenai River can differ greatly from one year to the next. The 2013 pattern of small fish preferentially migrating near shore did not repeat itself in 2014. However, if and when this pattern repeats, the availability of full-river netting data should provide us with the ability to produce accurate abundance estimates.

2014 Early Run: Difficulty in Obtaining Timely and Accurate Inseason Estimates

During the 2014 early run, the daily estimates of small Chinook salmon abundance obtained in real time during the season and based partially on historical age composition priors were too low compared to the final revised daily estimates (based entirely on 2014 data).

When run sizes are small in May and early June, the numbers of Chinook salmon caught in the inriver gillnet samples can be very small. For example, during the first 3 weeks of the 2013 and 2014 seasons, an average of only 1 Chinook salmon per day was caught during midriver drifts by the netting project (Perschbacher 2015; Perschbacher and Eskelin *In prep*). Small catches make it difficult to obtain estimates of Chinook salmon size composition that are accurate and also timely. For estimates produced on a daily basis during the fishing season, our solution to the data limitation problem has been to use a weighted average of current and historical size data from prior years[13]. Such methodology has been used since 2010 at both the lower and upper sonar sites to produce daily inseason estimates of Chinook salmon abundance. The influence of the historical "prior" information on the estimates is greatest early in the season when net catches are small, and it declines as catches increase.

For the final postseason estimates (reported here), all the data have been re-analyzed without using any historical prior information, pooling multiple days as necessary when sample sizes were small (see Methods and Appendix C6).

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[13] For a hierarchical model of historical age composition see Appendix B4 in Key et al. (2016b).

From 2010 to 2013, inseason estimates were reasonably close to the final postseason estimates. `For example, final RM-8.6 estimates were from 3% lower to 14% higher than the inseason estimates (Appendix C7). However, inseason ALMM estimates for the 2014 early run underwent a much larger revision: the final estimate of total passage of all Chinook salmon reported in Table 7 is 37% higher than the sum of the daily estimates produced during the season (Appendix C7). The outsized revision occurred primarily because the 2014 early run was composed of an anomalously large fraction of small fish, relative to recent history. Among Chinook salmon caught by midriver gillnets, the proportion that were less than 75 cm (METF) was 61% in 2014, whereas the 2002–2015 mean was 30% and the range (excluding 2014) was 18–41% (S. Fleischman, Fisheries Scientist, ADF&G, unpublished data). Because the 2014 early run was so unusual, the historical data served as a poor surrogate for the current data, and the proportion of small fish was greatly underestimated inseason, due to the influence of the historical data. Consequently, the daily inseason ALMM estimates of Chinook salmon abundance were too small. DLMM estimates of the 2014 early run from the RM 8.6 sonar also were subject to a large (+42%) revision for the same reasons (Key et al. 2016b).

Final unbiased estimates of small Chinook salmon abundance that do not require the infusion of historical information can be difficult to produce on a daily basis because pooling of data is often required. However, in 2015, we will statistically reduce the influence of prior historical information on the inseason estimates and thereby also reduce the magnitude of postseason revisions.

SUMMARY AND CONCLUSIONS

ARIS was successfully operated at RM 13.7 in 2013 and 2014. Transducers at RM 13.7 were configured to sample nearly 100% of the river cross section and therefore ARIS-based abundance estimates required no spatial expansion factors. Uncertainty and errors due to changing detection rates at RM 8.6 have been eliminated.

Abundance of Chinook salmon 75 cm AL or longer can be estimated directly by ARIS at RM 13.7. These daily estimates of medium and large Chinook salmon are timely and accurate. A Chinook salmon measuring 75 cm AL is approximately 75.4 cm METF or 33.3 in total length (TL; Table 14).

ARIS-based RM 13.7 estimates are, on average, approximately equivalent to expanded RM 8.6 DIDSON estimates and can be used to monitor the attainment of escapement goals currently in effect.

It can take a Chinook salmon several hours to several days to transit the 5 river miles between the old and new sonar sites. As a result, inseason information about daily abundance is delayed to some degree, introducing more uncertainty into projections of end-of-season abundance.

Estimates of small Chinook salmon can be sensitive to how the netting data are collected and to other methodological details. Failure to obtain accurate and timely size information from the nets can cause errors in small Chinook salmon inseason abundance estimates during the early run. Steps have been taken to reduce the probability and size of such errors in the future (see above).

The estimates presented in this report represent our best assessment of 2014 Kenai River Chinook salmon abundance passing RM 13.7 at the time of publication. Final estimates of small Chinook salmon (<75 cm METF) have been revised upward from the inseason values produced during and shortly after the 2014 season.

Many of the issues described above could be avoided by establishing minimum-size-based escapement goals and managing the runs based on abundance of Chinook salmon measuring 75 cm AL (33.3 in measured from snout to tail) or longer. Under this system, daily estimates could be directly and accurately estimated by the sonar without requiring netting data, thereby preventing assessment shortfalls such as those that occurred during the 2013 and 2014 early runs. Also, by focusing assessment on the most reproductively active segment of the population, management actions could provide more direct control of spawning abundance (Fleischman and Reimer *In prep*). Similar goals are being used successfully to manage Chinook salmon stocks in Southeast Alaska (Heinl et al. 2014).

RECOMMENDATIONS

Base management decisions on RM 13.7 ARIS in 2015. ALMM estimates from RM 13.7 are not subject to uncertainty due to spatial expansion.

Continue to conduct nearshore and midriver drifts at the inriver netting project at RM 8.6. We will need a consistent index of small Chinook salmon abundance near shore in order to accurately reconstruct abundance of Chinook salmon regardless of size, and midriver data are valuable for their comparability with historical data.

Investigate the feasibility of managing to minimum-size-based escapement goals based on direct sonar estimates of Chinook salmon greater than or equal to 75 cm AL, which are more accurate and timely and which can be produced without netting data. Such goals would also focus management on the most reproductively active segment of the population.

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TABLES

Table 1.–On-site components of the ARIS systems used in 2014.

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)	
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, 2014.

Sonar location	Range stratum	Time (min) [a]	Coverage range (m) by date							
			16 May	19 May	28 May	2 Jun	11 Jun	23 Jun	15 Jul	22 Jul
Left nearshore	1	:00 / :30	[b]	[b]	2.5–9.5	2.5–9.5	2.5–9.5	2.4–12.1	2.4–12.1	2.4–12.1
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	22.0–36.0	22.0–35.0	22.0–35.0	22.0–35.0	22.0–35.0	22.0–35.0	22.0–35.0	22.0–35.0
Right offshore	1	:00 / :30	3.5–8.0	3.5–8.0	3.5–8.0	[c]	[c]	[c]	[c]	[c]
	2	:10	8.0–35.0	8.0–24.0	8.6–23.0	8.6–23.0	8.6–23.0	8.6–23.0	8.6–23.0	8.6–23.0
	3	:20	22.0–35.0	22.0–35.0	22.0–35.0	22.0–35.0	22.0–35.0	22.0–35.0	22.0–35.0	22.0–35.0
Right nearshore	1	:40	[d]	[d]	[d]	3.5–8.7	3.5–8.7	3.5–9.0	3.5–9.0	3.5–9.0
	2	:50	[d]	[d]	[d]	8.7–16.0	8.7–16.0	9.0–18.0	9.0–21.0	9.0–21.0
Minor channel	1	:00	[e]	[e]	[e]	[e]	3.4–6.3	2.6–6.2	2.6–6.2	2.6–6.2
	2	:10	[e]	[e]	[e]	[e]	6.3–10.3	6.2–11.2	6.2–11.2	6.2–12.0
	3	:30	[e]	[e]	[e]	[e]	10.3–19.7	11.2–20.6	11.2–20.6	12.0–22.0

[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] Sonar was not deployed in this stratum until 28 May.
[c] Beginning 2 June, right offshore stratum 1 was covered by right nearshore stratum 2.
[d] Sonar was not deployed in this stratum until 2 June.
[e] Sonar was not deployed in this stratum until 11 June.

Table 3.–Sampling schedule and parameter values on 22 July 2014 for each range stratum sampled by 5 ARIS systems in 2014.

Sonar location	ARIS serial no.	Range stratum	Time (min) [a]	Frame rate (fps) [b]	Start range (m)	End range (m)	Frequency (MHz)	Transmit level	Gain (dB)	Pulse width (µs)	Start delay (µs)	Sample period (µs)	Samples per beam	Pitch (°)	Heading (°)
Left nearshore	1096	1	:00 / :30	8	2.4	12.1	High (1.8)	Max	17	17	3,495	6	2,217	-4	178
Left offshore	1064	1	:00 / :30	9	3.5	8.0	High (1.2)	Max	10	20	4,821	5	1,237	-8.5	68
		2	:10 / :40	9	8.0	22.0	High (1.2)	Max	17	20	11,021	10	1,928	-5.8	68
		3	:20 / :50	6	22.0	35.0	High (1.2)	Max	17	31	30,308	11	1,627	-1.8	68
Right offshore	1063	1	:00 / :30	[c]	[c]	[c]	[c]	[c]	[c]	[c]	[c]	[c]	[c]	[c]	[c]
		2	:10	8	8.0	22.0	High (1.2)	Max	14	20	11,046	12	1,608	-3.9	302
		3	:20	6	22.0	35.0	Low (1.2)	Max	21	24	30,522	8	2,225	-4.1	302
Right nearshore	1098	1	:40	12	3.5	9.0	High (1.2)	Max	6	9	4,844	4	1,903	-6.1	263
		2	:50	9	9.0	21.0	High (1.2)	Max	6	20	12,457	7	2,372	-4.9	263
Minor channel	1095	1	:00	10	2.6	6.0	High (1.2)	Max	12	5	3,580	5	935	-12.3	13
		2	:10	9	6.0	12.0	High (1.2)	Max	20	10	8,265	6	1,378	-7.5	13
		3	:30	9	12.0	22.0	High (1.2)	Max	20	20	16,531	10	1,377	-3.3	13

[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] Data were collected in right-bank offshore stratum 1 from 16 May to 1 June. Increased water level allowed the right bank inshore sonar to be deployed on 2 June 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 11).

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

Parameter	ARIS 1200	ARIS 1800	DIDSON LR (1200)	DIDSON SV (1800)
Transmit pulse length	4 –100 µs	4 –100 µs	7 µs, 13 µs, 27 µs, 54 µs [a]	4.5 µs, 9 µs, 18 µs, 36 µs [a]
Detail [b]	3–100 mm	3–100 mm	5 mm, 10 mm, 20 mm, 40 mm [a]	2.5 mm, 5.0 mm, 10.0 mm, 20.0 mm [a]
Source level	~206–212 dB re 1 µPa at 1 m	~200–206 dB re 1 µPa at 1 m		
Window length	Any	Any	2.5 m, 5.0 m, 10.0 m, 20.0 m	1.25 m, 2.50 m, 5.00 m, 10.00 m
Samples per beam	128–4,000	128–4,000	512	512

[a] Relative to window length.

[b] Window length per number of samples.

Table 5.–Spatial and temporal distribution (percent of total run) of upstream bound medium and large fish (ARIS length ≥ 75cm), by river bank, transducer, and time (day or night) at RM 13.7 for the Kenai River early and late runs, 2014.

		Main Channel							
		Left bank transducer		Right bank transducer					
Run	Time of day	Nearshore	Offshore	Offshore	Nearshore	All left bank	All right bank	Minor channel	All strata
Early									
	Day	10	27	20	18	37	38	0	75
	Night	3	8	6	8	11	13	0	25
	Both	13	35	26	26	48	52	0	100
Late									
	Day	2	23	26	26	25	52	1	78
	Night	2	4	7	10	5	16	1	22
	Both	3	27	33	36	30	68	2	100

Table 6.–Percentage of all (upstream and downstream) fish migrating downstream, by river bank, transducer, and fish size at RM 13.7 for the 2014 Kenai River early and late runs.

		Main channel							
		Left bank transducer		Right bank transducer				Minor	
Run	Fish size [a]	Nearshore	Offshore	Offshore	Nearshore	All left bank	All right bank	channel	All strata
Early									
	Small	2.3	2.6	2.3	0.5	2.5	1.0		1.6
	Medium	2.4	0.9	1.2	1.2	1.4	1.2	0.0	1.3
	Large	0.0	3.0	4.5	6.3	2.4	5.3	[b]	3.8
	Med and large	2.0	1.4	1.9	2.0	1.6	2.0	0.0	1.8
Late									
	Medium	18.9	13.4	9.6	14.0	14.0	8.6	16.7	10.5
	Large	20.0	12.5	5.0	13.5	13.5	5.9	30.0	8.5
	Med and large	19.5	13.0	7.2	13.7	13.7	7.3	20.0	9.6

[a] Small fish are 40 cm ≤ AL < 75 cm, medium fish are 75 cm ≤ AL < 90 cm, and large fish are ≥ 90 cm AL. The only reliable direction of travel information for small fish was from the main channel during the early run.

[b] No “large” fish were detected moving upstream or downstream in the minor channel during the early run.

Table 7.–ARIS-length mixture model (ALMM) estimates of net upstream passage for all Chinook salmon (regardless size) and small Chinook salmon (AL < 75 cm), RM 13.7 Kenai River, early run 2014.

	ALMM Chinook salmon (all sizes)			ALMM Chinook salmon < 75 cm AL		
Date	Passage	SE	CV	Passage	SE	CV
16 May	1	0	0.5	1	0	0.45
17 May	1	1	0.5	1	1	0.53
18 May	2	1	0.3	-4	4	1.01
19 May	1	1	0.5	-5	6	1.2
20 May	1	1	0.6	1	1	0.56
21 May	4	1	0.3	-8	11	1.39
22 May	4	2	0.4	-3	6	2.07
23 May	5	1	0.3	-1	6	NA
24 May	0	0	NA	0	8	NA
25 May	9	3	0.3	9	3	0.32
26 May	20	7	0.3	14	9	0.63
27 May	31	12	0.4	25	13	0.53
28 May	38	13	0.3	20	18	0.92
29 May	43	14	0.3	37	15	0.41
30 May	49	16	0.3	19	20	1.06
31 May	34	10	0.3	16	14	0.9
1 Jun	44	14	0.3	13	16	1.3
2 Jun	68	22	0.3	42	25	0.61
3 Jun	180	75	0.4	101	78	0.78
4 Jun	278	73	0.3	145	77	0.53
5 Jun	281	92	0.3	178	95	0.53
6 Jun	433	111	0.3	230	129	0.56
7 Jun	259	69	0.3	130	75	0.58
8 Jun	197	58	0.3	100	64	0.64
9 Jun	240	64	0.3	131	68	0.52
10 Jun	126	42	0.3	66	44	0.67
11 Jun	252	67	0.3	131	75	0.57
12 Jun	198	60	0.3	105	65	0.61
13 Jun	148	53	0.4	82	54	0.66
14 Jun	226	63	0.3	115	66	0.57
15 Jun	202	72	0.4	123	75	0.61
16 Jun	142	57	0.4	81	59	0.72
17 Jun	176	52	0.3	89	58	0.66
18 Jun	174	53	0.3	102	57	0.55
19 Jun	190	60	0.3	112	66	0.59
20 Jun	246	86	0.4	168	88	0.52
21 Jun	156	64	0.4	102	65	0.64
22 Jun	256	93	0.4	171	96	0.56
23 Jun	168	63	0.4	113	66	0.59
24 Jun	98	53	0.5	74	54	0.73
25 Jun	112	59	0.5	82	60	0.73
26 Jun	155	62	0.4	106	66	0.62
27 Jun	203	85	0.4	137	87	0.63
28 Jun	106	51	0.5	70	52	0.75
29 Jun	83	44	0.5	59	46	0.78
30 Jun	128	63	0.5	91	64	0.7
Total	5,768	359	0.1	3,371	383	0.11

Note: NA means calculation not possible.

Table 8.–ARIS-length mixture model (ALMM) estimates of net upstream passage for all Chinook salmon (regardless size) and small Chinook salmon (AL < 75 cm), RM 13.7 Kenai River, late run 2014.

	ALMM Chinook salmon (all sizes)			ALMM Chinook salmon < 75 cm AL		
Date	Passage	SE	CV	Passage	SE	CV
1 Jul	170	75	0.44	134	78	0.58
2 Jul	103	47	0.46	73	48	0.66
3 Jul	13	25	1.93	1	26	26.38
4 Jul	153	54	0.36	93	57	0.61
5 Jul	328	111	0.34	237	116	0.49
6 Jul	465	129	0.28	289	134	0.46
7 Jul	457	115	0.25	275	118	0.43
8 Jul	233	72	0.31	142	78	0.55
9 Jul	155	65	0.42	95	67	0.71
10 Jul	125	55	0.44	77	57	0.73
11 Jul	323	96	0.3	238	98	0.41
12 Jul	485	146	0.3	329	149	0.45
13 Jul	424	146	0.35	285	148	0.52
14 Jul	293	79	0.27	178	81	0.45
15 Jul	498	125	0.25	276	128	0.47
16 Jul	223	63	0.28	108	71	0.66
17 Jul	419	86	0.21	202	93	0.46
18 Jul	563	102	0.18	249	105	0.42
19 Jul [a]	367	135	0.37	145	142	0.98
20 Jul [a]	526	193	0.37	208	203	0.97
21 Jul [a]	524	192	0.37	207	204	0.98
22 Jul	281	53	0.19	99	61	0.62
23 Jul	367	58	0.16	112	73	0.66
24 Jul	217	45	0.21	90	53	0.59
25 Jul	448	65	0.15	128	81	0.63
26 Jul	387	56	0.14	81	71	0.87
27 Jul	373	61	0.16	98	81	0.83
28 Jul	430	63	0.15	110	80	0.73
29 Jul	469	65	0.14	119	81	0.68
30 Jul	632	79	0.13	191	91	0.48
31 Jul	776	85	0.11	239	110	0.46
1 Aug	519	76	0.15	183	86	0.47
2 Aug	442	68	0.15	128	81	0.64
3 Aug	593	76	0.13	154	101	0.65
4 Aug	484	65	0.13	116	85	0.73
5 Aug	651	69	0.11	75	90	1.19
6 Aug	606	60	0.1	32	85	2.65
7 Aug	239	33	0.14	22	65	2.97
8 Aug	248	31	0.12	19	60	3.15
9 Aug	530	52	0.1	23	92	4.01
10 Aug	329	41	0.13	21	69	3.26
11 Aug	235	35	0.15	30	61	2.04
12 Aug	191	32	0.17	5	48	9.59
13 Aug	131	28	0.22	25	46	1.85
14 Aug	252	42	0.17	28	56	2
15 Aug	194	37	0.19	31	49	1.6
Total	16,871	580	0.03	6,000	649	0.11

[a] For 19–21 July, net upstream Chinook salmon estimates were imputed from estimates of Chinook salmon greater than 75 cm AL in Table 12.

Table 9.–Daily estimates of Chinook salmon age composition derived from fitting a mixture model to length measurements from ARIS at RM 13.7 and midriver gillnet catches from RM 8.6, Kenai River early run 2014.

	Ages 3 and 4		Age 5		Ages 6 and 7	
Date	Proportion	SE	Proportion	SE	Proportion	SE
16 May	0.43	0.15	0.54	0.14	0.02	0.03
17 May	0.43	0.15	0.54	0.14	0.02	0.03
18 May	0.43	0.15	0.54	0.14	0.02	0.03
19 May	0.43	0.15	0.54	0.14	0.02	0.03
20 May	0.43	0.15	0.54	0.14	0.02	0.03
21 May	0.43	0.15	0.54	0.14	0.02	0.03
22 May	0.43	0.15	0.54	0.14	0.02	0.03
23 May	0.43	0.15	0.54	0.14	0.02	0.03
24 May	0.43	0.15	0.54	0.14	0.02	0.03
25 May	0.43	0.15	0.54	0.14	0.02	0.03
26 May	0.43	0.15	0.54	0.14	0.02	0.03
27 May	0.43	0.15	0.54	0.14	0.02	0.03
28 May	0.43	0.15	0.54	0.14	0.02	0.03
29 May	0.43	0.15	0.54	0.14	0.02	0.03
30 May	0.43	0.15	0.54	0.14	0.02	0.03
31 May	0.43	0.15	0.54	0.14	0.02	0.03
1 Jun	0.43	0.15	0.54	0.14	0.02	0.03
2 Jun	0.43	0.15	0.54	0.14	0.02	0.03
3 Jun	0.51	0.14	0.47	0.14	0.02	0.03
4 Jun	0.46	0.11	0.53	0.11	0.01	0.02
5 Jun	0.52	0.14	0.46	0.13	0.02	0.02
6 Jun	0.50	0.10	0.45	0.10	0.05	0.04
7 Jun	0.47	0.11	0.50	0.11	0.03	0.02
8 Jun	0.49	0.10	0.46	0.10	0.05	0.03
9 Jun	0.53	0.09	0.42	0.09	0.05	0.03
10 Jun	0.54	0.09	0.42	0.08	0.05	0.03
11 Jun	0.52	0.09	0.42	0.08	0.06	0.04
12 Jun	0.53	0.08	0.43	0.08	0.03	0.03
13 Jun	0.51	0.09	0.47	0.09	0.01	0.02
14 Jun	0.51	0.08	0.48	0.08	0.01	0.02
15 Jun	0.51	0.08	0.47	0.08	0.02	0.02
16 Jun	0.50	0.09	0.46	0.09	0.04	0.03
17 Jun	0.51	0.09	0.47	0.09	0.02	0.03
18 Jun	0.55	0.09	0.43	0.09	0.02	0.02

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Table 9.–Page 2 of 2.

Date	Ages 3 and 4		Age 5		Ages 6 and 7	
	Proportion	SE	Proportion	SE	Proportion	SE
19 Jun	0.59	0.08	0.39	0.08	0.02	0.02
20 Jun	0.66	0.08	0.29	0.08	0.05	0.03
21 Jun	0.69	0.09	0.29	0.09	0.03	0.03
22 Jun	0.69	0.09	0.28	0.09	0.03	0.03
23 Jun	0.70	0.09	0.26	0.08	0.04	0.03
24 Jun	0.75	0.10	0.21	0.10	0.04	0.03
25 Jun	0.71	0.10	0.23	0.09	0.06	0.05
26 Jun	0.69	0.09	0.28	0.08	0.03	0.03
27 Jun	0.67	0.09	0.29	0.09	0.04	0.03
28 Jun	0.65	0.09	0.26	0.08	0.09	0.05
29 Jun	0.72	0.08	0.21	0.08	0.07	0.05
30 Jun	0.73	0.08	0.23	0.07	0.04	0.03
Weighted mean	0.56	0.05	0.40	0.04	0.04	0.01

Note: Mean proportions are weighted by daily ALMM estimates in Table 7.

Table 10.–Daily estimates of Chinook salmon age composition derived from fitting a mixture model to length measurements from ARIS at RM 13.7 and midriver gillnet catches from RM 8.6, Kenai River late run 2014.

	Ages 3 and 4		Age 5		Ages 6 and 7	
Date	Proportion	SE	Proportion	SE	Proportion	SE
1 Jul	0.74	0.07	0.24	0.07	0.03	0.03
2 Jul	0.70	0.08	0.26	0.08	0.03	0.03
3 Jul	0.70	0.09	0.17	0.09	0.13	0.06
4 Jul	0.64	0.09	0.26	0.08	0.10	0.05
5 Jul	0.69	0.10	0.28	0.10	0.03	0.02
6 Jul	0.68	0.08	0.22	0.08	0.10	0.05
7 Jul	0.61	0.08	0.32	0.07	0.07	0.04
8 Jul	0.63	0.08	0.26	0.07	0.11	0.05
9 Jul	0.69	0.08	0.18	0.07	0.13	0.05
10 Jul	0.74	0.07	0.16	0.07	0.10	0.05
11 Jul	0.75	0.06	0.20	0.07	0.06	0.05
12 Jul	0.71	0.06	0.23	0.07	0.06	0.05
13 Jul	0.70	0.07	0.28	0.07	0.02	0.03
14 Jul	0.67	0.07	0.31	0.07	0.02	0.02
15 Jul	0.64	0.07	0.34	0.07	0.02	0.03
16 Jul	0.55	0.08	0.41	0.08	0.04	0.03
17 Jul	0.46	0.08	0.47	0.08	0.08	0.05
18 Jul	0.40	0.09	0.55	0.09	0.05	0.03
19 Jul	0.37	0.08	0.53	0.08	0.10	0.05
20 Jul	0.35	0.08	0.48	0.08	0.18	0.07
21 Jul	0.31	0.08	0.51	0.08	0.17	0.06
22 Jul	0.32	0.07	0.49	0.08	0.19	0.07
23 Jul	0.33	0.06	0.48	0.08	0.20	0.08
24 Jul	0.33	0.07	0.50	0.07	0.16	0.06
25 Jul	0.29	0.06	0.48	0.08	0.23	0.08
26 Jul	0.27	0.06	0.55	0.07	0.18	0.07
27 Jul	0.28	0.06	0.46	0.10	0.26	0.10
28 Jul	0.28	0.06	0.52	0.09	0.20	0.08
29 Jul	0.26	0.05	0.54	0.08	0.21	0.08
30 Jul	0.28	0.06	0.50	0.10	0.22	0.10
31 Jul	0.29	0.05	0.52	0.07	0.19	0.07
1 Aug	0.27	0.06	0.42	0.11	0.32	0.11
2 Aug	0.22	0.06	0.44	0.11	0.34	0.12
3 Aug	0.19	0.05	0.47	0.09	0.34	0.10

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Table 10.–Page 2 of 2.

	Ages 3 and 4		Age 5		Ages 6 and 7	
Date	Proportion	SE	Proportion	SE	Proportion	SE
4 Aug	0.15	0.06	0.41	0.08	0.44	0.09
5 Aug	0.09	0.05	0.14	0.07	0.77	0.07
6 Aug	0.05	0.03	0.55	0.14	0.40	0.14
7 Aug	0.02	0.03	0.49	0.15	0.48	0.15
8 Aug	0.03	0.04	0.72	0.11	0.25	0.11
9 Aug	0.03	0.03	0.72	0.10	0.25	0.10
10 Aug	0.03	0.03	0.68	0.11	0.29	0.10
11 Aug	0.04	0.05	0.52	0.13	0.44	0.13
12 Aug	0.04	0.05	0.60	0.13	0.36	0.12
13 Aug	0.07	0.08	0.44	0.15	0.50	0.15
14 Aug	0.07	0.08	0.38	0.12	0.55	0.11
15 Aug	0.06	0.08	0.16	0.10	0.77	0.11
Weighted mean	0.34	0.02	0.43	0.03	0.23	0.02

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

Table 11.–Estimates of net upstream daily passage of medium (75 cm ≤ AL < 90 cm) and large (AL ≥ 90 cm) Chinook salmon at RM 13.7 Kenai River, early run 2014.

	75 cm ≤ AL < 90 cm		AL ≥ 90 cm		AL ≥ 75 cm	
Date	Passage	SE	Passage	SE	Passage	SE
16 May	0	0	0	0	0	0
17 May	0	0	0	0	0	0
18 May	6	4	0	0	6	4
19 May	6	6	0	0	6	6
20 May	0	0	0	0	0	0
21 May	12	11	0	0	12	11
22 May	0	0	7	6	7	6
23 May	6	6	0	0	6	6
24 May	0	8	0	0	0	8
25 May	0	0	0	0	0	0
26 May	6	6	0	0	6	6
27 May	6	6	0	0	6	6
28 May	6	6	12	8	18	13
29 May	6	6	0	0	6	6
30 May	18	10	12	7	30	12
31 May	12	8	6	6	18	10
1 Jun	19	10	12	7	31	9
2 Jun	20	11	6	6	26	12
3 Jun	61	16	18	10	79	23
4 Jun	103	29	30	11	133	26
5 Jun	91	21	12	8	103	23
6 Jun	157	44	46	30	203	67
7 Jun	123	27	6	6	129	30
8 Jun	72	25	24	11	97	26
9 Jun	103	22	6	6	109	25
10 Jun	54	14	6	6	60	14
11 Jun	97	34	24	11	121	35
12 Jun	82	23	11	11	93	23
13 Jun	66	11	0	0	66	14
14 Jun	93	19	18	8	111	21
15 Jun	79	23	0	0	79	23
16 Jun	54	13	7	7	61	14
17 Jun	62	17	25	12	87	26
18 Jun	54	20	18	9	72	19
19 Jun	66	26	12	12	78	27
20 Jun	48	18	30	13	78	19
21 Jun	36	11	18	7	54	13
22 Jun	60	17	24	11	85	23
23 Jun	49	20	6	6	55	22
24 Jun	24	11	0	0	24	11
25 Jun	18	10	12	6	30	11
26 Jun	43	22	6	6	49	22
27 Jun	66	15	0	0	66	15
28 Jun	24	11	12	8	36	13
29 Jun	6	10	18	10	24	14
30 Jun	24	10	12	8	37	11
Total	1,940	114	457	55	2,397	132

Table 12.–Estimates of net upstream daily passage of medium (75 cm ≤ AL < 90 cm) and large (AL ≥ 90 cm) Chinook salmon at RM 13.7 Kenai River, late run 2014.

	75 cm ≤ AL < 90 cm		AL ≥ 90 cm		AL ≥ 75 cm	
Date	Passage	SE	Passage	SE	Passage	SE
1 Jul	18	17	18	10	36	19
2 Jul	30	11	0	0	30	11
3 Jul	12	8	0	0	12	8
4 Jul	42	16	18	10	60	17
5 Jul	91	33	0	0	91	33
6 Jul	109	20	66	25	176	37
7 Jul	127	22	55	14	182	27
8 Jul	48	17	42	19	91	30
9 Jul	36	13	24	10	60	17
10 Jul	30	8	18	15	48	11
11 Jul	42	14	42	14	85	22
12 Jul	115	28	41	14	156	31
13 Jul	109	23	30	11	139	22
14 Jul	67	14	48	11	115	16
15 Jul	113	25	109	25	222	30
16 Jul	79	22	36	18	115	33
17 Jul	139	25	78	26	217	36
18 Jul	236	28	78	17	314	28
19 Jul	127	38	95	20	222	43
20 Jul	138	32	180	46	318	62
21 Jul	174	46	143	29	317	68
22 Jul	91	26	90	17	182	30
23 Jul	134	37	121	20	255	45
24 Jul	83	23	44	17	127	29
25 Jul	127	30	193	33	320	49
26 Jul	177	33	128	34	306	43
27 Jul	148	47	127	30	275	54
28 Jul	145	29	175	32	320	50
29 Jul	175	44	175	34	350	49
30 Jul	254	35	187	35	441	45
31 Jul	284	44	253	46	537	71
1 Aug	157	38	179	38	336	40
2 Aug	141	30	173	36	314	45
3 Aug	154	39	285	42	439	67
4 Aug	179	40	189	36	368	55
5 Aug	223	31	352	54	576	57
6 Aug	290	34	284	39	574	60
7 Aug	103	36	115	34	217	56
8 Aug	108	39	121	34	229	51
9 Aug	211	47	290	48	507	76
10 Aug	181	36	127	35	308	55
11 Aug	127	33	79	27	205	50
12 Aug	84	30	103	25	186	36
13 Aug	42	26	64	26	106	37
14 Aug	79	19	145	32	224	37
15 Aug	54	17	109	25	163	33
Total	5,641	205	5,230	192	10,871	291

Table 13.–Results of linear statistical models fit to ARIS and DIDSON tethered fish data, and corresponding estimates of intercept and slope parameters from daily mixture models fit to free-swimming fish data at Kenai RM 13.7.

Data	Label	Intercept	SE	Effect of FL	SE	Effect of range	SE	Effect of Freq = 0.7	SE	RMSE [a]	R^2
ARIS 2013–2014 data, *n* = 455 unique combinations of fish×range×setting×observer											
	"Full"	1.7 [b]	1.1	0.88	0.013	0.179	0.032	1.5	0.68	4.7	0.92
	"Range"	1.7 [b]	1.1	0.88	0.013	0.202	0.030			4.7	0.92
	"Length"	4.8 [c]	1.0	0.89	0.013					4.9	0.91
DIDSON 2007+2009 data, *n* = 55 fish, means of 2 observers											
	"DL"	6.9	2.3	0.87	0.029					3.9	0.94
Means of 2013–2014 daily ARIS mixture model estimates, *n* = 167 days											
	"ALmix"	3.03	0.81	0.866	0.053						

[a] Root mean squares errors (RMSE) for ARIS and DIDSON are not comparable; see Discussion.

[b] Intercept germane to range = 0 and frequency = 1.2.

[c] Intercept germane to mean range = 21 and frequency = 1.2.

Table 14.–Inverse predictions of fish size for ARIS lengths of 40, 75, and 90 cm.

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

Table 15.–Attributes of old and new sonar estimates of Kenai River Chinook salmon abundance.

Attribute	Sonar-based estimates		Comments
	"Old" [a]	"New"	
Location of sonar	River mile 8.6	River mile 13.7	
Years used for management	2013–2014	2015+	
Sonar technology	DIDSON	ARIS	Both are multi-beam imaging sonars. ARIS is next generation DIDSON.
Cross-river spatial coverage	Partial (midriver only)	Nearly complete	Nearshore regions not insonified at RM 8.6
Expansion factors	1.55 (early run); 1.28 (late run)	None	RM-8.6 expansion factors were estimated in 2013 by fitting a state-space model to historical data
Direction of travel	Upstream only	Net upstream	"Net upstream" is upstream bound fish decremented by downstream bound fish to more accurately reflect spawning escapement
Statistical methods	Mixture model using midriver netting data	Mixture model using full-river netting data (first available in 2014)	Net catches must reflect the true size distribution of Chinook salmon in order to obtain unbiased estimates

[a] See Key et al. 2016a, 2016b.

Table 16.–Inriver abundance of Kenai River Chinook salmon, as expanded from DIDSON observations at RM 8.6, and as reconstructed from ARIS observations at RM 13.7 plus the number of harvested and spawning fish between the 2 sites.

Run and year	Harvest between sites (H)	Spawned between sites (S)	Observed by ARIS at RM 13.7 (IR_{14})	Reconstructed inriver run at RM 8.6 (IR_{RA}= H + S + IR14)	Expanded DIDSON at RM 8.6 (IR_{XD})	ARIS:DIDSON ratio (IR_{RA} / IR_{XD})
Early run						
2013	0	0	2,845 [a]	2,845	2,230 [e]	1.28
2014	0	0	5,768 [b]	5,768	7,536 [f]	0.77
					Mean	1.02
Late run						
2013	708	550	19,373 [c]	20,631	19,437 [g]	1.06
2014	242	951	16,871 [d]	18,064	17,859 [h]	1.01
					Mean	1.04

[a] Miller et al. (2016), their Table 9.
[b] This report, Table 7.
[c] Miller et al. (2016), their Table 10.
[d] This report, Table 8.
[e] Key et al. (2016a), their Table 4 multiplied by 1.55.
[f] Key et al. (2016b), their Table 4 multiplied by 1.55.
[g] Key et al. (2016a), their Table 5 multiplied by 1.28.
[h] Key et al. (2016b), their Table 5 multiplied by 1.28.

FIGURES

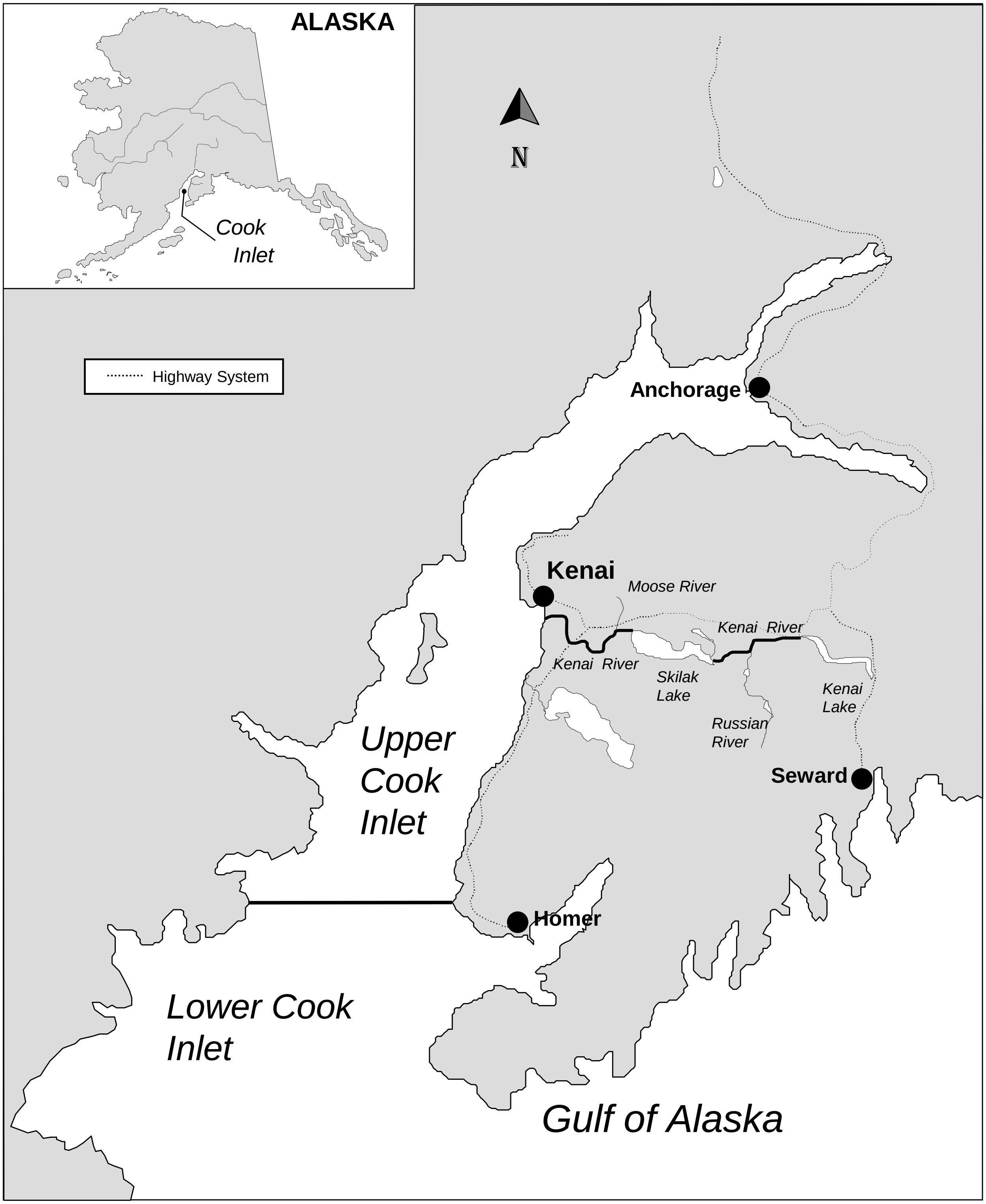

Figure 1.–Cook Inlet showing the location of the Kenai River.

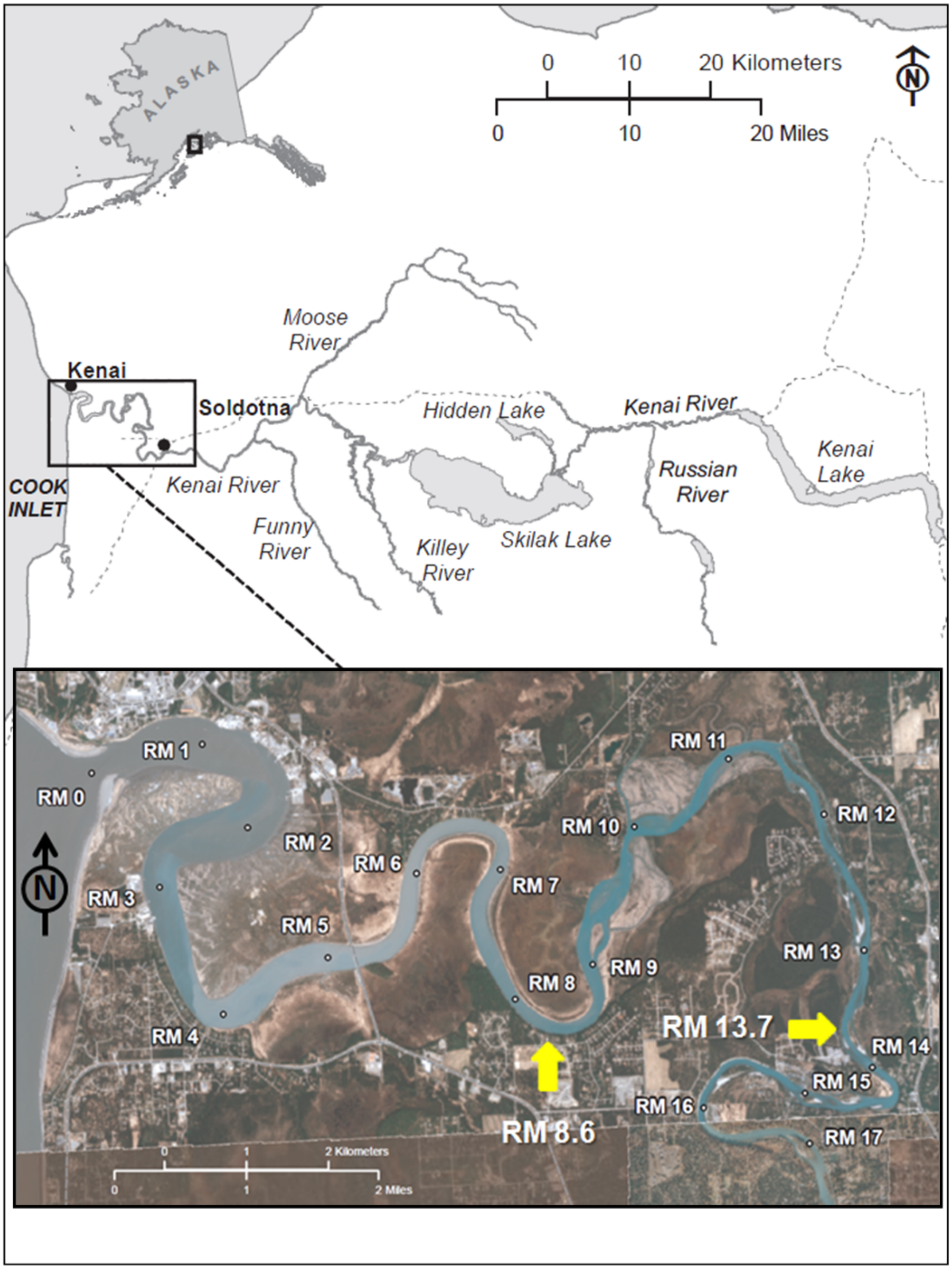

Figure 2.–Map of Kenai River showing location of Chinook salmon sonar sites at river miles 8.6 and 13.7.

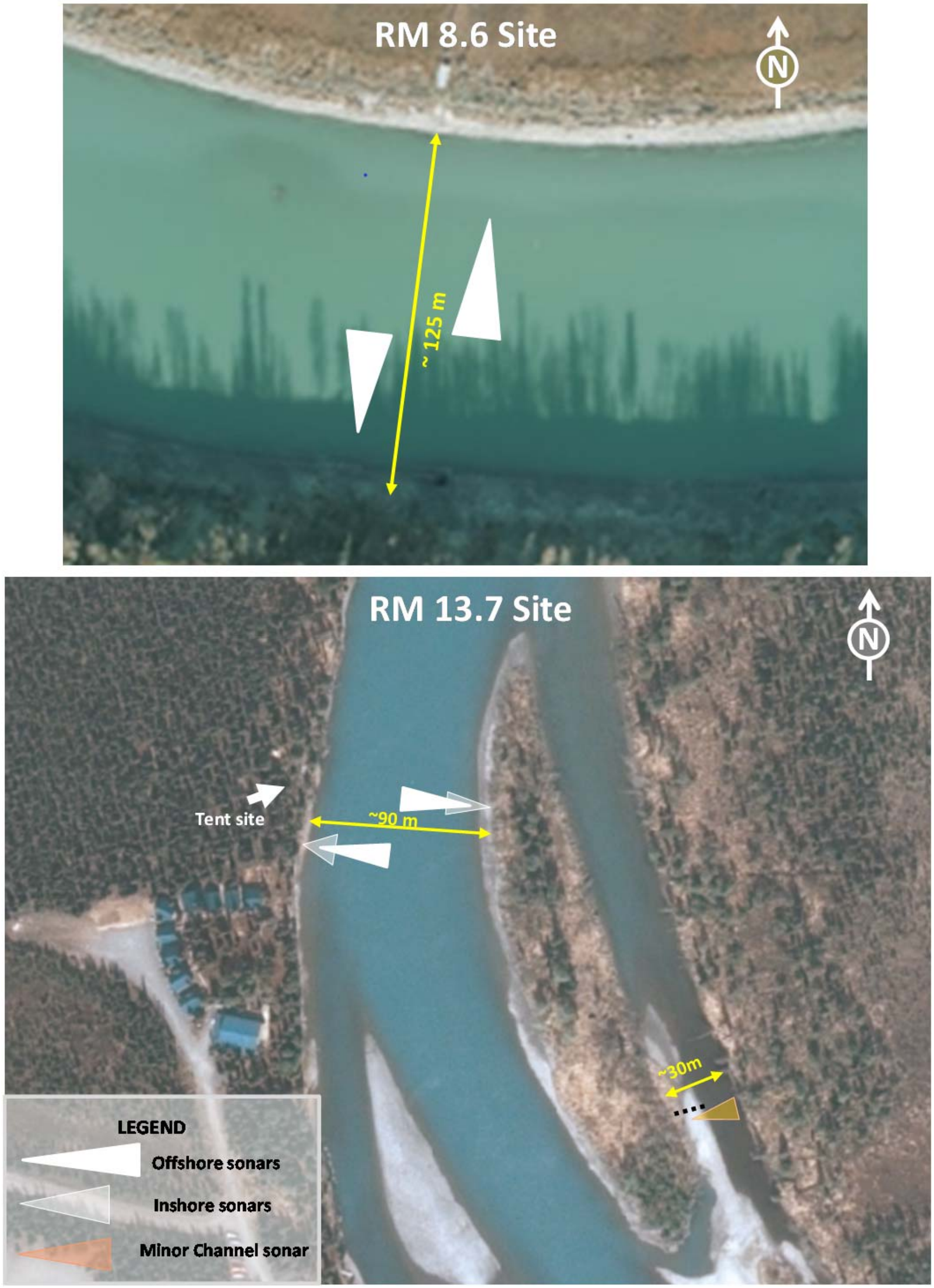

Figure 3.–Sonar sites showing approximate beam coverage at RM 8.6 (top) and RM 13.7 (bottom) of the Kenai River.

Note: Diagrams are not to scale. Tent site indicates location where sonar electronics are housed.

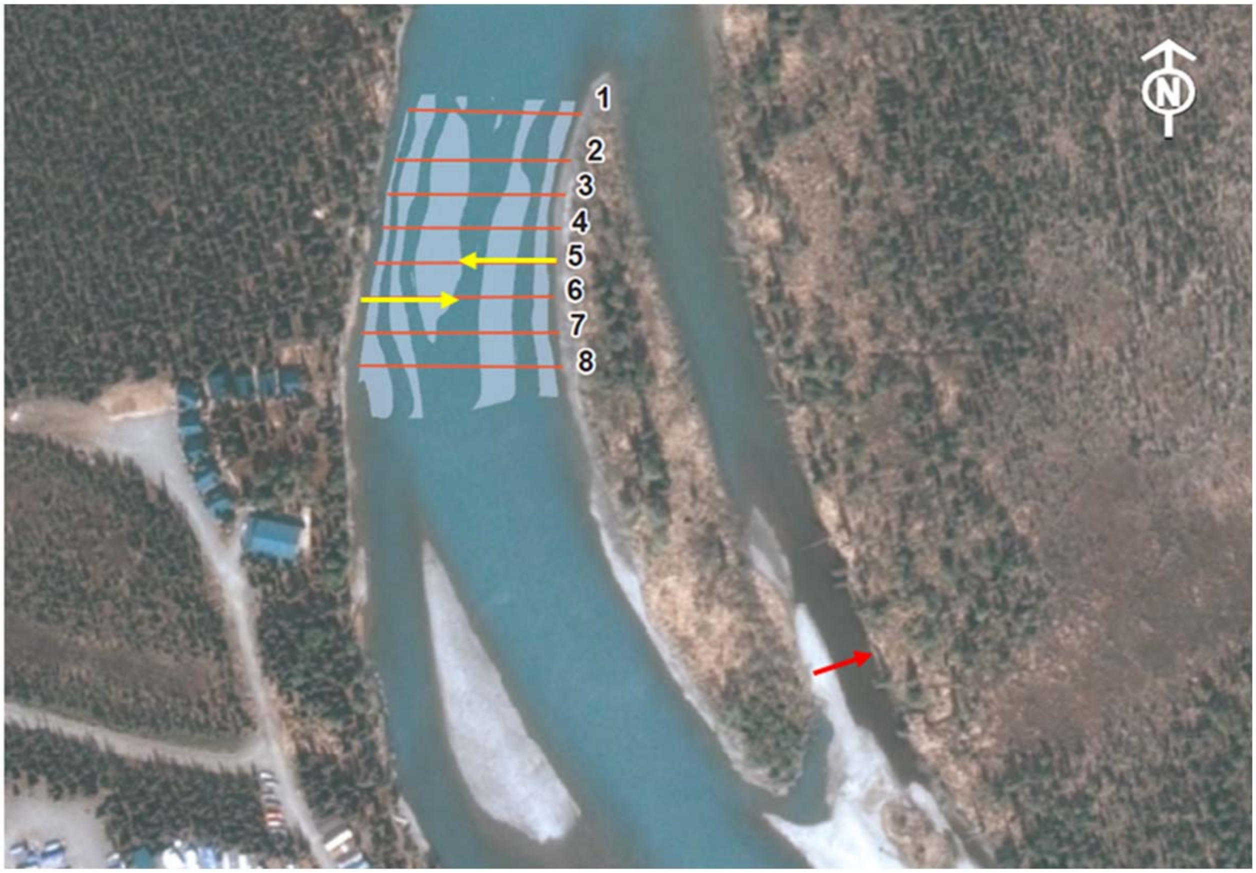

Figure 4.–Location of 8 transects conducted to examine bottom profile at the RM 13.7 site on 9 July 2012.

Note: Yellow arrows indicate preferred locations for sonars on each bank of the main channel. Red arrow indicates approximate location for sonar in the minor channel.

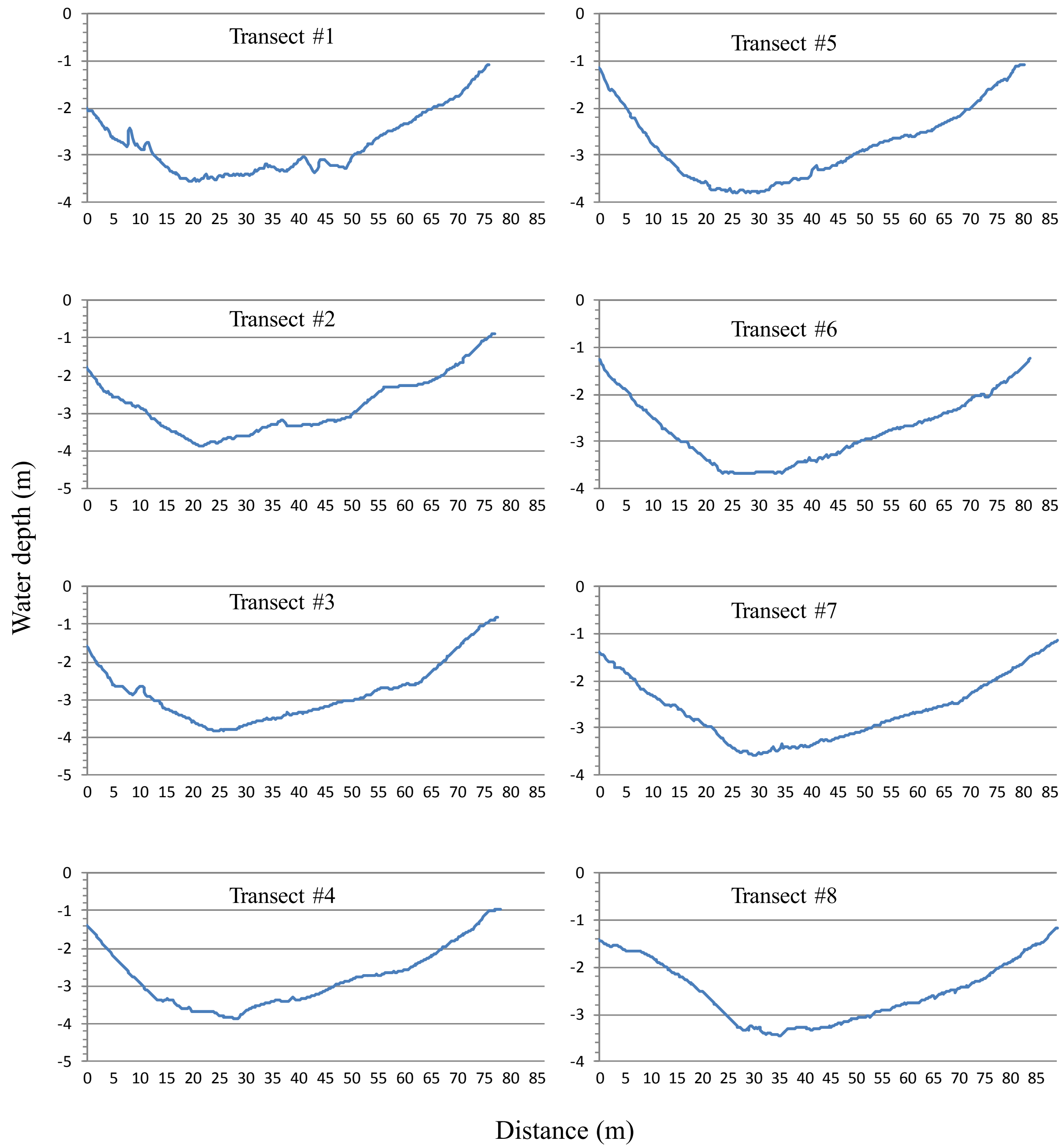

Figure 5.–Corresponding profiles for 8 transects conducted in 2012 near RM 13.7 of the Kenai River with respect to Figure 4.

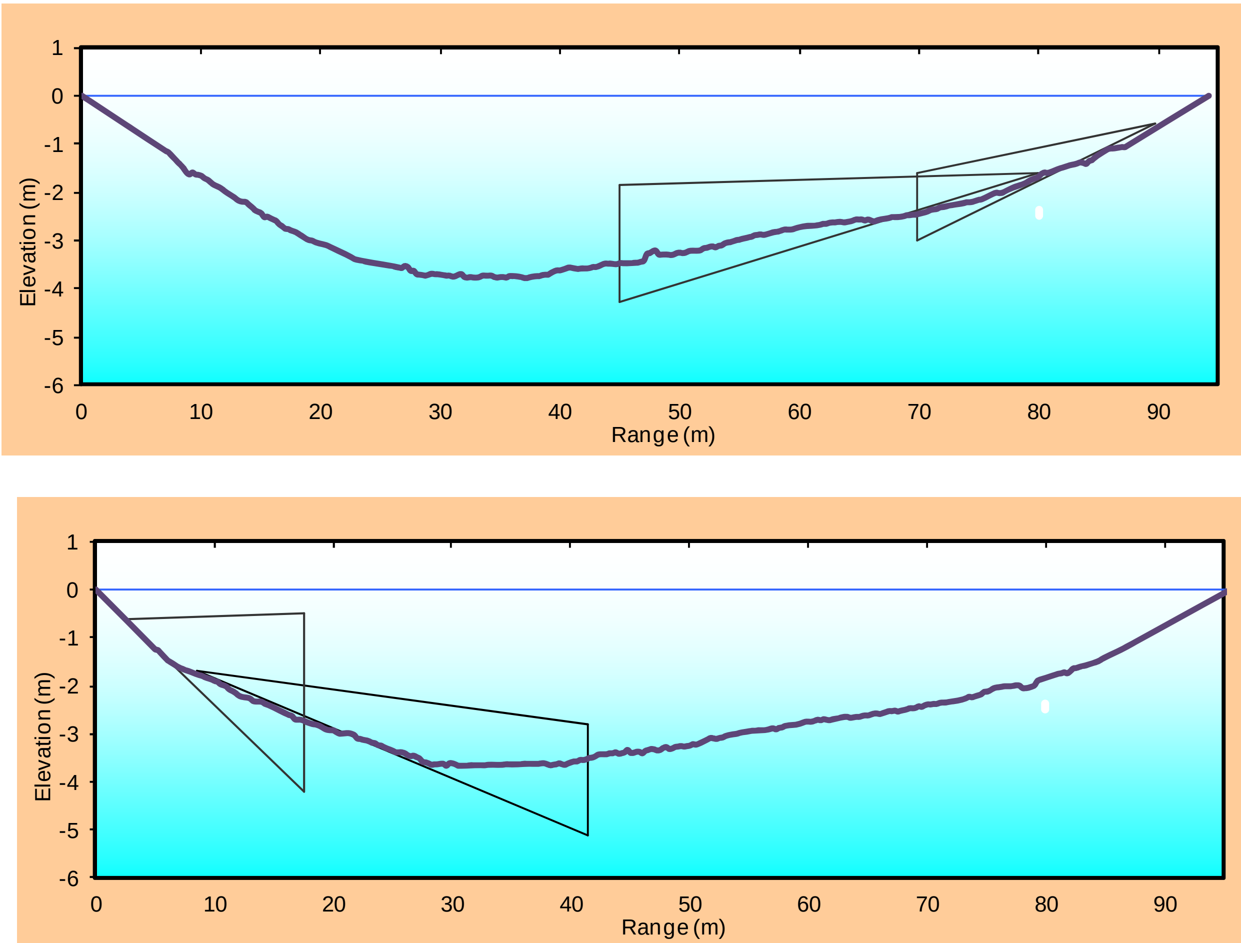

Figure 6.–Approximate coverage by nearshore and offshore sonars for the right bank (top; Transect 5 in Figure 5) and left bank (bottom; Transect 6 in Figure 5) main channel at RM 13.7 of the Kenai River.

Note: Aims are approximate because the actual aims were adjusted for each sample stratum.

Figure 7.–Sonar coverage of the minor channel at the RM 13.7 sonar site was achieved using an ARIS 1200 deployed on a tripod mount combined with a fixed weir.

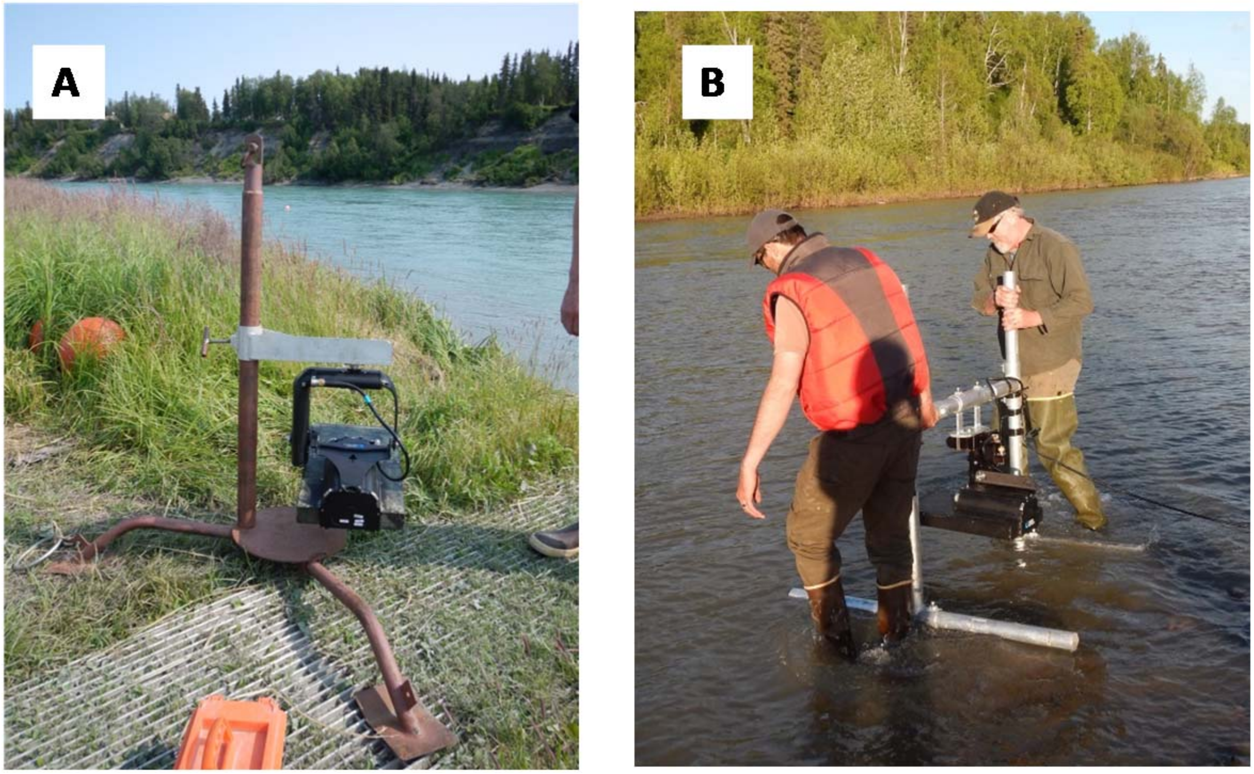

Figure 8.–An ARIS 1200 with a high-resolution lens mounted on a steel tripod for offshore deployment (A) and on an aluminum H-mount for nearshore deployment (B).

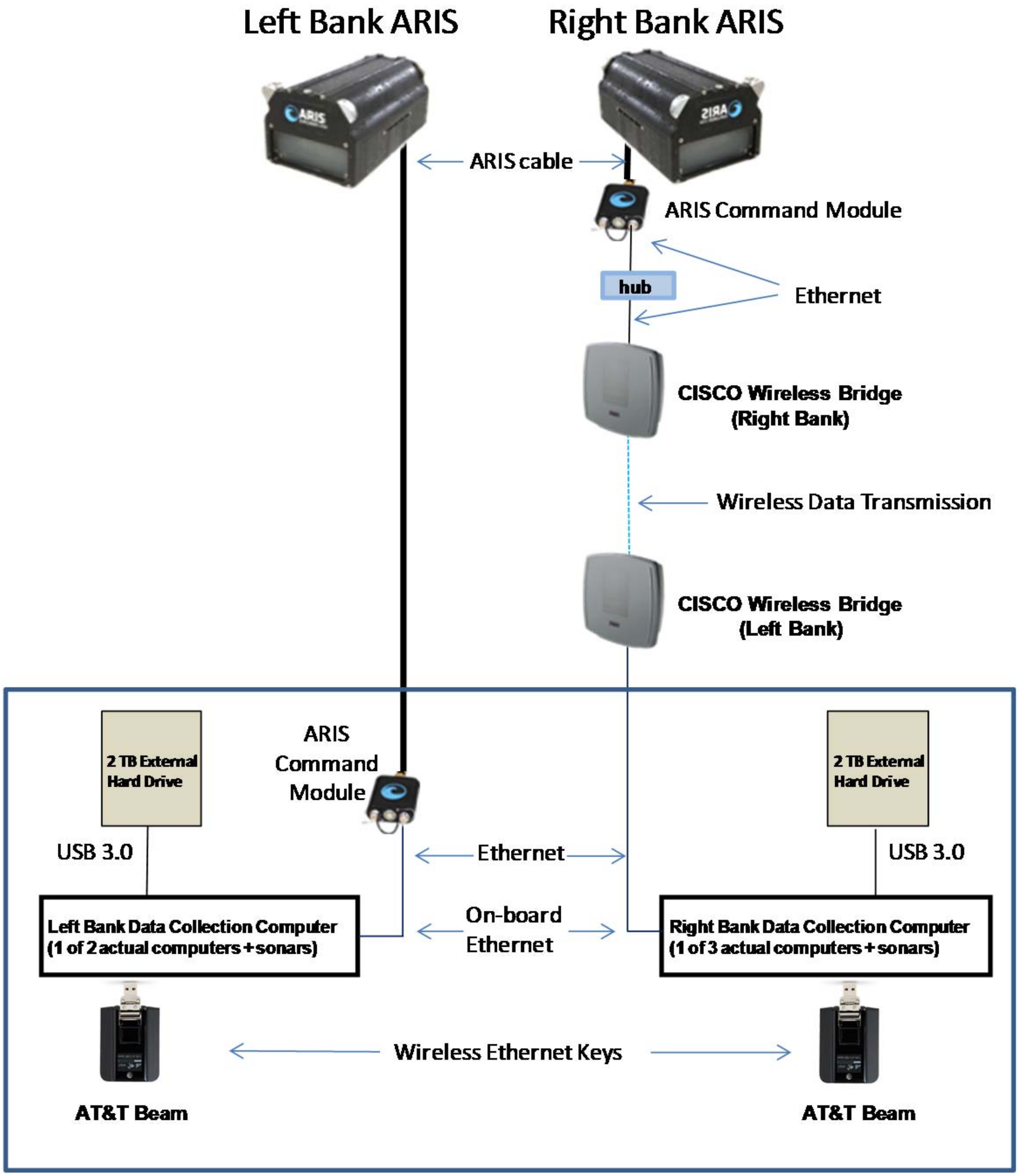

Figure 9.–ARIS data collection schematic for the RM 13.7 site on the Kenai River.

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

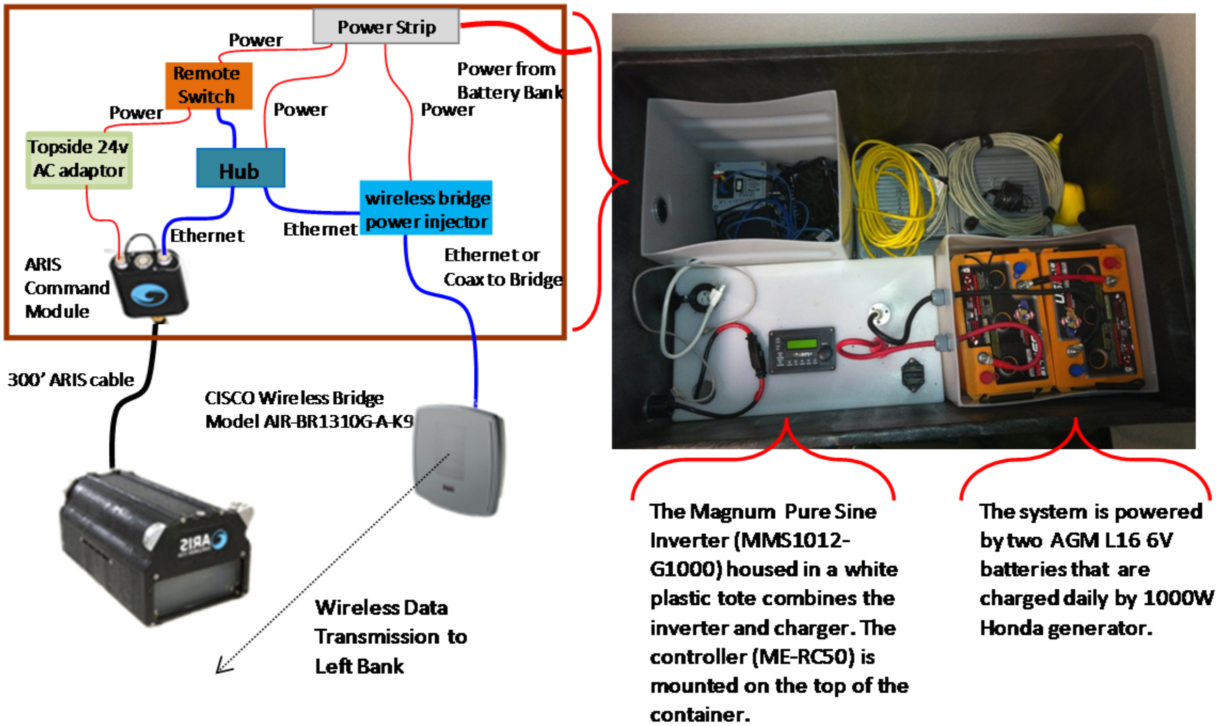

Figure 10.–Diagram showing components required on the right bank for wireless transmission of ARIS data to a data-collection computer located in the left-bank sonar tent.

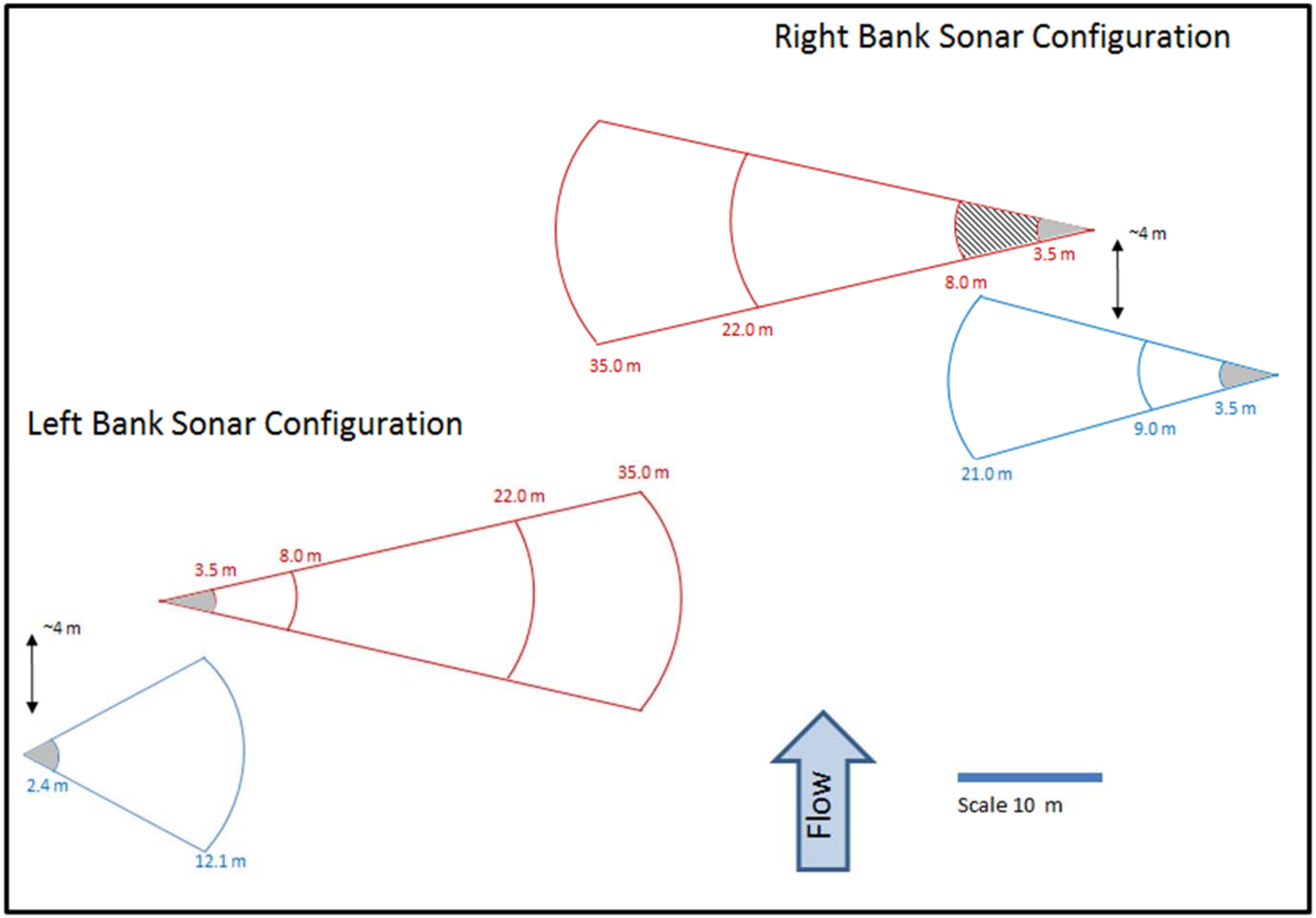

Figure 11.–Schematic for 4 left-bank (1 nearshore range [blue], 3 offshore ranges [red]) and 5 right-bank (2 nearshore ranges [blue], 3 offshore ranges [red]) range strata on the main channel of the Kenai River at RM 13.7.

Note: No data are collected between the face of the transducer and the start of the first range stratum in order to avoid range-related size bias caused by poor focal resolution at such close ranges (see Appendix A1). Data were collected in the right bank offshore 3.5–8.0 m stratum from 16 May to 1 June. Increased water level allowed the right bank inshore sonar to be deployed on 2 June and from that date forward, the area formerly covered by the right bank offshore 3.5–8.0 stratum was covered by the right bank inshore 9.0–21.0 m stratum.

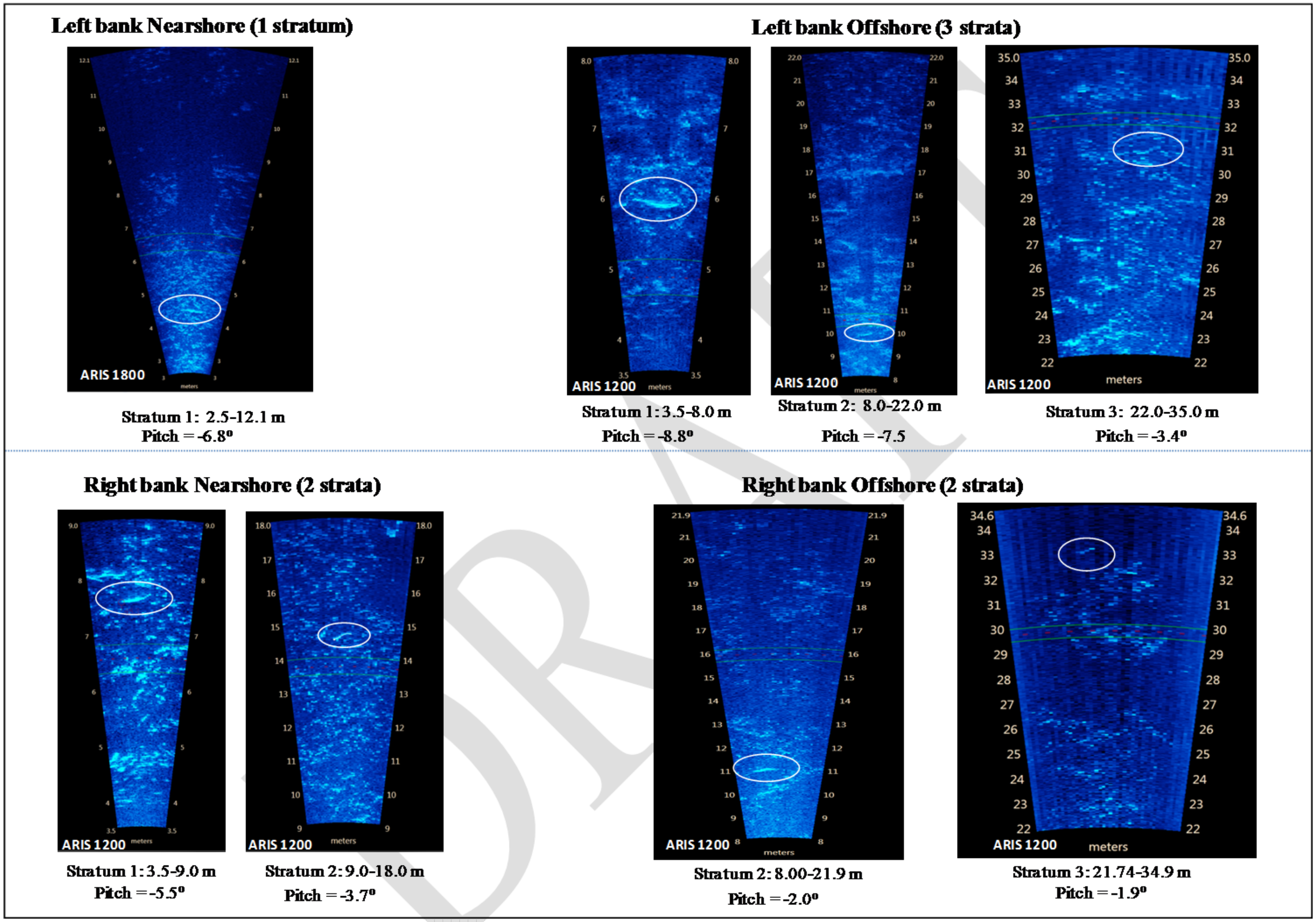

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Figure 12.–Example images from each of the 4 left-bank (top) and 4 right-bank (bottom) range strata taken at RM 13.7 Kenai River on 1 July 2014.

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

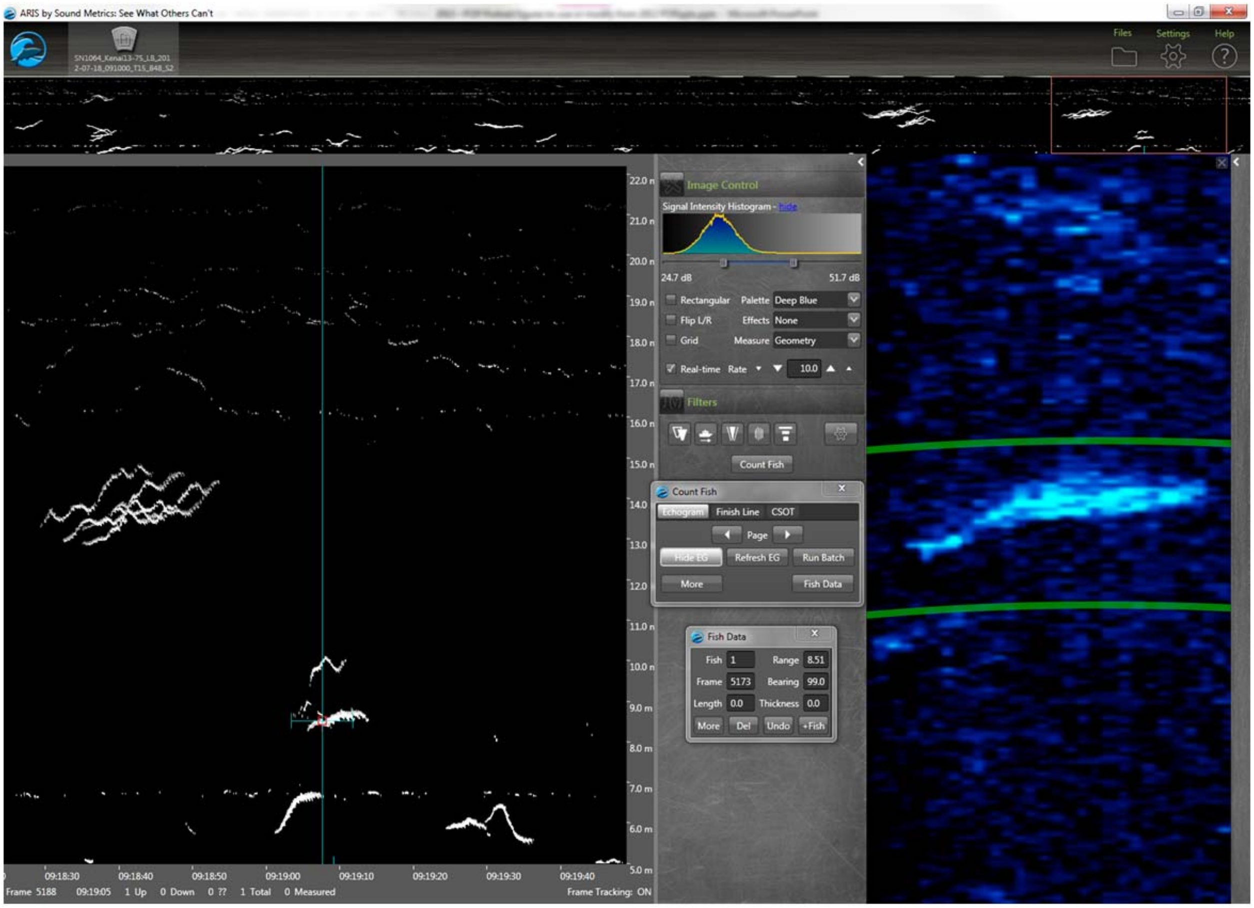

Figure 13.–ARISFish display window showing an echogram (at left) with traces of migrating fish that can be simultaneously displayed in video mode (at right) where fish images can be enlarged and measured.

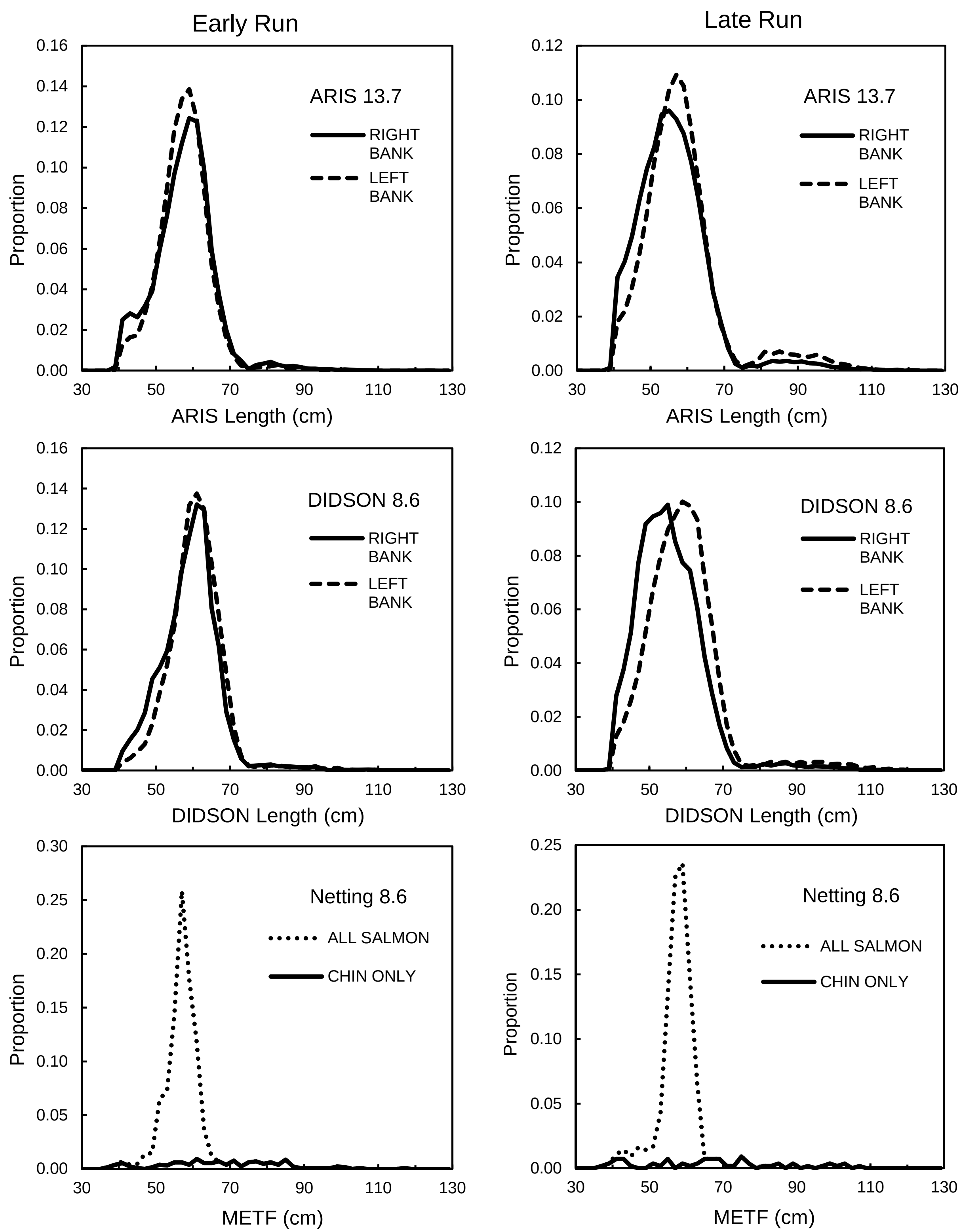

Figure 14.–Frequency distributions of ARIS lengths by bank at RM 13.7 (top), DIDSON lengths by bank at RM 8.6 (middle), and mid eye to tail fork (METF) lengths by species (all salmon vs. Chinook salmon only) from an onsite netting project (bottom), Kenai River early and late runs, 2014.

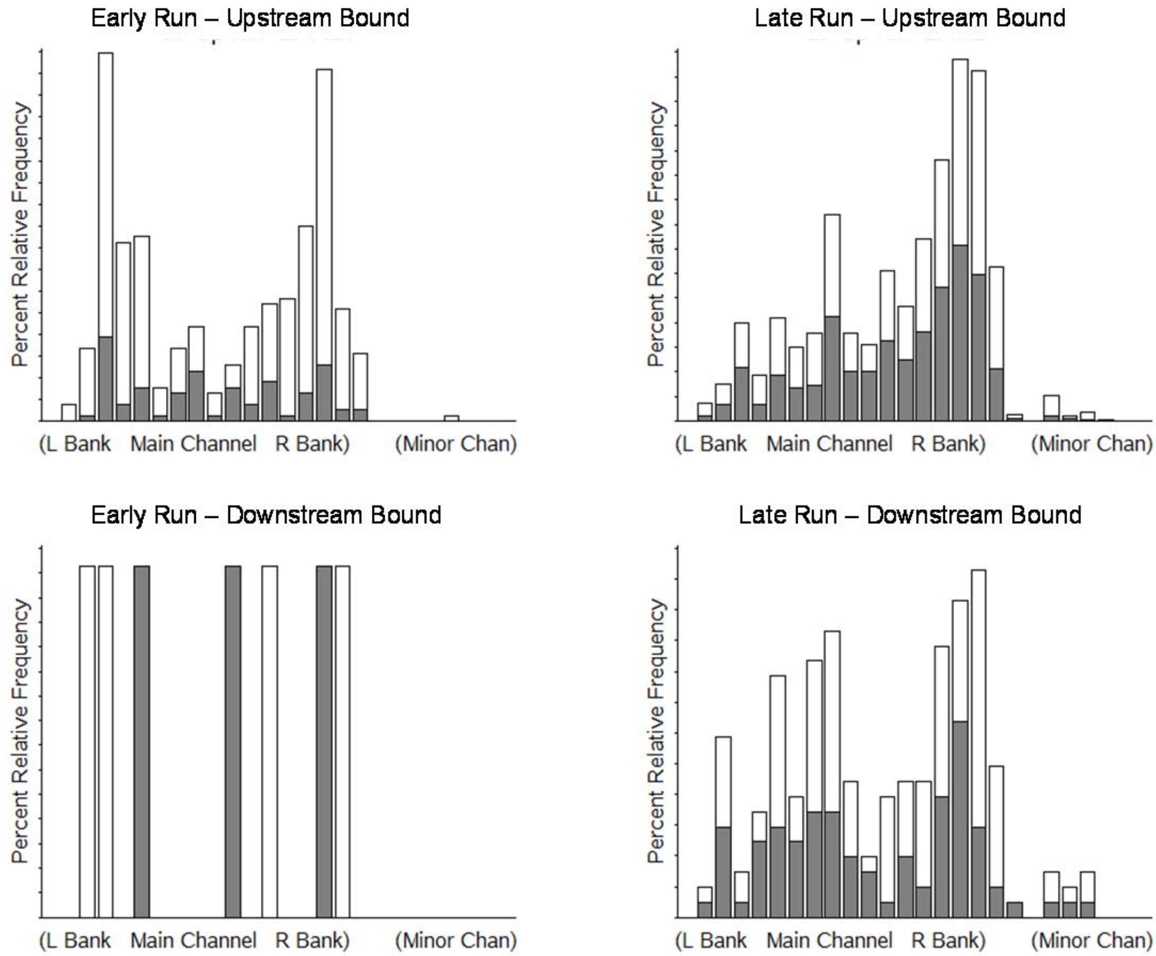

Figure 15.–Horizontal distribution, in 5 m increments from the left-bank main channel shore to the right-bank minor channel shore, of medium (75 cm ≤ AL < 90 cm, open bars) and large (AL ≥ 90 cm, solid bars) early- and late-run fish measured from ARIS, RM 13.7 Kenai River, 2014.

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

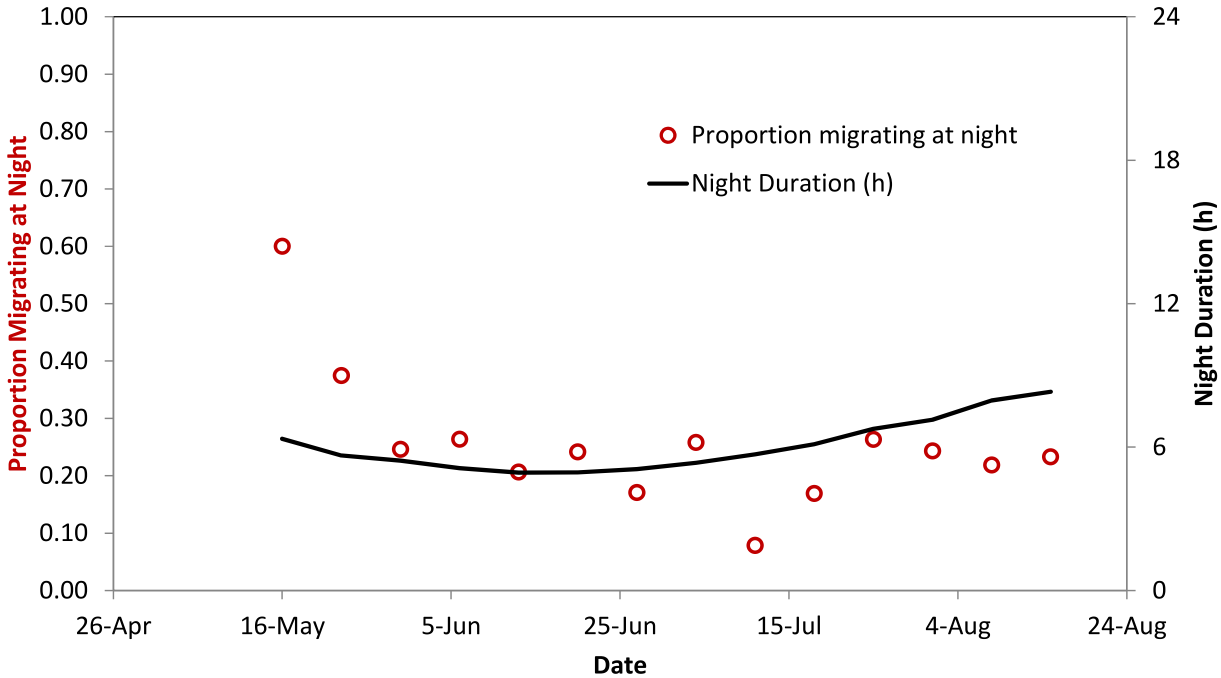

Figure 16.–Weekly proportions of fish greater than 75 cm AL migrating upstream at night (between sunset and sunrise; red circles), compared to relative night duration (solid line) in Kenai, Alaska.

Note: Proportions falling along the solid line are expected if there is no difference in the relative numbers of fish migrating between night and day. Proportions below the solid line indicate relatively fewer fish migrants at night; proportions above the solid line indicate relatively more.

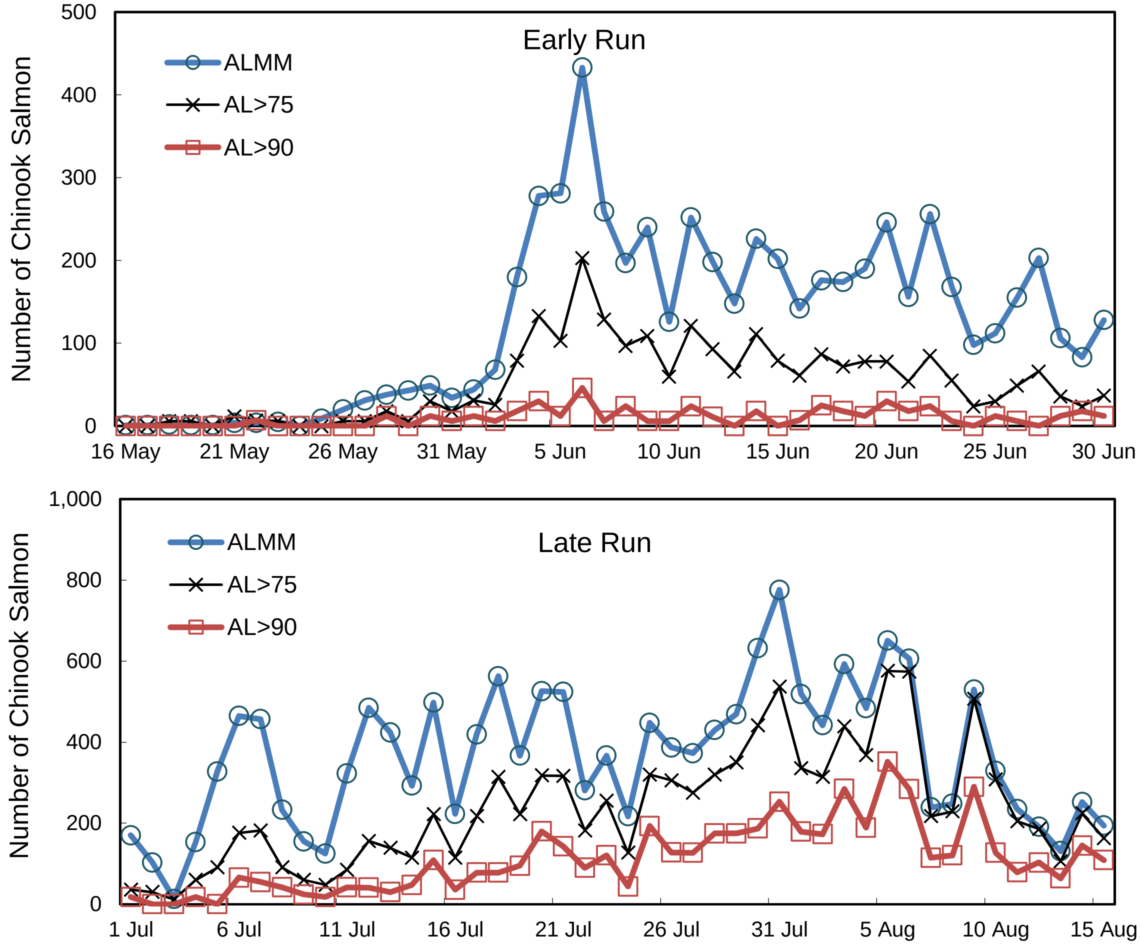

Figure 17.–Estimated net upstream passage of Chinook salmon based on an ARIS-length mixture model (ALMM) and estimated net upstream passage of medium and large Chinook salmon greater than or equal to 75 cm ARIS length (AL $\geq$ 75) and large Chinook salmon greater than or equal to 90 cm (AL $\geq$ 90) for early- (top) and late-run (bottom) Kenai River Chinook salmon, 2014.

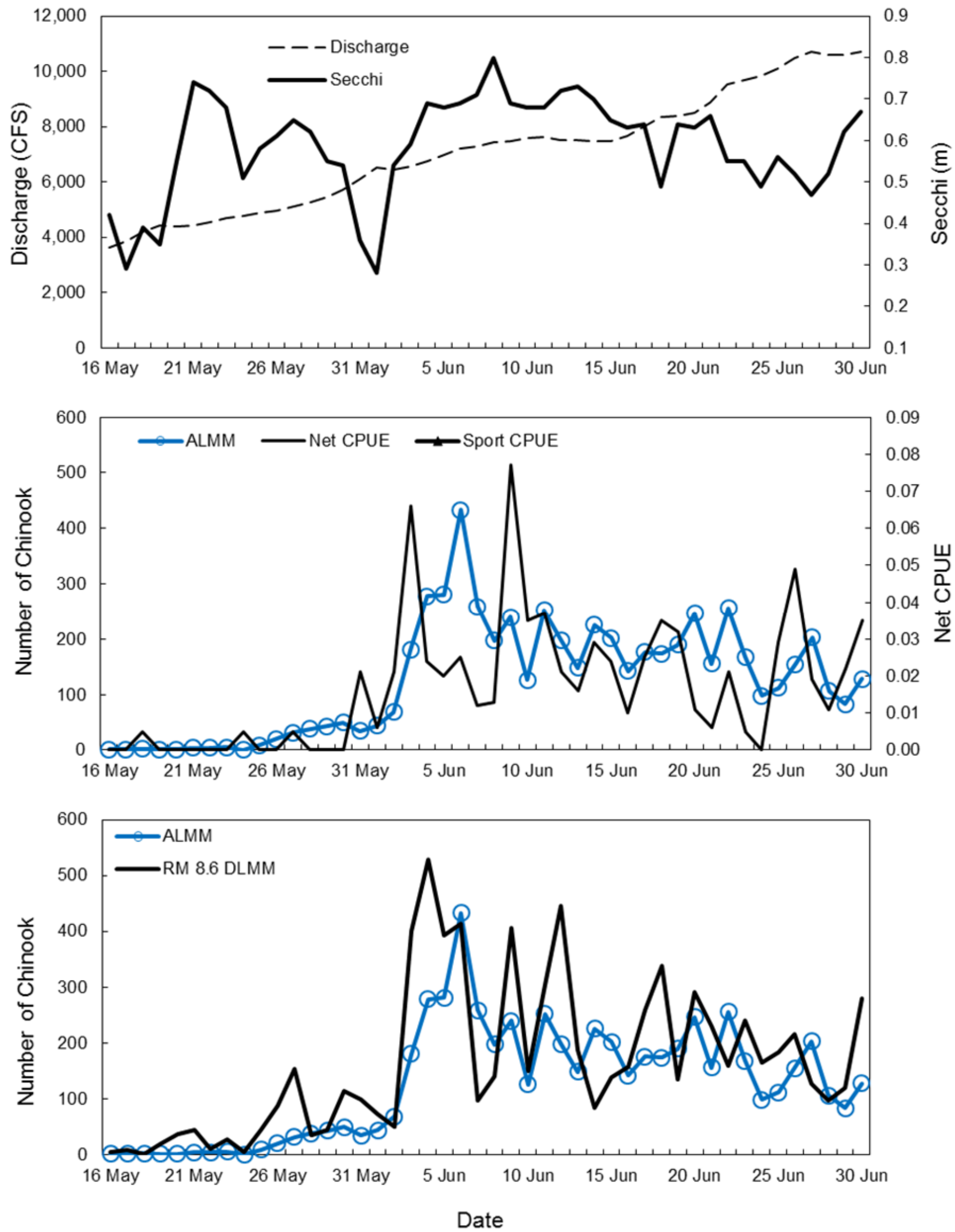

Figure 18.–Daily discharge rates collected at the Soldotna Bridge and Secchi disk readings taken at the RM 13.7 sonar site (top); ARIS-length mixture model (ALMM) estimates of net upstream Chinook salmon passage at RM 13.7, inriver gillnet Chinook salmon CPUE at RM 8.6, and sport fishery CPUE (middle); and expanded DIDSON-length mixture model (DLMM) upstream-only Chinook salmon passage at RM 8.6[14] compared to ALMM (bottom), Kenai River early run, 2014.

Note: River discharge taken from USGS[15]. Net CPUE and sport fish CPUE from Perschbacher and Eskelin (*In prep*). DLMM estimates were multiplied by 1.55[11] to account for Chinook salmon passage shoreward of the RM 8.6 transducers. The sport fishery closed during the entire 2014 early run.

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[14] Table 4 in Key et al. (2016b).

[15].USGS Water resource data, Alaska, water year 2014. Website Daily Streamflow for Alaska, Soldotna gauging station, site #15266300, accessed December 14, 2015. http://water.usgs.gov/ak/nwis/discharge.

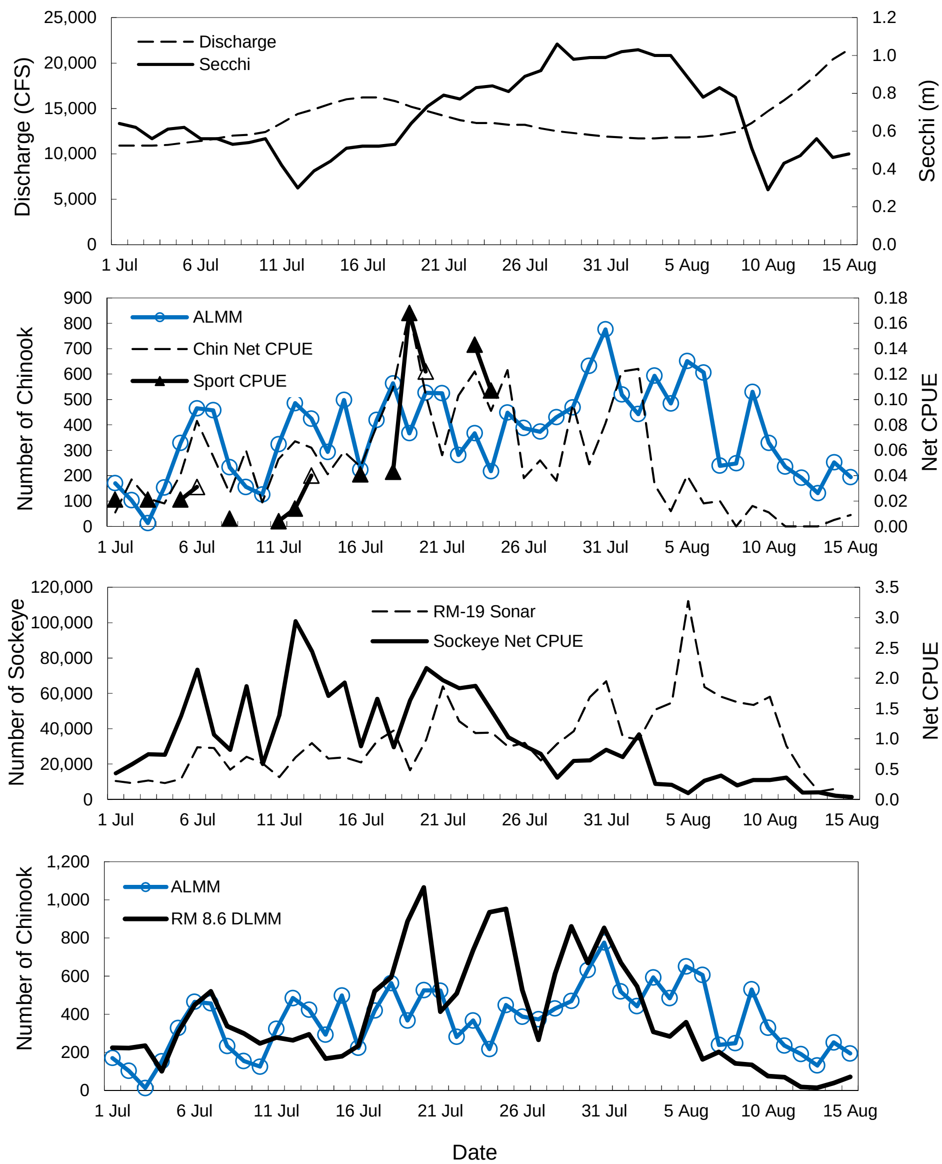

Figure 19.–Daily discharge rates collected at the Soldotna Bridge and Secchi disk readings taken at the RM 13.7 sonar site (top); ARIS-length mixture model (ALMM) estimates of net upstream Chinook salmon passage at RM 13.7, inriver gillnet Chinook salmon CPUE at RM 8.6, and Chinook salmon sport fishery CPUE (top-middle); RM 19 sockeye salmon sonar passage and inriver gillnet sockeye salmon CPUE at RM 8.6 (bottom-middle); and expanded DIDSON-length mixture model (DLMM) upstream only Chinook salmon passage at RM 8.6[16] compared to ALMM (bottom), Kenai River late run, 2014.

Note: River discharge taken from USGS[17]. Net CPUE and sport fish CPUE from Perschbacher and Eskelin (*In prep*). RM 19 sonar estimates from Glick and Willette. (2016). DLMM estimates were multiplied by 1.28[14] to account for Chinook salmon passage shoreward of the RM 8.6 transducers. Open triangles represent days on which only unguided anglers were allowed to fish. The sport fishery closed after 25 July.

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[16] Table 5 in Key et al. (2016b).

[17] .USGS Water resource data, Alaska, water year 2014. Website Daily Streamflow for Alaska, Soldotna gauging station, site #15266300, accessed December 14, 2015. http://water.usgs.gov/ak/nwis/discharge.

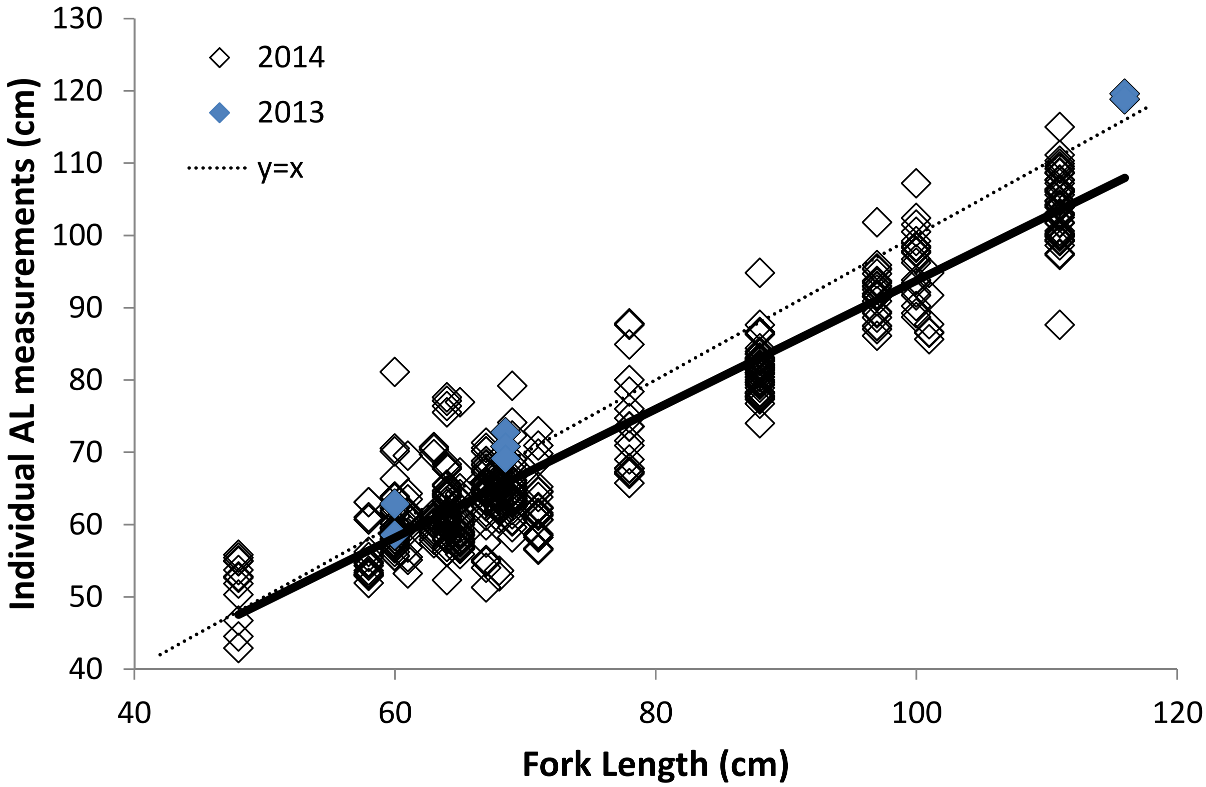

Figure 20.–Individual ARIS-based length estimates versus fork length (snout to fork of tail) for tethered salmon at RM 8.6 in the Kenai River, 2013–2014.

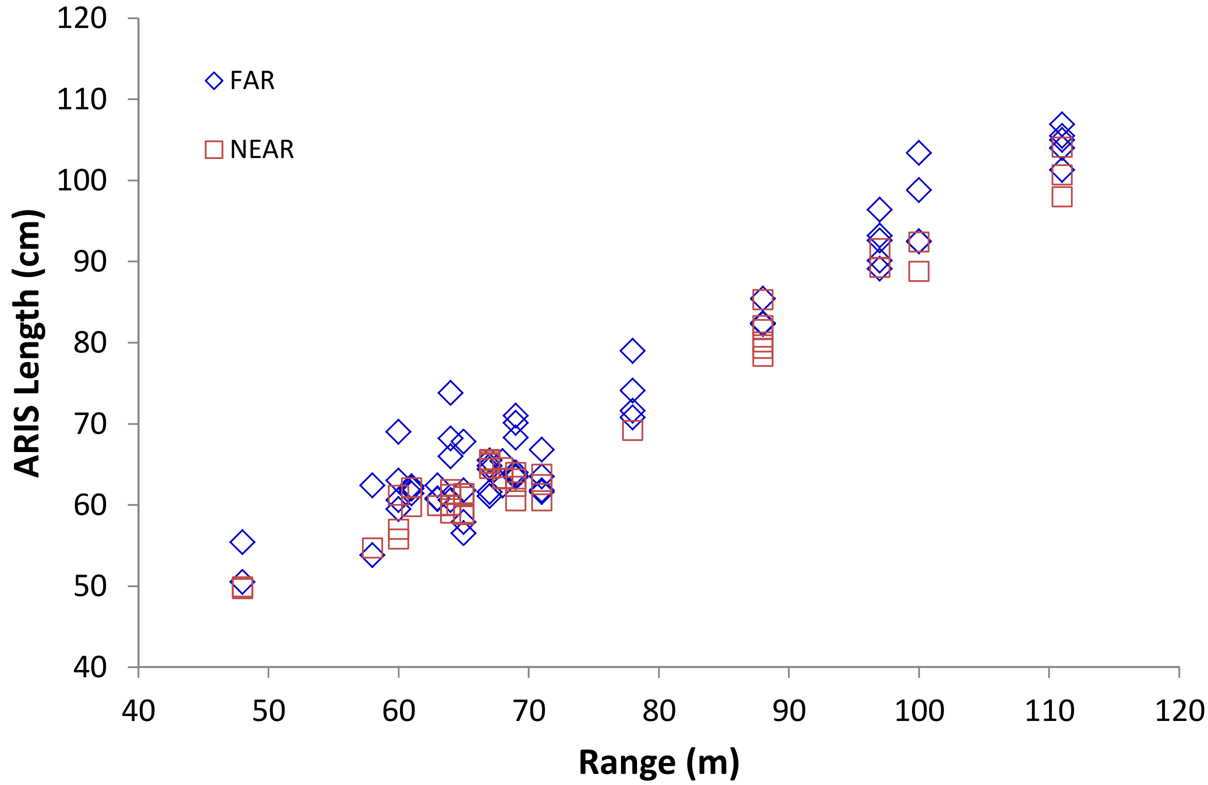

Figure 21.–Mean ARIS-based length estimates (individual estimates averaged across multiple observers and equipment settings) versus fork length of Kenai River salmon tethered from near- and far-range stations, 2013–2014.

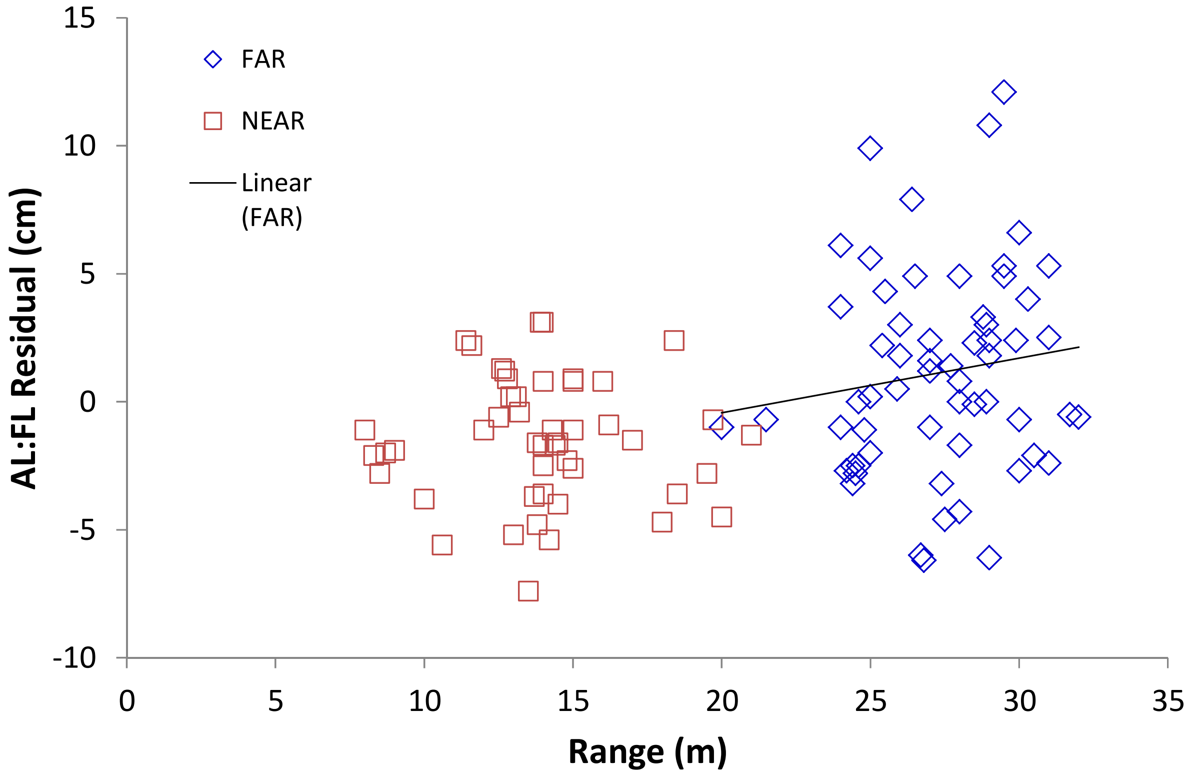

Figure 22.–Residuals from the relationship between individual ARIS-based length estimates and fork length plotted versus range and labeled by station for tethered salmon in the Kenai River, 2013–2014.

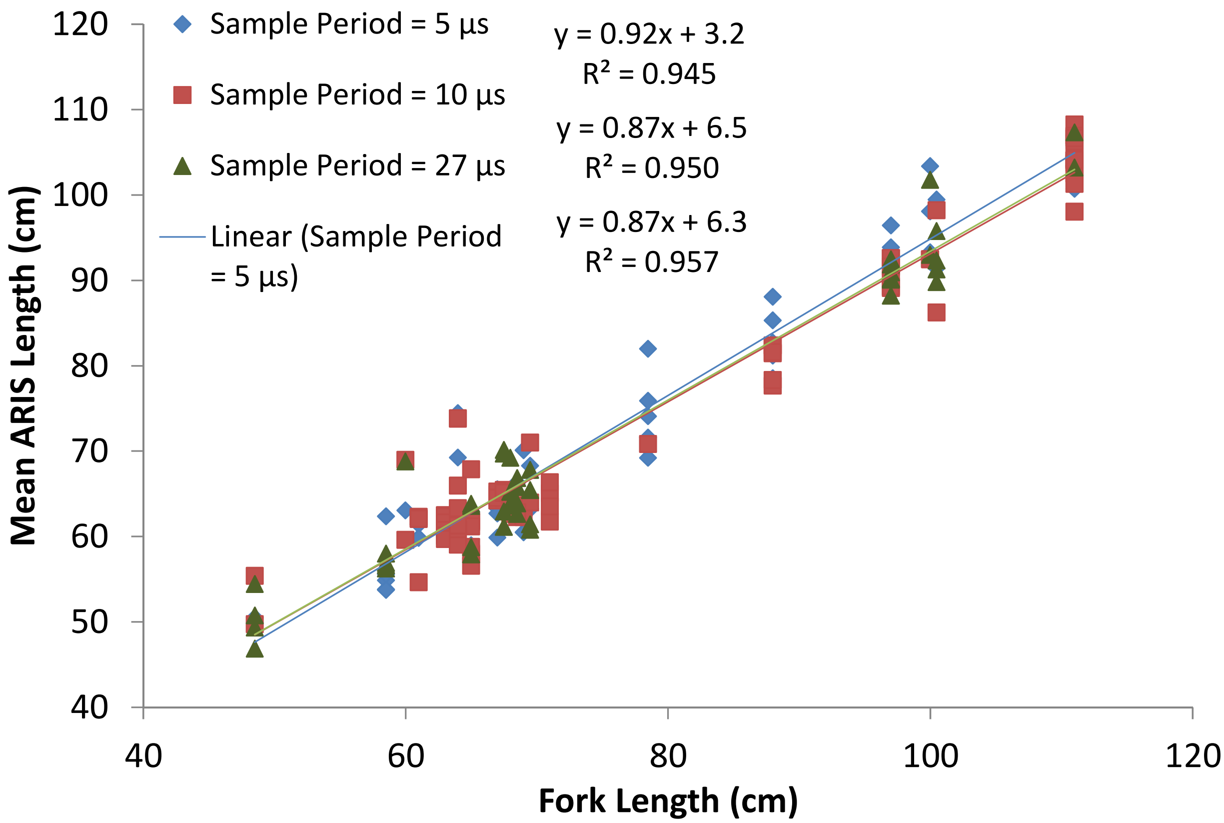

Figure 23.–Linear regressions of mean ARIS-based length estimates (individual estimates averaged across multiple observers) versus true fork lengths of tethered sockeye salmon and Chinook salmon collected using sample periods 5 µs, 10 µs, and 27 µs at RM 8.6 Kenai River, 2014.

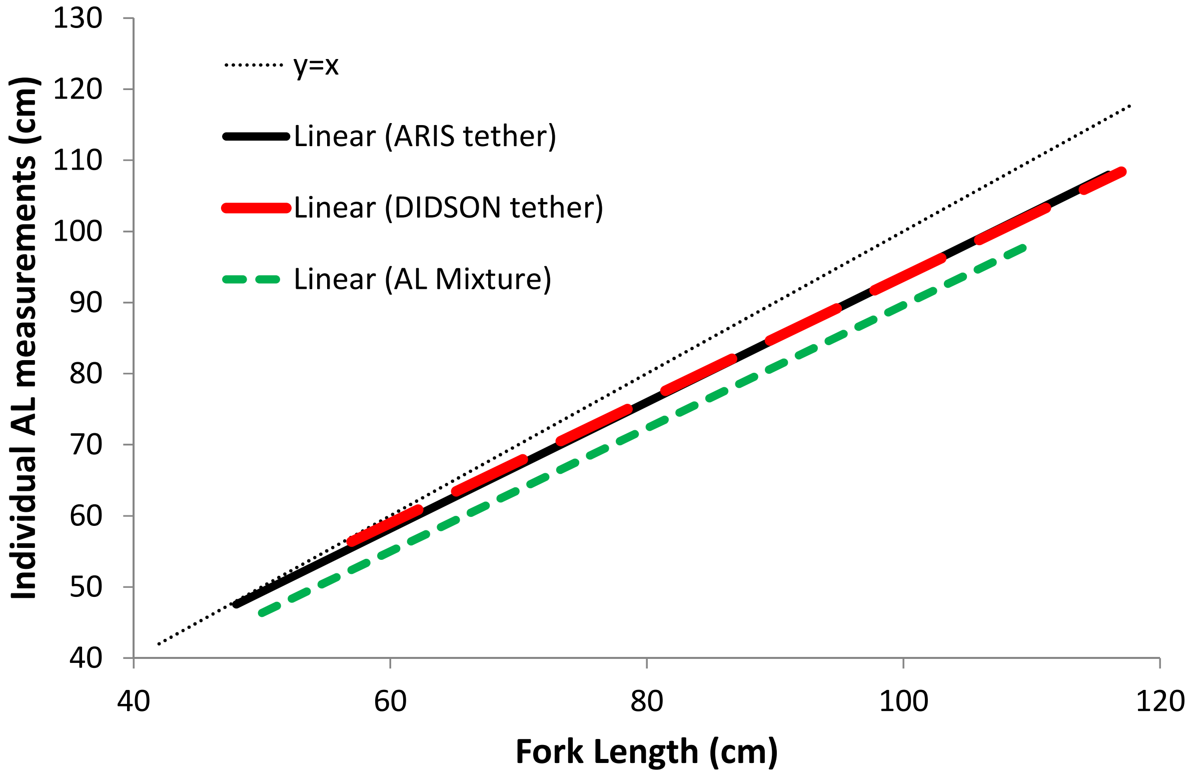

Figure 24.–Estimated linear relationships between ARIS- and DIDSON-based length estimates versus fork length for tethered salmon in the Kenai River.

Note: The 1:1 line is plotted for reference.

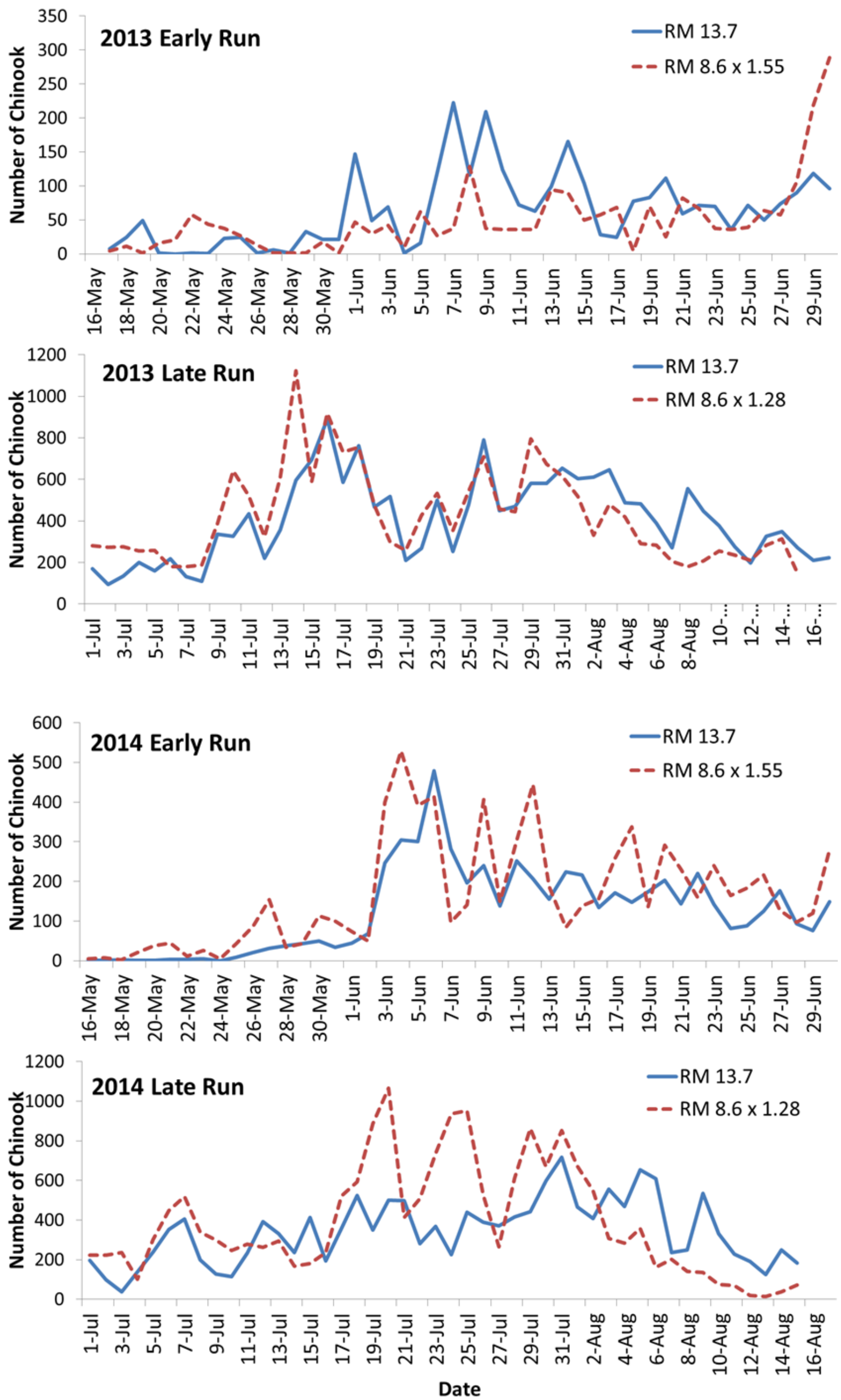

Figure 25.–Daily abundance estimates of Kenai River Chinook salmon as measured by sonar sites at river miles 8.6 and 13.7, 2013 and 2014.

Note: The 2013 and 2014 RM 8.6 estimates are derived from estimates presented in Key et al. (2016a) and Key et al. (2016b), respectively; the 2013 RM 13.7 estimates are presented in Miller et al. (2016) and the 2014 RM 13.7 estimates were derived using midriver netting data only.

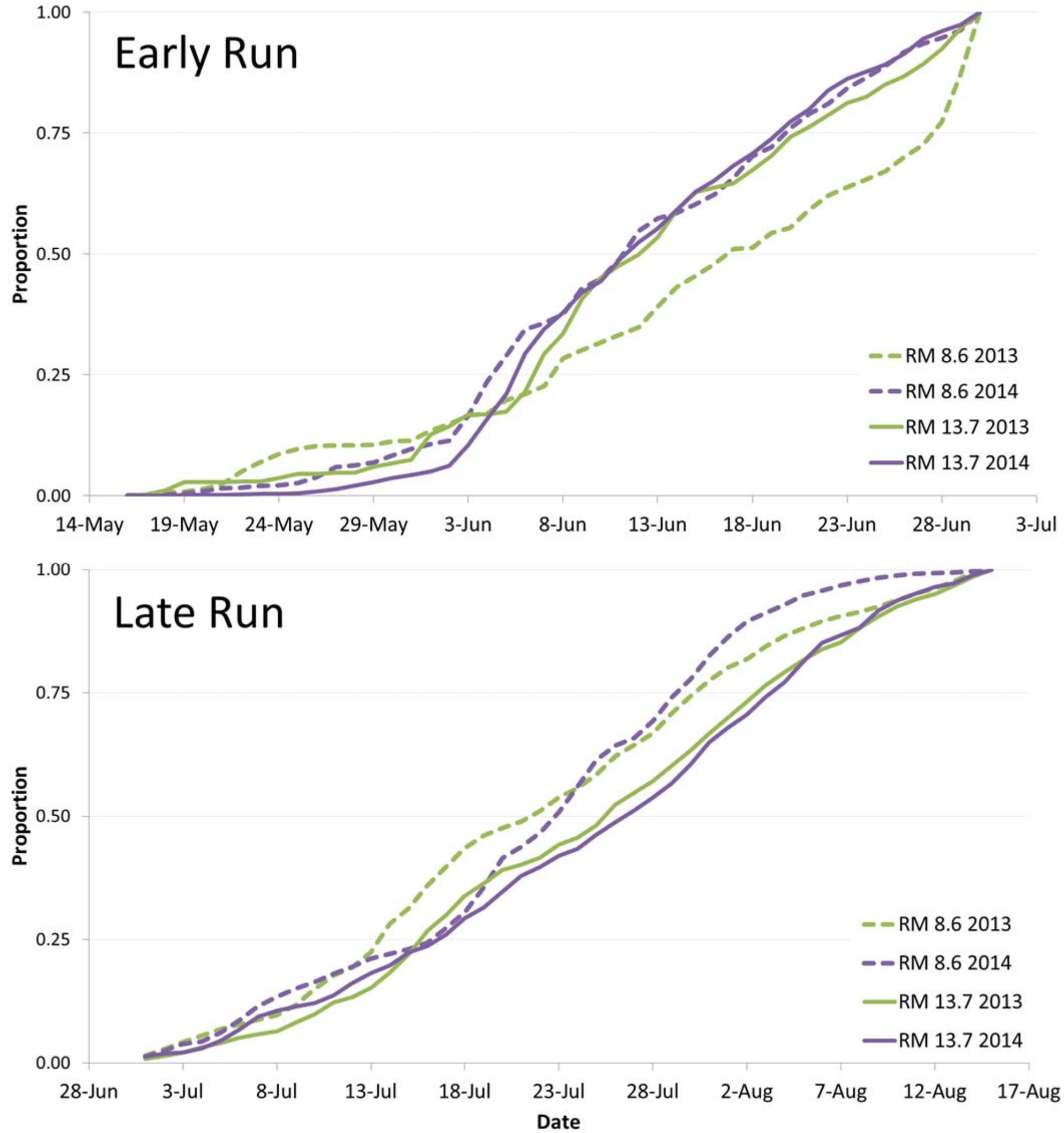

Figure 26.–Cumulative daily proportion of end-of-season abundance (run timing) for Kenai River Chinook salmon as measured by sonar at river miles 8.6 and 13.7, 2013 and 2014 early and late runs.

Note: The 2013 RM 13.7 estimates are presented in Miller et al (2016); the 2014 RM 13.7 estimates differ from those in Tables 9 and 10; they were derived using midriver netting data only.

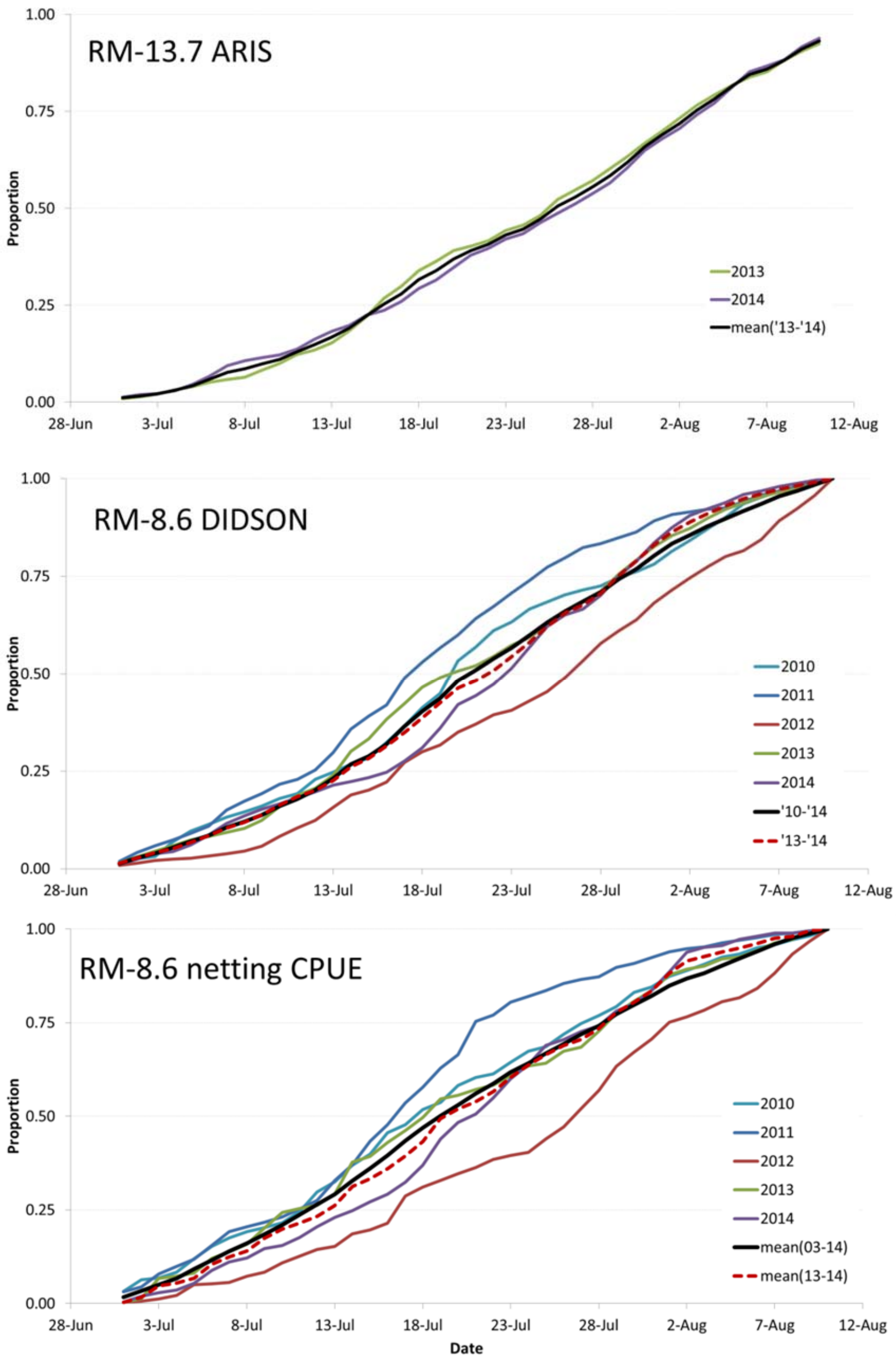

Figure 27.–Cumulative daily relative abundance of late-run Kenai River Chinook salmon as measured by sonar at RM 13.7 (2013 and 2014) and RM 8.6 (2010–2014, mean of 2010–2014, mean of 2013–2014), and cumulative daily netting CPUE at RM 8.6 (2003–2014, mean of 2003–2014, mean of 2013–2014).

Note: Run timing during years 2013 and 2014 was not atypical, and mean 2013–2014 run timing is very similar to mean run timing during 2010–2014 and 2003–2014.

APPENDIX A: COMPARISON OF DIDSON AND ARIS CONFIGURATIONS

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

Frequency

The dual-frequency identification sonar (DIDSON) operates 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. Two DIDSON models are currently available based on different operating frequencies (Appendix A2). The short-range or standard model (DIDSON SV) operates at 1.8 MHz to approximately 15 m in range and at 1.1 MHz to approximately 35 m and produces higher resolution images than the long-range model. The long-range model (DIDSON LR) with a high resolution lens operates at 1.2 MHz to approximately 30 m in range and at 0.7 MHz to ranges exceeding 100 m, but produces images with approximately half the resolution of the DIDSON SV (see explanation below).

Similar to DIDSON, adaptive resolution imaging sonar (ARIS) systems operate at 2 frequencies analogous to the DIDSON frequencies (Appendix A3). The two ARIS models used on this project, ARIS 1800 and ARIS 1200, are essentially updated versions of the DIDSON SV and DIDSON LR models (Appendices A2–A3). Both ARIS models used in the RM 13.7 study were operated in high frequency mode when possible to achieve maximum image resolution. One difference between ARIS and DIDSON with respect to low frequency data collection is that the ARIS 1800 uses 96 beams at low frequency by default, whereas the equivalent DIDSON SV is hard-wired for 48 beams at low frequency.

Beam Dimensions and Lens Selection

Both the DIDSON LR and ARIS 1200 can be used with high-resolution lenses (+HRL) to increase the image resolution to the level achieved by the DIDSON SV and ARIS 1800 (these modifications are referred to as DIDSON LR +HRL and 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 a DIDSON LR or an ARIS 1200 with a standard lens are approximately 28° in the horizontal axis and 14° 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 DIDSON LR and 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).

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Focal Resolution of DIDSON and ARIS Lenses: considerations for measurement accuracy

When sizing fish from DIDSON or 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.

For DIDSON, focus counts of 0–255 represent the total range of travel of the middle (focus) lens. For the ARIS 1200 and 1800, which use the same lens sets and have the same focus curves, 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 a DIDSON or 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 a DIDSON or 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. Appendix A6 shows that image pixels are sometimes broken down into smaller screen pixels (e.g., pixels immediately to the right of the enlarged pixels), which are an artifact of conversions between rectangular and polar coordinates.

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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., DIDSON LR +HRL at 1.8 MHz, 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 or DIDSON 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 DIDSON LR and 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.

ARIS 1800 images can attain a finer crossrange resolution than the equivalent DIDSON SV at low frequency because, as mentioned previously, ARIS 1800 can use 96 beams at low frequency whereas DIDSON is hard-wired for 48 beams at low frequency. This means the ARIS 1800 can achieve twice the resolution that a DIDSON SV can achieve at ranges requiring low frequency mode (i.e., ranges exceeding approximately 15–20 m). However, using all 96 beams will cut the maximum frame rate by half, which can be an issue when insonifying longer ranges.

Downrange Resolution

Window length, i.e., the range interval sampled by the sonar, controls the downrange resolution of the DIDSON image, which is calculated using the formula:

$$Y = W/N \tag{A2}$$

where

W = window length (cm), and

N = number of range samples (or pixels).

-continued-

With DIDSON, *N* is fixed at 512 samples (pixels) and images with shorter window lengths are always better resolved. The DIDSON LR +HRL “Window Length” parameter can only be set at discrete values: 2.5, 5.0, 10.0, or 20.0 m at 1.2 MHz. Although using shorter window lengths increases resolution, it also requires more individual strata to cover the desired range. Dividing the total range covered into too many discrete strata increases the data-processing time. Typically, a window length of 5 m is used for the first 2 range strata to minimize the bias associated with close-range targets (see below). A window length of 10 m is used for each subsequent range stratum sampled, a compromise that allows a relatively high resolution while allowing a reasonable distance to be covered by each stratum. The downrange resolution (or pixel height) for a 5 m range window is 1 cm (500 cm per 512 samples) and for a 10 m window length is 2 cm (1,000 cm per 512 samples).

ARIS images can attain a finer downrange resolution than DIDSON. With ARIS, *N* can vary from 128 to a maximum of 4,000 samples (pixels) and window length is user selectable. This allows the user to collect data over longer window lengths but increases the number of samples per beam to compensate. Appendix A6 contrasts images from a DIDSON LR +HRL with an ARIS 1200 +HRL. The ARIS image in Appendix A6 has twice the downrange resolution of the DIDSON image because it was collected at 2,000 samples (pixels) per beam with a 20 m range window yielding a downrange resolution of 1 cm (2,000 cm per 2,000 samples) compared to a downrange resolution of 2 cm for the DIDSON image, which was collected at 512 samples with a 10 m range window (1,000 cm per 512 samples). Note that the pixels composing the ARIS image in Appendix A6 appear less well defined because a smoothing algorithm has been applied.

Setting the Downrange Resolution in ARIS

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.

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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 DIDSON SV, DIDSON LR, 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]
DIDSON SV or 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°
DIDSON LR or 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 (e.g., the center beam spacing is closer to 0.34°, and the beam width is 0.27° for a DIDSON SV at 1.8 MHz; Bill Hanot, Sound Metrics Corporation, personal communication). Nonlinear corrections are applied by the manufacturer in software to correct for these effects in the DIDSON with standard lens but not with the high-resolution lens. 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, whereas DIDSON is hard-wired for 48 beams at low frequency. 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, ARIS 1800, DIDSON SV, and DIDSON LR.

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

-continued-

ARIS 1200 Specifications (continued)

Both Modes
Number of beams 48
Beam Spacing 0.6° nominal
Horizontal Field-of-View 28°
Max frame rate (range dependent) 2.5–15 frames/s
Minimum Range Start 0.7 m
Downrange Resolution 3 mm to 10 cm
Transmit Pulse Length 4 µs to 100 µs
Remote Focus 0.7 m to max range
Power Consumption 18 Watts typical
Weight in Air 5.5 kg (12.1 lb)
Weight in Water ~1.4 kg (3 lb)
Dimensions 31 cm × 17 cm × 14 cm
Depth rating 300 m
Data Comm Link 100BaseT Ethernet or HomePlug
Maximum cable length (Ethernet) 90 m (300 ft)
Maximum cable length (HomePlug) 300 m (1000 ft)

DIDSON SV Specifications

Detection Mode
Operating Frequency 1.1 MHz
Beamwidth (2-way) 0.4° H by 14° V
Source Level (average) ~204 dB re 1 µPa at 1 m
Number of Beams 48
Beam Spacing 0.6°
(Extended) Window Start 0.83 m to 52.3 m in 0.83 m steps
(Extended) Window Length 5 m, 10 m, 20 m, 40 m
Range Bin Size (relative to window length) 10 mm, 20 mm, 40 mm, 80 mm
Pulse Length (relative to window length) 18 µs, 36 µs, 72 µs, 144 µs

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
Number of Beams 96
Beam Spacing 0.3°
(Extended) Window Start 0.42 m to 26.1 m in 0.42 m steps
(Extended) Window Length 1.25 m, 2.5 m, 5 m, 10 m
Range Bin Size (relative to window length) 2.5 mm, 5 mm, 10 mm, 20 mm
Pulse Length (relative to window length) 4.5 µs, 9 µs, 18 µs, 36 µs

-continued-

DIDSON SV Specifications (continued)

Both Modes
Max Frame Rate (range dependent) 4–21 frames/s
Field-of-view 29°
Remote Focus 1 m to Infinity
Control & Data Interface UDP Ethernet
Aux Display NTSC Video
Max cable length (100/10BaseT) 61m/152 m (200 ft/500 ft)
Max cable length (twisted pair, Patton Extender) 1220 m (4000 ft)
Power Consumption 25 Watts typical
Weight in Air 7.9 kg (17.4 lb)
Weight in Sea Water 1.0 kg (2.2 lb)
Dimensions 31.0 cm × 20.6 cm × 17.1 cm
Topside PC Requirements Windows (XP, Vista, 7), Ethernet
Optional NTSC video monitor

DIDSON LR 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
Number of Beams 48
Beam Spacing 0.6°
Extended Range Settings
(Extended) Window Start 0.83 m to 52.3 m in 0.83 m steps
(Extended) Window Length 10 m, 20 m, 40 m, 80 m
Range Bin Size (relative to window length) 20 mm, 40 mm, 80 mm, 160 mm
Pulse Length (relative to window length) 23 µs, 46 µs, 92 µs, 184 µs

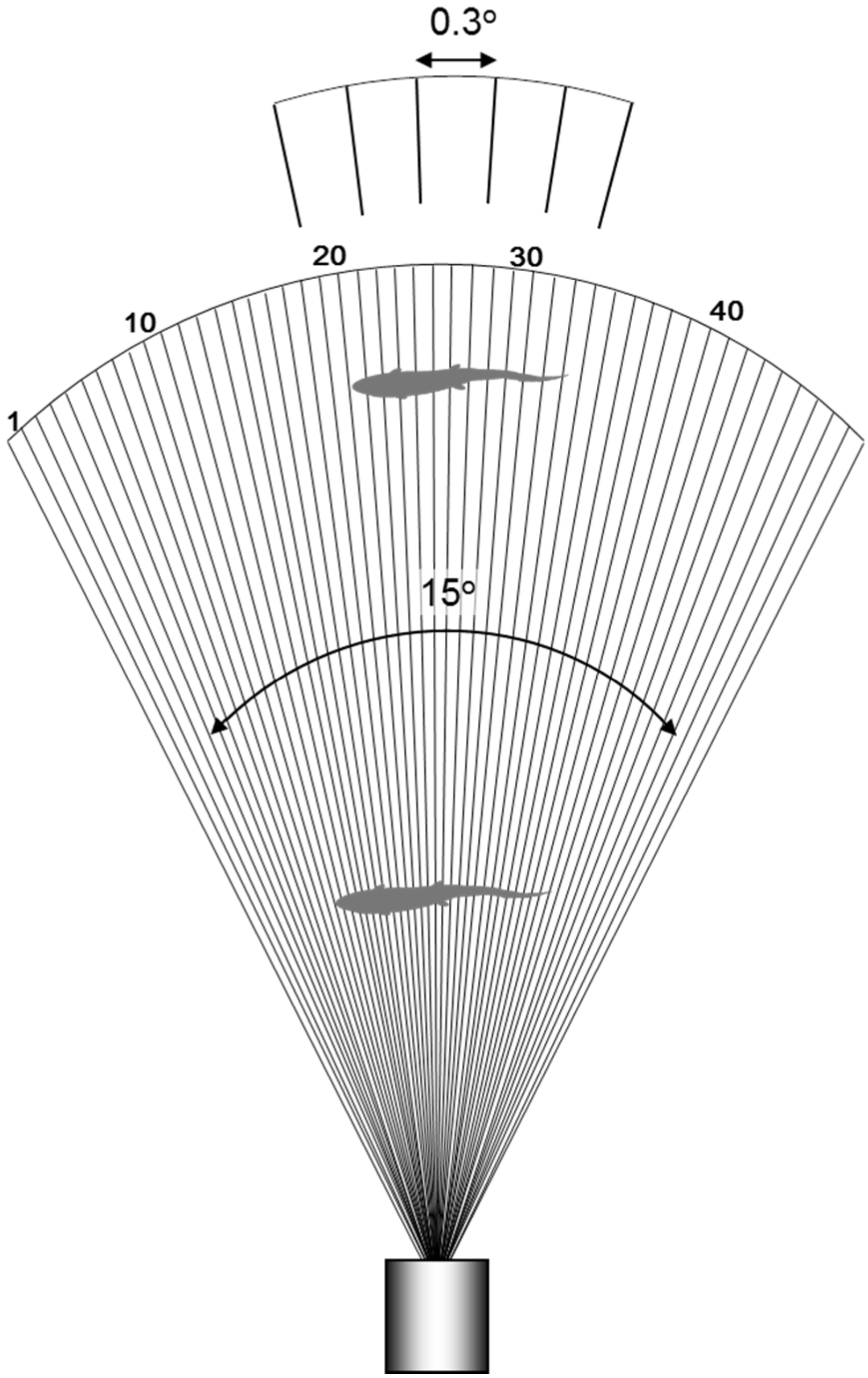
Identification Mode
Operating Frequency 1.2 MHz
Beamwidth (2-way) 0.5° H by 14° V
Source Level (average) ~206 dB re 1 µPa at 1 m
Number of Beams 48
Beam Spacing 0.3° nominal
Extended Range Settings
(Extended) Window Start 0.42 m to 26.1 m in 0.42 m steps
(Extended) Window Length 2.5 m, 5 m, 10 m, 20 m
Range Bin Size (relative to window length) 5 mm, 10 mm, 20 mm, 40 mm
Pulse Length (relative to window length) 7 µs, 13 µs, 27 µs, 54 µs

-continued-

DIDSON LR Specifications (continued)

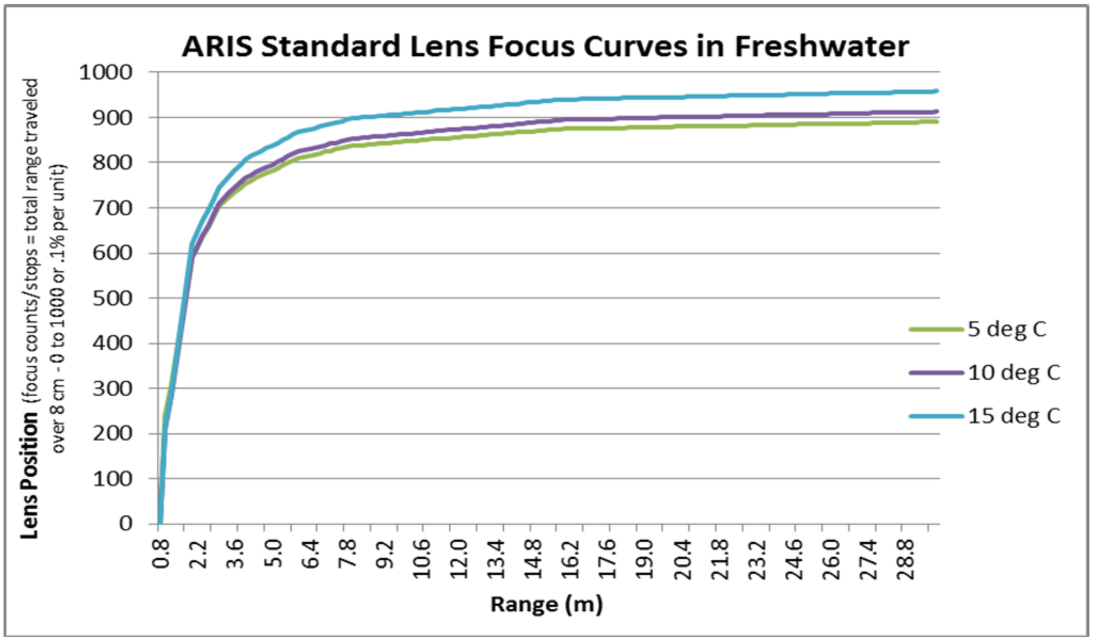
Both Modes

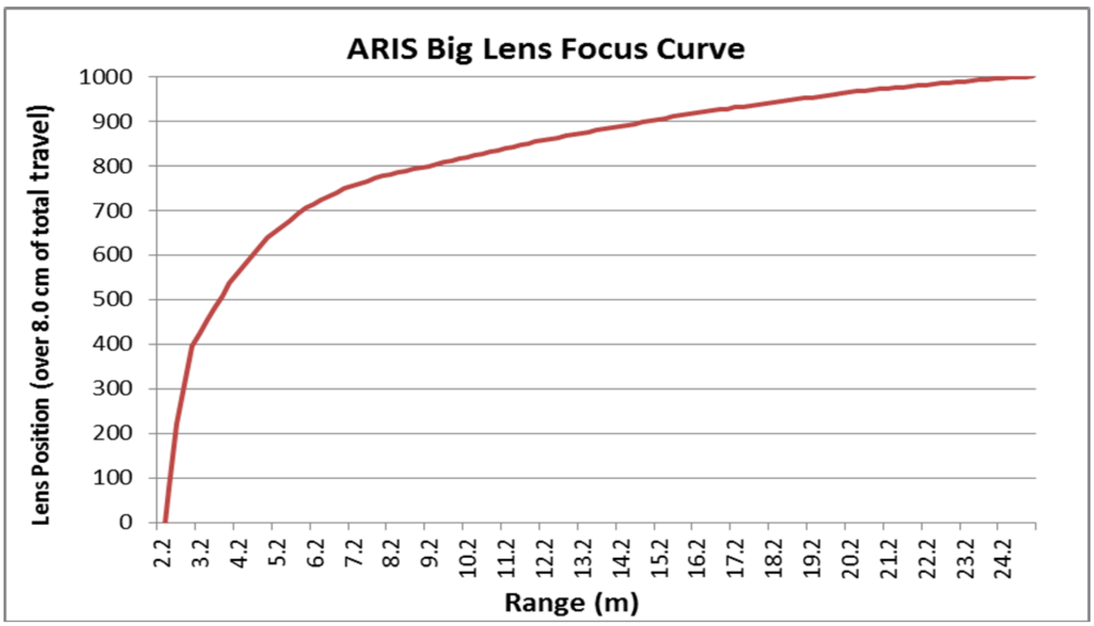
Max Frame Rate (range dependent) 2–21 frames/s
Field-of-view 29°
Remote Focus 1 m to Infinity
Control & Data Interface UDP Ethernet
Aux Display NTSC Video
Max cable length (100/10BaseT) 61 m/152 m (200 ft/500 ft)
Max cable length (twisted pair, Patton Extender) 1220 m (4000 ft)
Power Consumption 25 Watts typical
Weight in Air 7.9 kg (17.4 lb)
Weight in Sea Water 1.0 kg (2.2 lb)
Dimensions 31.0 cm × 20.6 cm × 17.1 cm
Topside PC Requirements Windows (XP, Vista, 7), Ethernet
Optional NTSC video monitor



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

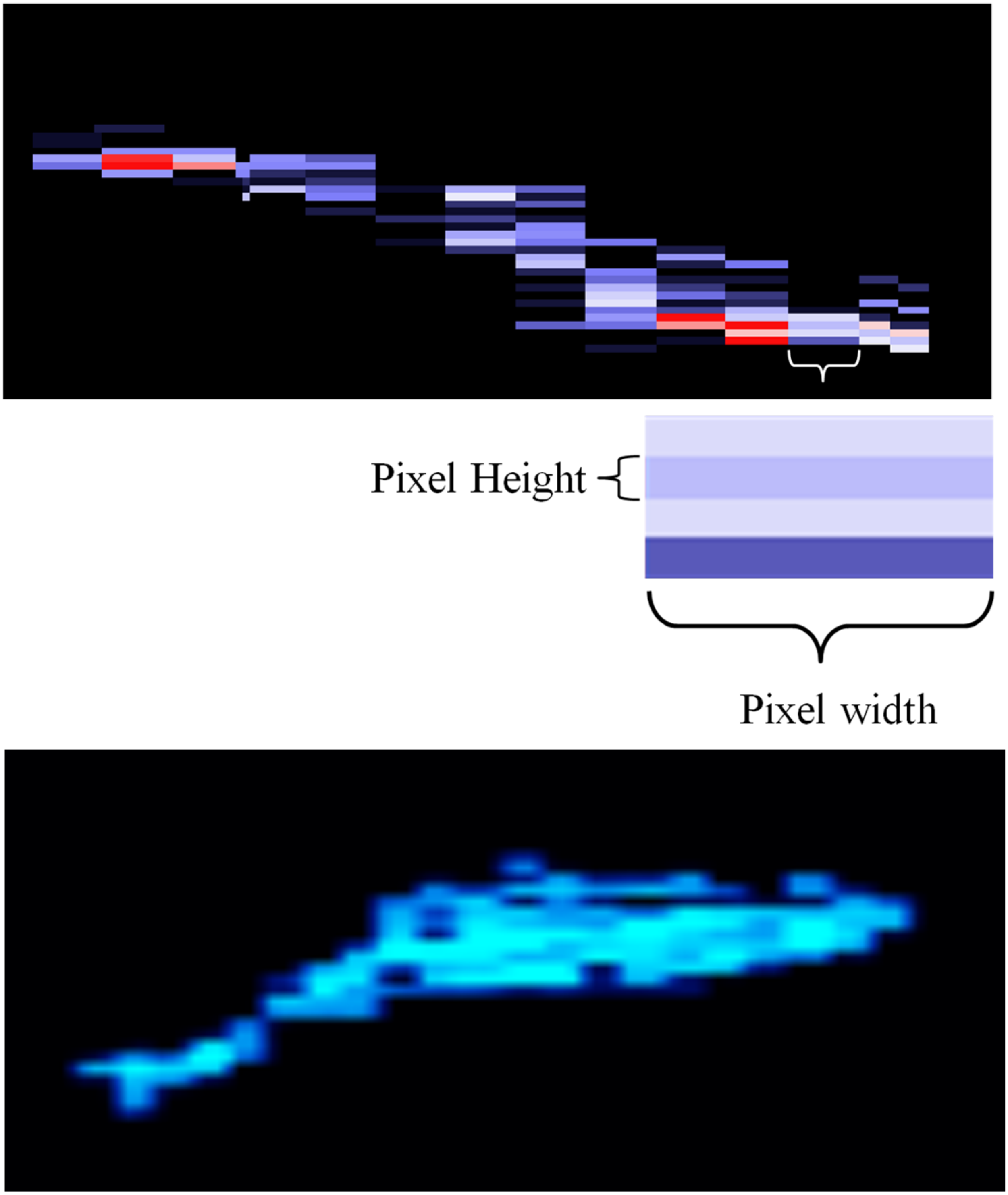
Note: The overall horizontal beam width of 15° is composed of 48 sub-beams with approximately 0.3° beam widths. Because sub-beams grow wider with range, fish at close range are better resolved than fish at far range (adapted from Burwen et al. [2007]).



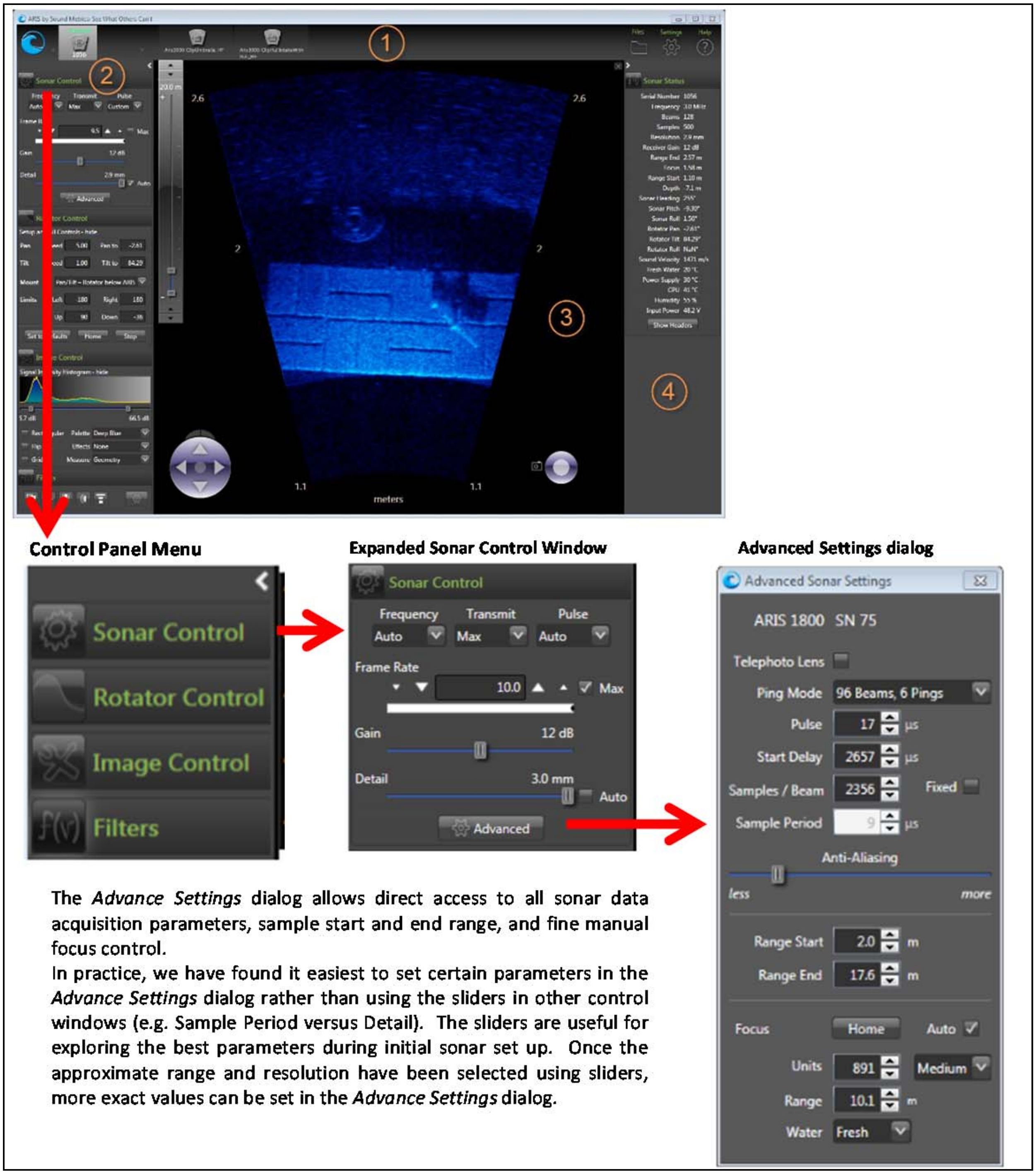


Appendix A5.–Relationships between focal length and lens position for ARIS standard lens (top) and high resolution lens (bottom).

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



Appendix A6.–An enlargement of a tethered Chinook salmon showing the individual pixels that compose a DIDSON image (top) contrasted with 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.

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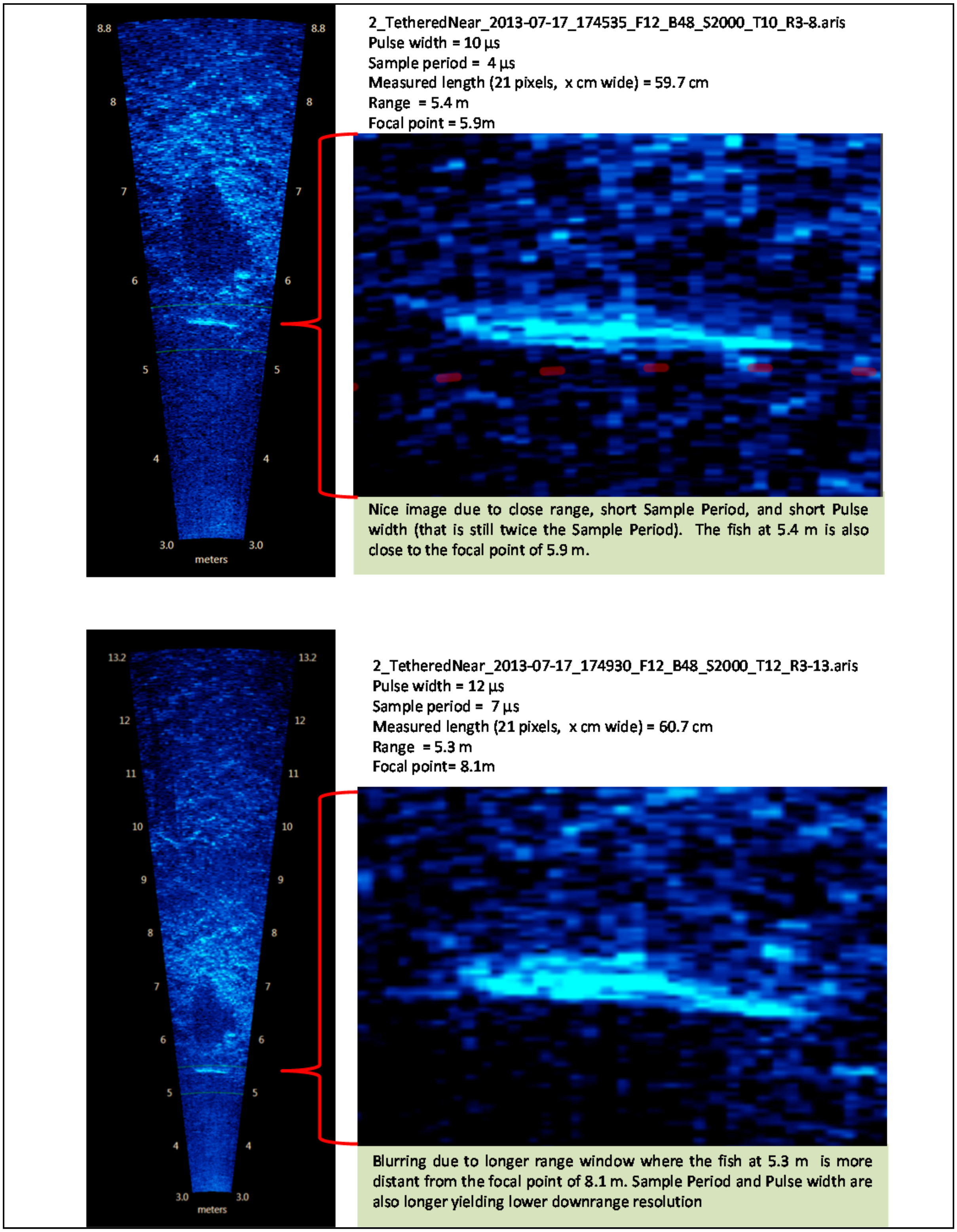
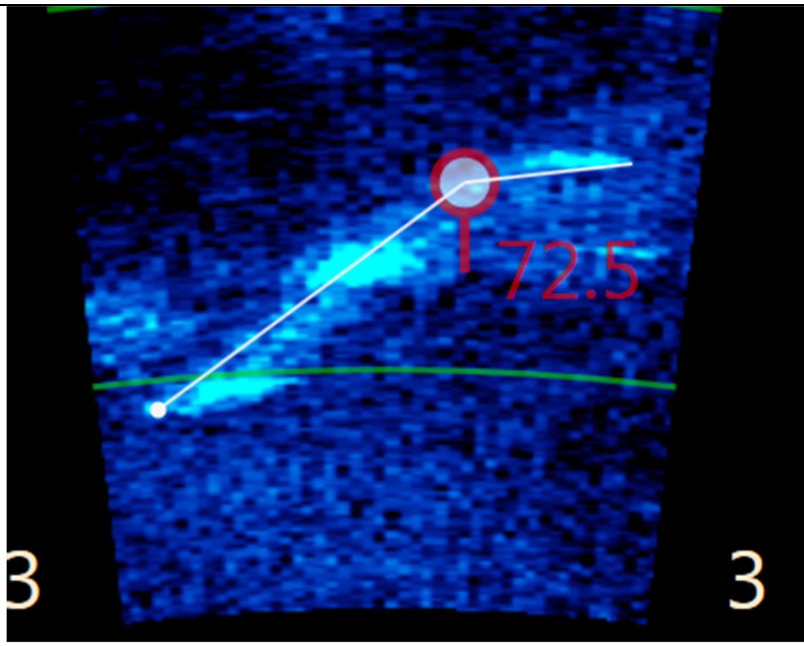
Parameter	Description
Sample Period (µs)	The <**Sample Period**> parameter sets the image data sample period within a beam in microseconds. Shorter values provide higher downrange resolution at the expense of larger frame sizes and potentially restricted frame rates. <**Sample Period**> can be set with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

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

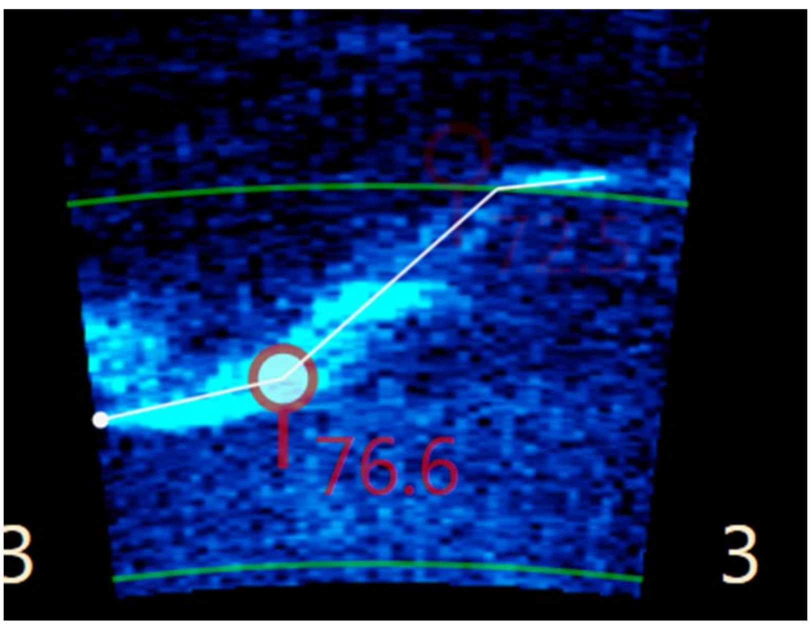


Appendix A9.–Images from a close-range tethered fish at 2 different range windows demonstrate the advantage of a shorter range window and higher sample period for close-range sampling.

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

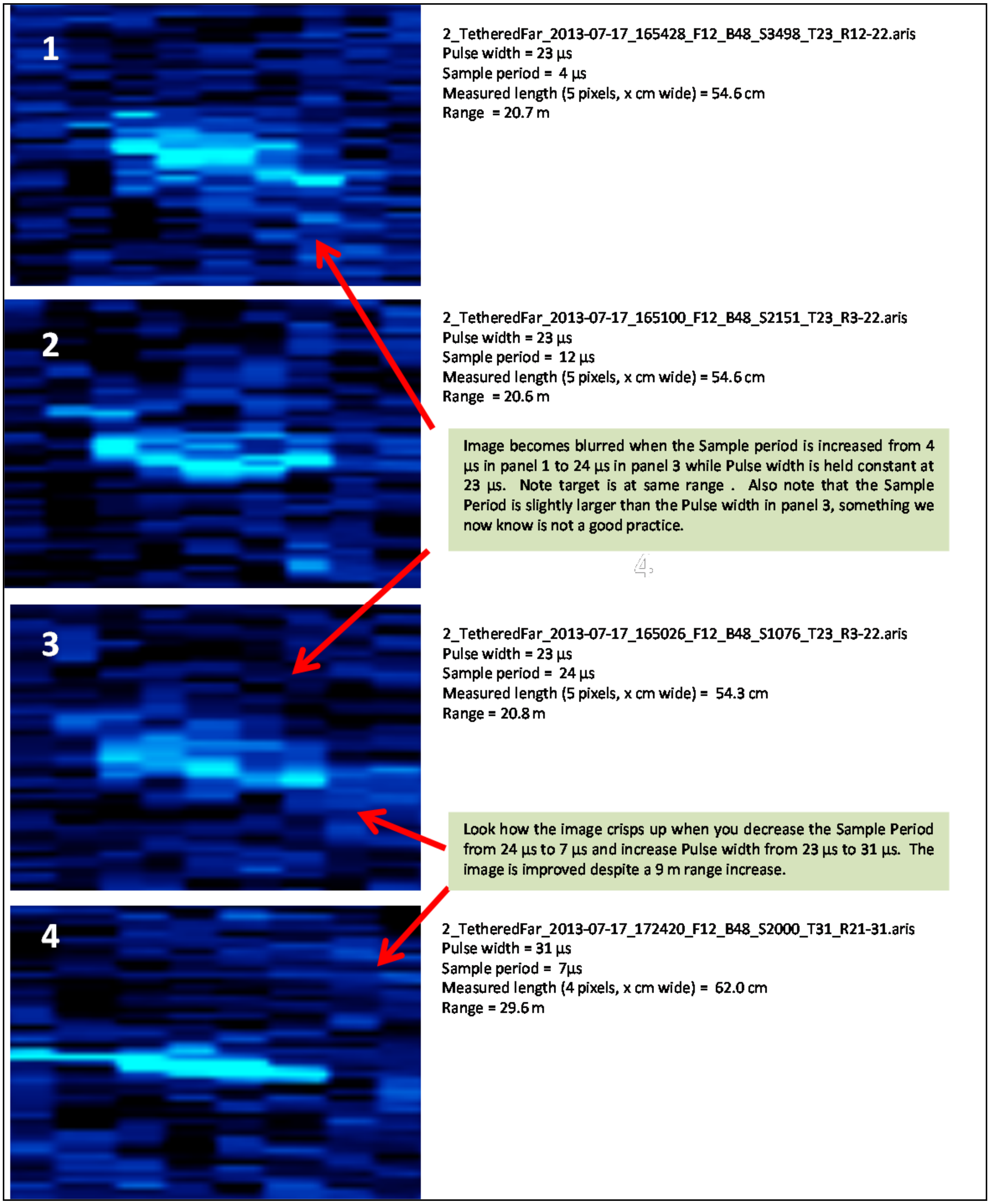


3_TetheredNear_2013-07-17_182746_F12_B48_S1724_T08_R3-8.aris
Fish Range: 3.35 m
Frame 2498
Fish size 72.5 cm



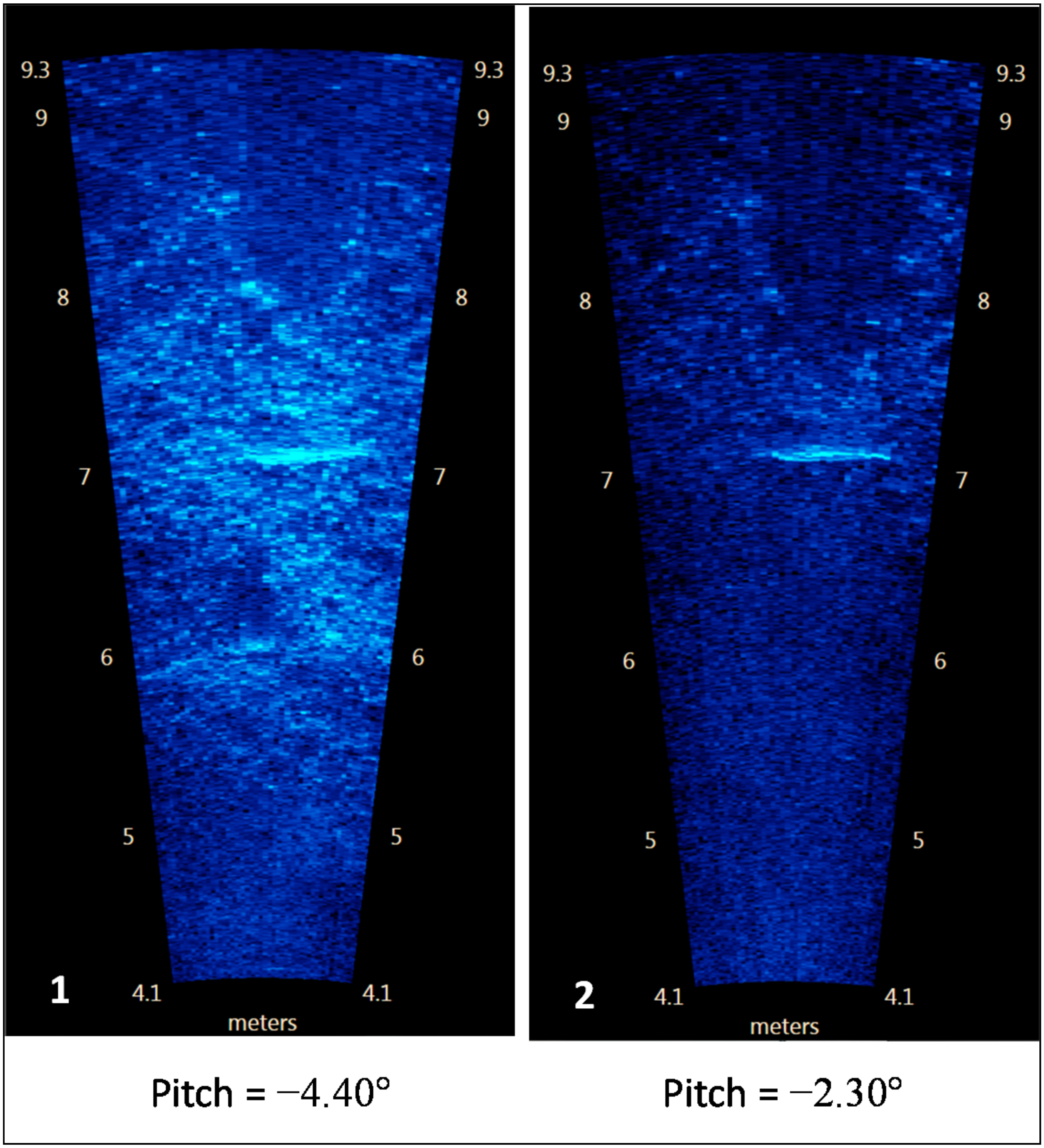
3_TetheredNear_2013-07-17_182746_F12_B48_S1724_T08_R3-8.aris
Fish Range: 3.17 m
Frame 1896
Fish size 76.6 cm

Appendix 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.



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

Note: This is a 60 cm sockeye salmon.



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

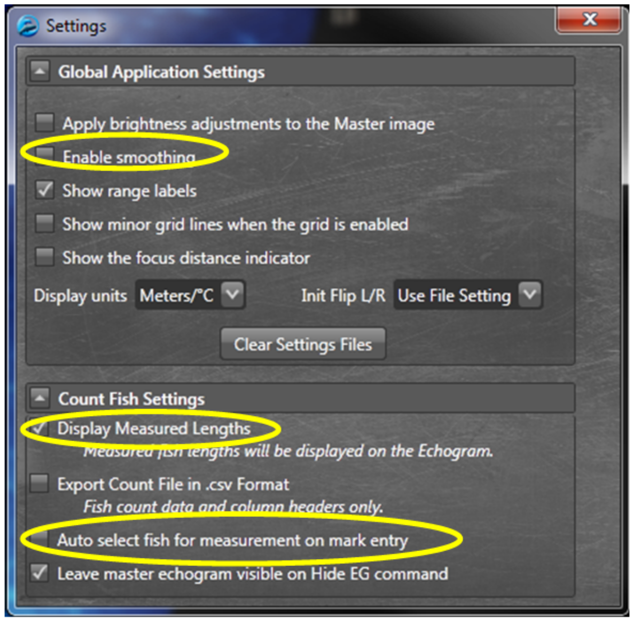
Note: Aiming the sonar farther into the bottom than required to cover the near-bottom region can cause unnecessary loss of vertical beam width and water column coverage and degrade the fish image.

APPENDIX B: INSTRUCTIONS AND SETTINGS FOR MANUAL FISH LENGTH MEASUREMENTS

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

Set Global Settings after a new installation of ARISFish

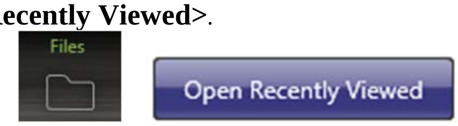
1. Open the ARISFish **<Global Application Settings>** menu (using the **<Settings>** cog in the upper right hand corner) and use the following settings:



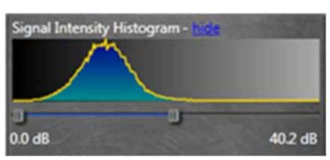
2. **<Enable smoothing>** is off.
3. **<Display Measured Lengths>** is on.
4. **<Auto select fish for measurement ….>** can be either on or off, as desired.

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

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



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



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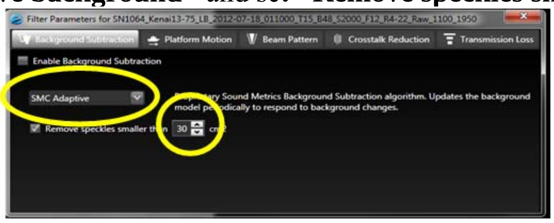
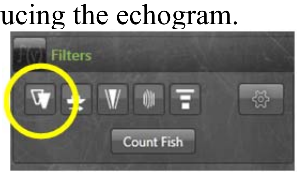
4. Select the **<Settings>** cog from the **<Filters**> menu.

5. Select **<SMC adaptive background>** and set **<Remove speckles smaller than>** to 30 cm^2.

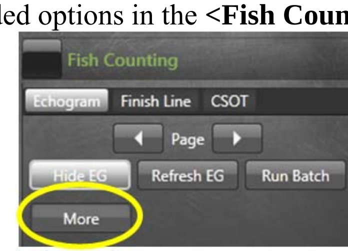


6. Select the **<Background Subtraction>** icon on the **<Filters>** menu (toggle); this will enable background subtraction for producing the echogram.



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.



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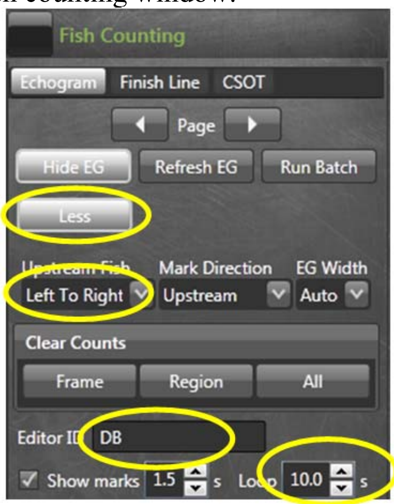
9. *Increase **<Loop>** length to at least 8 seconds.
   *Enter initials for **<Editor ID>.**
   *set **<Mark Direction>** “upstream” and **<Upstream Fish>** direction parameter (usually “left to right” for left bank sonar files and “right to left” for right bank sonar files).
   *Select **<Less>** to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

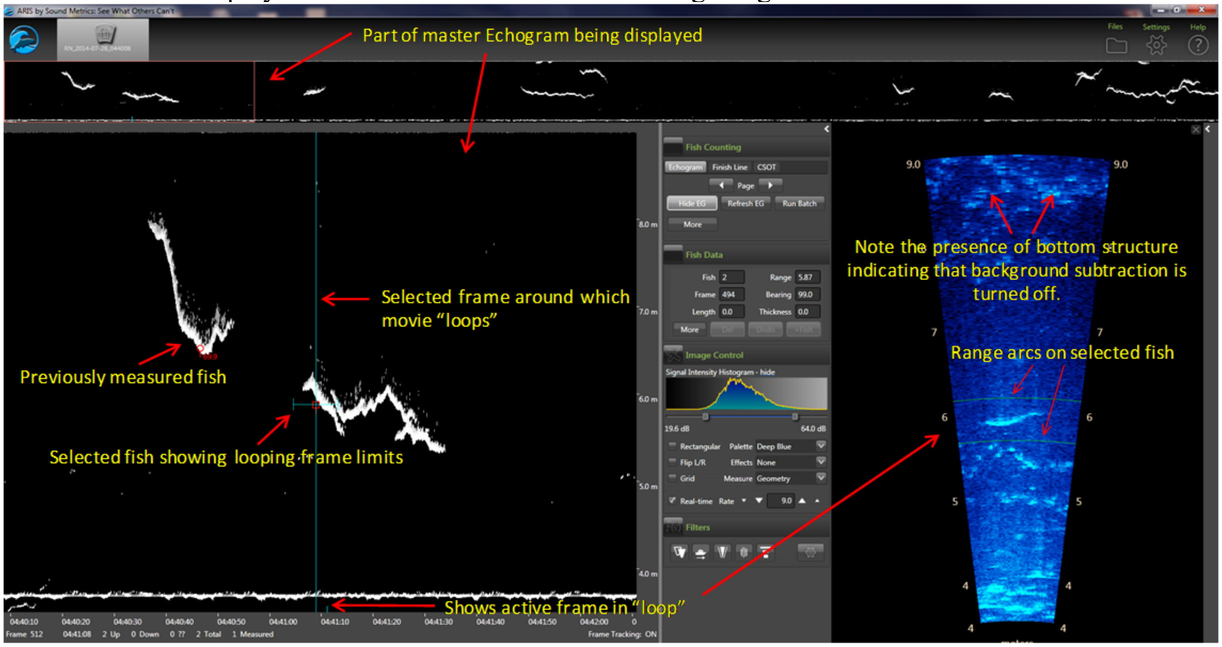


Now select the **<Background Subtraction>** icon on the **<Filters>** menu (toggle) to turn the background subtraction “off” on the video image. Failing to turn background subtraction off prior to measuring the fish image length may result in an underestimate of actual fish length [18].

-continued-

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

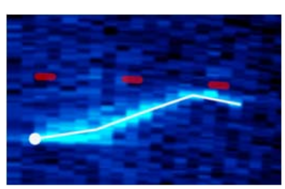
10. The overall display should look similar to the following image:



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

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

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



-continued-

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

Hot keys

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

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

<u> to "undo" the last segment

<d> to "delete" 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

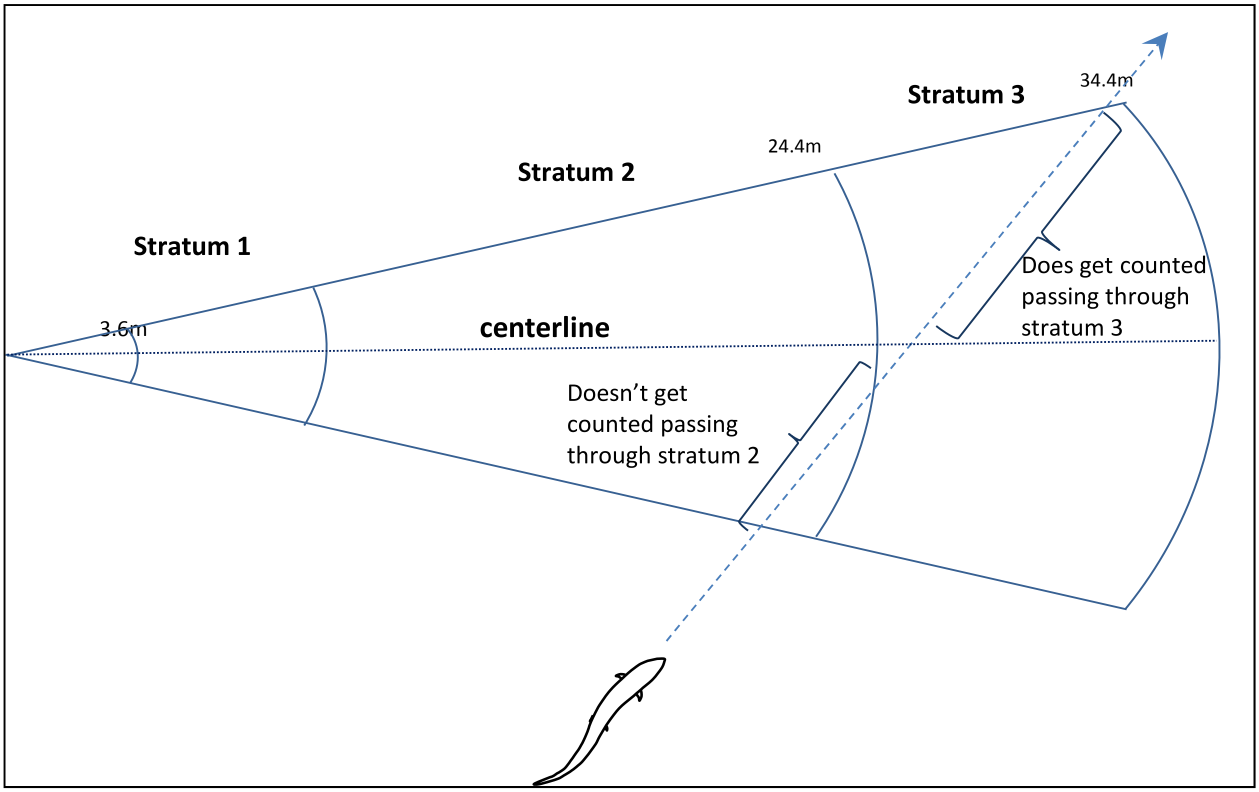
In order to optimize the aim of the sonar beams relative to the river bottom, the insonified zone is often divided into individual range strata that are sampled separately. In order to avoid overcounting fish as they cross stratum boundaries, we apply the "centerline rule" where a fish is not counted 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.

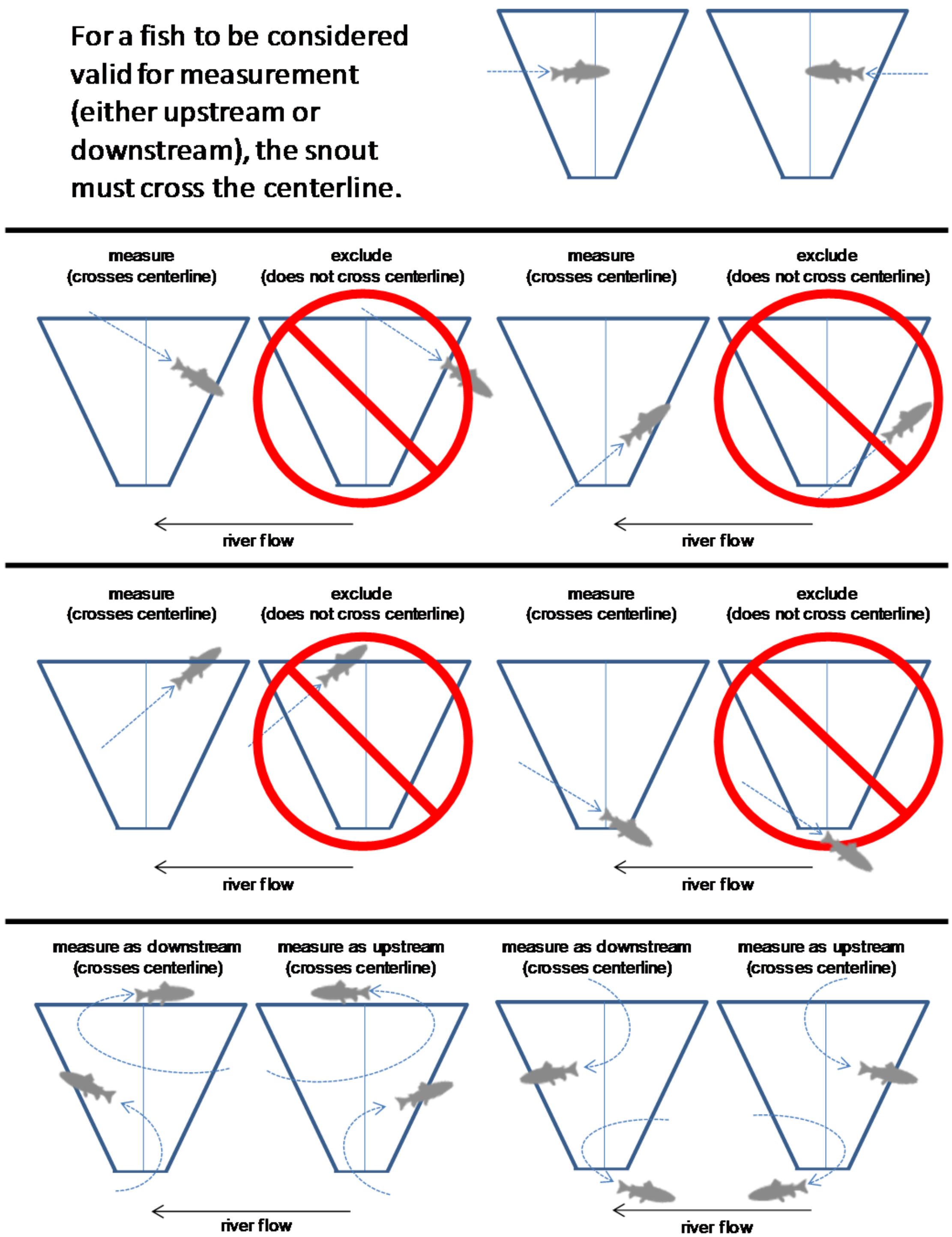
-continued-

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



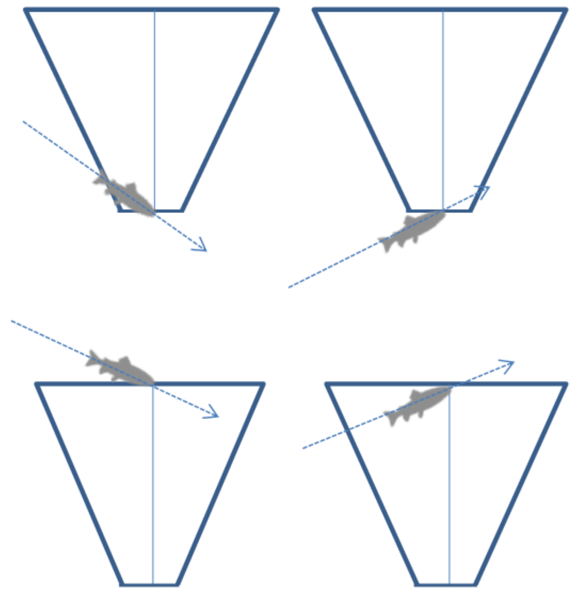
Appendix B2.–To avoid counting this fish in both Stratum 2 and Stratum 3, the fish will only be counted in Stratum 3 where it crosses the centerline of the beam.

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

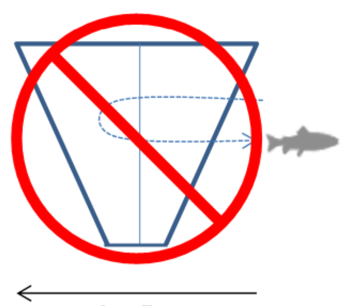


-continued-

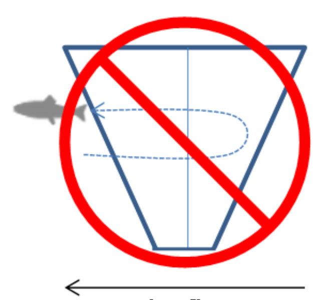
If the snout of the fish enters the near- or far-range boundary right on the centerline, the fish should be considered valid for measurement.



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

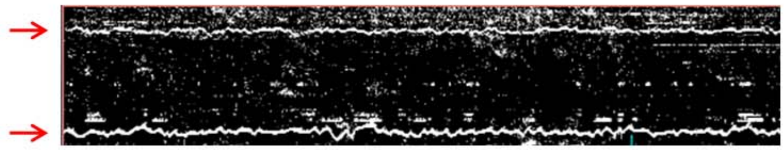


Exclude fish that enter the beam from downstream, then exit the beam downstream (do not measure even if they cross the centerline).



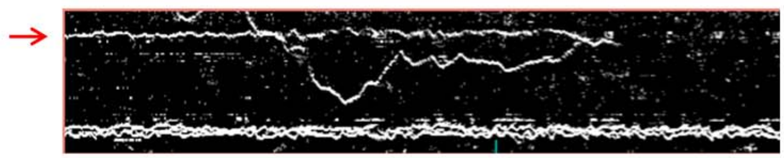
-continued-

Exclude fish that hold throughout the length of the sample.

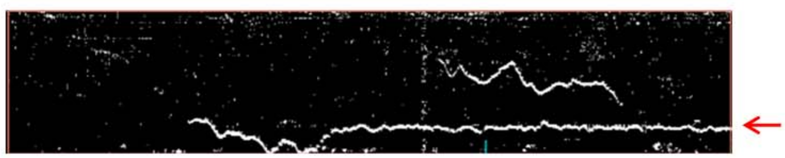


Two fish hold throughout the entire file.
Exclude both fish.

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



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

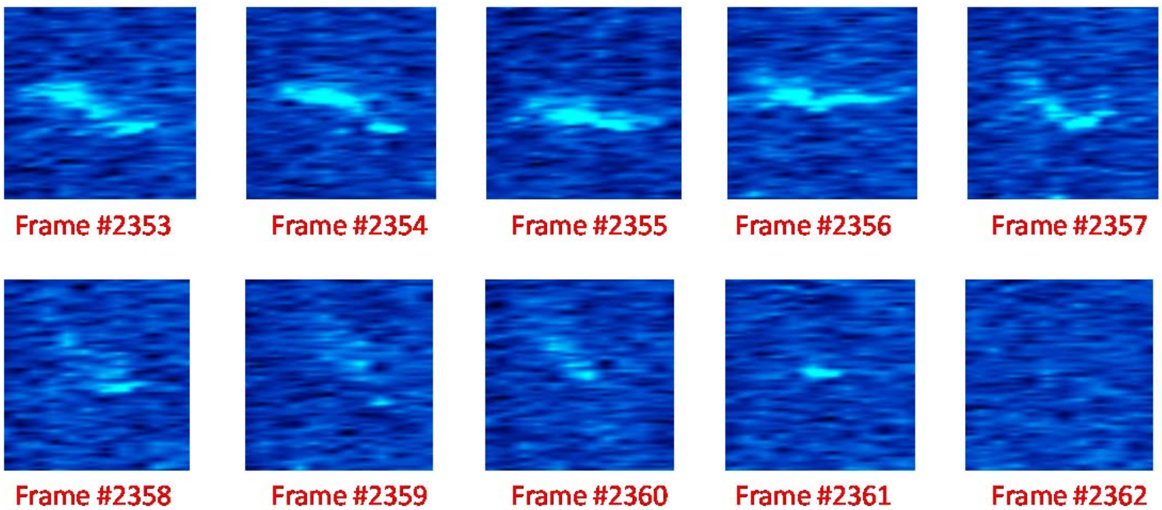


Fish enters the beam mid sample, then holds through the end of the sample. Exclude this fish

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

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

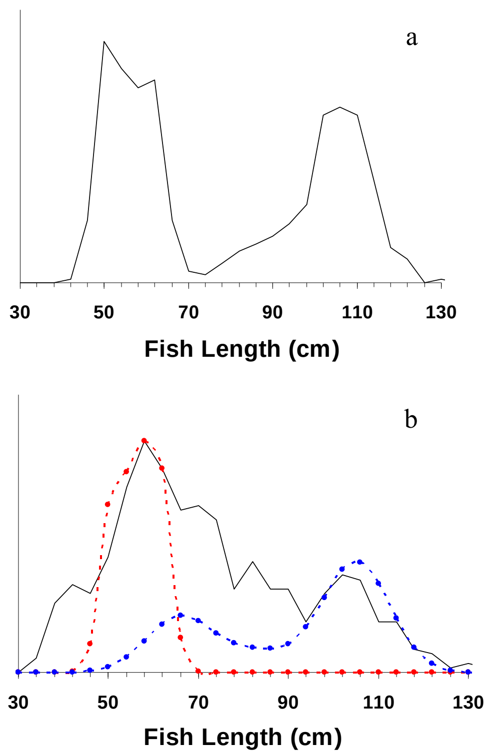
A fish passing through the beam that turns perpendicular to the axis and disappears should be excluded unless there is other evidence to indicate direction of travel.



APPENDIX C: ARIS LENGTH MIXTURE MODEL AND ASSOCIATED BUGS 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:

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

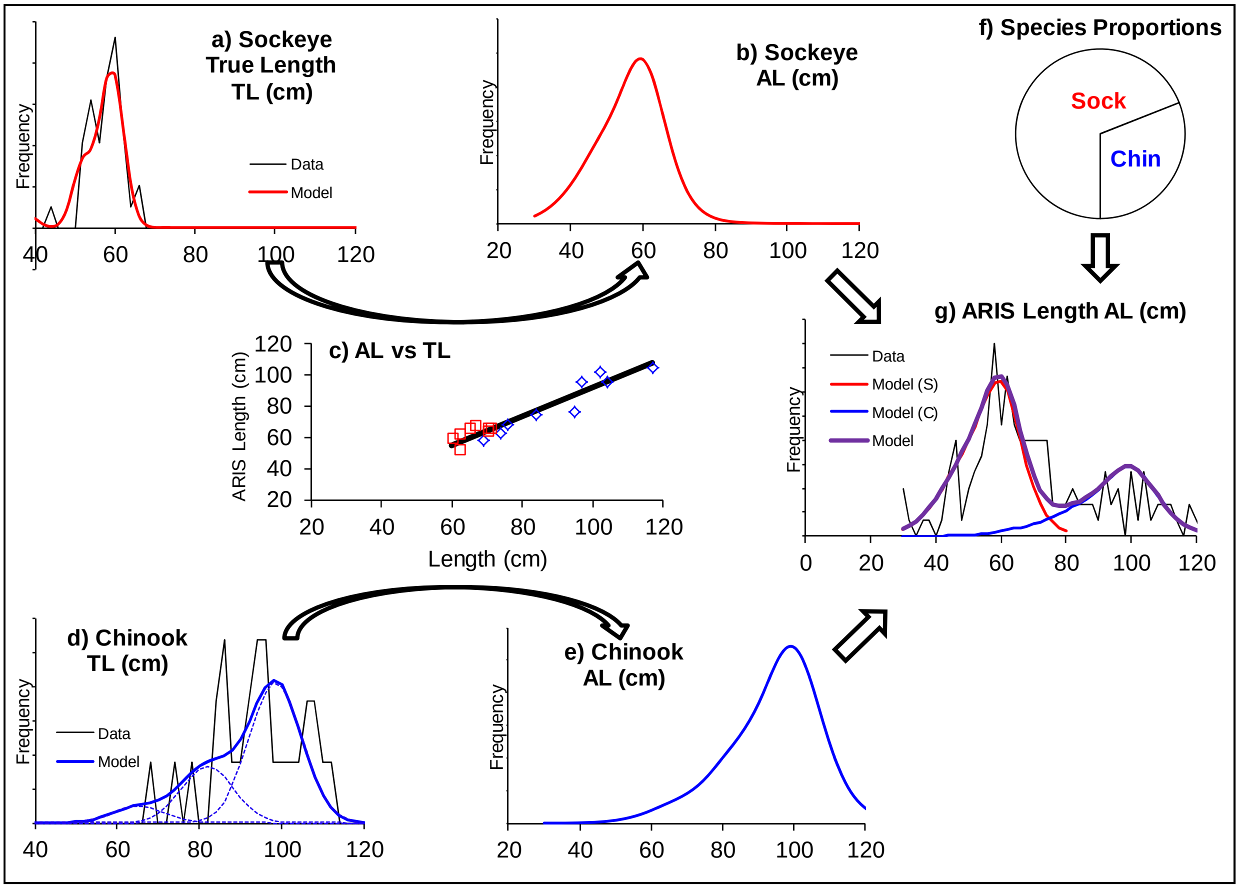
$$f_C(x) = \theta_{C1} f_{C1}(x) + \theta_{C2} f_{C2}(x) + \theta_{C3} f_{C3}(x) \tag{C4}$$

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.

Bayesian statistical methods 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 (Gelman et al. 2004). Species proportions π_S and π_C (Equation C1) were assigned an uninformative Dirichlet(0.1,0.9) prior. Informative normal priors based on historical data were used for the length-at-age means μ and standard deviations τ (Appendix C6). A linear statistical model of tethered fish data (Burwen et al. 2003) was integrated into the mixture model (Appendix C5) to provide information on regression parameters β_0, β_1, and σ^2.

The end product of a Bayesian analysis is the joint posterior probability distribution of all unknowns in the model. For point estimates, posterior means were used. Posterior standard deviations were reported as analogues to the standard error of an estimate from a classical (non-Bayesian) statistical analysis.

Mixture model results were more robust to length measurement error if only a minimal number of tethered fish data points were used, so a subset of tethered fish data from 2007 DIDSON experiments (Burwen et al. 2010) provided a mildly informative prior for the β_0 and β_1 parameters (Equation C2). Species proportions π_C and π_S were assigned a Dirichlet(0.1,0.9) prior. Prior distributions for age proportions $\{\theta_{Ca}\}$ and $\{\theta_{Sa}\}$ were constructed with 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.

WinBUGS uses Markov chain Monte Carlo methods to sample from the joint posterior distribution of all unknown quantities in the model. A single Markov chain[19] 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.

See Fleischman and Burwen (2003) for an application of these methods to split-beam sonar data. Some of the methodological details used to produce the estimates in this report differ from those used to produce preliminary estimates during the fishing season. These modifications are summarized in Appendix C6.

[19] 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.

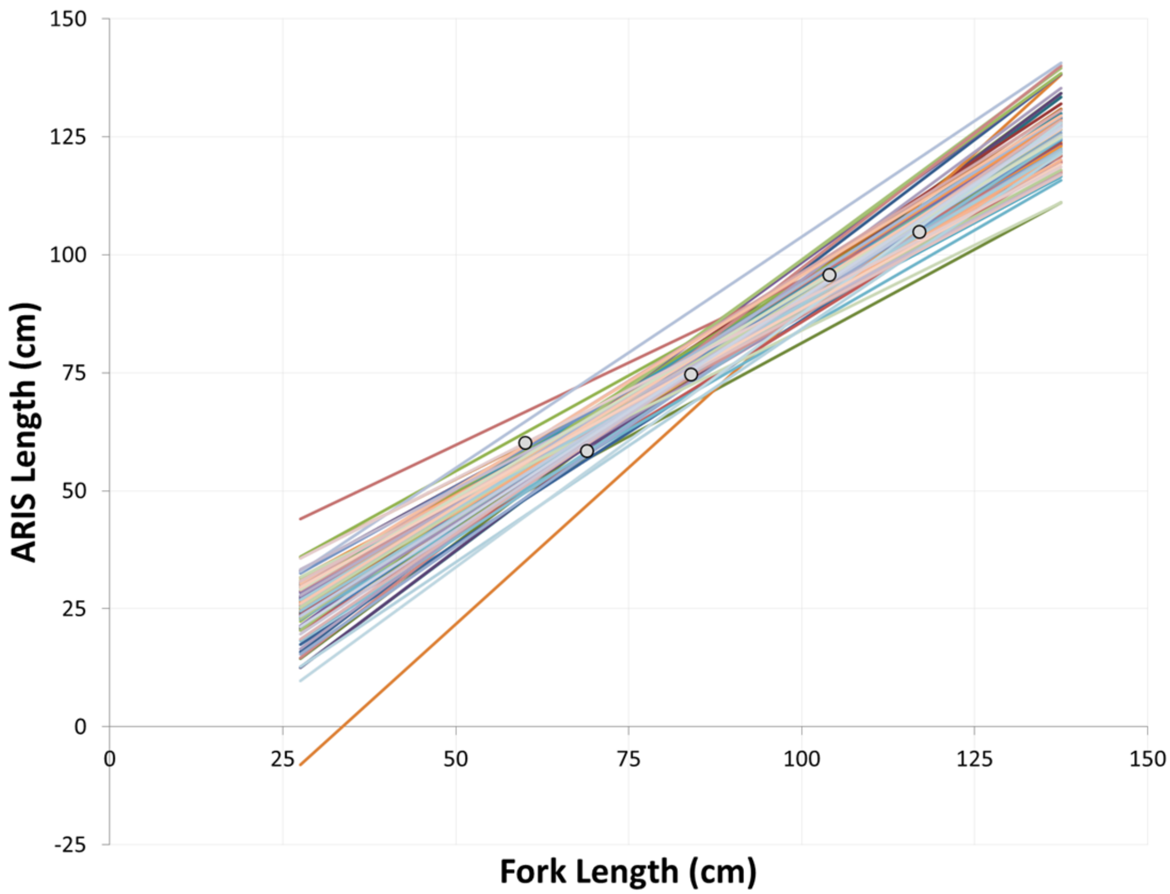
Appendix C4.–WinBUGS code for ARIS length mixture model.

```
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.–Differences in methodology between inseason and final DLMM–ALMM (DIDSON–ARIS-length mixture model) estimates.

A summary of the methodology particular to inseason estimates and the final passage estimate is provided in the following table:

	Inseason	Final	
Modification	DIDSON RM 8.6 and ARIS RM 13.7	DIDSON RM 8.6[a]	ARIS RM 13.7[b]
Age composition prior	informative[c]	noninformative[d]	noninformative[d]
Species composition prior	Dirichlet(0.5,0.5)	Dirichlet(0.1,0.9)	Dirichlet(0.1,0.9)
Netting data	Midriver only	Midriver only	Midriver only (2013) Midriver and nearshore (2014)
Days of netting data pooled and paired with day *d* of sonar data	*d−6* to *d*	*d−3* to *d+3*	*d−6* to *d*
Chinook salmon size selectivity by age class	0.61, 0.57, 0.41	1, 1, 1	1, 1, 1

[a] Key et al. (2016a, 2016b)

[b] Miller et al (2016) and this report.

[c] Informative priors differed by week, as developed from a hierarchical age composition model.

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

The methods used to produce DLMM and ALMM estimates of Chinook salmon passage during the fishing season to inform inseason management differed in several respects from those used to produce the final estimates published in this and previous reports (Miller et al. 2013-2016):

1) Inseason estimates used netting data from midriver drifts only. Beginning in 2014 for the RM 13.7 site, final estimates are produced using midriver and nearshore drifts (Perschbacher and Eskelin *In prep*).
2) When abundance is low, it can be difficult to capture enough Chinook salmon in the inriver netting project to provide reliable information about Chinook salmon age proportions $\{\theta_{Ca}\}$ in "real time." Therefore, for inseason estimates, the $\{\theta_{Ca}\}$ were assigned informative Dirichlet priors based on a hierarchical analysis of historical data (Key et al. 2016b: Appendix B4). These particular priors differ by week and the information accumulated over previous seasons provides (approximately) the Chinook salmon age compositions that can be expected on a given day. Essentially, the resulting DLMM and ALMM estimates incorporate a weighted average of the historical age proportions and information from the current year's data. When netting sample sizes are small early in the season, the prior (historical) information carries relatively more weight. As netting catches increase, the current data eventually outweigh the prior information.

-continued-

3) Inseason DLMM (or ALMM) estimates also assumed that probability of capture differed by age class, based on a previous analysis of net selectivity. Probability of capture was assumed to be equal across age classes for the estimates in this report.
4) The current escapement goals for Kenai River Chinook salmon were based on a comprehensive analysis of data that included inseason ("preliminary") DLMM estimates for 2010–2012 (Fleischman and McKinley 2013: Table 4; and McKinley and Fleischman 2013: Table 5). Inseason management estimates were based on these same preliminary estimates in order to preserve comparability to the goals.

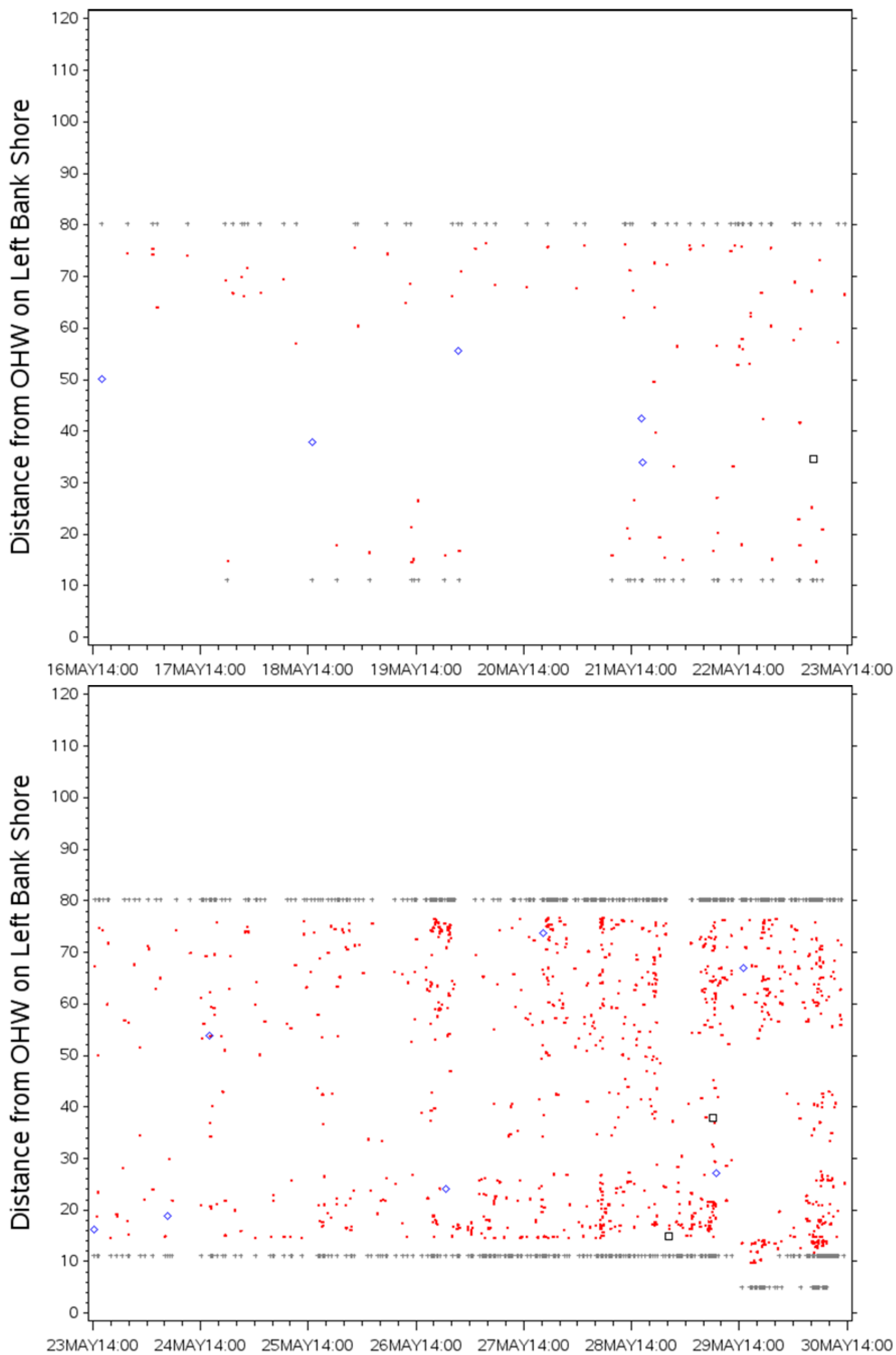
Appendix C7.–Sum of daily inseason estimates versus final postseason mixture model estimate of Kenai River Chinook salmon abundance from DIDSON at RM 8.6 and ARIS at RM 13.7 for 2010–2014.

		Early run			Late run		
Mixture model estimates	Year	Inseason	Final	Revised (%)	Inseason	Final	Revised (%)
DIDSON length RM 8.6, unexpanded							
	2010	5,376	5,874	9%	19,000	18,401	-3%
	2011	6,515	7,366	13%	21,036	23,713	13%
	2012	3,339	3,228	-3%	21,914	21,613	-1%
	2013	1,314	1,439	10%	13,290	15,185	14%
	2014	3,426	4,862	42%	13,125	13,952	6%
ARIS length RM 13.7							
	2013	2,307	2,845	23%	16,643	19,373	16%
	2014	4,211	5,768	37%	14,134	16,871	19%

[a] Inseason 2013 and 2014 ALMM numbers from memo Fleischman et al. to Vania, 9 February 2015

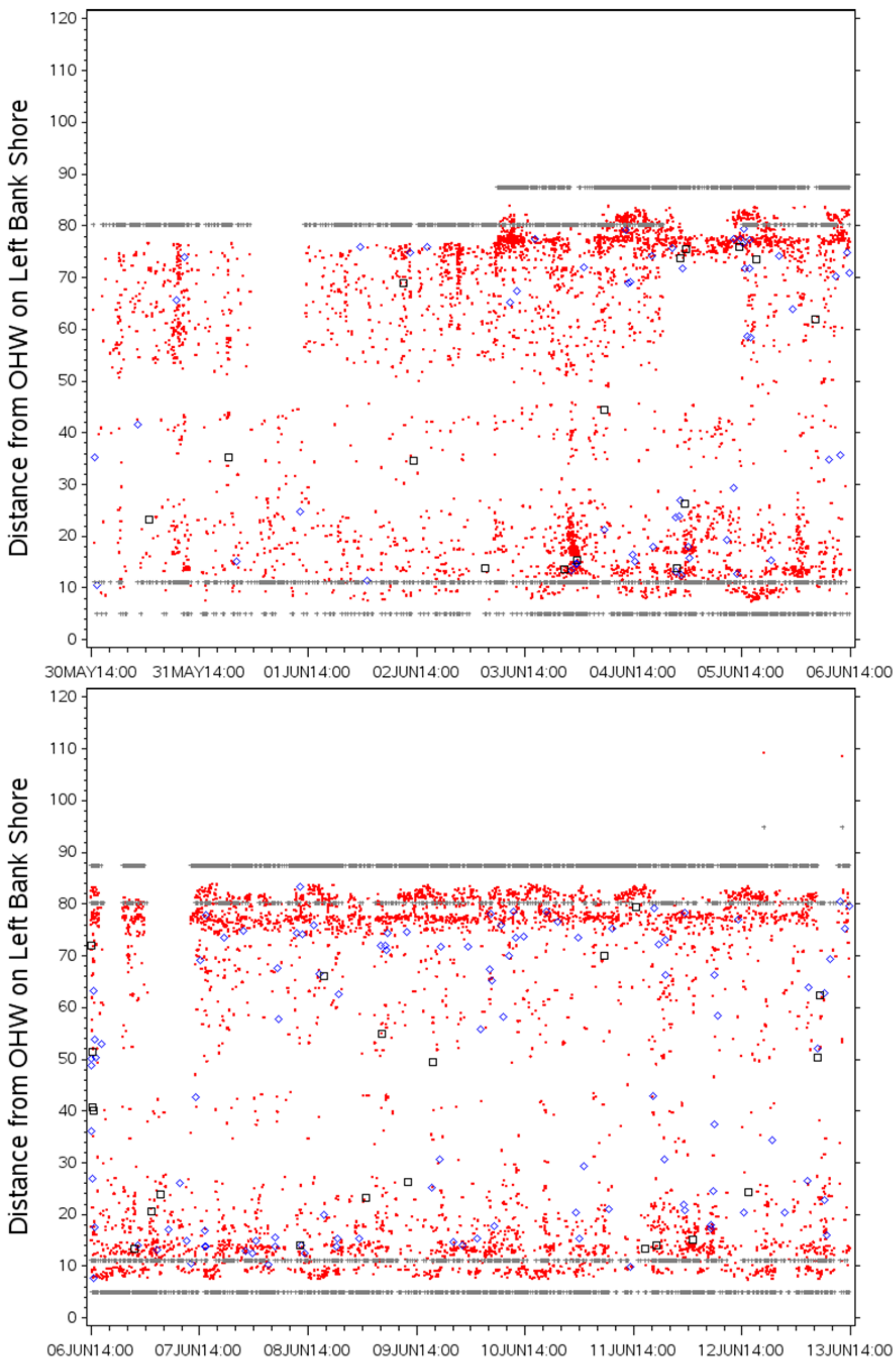
[b] Final 2013 from Miller et al. 2016; final 2014 from Tables 7 and 8.

APPENDIX D: SPATIAL AND TEMPORAL DISTRIBUTION OF FISH BY SIZE AS MEASURED BY ARIS, RM 13.7 KENAI RIVER, 2014



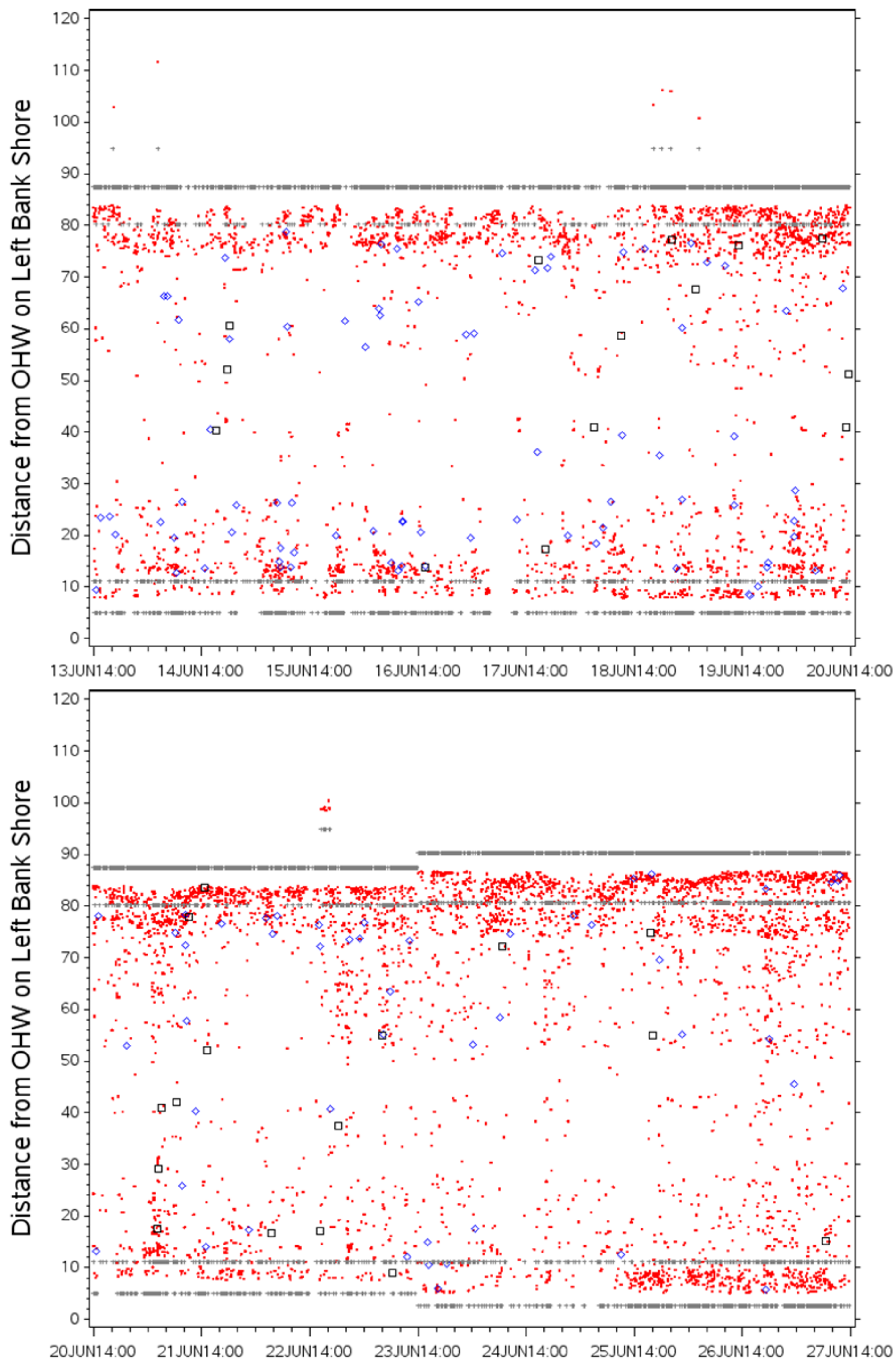
Appendix D1.–Spatial and temporal distribution of small (ARIS length [AL] < 75 cm; small red dots), medium (75 cm ≤ AL < 90 cm; larger blue diamonds), and large fish (AL ≥ 90 cm; large black squares), RM 13.7 Kenai River, 16–29 May 2014.

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.



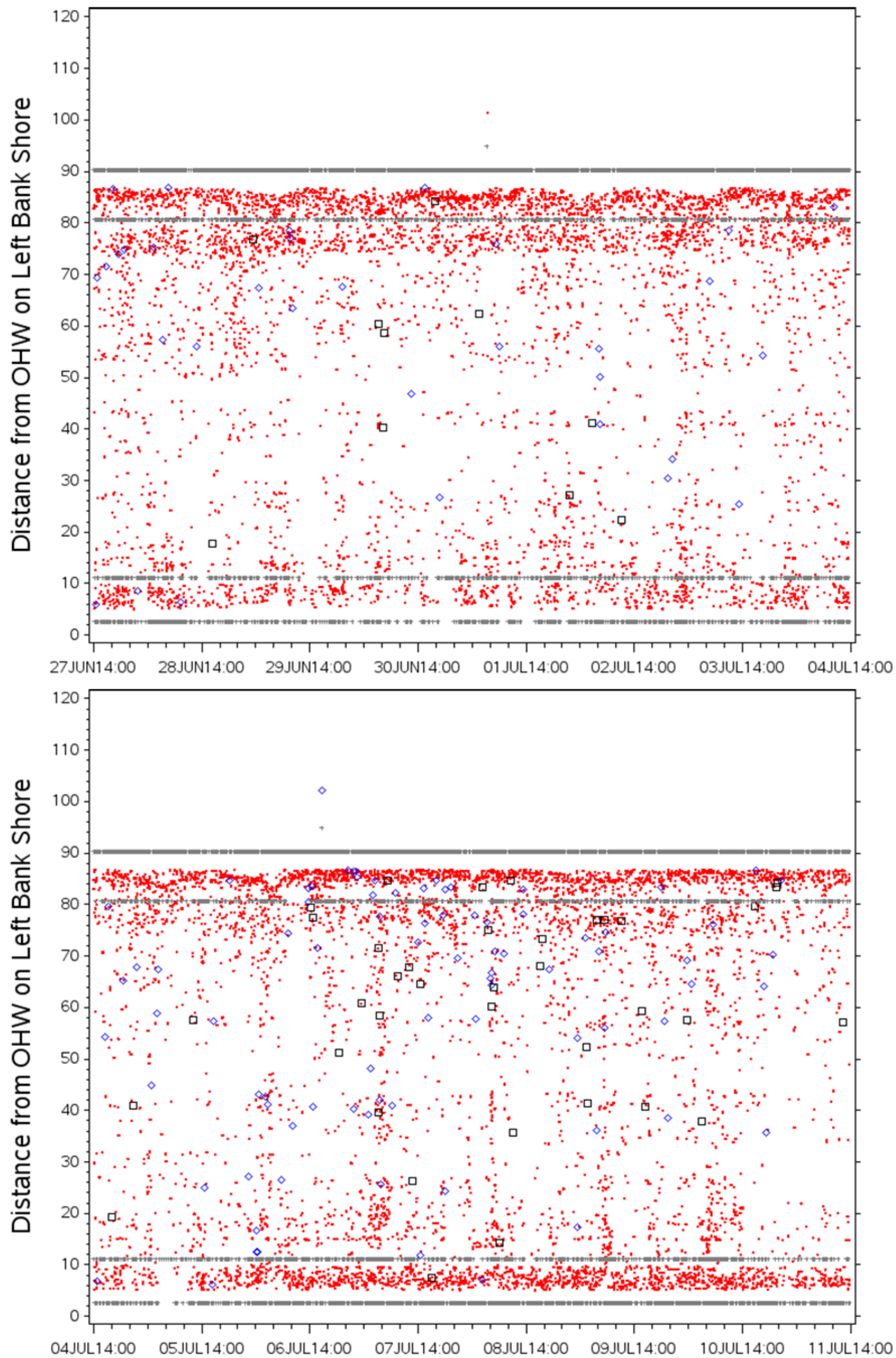
Appendix D2.–Spatial and temporal distribution of small (ARIS length [AL] < 75 cm; small red dots), medium (75 cm ≤ AL < 90 cm; larger blue diamonds), and large fish (AL ≥ 90 cm; large black squares), RM 13.7 Kenai River, 30 May–12 June 2014.

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.



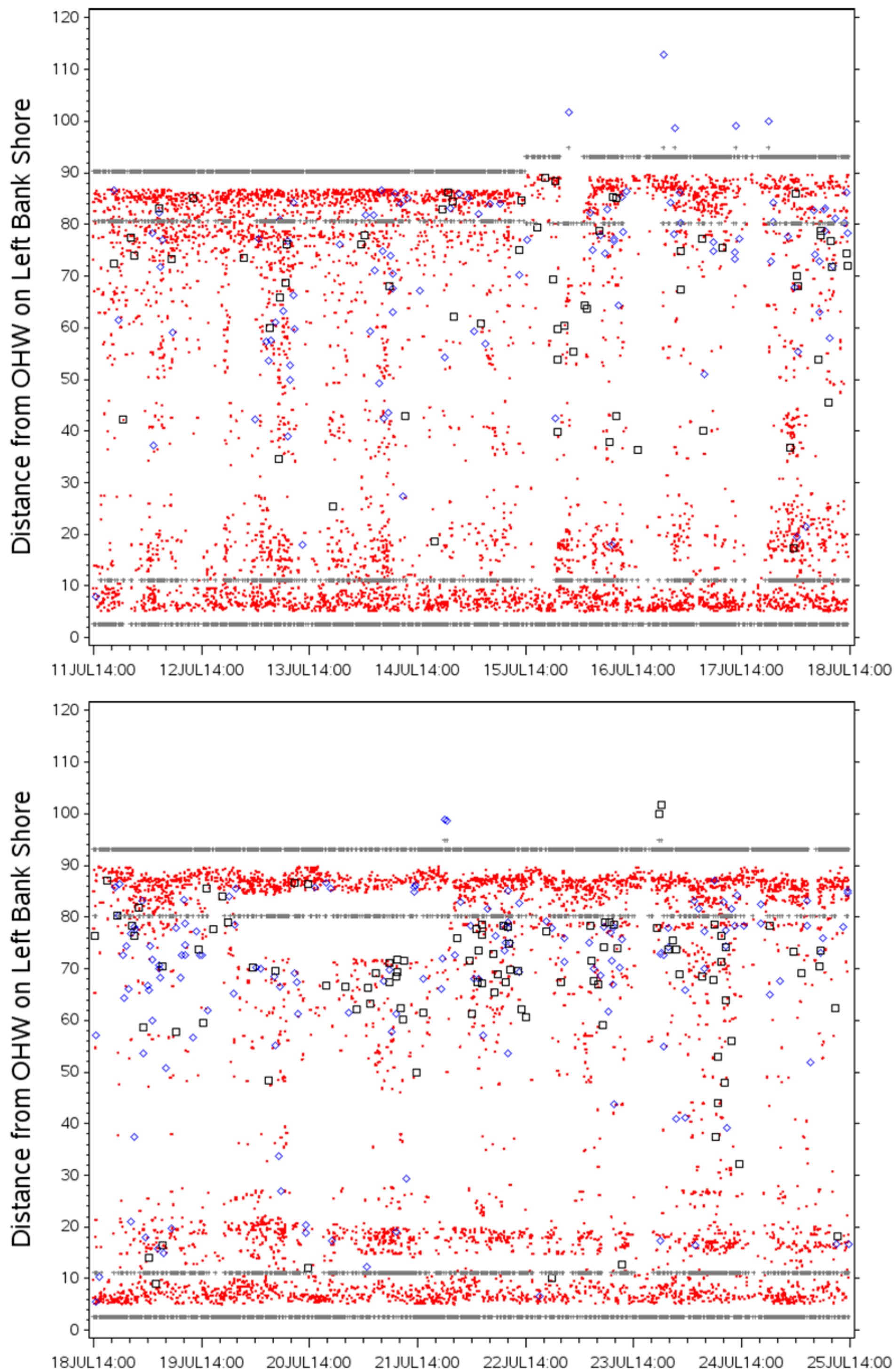
Appendix D3.–Spatial and temporal distribution of small (ARIS length [AL] < 75 cm; small red dots), medium (75 cm ≤ AL < 90 cm; larger blue triangles), and large fish (AL ≥ 90 cm; large black squares), RM 13.7 Kenai River, 13–26 June 2014.

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.



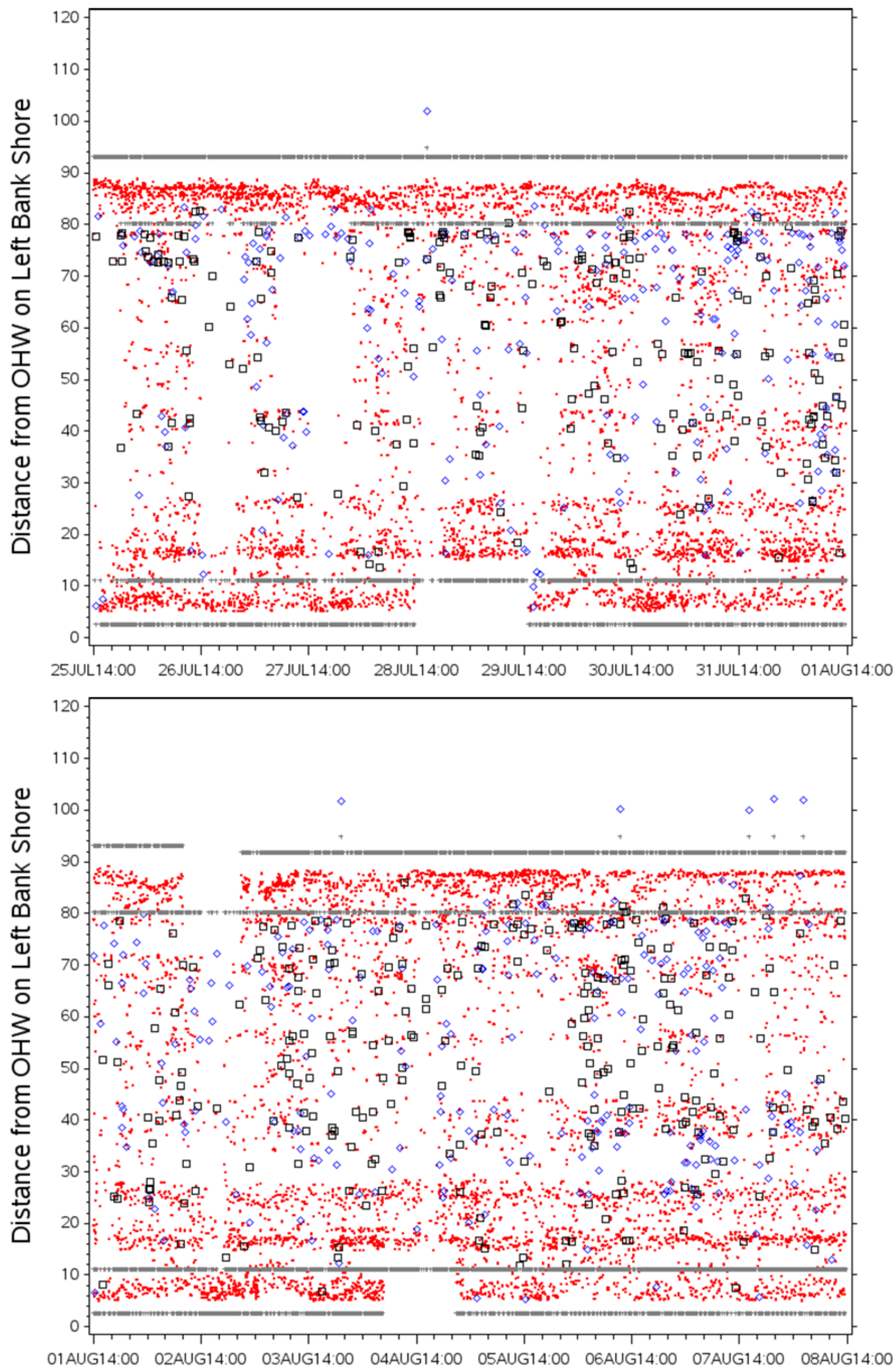
Appendix D4.–Spatial and temporal distribution of small (ARIS length [AL] < 75 cm; small red dots), medium (75 cm ≤ AL < 90 cm; larger blue diamonds), and large fish (AL ≥ 90 cm; large black squares), RM 13.7 Kenai River, 27 June–10 July 2014.

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.



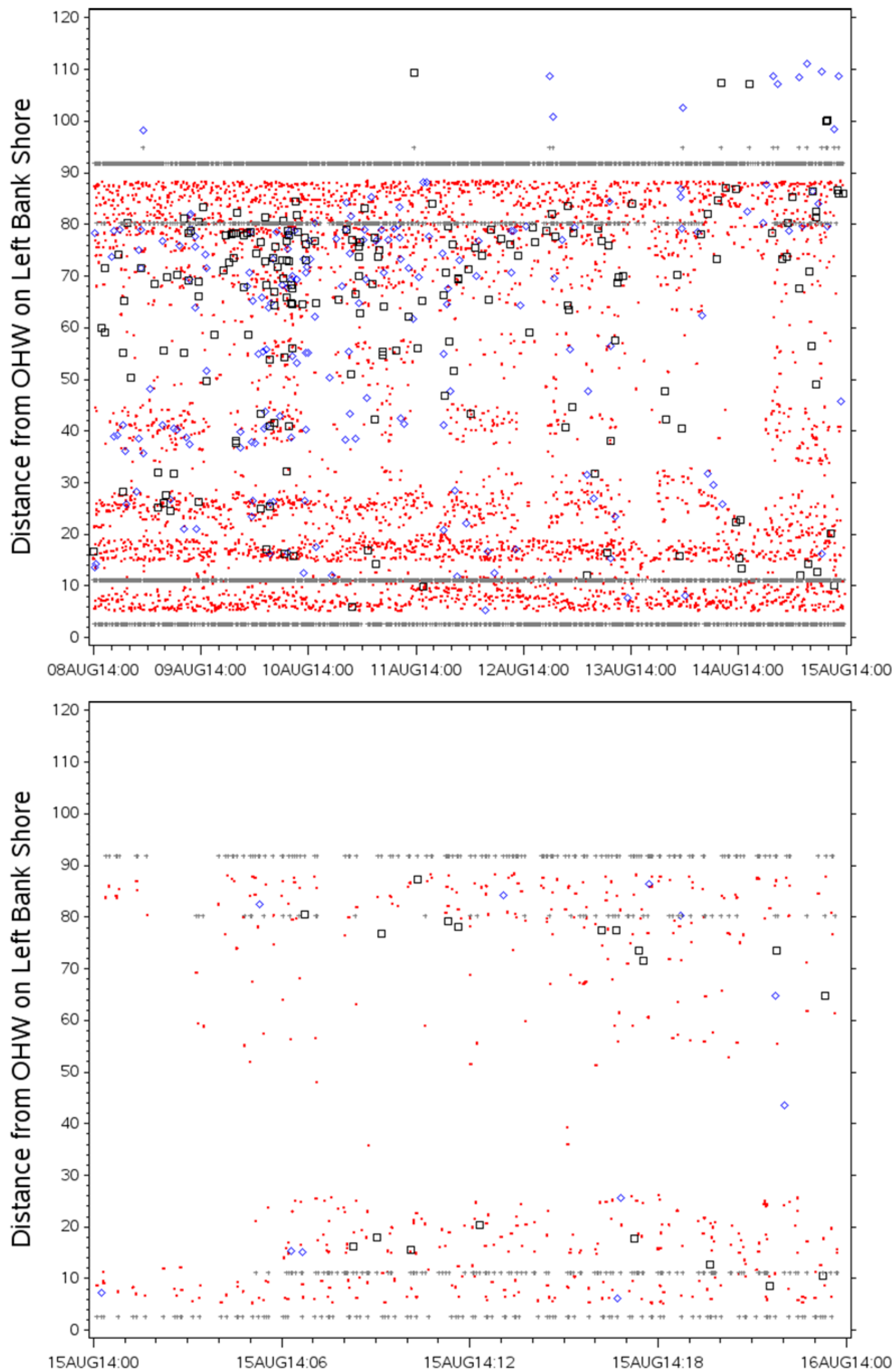
Appendix D5.–Spatial and temporal distribution of small (ARIS length [AL] < 75 cm; small red dots), medium (75 cm ≤ AL < 90 cm; larger blue diamonds), and large fish (AL ≥ 90 cm; large black squares), RM 13.7 Kenai River, 11–24 July 2014.

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 D6.–Spatial and temporal distribution of small (ARIS length [AL] < 75 cm; small red dots), medium (75 cm ≤ AL < 90 cm; larger blue diamonds), and large fish (AL ≥ 90 cm; large black squares), RM 13.7 Kenai River, 25 July–7 August 2014.

Note: Small fish can be underrepresented in the sample. Transducer locations are plotted as small grey crosses, one per fish. For the main channel, vertical axis is the distance 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 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, 8–15 August 2014.

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, 2014.

Appendix E1.–Daily count and proportion of fish greater than or equal to 75 cm ARIS length moving upstream and downstream for the early run, RM 13.7 Kenai River, 2014.

	Downstream		Upstream		Total number
Date	Number	Percent	Number	Percent	sampled
16 May	0	NA	0	NA	0
17 May	0	NA	0	NA	0
18 May	0	0%	1	100%	1
19 May	0	0%	1	100%	1
20 May	0	NA	0	NA	0
21 May	0	0%	2	100%	2
22 May	0	0%	1	100%	1
23 May	0	0%	1	100%	1
24 May	1	50%	1	50%	2
25 May	0	NA	0	NA	0
26 May	0	0%	1	100%	1
27 May	0	0%	1	100%	1
28 May	0	0%	3	100%	3
29 May	0	0%	1	100%	1
30 May	0	0%	5	100%	5
31 May	0	0%	3	100%	3
1 Jun	0	0%	5	100%	5
2 Jun	0	0%	4	100%	4
3 Jun	0	0%	13	100%	13
4 Jun	0	0%	22	100%	22
5 Jun	0	0%	17	100%	17
6 Jun	1	4%	23	96%	24
7 Jun	0	0%	21	100%	21
8 Jun	0	0%	16	100%	16
9 Jun	1	5%	19	95%	20
10 Jun	0	0%	10	100%	10
11 Jun	0	0%	20	100%	20
12 Jun	1	6%	16	94%	17
13 Jun	0	0%	11	100%	11
14 Jun	0	0%	18	100%	18
15 Jun	0	0%	13	100%	13
16 Jun	0	0%	9	100%	9
17 Jun	0	0%	14	100%	14
18 Jun	1	7%	13	93%	14
19 Jun	1	7%	14	93%	15
20 Jun	0	0%	13	100%	13
21 Jun	0	0%	9	100%	9
22 Jun	0	0%	14	100%	14
23 Jun	0	0%	9	100%	9
24 Jun	0	0%	4	100%	4
25 Jun	0	0%	5	100%	5
26 Jun	0	0%	8	100%	8
27 Jun	0	0%	11	100%	11
28 Jun	0	0%	6	100%	6
29 Jun	1	17%	5	83%	6
30 Jun	0	0%	6	100%	6
Total	7	1.8%	389	98.2%	396

Note: NA means percentage cannot be calculated.

Appendix E2.–Daily count and proportion of fish greater than or equal to 75 cm ARIS length moving upstream and downstream for the late run, RM 13.7 Kenai River, 2014.

	Downstream		Upstream		
Date	Number	Percent	Number	Percent	Total number sampled
1 Jul	0	0%	6	100%	6
2 Jul	0	0%	5	100%	5
3 Jul	0	0%	2	100%	2
4 Jul	0	0%	10	100%	10
5 Jul	1	6%	16	94%	17
6 Jul	0	0%	29	100%	29
7 Jul	1	3%	31	97%	32
8 Jul	0	0%	15	100%	15
9 Jul	0	0%	10	100%	10
10 Jul	1	10%	9	90%	10
11 Jul	1	6%	15	94%	16
12 Jul	0	0%	22	100%	22
13 Jul	0	0%	23	100%	23
14 Jul	0	0%	19	100%	19
15 Jul	0	0%	31	100%	31
16 Jul	0	0%	19	100%	19
17 Jul	0	0%	36	100%	36
18 Jul	0	0%	52	100%	52
19 Jul	1	3%	29	97%	30
20 Jul	0	0%	30	100%	30
21 Jul	1	2%	44	98%	45
22 Jul	3	8%	33	92%	36
23 Jul	2	4%	44	96%	46
24 Jul	2	8%	22	92%	24
25 Jul	2	4%	55	96%	57
26 Jul	7	12%	52	88%	59
27 Jul	3	7%	43	93%	46
28 Jul	4	7%	57	93%	61
29 Jul	3	5%	61	95%	64
30 Jul	5	6%	78	94%	83
31 Jul	9	8%	98	92%	107
1 Aug	5	8%	59	92%	64
2 Aug	7	12%	53	88%	60
3 Aug	3	4%	74	96%	77
4 Aug	3	5%	62	95%	65
5 Aug	8	7%	103	93%	111
6 Aug	7	6%	102	94%	109
7 Aug	16	24%	52	76%	68
8 Aug	27	29%	65	71%	92
9 Aug	27	20%	111	80%	138
10 Aug	13	17%	64	83%	77
11 Aug	13	22%	47	78%	60
12 Aug	11	22%	39	78%	50
13 Aug	7	23%	24	77%	31
14 Aug	8	16%	43	84%	51
15 Aug	3	9%	30	91%	33
Total	204	9.6%	1,924	90.4%	2,128