Fishery Data Series No. 17-33

Chinook Salmon Passage in the Kenai River at River Mile 13.7 Using Adaptive Resolution Imaging Sonar, 2015

by

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and

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December 2017

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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ABSTRACT

In 2015, 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 4,212 (SE 168) during the early run (16 May–30 June) and 17,687 (SE 377) during the late run (1 July–20 August). Net upstream passage of all Chinook salmon regardless of size was estimated to be 7,332 (SE 312) during the early run and 28,918 (SE 703) 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 2015 season, goals of 5,300–9,000 early-run and 15,000–30,000 late-run Chinook salmon were in effect, as assessed by ARIS-based sonar estimates at river mile (RM) 13.7. Sonar estimates of inriver Chinook salmon passage provide the basis for estimating spawning escapement and implementing management plans that regulate harvest in the competing fisheries for this stock.

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

The RM 8.6 site was originally selected in 1985, based primarily on its suitability for operating a dual-beam (and subsequently a split-beam) sonar system, which required a near-perfect linear bottom profile over the entire insonified zone or, in this case, from the nearshore region to the thalweg. 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 had many disadvantages, primarily related to its location within tidal influence: 1) incomplete coverage of the river during high tides that flood the region behind the transducers, 2) milling fish behavior related to tidal flux, 3) physical risk to gear by large debris carried by extreme tidal fluxes, and 4) lack of legal access to the property on one bank. It became evident that relocating the site farther upriver could improve the estimates of Chinook salmon passage by minimizing or eliminating these negative factors. In 1999, ADF&G evaluated a second sonar site at RM 13.2 for use of split-beam sonar to assess fish passage, but the bottom topography was less acoustically favorable and 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 (Figure 3), which was not possible at the RM 8.6 site. ADF&G operated a full-scale experimental project at the RM 13.7 site using ARIS during 17 May–17 August 2013 (Miller et al. 2016a) and again during 16 May–15 August 2014 while also continuing to operate the DIDSON at the RM 8.6 site.

Estimates of Chinook salmon abundance require information on Chinook salmon size, which has been obtained historically from an inriver gillnetting program operated at RM 8.6 (Perschbacher 2012a, 2012b, 2012c, 2012d, 2014, 2015). 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 DIDSON. In 2012, Chinook salmon sampled at the RM 8.6 netting project differed in size from those sampled at tributary weirs upstream, 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. Sonar operations were discontinued at the RM 8.6 site following the 2014 season in favor of abundance estimates

[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.

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

This report documents data collection methods, analyses, and results from sonar operations at RM 13.7 in 2015. Daily estimates are reported for net upstream Chinook salmon passage. The estimates reported here represent the third season of operation at RM 13.7 and the first season data from this site were used for stock assessment and inseason management decisions. The current escapement goals were designed to be assessed by sonar counts at RM 13.7. This report also presents findings of a study designed to investigate the degree to which fish migrate upstream outside the portion of the water column insonified by the sonar.

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

ACOUSTIC SAMPLING

Acoustic sampling was conducted using Sound Metrics Corporation (SMC[3]) ARIS systems. Daily abundance estimates were generated from 16 May through 20 August 2015. Components of the ARIS systems are listed in Table 1. Appendices A1–A12 provide greater detail on ARIS

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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.

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

technology and a comparison with DIDSON technology used during previous years at the RM 8.6 site.

Sonar System Configuration and River Coverage

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

A total of 5 sonars were required to provide coverage: a nearshore and offshore sonar on each bank of the main channel plus 1 sonar on the minor channel (Figure 3). During the early part of the season, when the water level was low, 1 sonar on each bank was sufficient to insonify most of the 60–70 m of river cross-section in the main channel (Table 2), but later in the season, as water levels rose, a second sonar was deployed on each bank to insonify the nearshore zone and the first 3–5 m in front of the offshore sonars (Figure 4). The nearshore sonars were first deployed on 26 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 94 m in width. In the main channel, the original (now offshore) sonars were not moved closer to shore as water levels rose because they were already insonifying the maximum range recommended for operation in high-frequency mode (approximately 30 m; Appendix A2). The minor channel was dry when the project began in mid-May, but had sufficient water for fish passage by the time the sonar was deployed on 4 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 5).

Two different ARIS models were used to provide optimal cross-river coverage of the main channel (Figures 4, Table 1). ARIS 1200 models with high-resolution lenses (+HRL) were used as offshore sonars because they have the longer range capabilities (up to about 33 m in high frequency mode) needed to insonify most of the main channel at lower water levels as well as the offshore region of the main channel during higher water levels. An ARIS model 1200 +HRL was also used to cover the right bank nearshore region (Figure 4) and on the minor channel due to the longer (approximately 25 m) range requirements. An ARIS 1800 with a standard lens was deployed as the nearshore sonar on the left bank of the main channel because 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.

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

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

H-style mount (used for nearshore deployment; Figure 6). In the horizontal plane, the sonars were aimed perpendicular to the flow of the river current to maximize the probability of insonifying migrating salmon from a lateral aspect. In the vertical plane, the sonars were aimed to insonify the near-bottom region of the river (Figure 4). Internal sensors in the ARIS units provided measurements of compass heading, pitch, and roll as well as water temperature.

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

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 4 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 9). By 29 June, 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 20 August. A systematic sampling 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 sampling design at the RM 8.6 sonar site in 1999 found no significant difference between estimates of Chinook salmon passage obtained using 1-hour counts and estimates obtained by extrapolating 20-minute counts to 1 hour (Miller et al. 2002). Systematic 10-minute counts have been used for decades at counting towers elsewhere in Alaska (Seibel 1967).

Data Collection Parameters

In designing ARIS, the manufacturers separated the data collection (ARIScope) and data processing (ARISFish) software components. ARIScope has several data collection parameters that are user selectable including "Window Length," transmit "Pulse" width, "Sample Period," number of "Samples/Beam," and "Detail" (Tables 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 11 to 14 May 2015 to assist project personnel with selecting the initial sampling strata and optimizing the aim and data collection parameters for each stratum. Parameters that varied among strata were ping mode, frame rate, frequency, window length, sample period (which controls samples per beam and "Detail"), and transmit pulse width (Table 3).

Ping Mode

Ping mode sets the number of beams used, which in turn determines the ping rate (number of active beams [48 or 96] divided by the number of active channels [16 channels]). The ARIS 1800 can produce 6 pings per frame (96 beams) or 3 pings per frame (48 beams) whereas the ARIS 1200 will always produce 3 pings per frame because it can only operate at 48 beams. Data were collected using 48 beams in all strata except the left-bank nearshore stratum which used an ARIS 1800 set to 96 beams. Using all 96 beams has the advantage of greater cross-range resolution at the expense of frame rate.

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 4 and 9). Window lengths for the first strata sampled by the ARIS 1200 sonars were always set to approximately 5 m to minimize the bias due to focal length caused by the high-resolution lens (Appendix A1). Window lengths for the other strata were selected to optimize bottom coverage while still considering frame rates. For example, the right bank offshore Stratum 2 and Stratum 3 could be combined based on aiming criteria only (note the similar vertical aiming angles or pitch in Figure 10). However, the frame rate of 5 frames per second (fps) needed to extend the range to approximately 35 m is too slow for ranges close to 10 m, where the beam width is narrow and the number of frames per fish would not provide good measurements. At longer ranges, where the beam is wide and fish spend a longer time transiting the beam, getting a sufficient number of frames is not an issue.

Frequency

All strata were sampled at high frequency (1.2 MHz for ARIS 1200 and 1.8 MHz for ARIS 1800) to optimize the cross-range resolution (Appendix A1) with 1 exception. The last stratum on the right bank offshore sonar was sampled at low frequency (0.7 MHz) from 16 May to 2 June. Two factors combined to necessitate sampling the last stratum of the right bank offshore sonar using low frequency. First, colder water temperatures (as low as 8°C) resulted in transmission loss at far range and required the use of low frequency mode to improve image quality in the last stratum (22–35 m). Second, the right bank offshore sonar experienced high background noise from an unknown source when sampling at high frequency but not low frequency. Although the noise was present in the first 2 strata as well, it was not sufficiently strong to warrant the change to low frequency mode. The background noise appeared to decline (possibly related to higher water level) as the season progressed. By 2 June, water temperatures had warmed enough (11°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 the right bank offshore sonar.

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 a sample period of 10 µs because this resolution was recommended by the manufacturer (Bill Hanot, personal communication, Sound Metrics Corporation, Seattle, WA) and because tethered fish experiments conducted by Miller et al. (2016b) indicated a sample period of 10 µs provides an adequate balance between the accuracy of AL measurements and the amount of storage space required for processing and archiving data.

Transmit Pulse Width

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

Other Settings

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

MANUAL ARIS FISH LENGTH MEASUREMENTS

Measurements of fish length were obtained using ARISFish V2.3 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 11).

Measured fish were subjected to a "centerline rule" (Appendices B2 and B3). Only those fish that crossed the longitudinal central axis of the ARIS video image were candidates for measuring. Fish that did not cross the centerline were ignored. This removed the opportunity for fish to be counted in multiple spatial strata, which would create a positive bias in the passage estimates. Note that the 2010–2014 DIDSON-based abundance estimates at the RM 8.6 site (Miller et al. 2013-2015; Key et al. 2016a, 2016b) were not subjected to a centerline rule.

For the purpose of this 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[5] provided information on fish length by species, which was needed for some of the estimates produced in this report. Fish length measurements from the netting project were one source of input data required for mixture model estimates of Chinook salmon abundance (see below). Beginning in 2014, sampling effort was equally distributed between midriver and nearshore drifts. The Chinook salmon abundance estimates in this report used all inriver gillnetting data, including midriver and nearshore. This differs from methods used to produce the 2013 RM 13.7 Chinook salmon abundance estimates (Miller et al. 2016a), when only pilot netting data were available from the nearshore stratum, and the estimates were derived from midriver data alone.

DATA ANALYSIS

Methods used to estimate fish passage are detailed below. Unlike past DIDSON sonar estimates at RM 8.6, which estimated the number of fish that migrated 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.

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[5] Perschbacher, J., and Eskelin *In prep* Chinook salmon creel survey and inriver gillnetting study, lower Kenai River, Alaska, 2015. Alaska Department of Fish and Game, Fishery Data Series, Anchorage.

Fish Passage

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

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

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

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

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[6]; Wolter 1985) with adjustments for missing data as follows:

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

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

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

[6] 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).

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

Chinook Salmon Passage

Upstream Chinook salmon passage, regardless of size, was estimated by fitting a mixture model to upstream ARIS length 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[7] as described in Appendices C1–C6.

The variance estimate followed Goodman (1960):

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

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.

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.

[7] Perschbacher, J., and T. Eskelin. *In prep*. Chinook salmon creel survey and inriver gillnetting study, lower Kenai River, Alaska, 2015. Alaska Department of Fish and Game, Fishery Data Series, Anchorage.

Vertical Fish Distribution

A DIDSON-LR with a high-resolution lens was deployed in the vertical orientation (Figure 12) on the left bank from 11 to 13 June and on the right bank from 9 to 11 July and 18–19 July for the purpose of observing vertical distribution of passing fish. In the vertical orientation, the 14° vertical field of view (Appendix A1) provided coverage of a significant portion of the water column at close range and complete coverage of the water column at far range. On the left bank, the vertical DIDSON was positioned approximately 2 m offshore of the inshore ARIS unit (Figure 13). On the right bank the vertical DIDSON was positioned parallel with the inshore ARIS unit (Figure 14). The DIDSON-LR was attached to a tripod-style mount via an X2 rotator that provided pan and tilt capabilities (Figure 12). A data cable led from the DIDSON-LR to a laptop computer on shore. Data was temporarily stored to the laptop hard drive and was transferred to the sonar office using 32-gigabyte USB flash drives.

The DIDSON-LR was positioned approximately 60 cm above the substrate (measured to the center of the lens) on each river bank and operated in low frequency (0.7 MHz) in order to cover the offshore range insonified by the horizontally deployed ARIS units (11–40 m from shore on the left bank; 8–50 m from shore on the right bank). Operating at low frequency also reduced interference (crosstalk) with the ARIS units operating at high frequency. The sample range on each bank was divided into 3 range strata relative to distance from shore: 5–15 m, 15–35 m, and 30–50 m on the left bank; and 8–28 m, 20–40 m, and 30–50 m on the right bank (Figures 13 and 14). Although horizontally deployed ARIS data collection occurs inside of 5 m on the left bank and 8 m on the right bank for the purpose of producing Chinook salmon passage estimates, vertically oriented DIDSON data collection was concentrated in the offshore area where the majority of Chinook salmon passage occurs. Overlap between range strata was not a concern because we were not attempting to quantify vertical distribution by range; rather, we were attempting to determine presence or absence of migrating fish in the middle to upper water column outside the area of river insonified by the horizontally deployed ARIS units. Each stratum was sampled for 10 minutes per hour. The tilt angle of the DIDSON was adjusted to align the reflection from the river bottom near the center axis of the DIDSON image (Figure 15).

For each 10-minute sample, passing fish were identified and distance from the center of the fish image to the substrate was measured using DIDSON Control and Display software version 5.25 (Figure 16). These distances were then used to plot the horizontal and vertical location of passing fish relative to river bottom profiles generated from each bank prior to data collection using methods described in Faulkner and Maxwell (2009).

RESULTS

Data collection began on 16 May for the main channel offshore transducers, 26 May for the main channel left bank nearshore transducer, 2 June for the main channel right bank nearshore transducer, and 4 June for the minor channel transducer (Table 2). All sampling ended after 20 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 17, top panels). The modes of the AL distributions line up well[8] with mid eye to tail fork (METF) length distributions from salmon measured by the inriver netting project (Figure 17, 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 17, bottom panels). From inspection of AL frequency distributions (Figure 17, top panels), it is evident that the right tail of the left-hand mode (presumably non-Chinook salmon) very rarely exceeded 75 cm AL. The frequency distributions of early- and late-run ARIS lengths possess a small separate mode near 40 cm (Figure 17, top panels) that is more prominent in the offshore strata than in the inshore strata during both runs (Figure 17, middle panels). This mode was observed during the 2013 and 2014 early runs and was attributed to resident fish (e.g., rainbow trout [*O. mykiss*] and Dolly Varden [*Salvelinus malma*]) rather than sockeye salmon[9].

SPATIAL AND TEMPORAL DISTRIBUTION

Spatial and temporal patterns of migration are displayed for medium (75 cm ≤ AL < 90 cm) and large (AL ≥ 90 cm) fish in Appendices D1–D7. Small (40 cm ≤ AL < 75 cm) fish that were measured are also displayed, although they are underrepresented, especially during the late run. In general, small fish migrated closer to the 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 (63% early run, 67% 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 18). Only 3% of early- and late-run upstream bound medium and large (AL ≥ 75 cm) fish were found migrating in the minor channel.

The early run had slightly higher percentage of fish greater than or equal to 75 cm AL migrating nearshore when compared to the late run (42% and 39 % respectively; nearshore values in Table 5 summed over left and right banks). Nearshore migrants accounted for larger fractions of right bank fish than left bank fish during both runs (Table 5, Figure 18, Appendices D1–D7).

In 2015, diurnal migration cycles were fairly consistent. When upstream bound medium and large fish were classified as day (sunrise to sunset) versus night (sunset to sunrise) migrators, the number migrating at day was disproportionately large compared to the relative length of night and day (Figure 19) throughout most of the early and late runs. The relative ratio of day to night migrators was 84:16 in the early run and 74:26 in the late run (Table 5).

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 were traveling downstream in the late run (8.6%) than in the early run (5.4%; Table 6). During both the early and late run,

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[8] 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.

[9] No ocean-age-1 sockeye salmon (which average approximately 40 cm METF) were sampled during the early run at the Russian River weir in 2015 (the main component of early-run Kenai River sockeye salmon; Jason Pawluk, Sport Fish Biologist, ADF&G, Soldotna; personal communication).

relatively more medium and large fish migrated downstream in the minor channel (20.0%, and 21.8%) than on the left (4.2%, and 6.8%) or right (5.4%, and 8.7%) banks of the main channel.

Among small fish (AL < 75 cm) migrating during the late run, a greater fraction were observed traveling downstream on the right bank of the main channel (8.7%) than on the left bank (4.6%) (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: 7,332 (SE 312) Chinook salmon during the early run (16 May–30 June; Table 7) and 28,918 (SE 703) during the late run (1 July–20 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 20. Other measures of abundance are plotted for comparison in Figures 21 and 22.

Median early-run Chinook salmon (regardless of size) passage in 2015 occurred on 10 June, 3 days earlier than the 2013–2014 average of 13 June. Median late-run passage occurred on 22 July, 4 days earlier than the 2013–2014 average of 26 July (Table 11; Figure 23).

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 2015 early run (16 May–30 June), an estimated 4,212 (SE 168) fish greater than or equal to 75 cm AL passed RM 13.7, including 3,143 (SE 143) medium and 1,069 (SE 83) large fish (Table 12). During the 2015 late run (1 July–20 August), an estimated 17,687 (SE 377) fish greater than or equal to 75 cm AL passed RM 13.7, including 8,151 (SE 248) medium (75 cm ≤ AL < 90 cm) and 9,536 (SE 265) large (AL ≥ 90 cm) fish (Table 13).

Median passage of Chinook salmon ≥ 75 cm AL during the early run occurred on 9 June, one day earlier than the median passage of all Chinook salmon (regardless of size). Median passage of Chinook salmon ≥ 75 cm AL during the late run occurred on 25 July, 5 days later than the median passage of all Chinook salmon regardless of size (Table 11, Figures 23 and 24).

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 2015 early run (16 May–30 June), an estimated 3,120 (SE 355) Chinook salmon less than 75 cm AL passed RM 13.7 (Table 7). During the 2015 late run (1 July–20 August), an estimated 11,231 (SE 797) 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.

VERTICAL FISH DISTRIBUTION

Vertical sampling was conducted using a DIDSON-LR from 11 to 13 June on the left bank and from 9 to 11 July and 18–19 July on the right bank. A total of 220 fish were observed passing on the left bank and 1,378 fish on the right bank during the time periods sampled. Although direction of travel could not be determined from data collected using the vertically oriented DIDSON-LR, it was assumed most fish were passing in the upstream direction.

Figures 25 and 26 display fish locations relative to both the bottom substrate and the insonified area of the horizontally-deployed ARIS units. Of the 220 fish observed on the left bank, only 2 were found to be a substantial distance from the river bottom and well outside the area covered by the horizontally-deployed ARIS (Figure 25). Similarly on the right bank, only 1 of 1,378 fish was found to be a substantial distance from the river bottom and well outside the area covered by the horizontally-deployed ARIS (Figure 26). Most fish on both banks migrated upstream within 20 cm of the river bottom.

DISCUSSION

POSTSEASON REVISION OF SMALL CHINOOK SALMON ABUNDANCE ESTIMATES

Recently, it became evident that estimates of small Chinook salmon in the Kenai River are sensitive to migration patterns (nearshore vs. offshore) at the RM 8.6 inriver gillnetting study site (Miller et al. 2016a) and to the relative weight given to current versus historical netting data used in mixture model estimates (Miller et al. 2016b). The first problem has been successfully addressed by expanding the sampling design of the inriver gillnetting project to include nearshore drifts (Perschbacher and Eskelin 2016). The second problem stems from small netting catches when Chinook salmon abundance is low, which make it difficult to obtain estimates of Chinook salmon size composition that are accurate and timely. Until now, our solution to the data limitation problem has been to use a weighted average of current and historical size data during the fishing season, but then to re-analyze the data postseason without using any historical prior information, pooling multiple days as necessary when sample sizes are small (see Methods and Appendix C6). The problem arises when size composition differs greatly from the historical average, and the influence of the historical data causes a bias in the inseason estimates. For instance, the published final passage estimate for early-run Chinook salmon of all sizes in 2014 was 37% higher than the sum of the daily estimates produced during the season because small fish comprised an anomalously large fraction of the Chinook salmon run in 2014. See Miller et al. (2016b) for more details.

In 2015, we statistically reduced the influence of prior historical information on the inseason estimates in order to reduce the potential magnitude of postseason revisions. However, the final estimates of Chinook salmon regardless of size published herein are 18% (early run) and 22% (late run) higher than the sum of the daily estimates produced during the 2015 season.

Because the threshold estimate of Chinook salmon 75 cm or longer did not change, all of the difference between inseason and postseason estimates was due to differences in the estimates of the number of small Chinook salmon. In 2016, we intend to eliminate the use of historical data for inseason estimates to further reduce the necessity for postseason revisions.

VERTICAL FISH DISTRIBUTION

Vertical sampling results suggest that very few fish migrate upstream outside the area of the river covered by sonar. Less than 1% of fish on either bank were found to be swimming a substantial distance above the river bottom outside the area insonified by the horizontally deployed ARIS units.

It is assumed that almost all fish observed were moving in the upstream direction. In a vertical configuration, fish appear in the DIDSON image as dots that briefly appear in the image as the fish moves through the beam, then disappear as the fish leaves the beam. As fish actively swim upstream or slowly back downstream, the dot shows an obvious side-to-side motion as the body of the fish undulates. It is assumed that debris floating downstream or fish passively drifting downstream with the current would pass through the beam quickly and show little or no side-to-side motion. All traces that passed rapidly through the beam and showed no side-to-side motion were assumed to be either downstream debris or fish passively drifting downstream and were ignored because no differentiation between the two could be made. Therefore, it is likely the presented results apply mostly to upstream passing fish.

An attempt was made to identify downstream-moving fish by rotating the DIDSON-LR to 30° from horizontal. Although this configuration does not allow one to measure distance from substrate, it does provide direction of travel and can provide some indication whether the passing fish is near the river bottom or higher up in the water column (Enzenhofer et al. 2010). As with the vertical configuration, however, it was difficult to differentiate downstream debris from fish that were passively drifting downstream, so it was not possible to definitively identify all downstream passing fish with the 30° from horizontal configuration. Of the observed downstream-moving images that did display swimming behavior (side-to-side motion), most were observed passing lower in the water column.

SUMMARY AND CONCLUSIONS

ARIS was successfully operated at RM 13.7 in 2015. Transducers were configured to sample nearly 100% of the river cross-section, therefore no spatial expansion factors were required. Uncertainty and errors due to changing detection rates at RM 8.6 have been eliminated.

Despite measures taken after the 2014 season (Miller et al. 2016b), final estimates of Chinook salmon abundance (early run 7,332 SE 312; late run 28,918 SE 703) were 18–22% higher than those produced during and shortly after the 2015 season. Estimates of Chinook salmon 75 cm METF or longer (early run 4,212 SE 168; late run 17,687 SE 377) did not change. In 2016, additional steps will be taken to further reduce the potential for large postseason revisions.

RECOMMENDATIONS

Discontinue inseason use of historical age composition information. This should greatly reduce the need for postseason revisions of Chinook salmon abundance estimates.

Continue to conduct nearshore and midriver drifts at the inriver netting project at RM 8.6. We will require 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 2015.

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, 2015.

Sonar location	Range stratum	Time (min) [a]	Coverage range (m) by date						
			16 May	26 May	2 June	4 Jun	5 Jun	9 Jun	29 Jun
Left nearshore	1	:00 / :30	[b]	2.5–10.0	2.5–10.0	2.5–10.0	2.5–12.5	2.5–13.5	2.5–13.5
Left offshore	1	:00 / :30	3.5–8.0	3.5–8.0	3.5–8.0	3.5–8.0	3.5–8.0	3.5–8.0	3.5–8.0
	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
	3	:20 / :50	22.0–33.5	22.0–33.5	22.0–33.5	22.0–33.5	22.0–33.5	22.0–33.5	22.0–33.5
Right offshore	1	:00 / :30	3.5–8.0	3.5–8.0	[c]	[c]	[c]	[c]	[c]
	2	:10	8.0–22.0	8.0–22.0	8.0–22.0	8.0–22.0	8.6–22.0	8.6–22.0	8.6–22.0
	3	:20	22.0–33.5	22.0–33.5	22.0–33.5	22.0–33.5	22.0–33.5	22.0–33.5	22.0–33.5
Right nearshore	1	:40	[d]	[d]	3.5–8.0	3.5–8.0	3.5–8.0	3.5–8.0	3.5–8.0
	2	:50	[d]	[d]	8.0–16.0	8.0–16.0	8.0–16.0	8.0–18.2	8.0–20.0
Minor channel	1	:00	[e]	[e]	[e]	2.6–6.0	2.6–6.0	2.6–6.0	2.6–6.0
	2	:10	[e]	[e]	[e]	6.0–12.0	6.0–12.0	6.0–12.0	6.0–12.0
	3	:30	[e]	[e]	[e]	12.0–22.0	12.0–22.0	12.0–22.0	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 26 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 4 June.

Table 3.–Sampling schedule and parameter values on 29 June 2015 for each range stratum sampled by 5 ARIS systems in 2015.

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	2.5	13.5	High (1.8)	Max	16	20	3,443	10	1,512	−1.7	183
Left offshore	1064	1	:00 / :30	10	3.5	8.0	High (1.2)	Max	2	13	4,836	10	621	−7.0	85
		2	:10 / :40	10	8.0	22.0	High (1.2)	Max	10	20	11,058	10	1,934	−3.9	86
		3	:20 / :50	7	22.0	33.5	High (1.2)	Max	16	33	30,412	10	1,589	−2.0	85
Right offshore	1063	1	[c]	[c]	[c]	[c]	[c]	[c]	[c]	[c]	[c]	[c]	[c]	[c]	[c]
		2	:00/:20	9	8.0	22.0	High (1.2)	Max	17	20	11,046	10	1,933	−2.5	22
		3	:10/:30	7	22.0	33.5	High (1.2)	Max	17	31	30,412	10	1,590	−2.0	21
Right nearshore	1098	1	:40	9	3.5	8.0	High (1.2)	Max	6	13	4,850	10	624	−6.0	271
		2	:50	9	8.0	20.0	High (1.2)	Max	6	20	11,086	10	1,663	−4.3	269
Minor channel	1095	1	:00	8	2.0	6.0	High (1.2)	Max	2	13	2,778	10	556	−11.5	25
		2	:10	9	6.0	12.0	High (1.2)	Max	8	13	8,256	10	826	−5.1	25
		3	:30	9	12.0	22.0	High (1.2)	Max	16	21	16,494	10	1373	−1.7	25

[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 9).

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, 2015.

		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	8	22	23	30	29	52	2	84
	Night	2	4	7	4	5	11	0	16
	Both	9	26	29	33	35	63	3	100
Late									
	Day	2	21	23	26	23	49	2	74
	Night	2	6	8	10	8	17	1	26
	Both	3	27	31	36	31	67	3	100

Note: columns may not sum due to rounding

Table 6.–Percentage of all fish migrating downstream, by river bank, transducer, and fish size at RM 13.7 for the 2015 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	1.1	7.7	10.5	0.4	2.3	2.0	17.7	6.7
	Medium	8.2	2.7	8.7	2.8	4.3	5.4	26.7	5.6
	Large	0.0	5.1	8.9	0	3.9	5.5	10.0	5.1
	Med and large	6.4	3.4	8.8	2.3	4.2	5.4	20.0	5.4
Late									
	Small	.06	11.0	27.1	4.9	4.6	8.7	6.4	6.4
	Medium	10.7	8.2	11.9	8.5	8.5	9.8	21.0	10.0
	Large	1.9	5.4	9.2	6.1	5.1	7.8	24.2	7.3
	Med and large	7.0	6.8	10.2	7.4	6.8	8.7	21.8	8.6

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

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 2015.

	ALMM Chinook salmon (all sizes)			ALMM Chinook salmon < 75 cm AL		
Date	Passage	SE	CV	Passage	SE	CV
16 May	10	3	0.29	4	10	2.60
17 May	0	0		0	8	
18 May	45	11	0.25	33	13	0.39
19 May	58	15	0.26	20	18	0.89
20 May	56	14	0.25	44	18	0.41
21 May	30	9	0.30	6	19	3.20
22 May	40	11	0.27	34	12	0.36
23 May	29	7	0.24	-1	18	18.0
24 May	61	15	0.24	13	22	1.67
25 May	69	17	0.24	51	21	0.42
26 May	77	20	0.26	35	24	0.69
27 May	94	22	0.24	40	27	0.67
28 May	80	25	0.32	26	30	1.16
29 May	172	42	0.24	51	61	1.20
30 May	81	24	0.30	15	32	2.15
31 May	94	28	0.30	22	38	1.74
1 Jun	166	36	0.22	33	41	1.2
2 Jun	229	41	0.18	42	59	1.41
3 Jun	170	36	0.21	37	54	1.45
4 Jun	207	49	0.24	44	64	1.45
5 Jun	175	36	0.21	48	48	0.99
6 Jun	390	77	0.20	185	86	0.46
7 Jun	437	79	0.18	190	87	0.46
8 Jun	288	65	0.23	131	69	0.52
9 Jun	328	65	0.20	141	69	0.49
10 Jun	284	63	0.22	145	67	0.46
11 Jun	336	70	0.21	165	77	0.47
12 Jun	449	98	0.22	206	111	0.54
13 Jun	264	66	0.25	129	69	0.53
14 Jun	192	52	0.27	88	56	0.64
15 Jun	165	48	0.29	67	55	0.82
16 Jun	116	37	0.32	68	42	0.62
17 Jun	165	50	0.30	86	53	0.61
18 Jun	223	57	0.25	81	68	0.84
19 Jun	85	32	0.38	34	38	1.11
20 Jun	189	50	0.26	68	53	0.78
21 Jun	140	41	0.30	67	49	0.73
22 Jun	152	47	0.31	61	51	0.83
23 Jun	50	24	0.47	20	28	1.40
24 Jun	156	44	0.28	71	48	0.68
25 Jun	166	60	0.36	81	62	0.77
26 Jun	222	62	0.28	107	67	0.63
27 Jun	163	53	0.32	91	55	0.61
28 Jun	98	37	0.37	50	40	0.81
29 Jun	200	56	0.28	102	60	0.59
30 Jun	131	59	0.45	89	60	0.68
Total	7,332	312	0.04	3,120	355	0.11

Note: CV not defined when passage equals zero.

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 2015.

	ALMM Chinook salmon (all sizes)			ALMM Chinook salmon < 75 cm AL		
Date	Passage	SE	CV	Passage	SE	CV
1 Jul	205	68	0.33	126	73	0.58
2 Jul	382	104	0.27	231	110	0.48
3 Jul	302	84	0.28	211	87	0.41
4 Jul	319	102	0.32	142	109	0.77
5 Jul	419	108	0.26	248	119	0.48
6 Jul	287	84	0.29	166	87	0.52
7 Jul	403	97	0.24	227	100	0.44
8 Jul	467	104	0.22	206	117	0.57
9 Jul	658	149	0.23	352	154	0.44
10 Jul	729	108	0.15	375	118	0.32
11 Jul	991	184	0.19	737	191	0.26
12 Jul	947	143	0.15	633	148	0.23
13 Jul	839	198	0.24	555	204	0.37
14 Jul	760	144	0.19	458	148	0.32
15 Jul	872	221	0.25	564	225	0.40
16 Jul	709	124	0.18	407	135	0.33
17 Jul	1297	168	0.13	820	176	0.21
18 Jul	999	146	0.15	474	158	0.33
19 Jul	598	94	0.16	218	102	0.47
20 Jul	518	78	0.15	198	98	0.50
21 Jul	699	83	0.12	216	100	0.46
22 Jul	978	125	0.13	331	137	0.41
23 Jul	1012	96	0.10	190	127	0.67
24 Jul	1411	136	0.10	385	163	0.42
25 Jul	863	106	0.12	259	124	0.48
26 Jul	759	82	0.11	210	97	0.46
27 Jul	578	71	0.12	186	87	0.47
28 Jul	522	64	0.12	147	86	0.58
29 Jul	496	65	0.13	163	83	0.51
30 Jul	475	64	0.14	137	80	0.59
31 Jul	299	51	0.17	60	70	1.17
1 Aug	254	44	0.17	91	59	0.65
2 Aug	423	59	0.14	121	82	0.68
3 Aug	492	63	0.13	100	96	0.96
4 Aug	641	68	0.11	189	95	0.50
5 Aug	706	64	0.09	114	89	0.78
6 Aug	806	73	0.09	100	106	1.06
7 Aug	464	55	0.12	35	67	1.92
8 Aug	548	62	0.11	65	74	1.14
9 Aug	504	59	0.12	81	90	1.11
10 Aug	586	61	0.10	66	82	1.24
11 Aug	219	32	0.15	38	51	1.34
12 Aug	216	34	0.16	48	63	1.31

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	ALMM Chinook salmon (all sizes)			ALMM Chinook salmon < 75 cm AL		
Date	Passage	SE	CV	Passage	SE	CV
13 Aug	431	56	0.13	80	79	0.99
14 Aug	327	48	0.15	55	60	1.08
15 Aug	294	42	0.14	82	75	0.92
16 Aug	176	29	0.17	38	54	1.42
17 Aug	315	51	0.16	85	70	0.83
18 Aug	368	64	0.17	133	85	0.64
19 Aug	163	31	0.19	43	63	1.46
20 Aug	192	39	0.20	35	75	2.14
Total	28,918	703	0.02	11,231	797	0.07

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 gillnet catches from RM 8.6, Kenai River early run 2015.

	Ages 3 and 4		Age 5		Ages 6 and 7	
Date	Proportion	SE	Proportion	SE	Proportion	SE
16 May	0.40	0.14	0.39	0.11	0.22	0.07
17 May	0.40	0.14	0.39	0.11	0.22	0.07
18 May	0.40	0.14	0.39	0.11	0.22	0.07
19 May	0.40	0.14	0.39	0.11	0.22	0.07
20 May	0.40	0.14	0.39	0.11	0.22	0.07
21 May	0.40	0.14	0.39	0.11	0.22	0.07
22 May	0.40	0.14	0.39	0.11	0.22	0.07
23 May	0.40	0.14	0.39	0.11	0.22	0.07
24 May	0.40	0.14	0.39	0.11	0.22	0.07
25 May	0.40	0.14	0.39	0.11	0.22	0.07
26 May	0.40	0.14	0.39	0.11	0.22	0.07
27 May	0.40	0.14	0.39	0.11	0.22	0.07
28 May	0.25	0.15	0.56	0.16	0.19	0.11
29 May	0.24	0.14	0.63	0.15	0.13	0.09
30 May	0.14	0.10	0.79	0.12	0.07	0.07
31 May	0.15	0.10	0.82	0.10	0.03	0.04
1 Jun	0.12	0.08	0.81	0.09	0.07	0.05
2 Jun	0.10	0.07	0.84	0.08	0.07	0.05
3 Jun	0.13	0.08	0.79	0.08	0.08	0.05
4 Jun	0.20	0.08	0.72	0.09	0.08	0.06
5 Jun	0.28	0.08	0.68	0.08	0.04	0.04
6 Jun	0.43	0.08	0.52	0.09	0.05	0.05
7 Jun	0.43	0.08	0.54	0.08	0.04	0.04
8 Jun	0.49	0.09	0.46	0.09	0.04	0.04
9 Jun	0.48	0.08	0.50	0.08	0.02	0.03
10 Jun	0.48	0.08	0.45	0.08	0.07	0.04
11 Jun	0.57	0.08	0.39	0.08	0.05	0.03
12 Jun	0.51	0.09	0.44	0.09	0.05	0.03
13 Jun	0.45	0.09	0.49	0.09	0.05	0.04
14 Jun	0.45	0.09	0.31	0.09	0.24	0.08
15 Jun	0.44	0.10	0.41	0.10	0.15	0.07
16 Jun	0.46	0.11	0.42	0.11	0.12	0.06
17 Jun	0.49	0.09	0.45	0.10	0.06	0.05
18 Jun	0.39	0.10	0.49	0.10	0.12	0.06

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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	0.41	0.10	0.50	0.11	0.09	0.06
20 Jun	0.37	0.10	0.58	0.10	0.05	0.05
21 Jun	0.45	0.10	0.52	0.10	0.02	0.03
22 Jun	0.46	0.10	0.51	0.10	0.03	0.04
23 Jun	0.46	0.11	0.40	0.14	0.15	0.12
24 Jun	0.38	0.10	0.59	0.11	0.03	0.05
25 Jun	0.52	0.12	0.40	0.14	0.07	0.09
26 Jun	0.48	0.12	0.46	0.13	0.06	0.08
27 Jun	0.50	0.11	0.44	0.12	0.06	0.07
28 Jun	0.46	0.11	0.51	0.11	0.03	0.04
29 Jun	0.48	0.09	0.46	0.11	0.05	0.06
30 Jun	0.62	0.10	0.30	0.10	0.08	0.06
Weighted mean	0.38	0.03	0.56	0.04	0.06	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 gillnet catches from RM 8.6, Kenai River late run 2015.

	Ages 3 and 4		Age 5		Ages 6 and 7	
Date	Proportion	SE	Proportion	SE	Proportion	SE
1 Jul	0.63	0.09	0.34	0.09	0.03	0.04
2 Jul	0.55	0.10	0.41	0.10	0.04	0.04
3 Jul	0.63	0.09	0.28	0.08	0.09	0.04
4 Jul	0.53	0.11	0.37	0.10	0.10	0.04
5 Jul	0.55	0.10	0.30	0.09	0.15	0.05
6 Jul	0.51	0.10	0.33	0.10	0.17	0.06
7 Jul	0.47	0.11	0.38	0.10	0.15	0.06
8 Jul	0.47	0.10	0.38	0.10	0.14	0.06
9 Jul	0.52	0.10	0.26	0.09	0.22	0.07
10 Jul	0.55	0.07	0.38	0.09	0.06	0.07
11 Jul	0.72	0.05	0.19	0.05	0.09	0.03
12 Jul	0.68	0.05	0.23	0.06	0.08	0.04
13 Jul	0.65	0.07	0.07	0.09	0.28	0.08
14 Jul	0.59	0.07	0.20	0.13	0.21	0.11
15 Jul	0.59	0.08	0.03	0.06	0.38	0.09
16 Jul	0.60	0.06	0.07	0.07	0.33	0.08
17 Jul	0.63	0.05	0.18	0.07	0.19	0.06
18 Jul	0.44	0.07	0.15	0.11	0.41	0.10
19 Jul	0.41	0.07	0.37	0.10	0.22	0.08
20 Jul	0.41	0.08	0.25	0.17	0.34	0.16
21 Jul	0.20	0.09	0.41	0.10	0.40	0.11
22 Jul	0.28	0.10	0.19	0.12	0.53	0.11
23 Jul	0.17	0.07	0.53	0.11	0.30	0.12
24 Jul	0.20	0.06	0.06	0.05	0.74	0.07
25 Jul	0.26	0.07	0.07	0.07	0.68	0.08
26 Jul	0.20	0.05	0.04	0.05	0.76	0.07
27 Jul	0.21	0.06	0.09	0.08	0.70	0.08
28 Jul	0.22	0.06	0.07	0.08	0.70	0.08
29 Jul	0.25	0.05	0.04	0.04	0.71	0.06
30 Jul	0.23	0.06	0.09	0.07	0.68	0.07
31 Jul	0.23	0.08	0.17	0.10	0.60	0.09
1 Aug	0.21	0.08	0.15	0.10	0.64	0.09
2 Aug	0.21	0.07	0.10	0.08	0.69	0.08
3 Aug	0.16	0.07	0.25	0.15	0.59	0.15

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Table 10.–Page 2 of 2.

Date	Ages 3 and 4		Age 5		Ages 6 and 7	
	Proportion	SE	Proportion	SE	Proportion	SE
4 Aug	0.13	0.06	0.23	0.13	0.64	0.13
5 Aug	0.03	0.03	0.09	0.09	0.88	0.09
6 Aug	0.06	0.04	0.03	0.04	0.91	0.04
7 Aug	0.05	0.04	0.04	0.05	0.91	0.05
8 Aug	0.04	0.04	0.09	0.08	0.87	0.08
9 Aug	0.04	0.04	0.08	0.07	0.88	0.07
10 Aug	0.04	0.04	0.05	0.06	0.90	0.06
11 Aug	0.03	0.03	0.11	0.10	0.87	0.10
12 Aug	0.08	0.06	0.23	0.12	0.70	0.12
13 Aug	0.06	0.06	0.31	0.14	0.63	0.14
14 Aug	0.06	0.05	0.27	0.18	0.67	0.18
15 Aug	0.07	0.06	0.51	0.13	0.42	0.13
16 Aug	0.08	0.07	0.48	0.18	0.44	0.18
17 Aug	0.15	0.10	0.68	0.11	0.17	0.08
18 Aug	0.22	0.11	0.34	0.17	0.44	0.16
19 Aug	0.12	0.11	0.60	0.13	0.29	0.11
20 Aug	0.17	0.11	0.13	0.12	0.70	0.13
Weighted mean	0.34	0.02	0.19	0.02	0.47	0.02

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

Table 11.–Median passage dates for Chinook salmon early and late runs by year and size class (≥75 cm vs. all sizes), Kenai River RM 13.7, 2013–2015.

	Early Run		Late Run	
Year	Chinook salmon ≥75 cm	All Chinook salmon	Chinook salmon ≥75 cm	All Chinook salmon
2013	14 Jun	12 Jun	30 Jul	26 Jul
2014	11 Jun	13 Jun	30 Jul	26 Jul
Average 2013–2014	13 Jun	13 Jun	30 Jul	26 Jul
2015	9 Jun	10 Jun	25 Jul	22 Jul

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, early run 2015.

	75 cm ≤ AL < 90 cm		AL ≥ 90 cm		AL ≥ 75 cm	
Date	Passage	SE	Passage	SE	Passage	SE
16 May	0	0	6	10	6	10
17 May	0	0	0	8	0	8
18 May	6	6	6	6	12	6
19 May	7	6	32	8	38	10
20 May	0	0	12	11	12	11
21 May	18	10	6	15	24	17
22 May	6	6	0	0	6	6
23 May	24	17	6	4	30	16
24 May	24	14	24	11	48	16
25 May	12	8	6	6	18	13
26 May	30	11	12	8	42	14
27 May	30	13	24	11	54	15
28 May	36	13	18	13	54	16
29 May	85	34	36	18	121	45
30 May	42	14	24	14	66	21
31 May	54	25	18	10	72	26
1 Jun	115	17	18	9	133	20
2 Jun	151	33	36	16	187	43
3 Jun	115	36	18	10	133	39
4 Jun	127	35	36	13	163	41
5 Jun	121	28	6	13	127	31
6 Jun	157	33	48	15	205	37
7 Jun	187	33	60	20	247	37
8 Jun	127	20	30	9	157	22
9 Jun	157	23	30	9	187	25
10 Jun	115	22	24	11	139	22
11 Jun	130	37	41	15	171	32
12 Jun	221	42	22	17	243	52
13 Jun	111	18	24	11	135	19
14 Jun	49	14	55	19	104	21
15 Jun	73	24	24	14	98	27
16 Jun	30	14	18	10	48	20
17 Jun	73	16	6	6	79	18
18 Jun	96	31	46	22	142	38
19 Jun	38	18	13	6	51	20
20 Jun	85	19	36	13	121	18
21 Jun	48	22	24	13	73	26
22 Jun	61	15	30	13	91	20
23 Jun	12	8	18	10	30	15
24 Jun	66	23	18	9	85	21
25 Jun	54	16	30	13	85	17
26 Jun	79	19	36	19	115	26
27 Jun	42	13	30	10	72	17
28 Jun	48	17	0	0	48	17
29 Jun	61	18	37	13	98	22
30 Jun	18	8	24	11	42	13
Total	3,143	143	1,069	83	4,212	168

Table 13.–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 2015.

	75 cm ≤ AL < 90 cm		AL ≥ 90 cm		AL ≥ 75 cm	
Date	Passage	SE	Passage	SE	Passage	SE
1 Jul	30	18	48	15	79	27
2 Jul	91	18	60	24	151	36
3 Jul	60	14	30	12	91	21
4 Jul	132	31	45	16	177	37
5 Jul	91	24	73	29	171	50
6 Jul	55	16	67	24	121	22
7 Jul	121	18	55	16	176	26
8 Jul	150	39	111	30	261	52
9 Jul	134	30	171	37	306	42
10 Jul	186	32	168	36	354	47
11 Jul	157	36	97	31	254	53
12 Jul	187	28	127	32	314	36
13 Jul	97	23	187	39	284	48
14 Jul	157	29	145	19	302	35
15 Jul	139	34	169	28	308	43
16 Jul	139	32	163	30	302	54
17 Jul	261	34	217	29	477	50
18 Jul	229	45	296	33	525	62
19 Jul	187	30	193	24	380	40
20 Jul	97	25	224	41	320	60
21 Jul	205	32	278	47	483	56
22 Jul	272	39	375	44	647	57
23 Jul	399	51	423	50	822	82
24 Jul	489	53	537	75	1,026	91
25 Jul	290	40	314	40	604	66
26 Jul	212	36	338	36	549	51
27 Jul	193	36	199	34	392	51
28 Jul	175	28	199	48	375	57
29 Jul	144	33	188	34	333	52
30 Jul	109	34	230	39	338	48
31 Jul	49	31	190	33	239	48
1 Aug	91	34	73	22	163	39
2 Aug	103	41	199	38	302	58
3 Aug	211	49	182	42	392	73
4 Aug	193	46	260	39	452	65
5 Aug	290	49	302	61	592	63
6 Aug	266	40	435	55	706	77
7 Aug	133	24	284	37	429	39
8 Aug	224	31	260	37	483	41
9 Aug	199	46	224	49	423	68
10 Aug	230	36	290	45	520	55
11 Aug	73	22	109	32	181	39
12 Aug	23	35	145	35	168	53

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Table 13.–Page 2 of 2.

Date	75 cm ≤ AL < 90 cm		AL ≥ 90 cm		AL ≥ 75 cm	
	Passage	SE	Passage	SE	Passage	SE
13 Aug	157	32	193	40	351	56
14 Aug	139	32	133	24	272	35
15 Aug	115	42	97	37	212	63
16Aug	66	33	72	31	138	45
17Aug	163	34	67	31	230	49
18Aug	97	45	139	34	235	56
19Aug	72	37	49	38	120	55
20Aug	61	31	97	45	157	64
Total	8,151	248	9,536	265	17,687	377

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

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

FIGURES

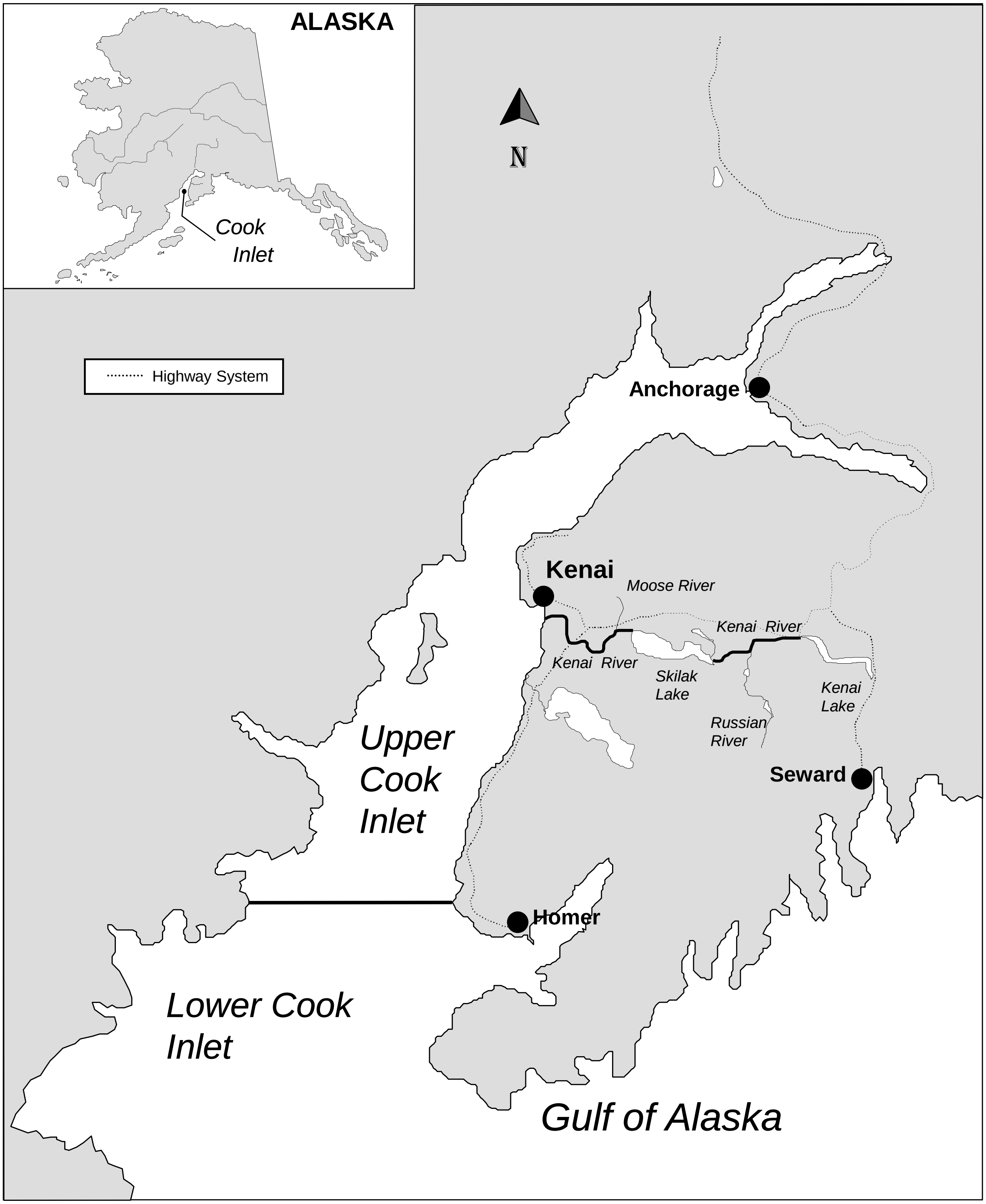

Figure 1.–Cook Inlet showing the location of the Kenai River.

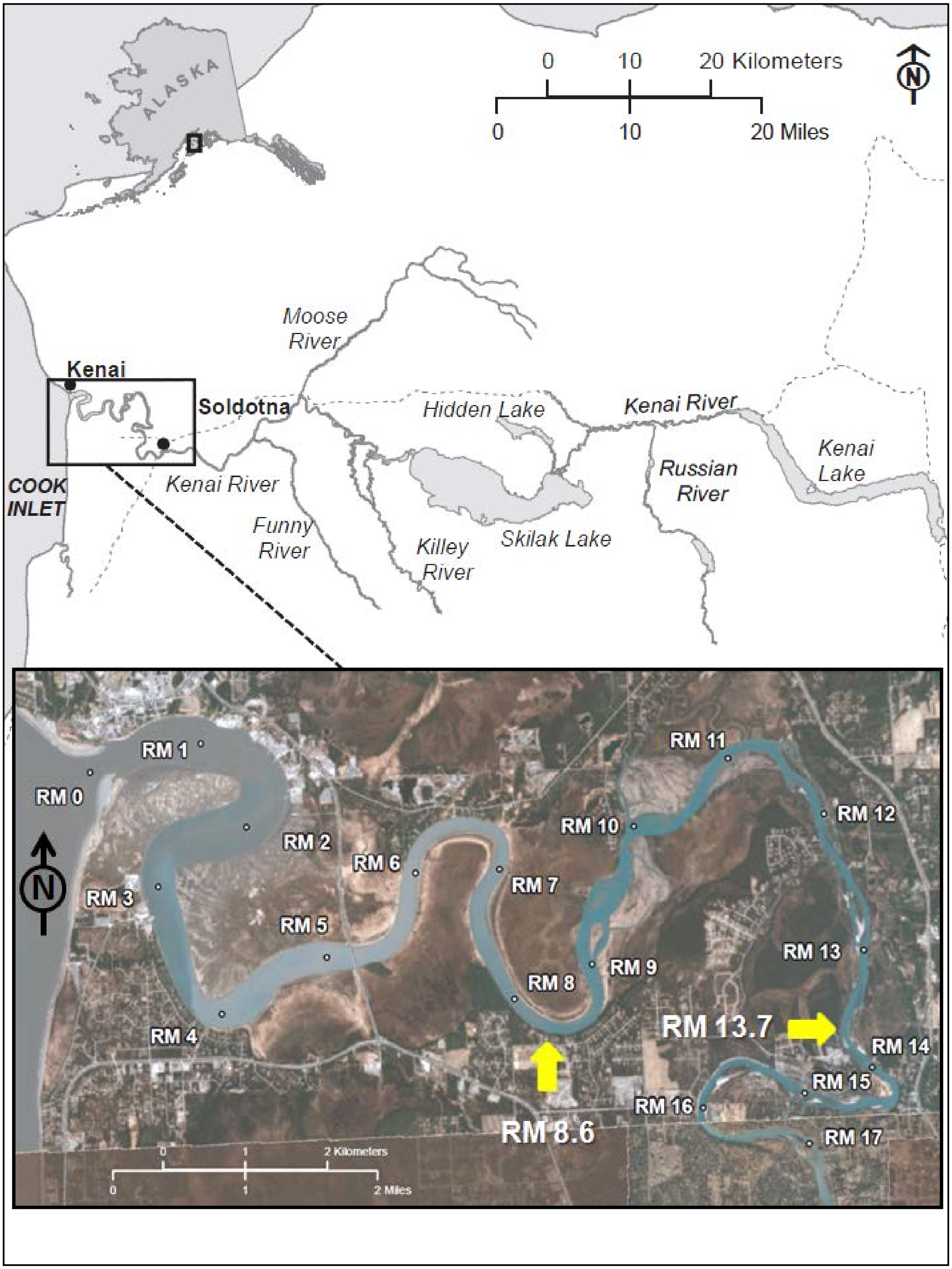

Figure 2.–Map of Kenai River showing location of RM 8.6 netting project and RM 13.7 Chinook salmon sonar site.

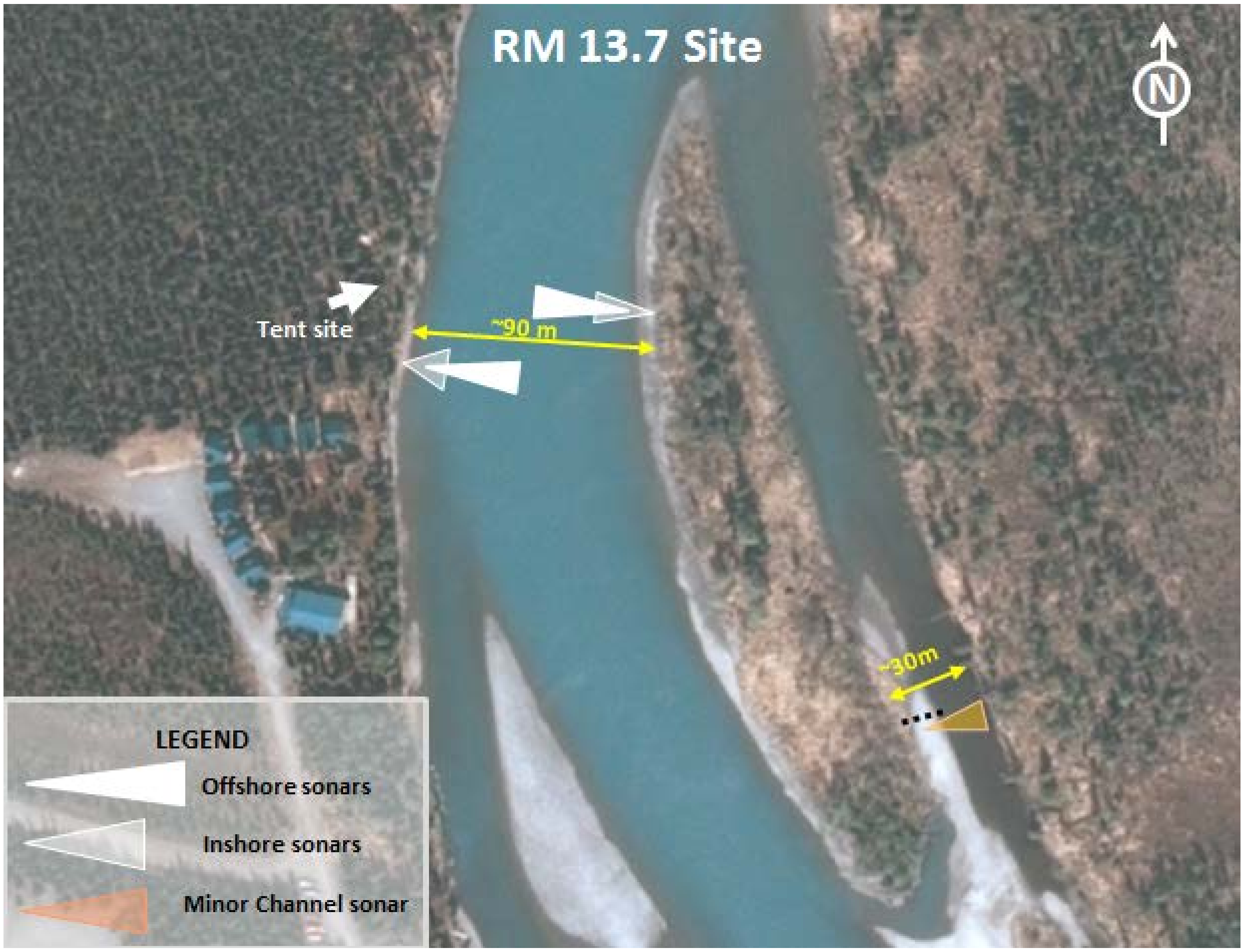

Figure 3.–Kenai River mile 13.7 sonar site showing approximate beam coverage.

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

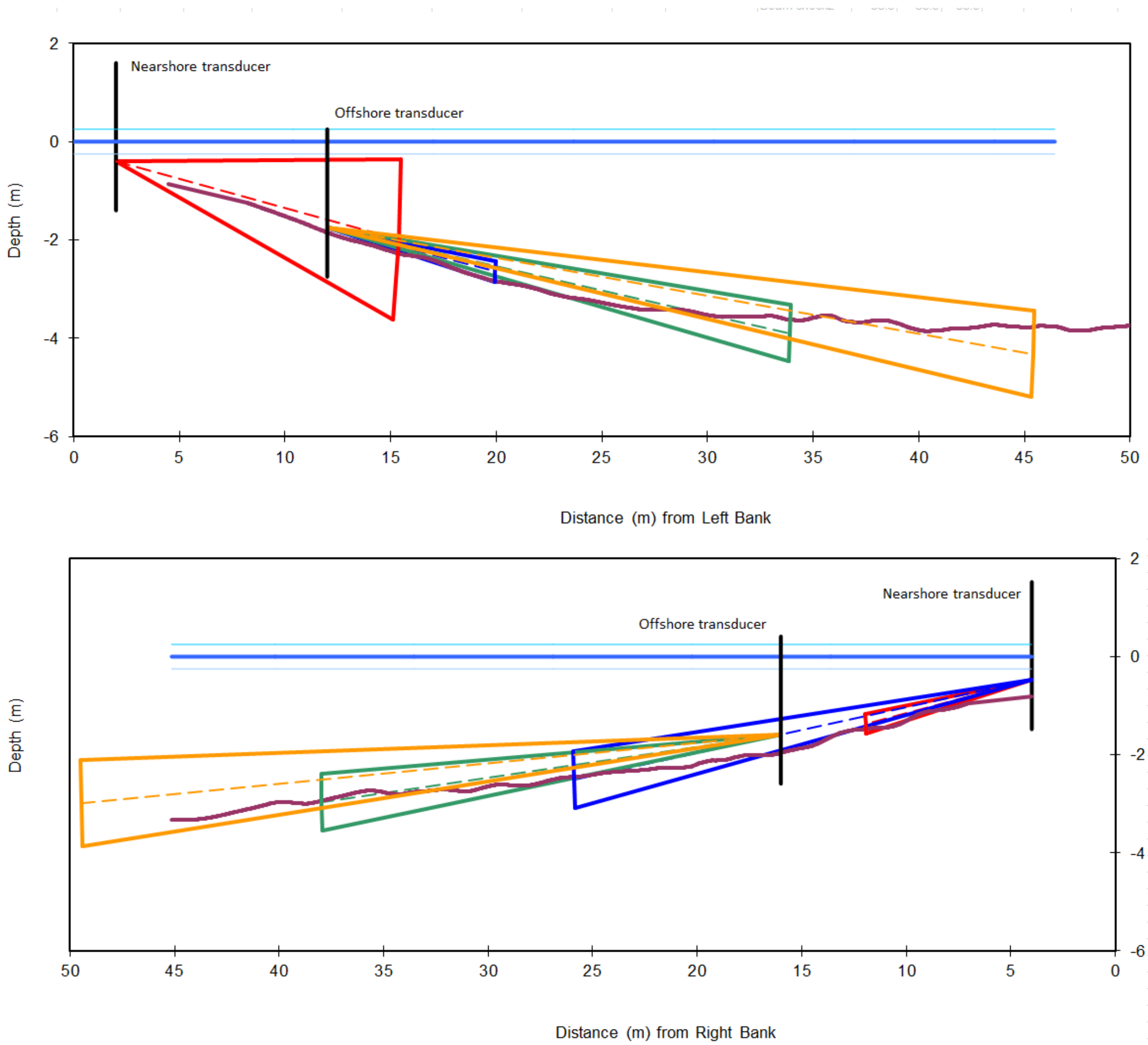

Figure 4.–Kenai River mile 13.7 main channel left and right bank bottom profiles collected on 8 July 2015 with nearshore and offshore sonar beams superimposed.

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

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

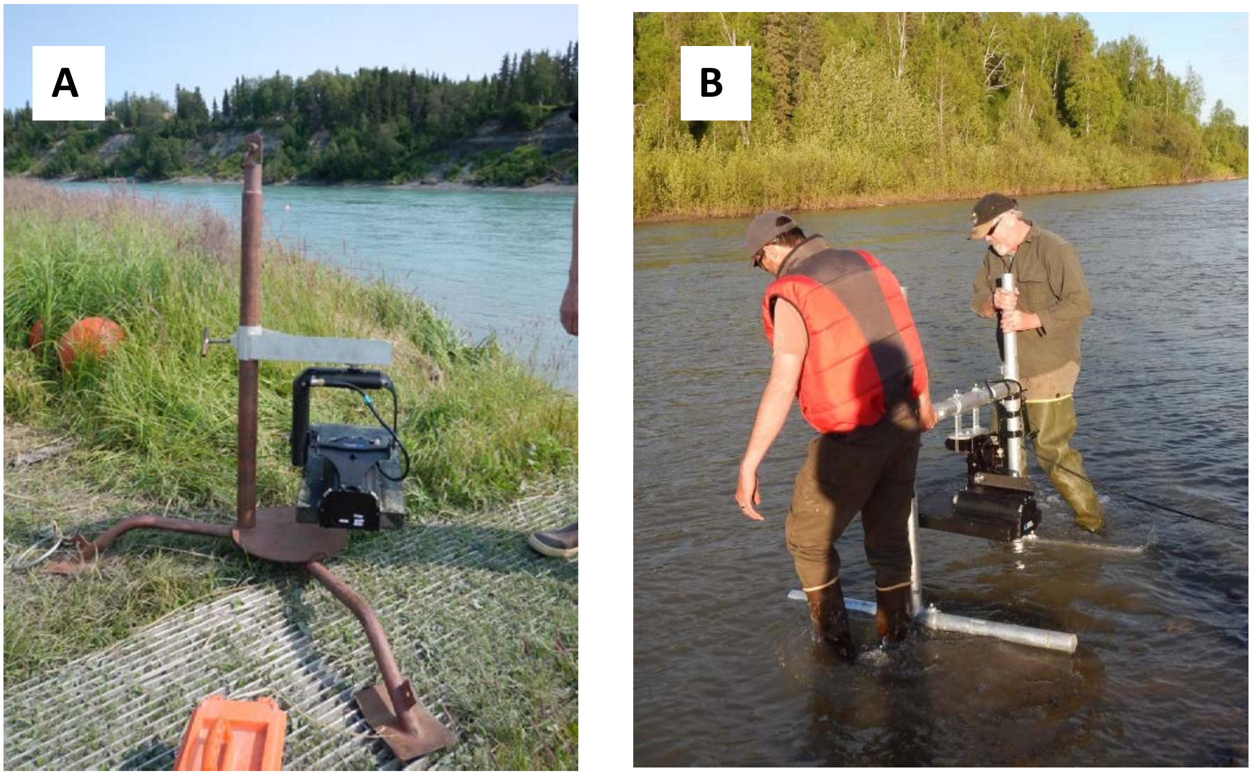

Figure 6.–An ARIS 1200 with a high-resolution lens mounted on a steel tripod for offshore deployment (A) and on an aluminum H-mount for nearshore deployment (B).

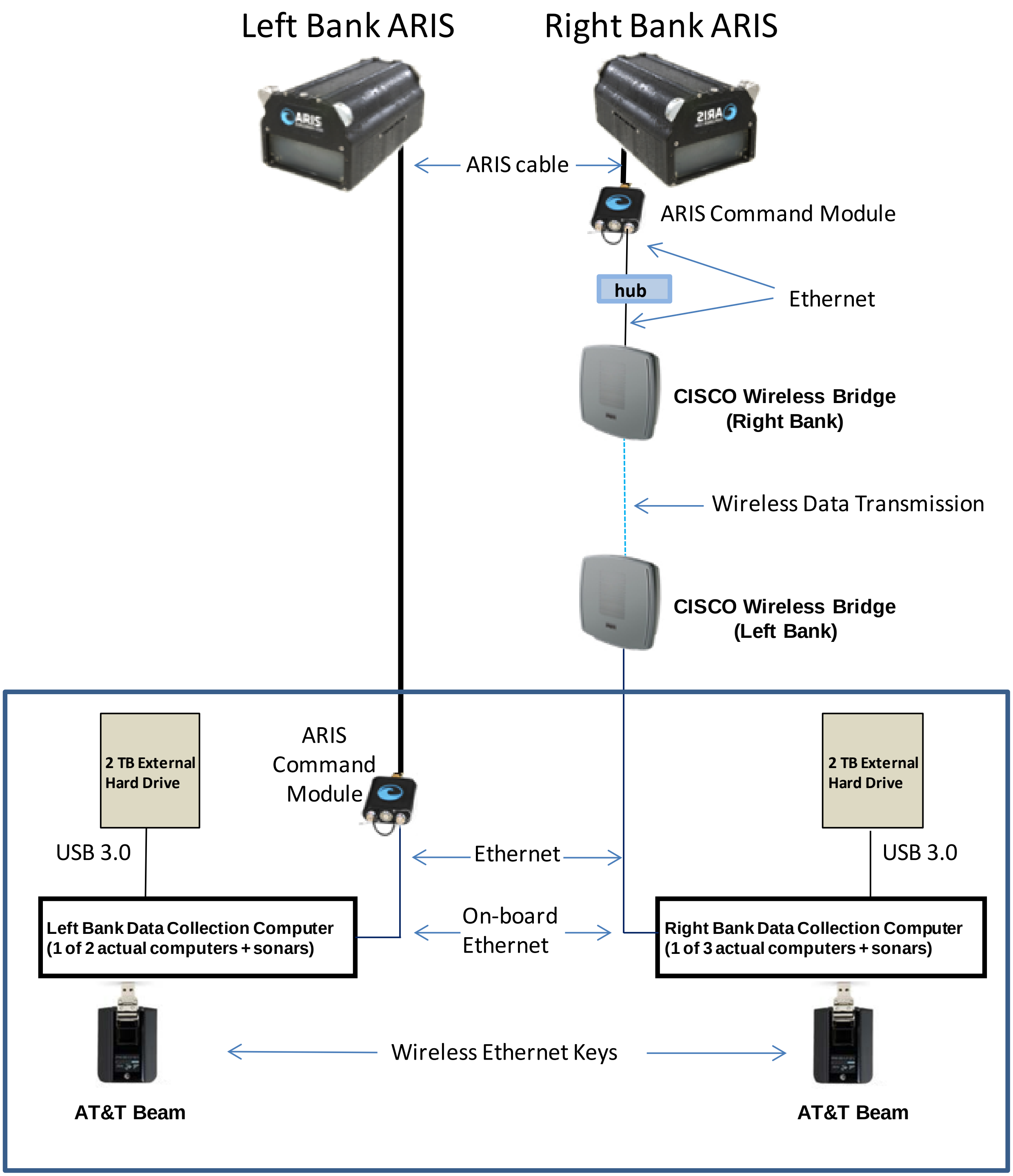

Figure 7.–ARIS data collection schematic for the RM 13.7 site on the Kenai River.

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

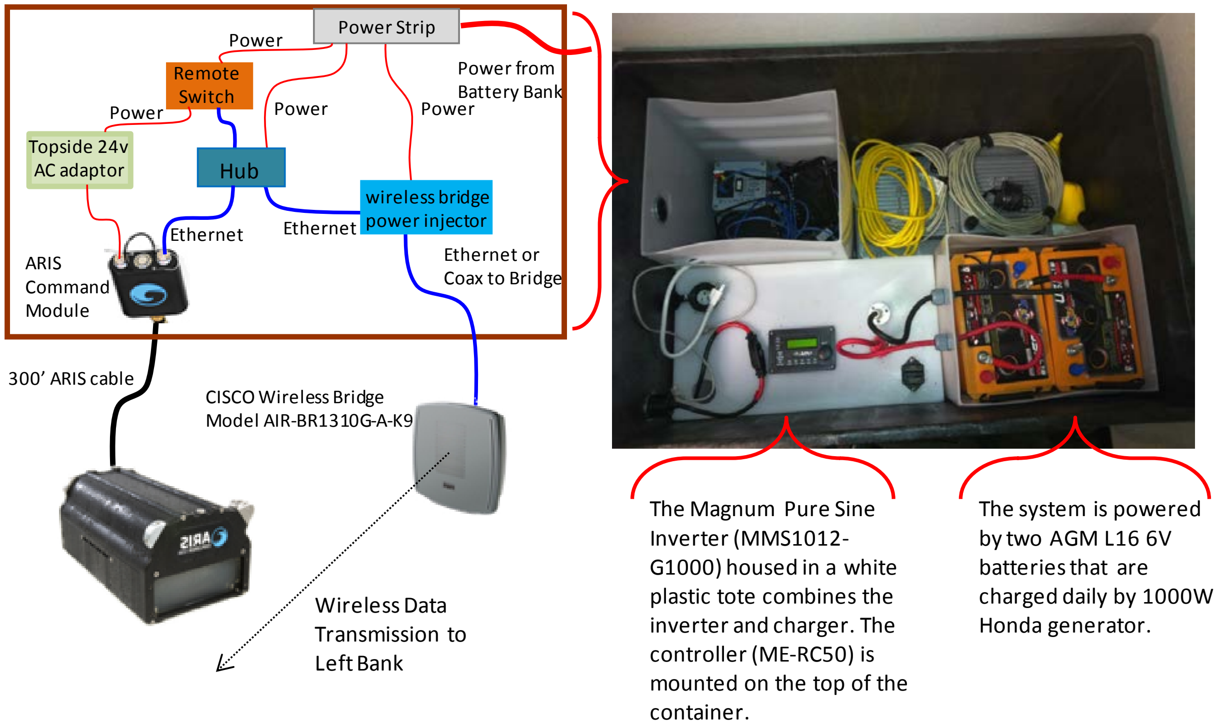

Figure 8.–Diagram showing components required on the right bank for wireless transmission of ARIS data to a data-collection computer located in the left-bank sonar tent.

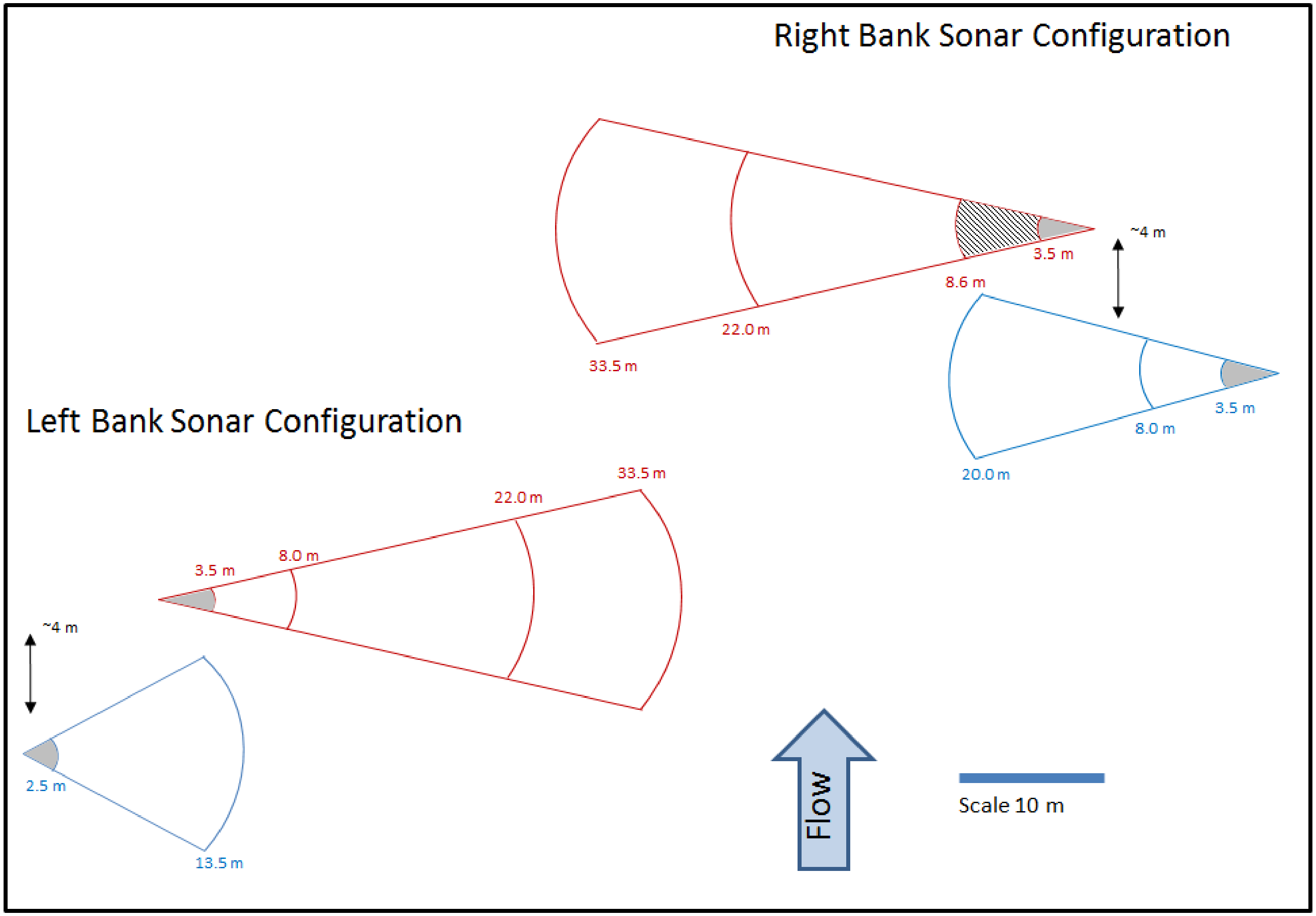

Figure 9.–Schematic for 4 left-bank (1 nearshore range [blue], 3 offshore ranges [red]) and 4 right-bank (2 nearshore ranges [blue], 2 offshore ranges [red]) range strata on the main channel of the Kenai River at RM 13.7.

Note: No data are collected between the face of the transducer and the start of the first range stratum in order to avoid range-related size bias caused by poor focal resolution at such close ranges (see Appendix A1). Data were collected in the right bank offshore 3.5–8.6 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 3.5–8.6 m stratum was covered by the right bank inshore 8.0–20.0 m stratum.

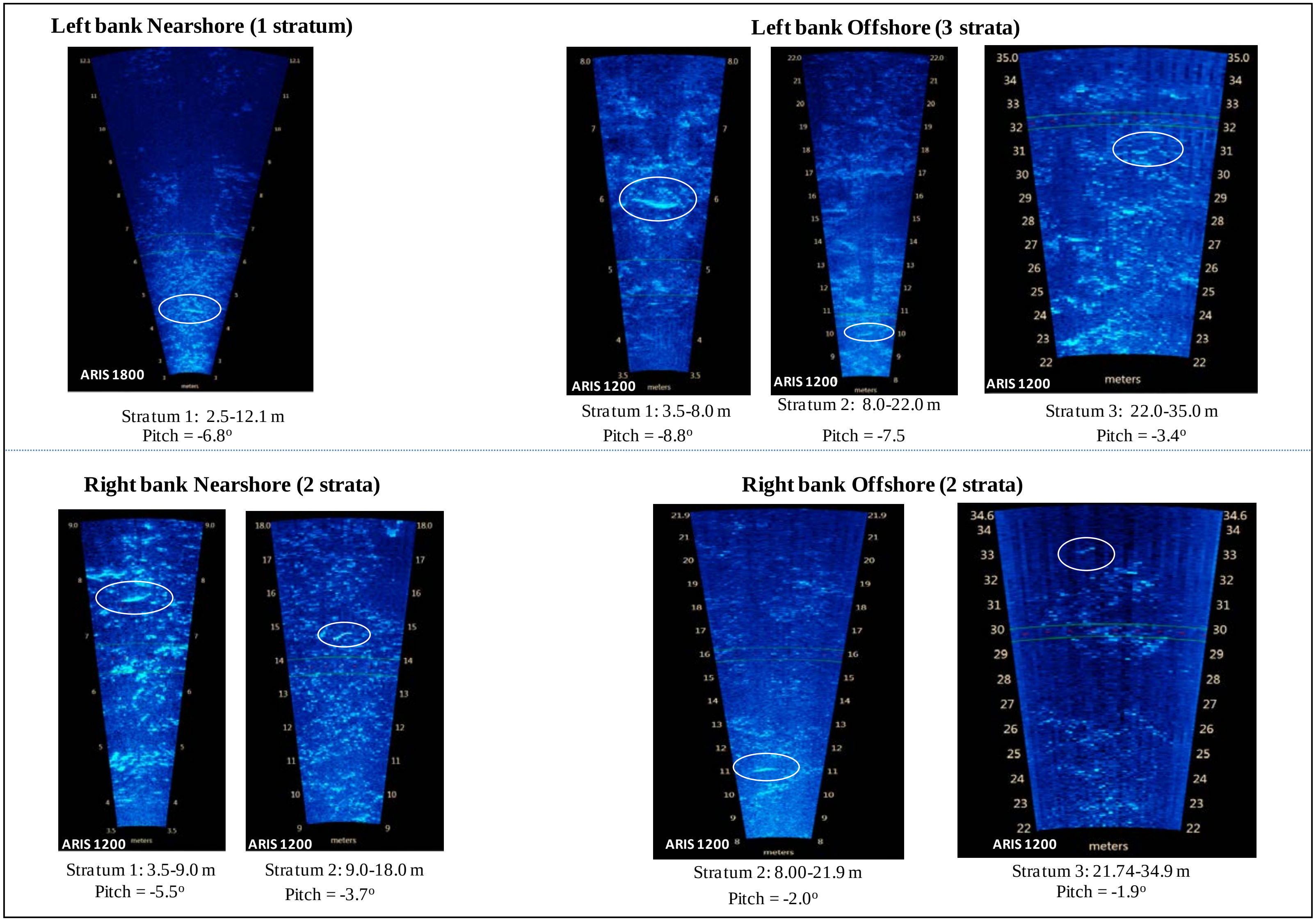

Figure 10.–Example images from each of the 4 left-bank (top) and 4 right-bank (bottom) range strata taken at RM 13.7 Kenai River on 1 July 2014.

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

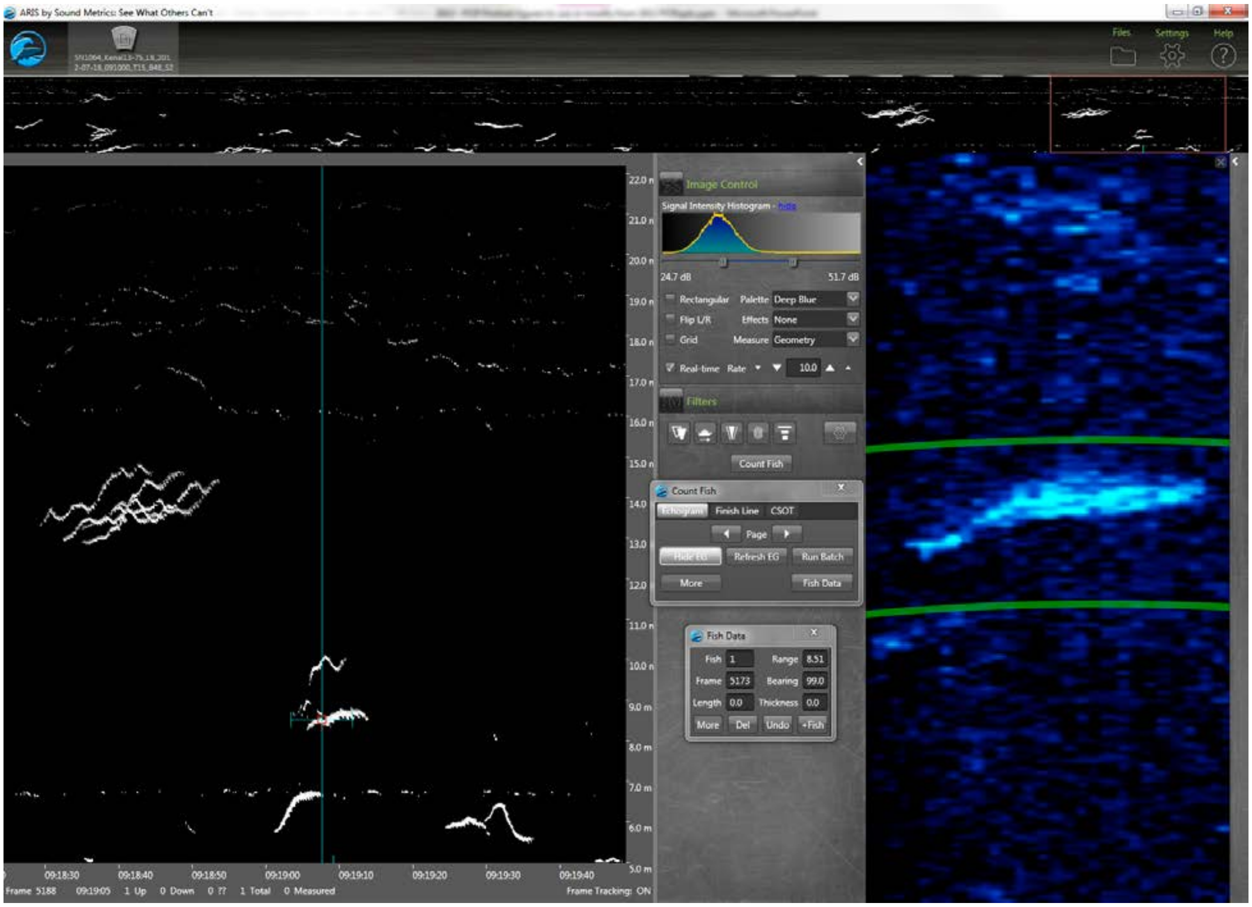

Figure 11.–ARISFish display window showing an echogram (at left) with traces of migrating fish that can be simultaneously displayed in video mode (at right) where fish images can be enlarged and measured.

Figure 12.–DIDSON-LR configured with a high-resolution lens covered with a silt sock and deployed in the vertical orientation using an X2 rotator and tripod-style mount, Kenai River mile 13.7, 2015.

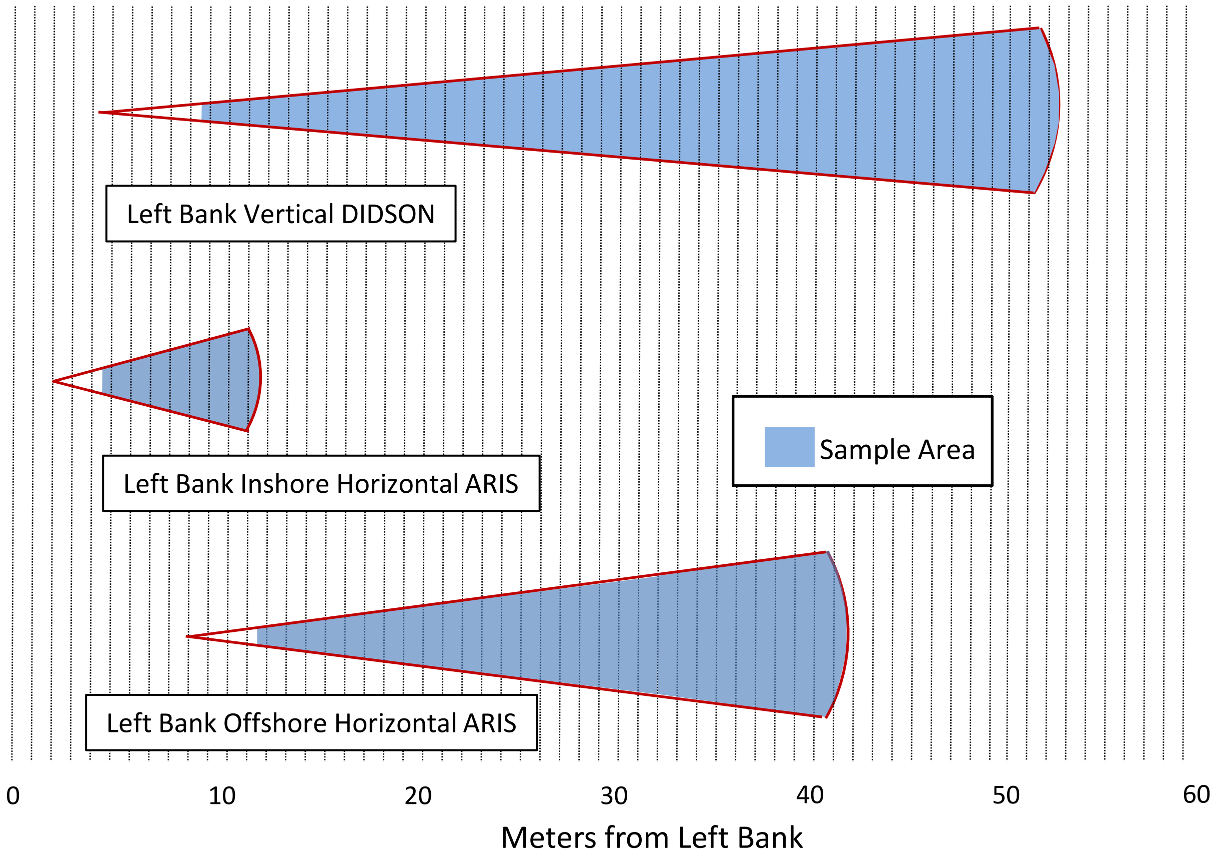

Figure 13.–Diagram depicting overlapping coverage of the left bank horizontally oriented ARIS and vertically oriented DIDSON-LR, Kenai River mile 13.7 sonar project, 2015.

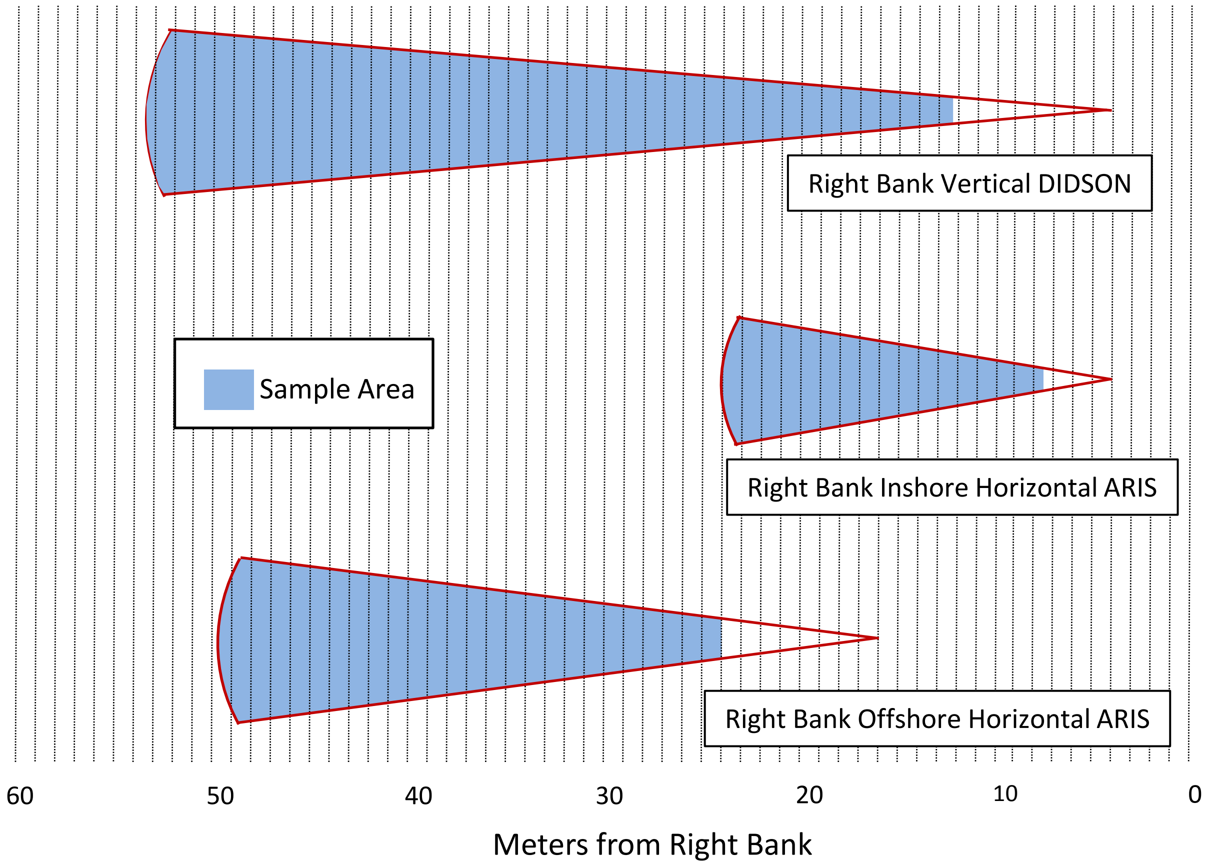

Figure 14.–Diagram depicting overlapping coverage of the right bank horizontally oriented ARIS and vertically oriented DIDSON-LR, Kenai River mile 13.7 sonar project, 2015.

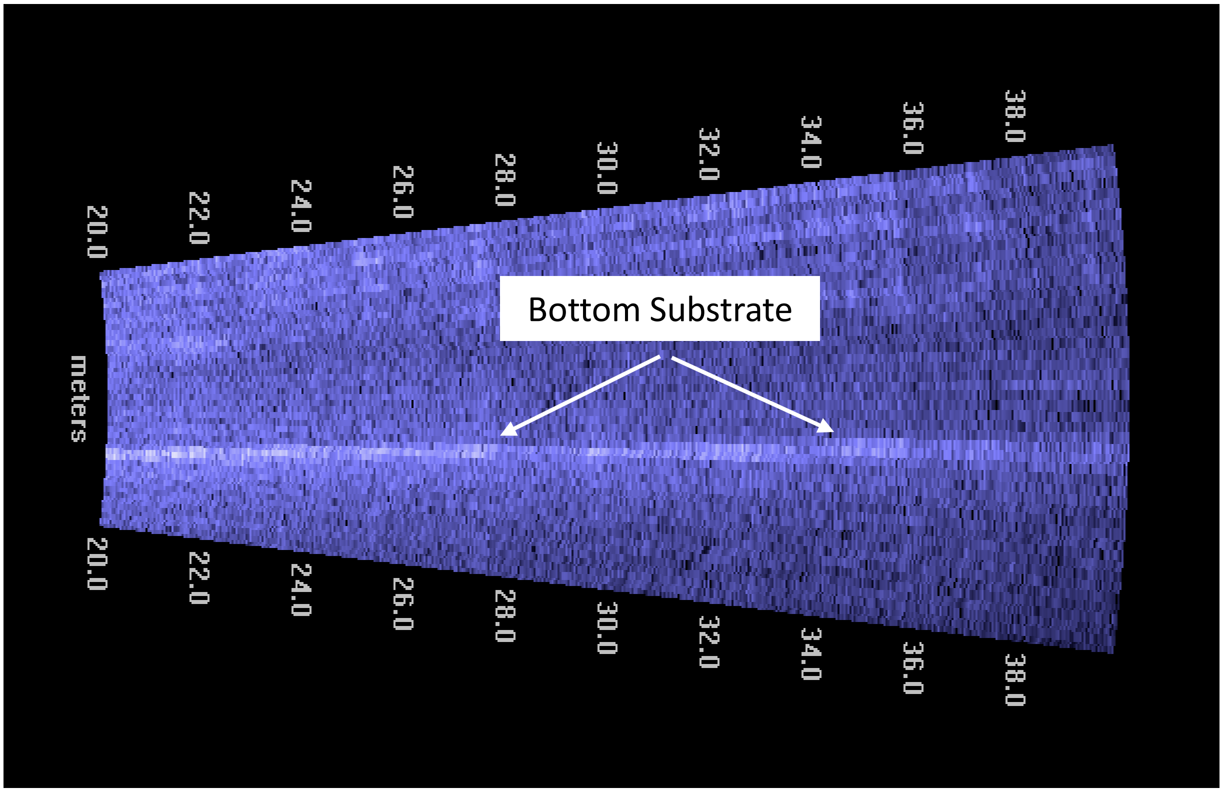

Figure 15.–Image from vertically oriented DIDSON-LR (left bank 20–40 m range stratum) with river bottom visible near the center axis of the image, Kenai River mile 13.7 sonar project, 2015.

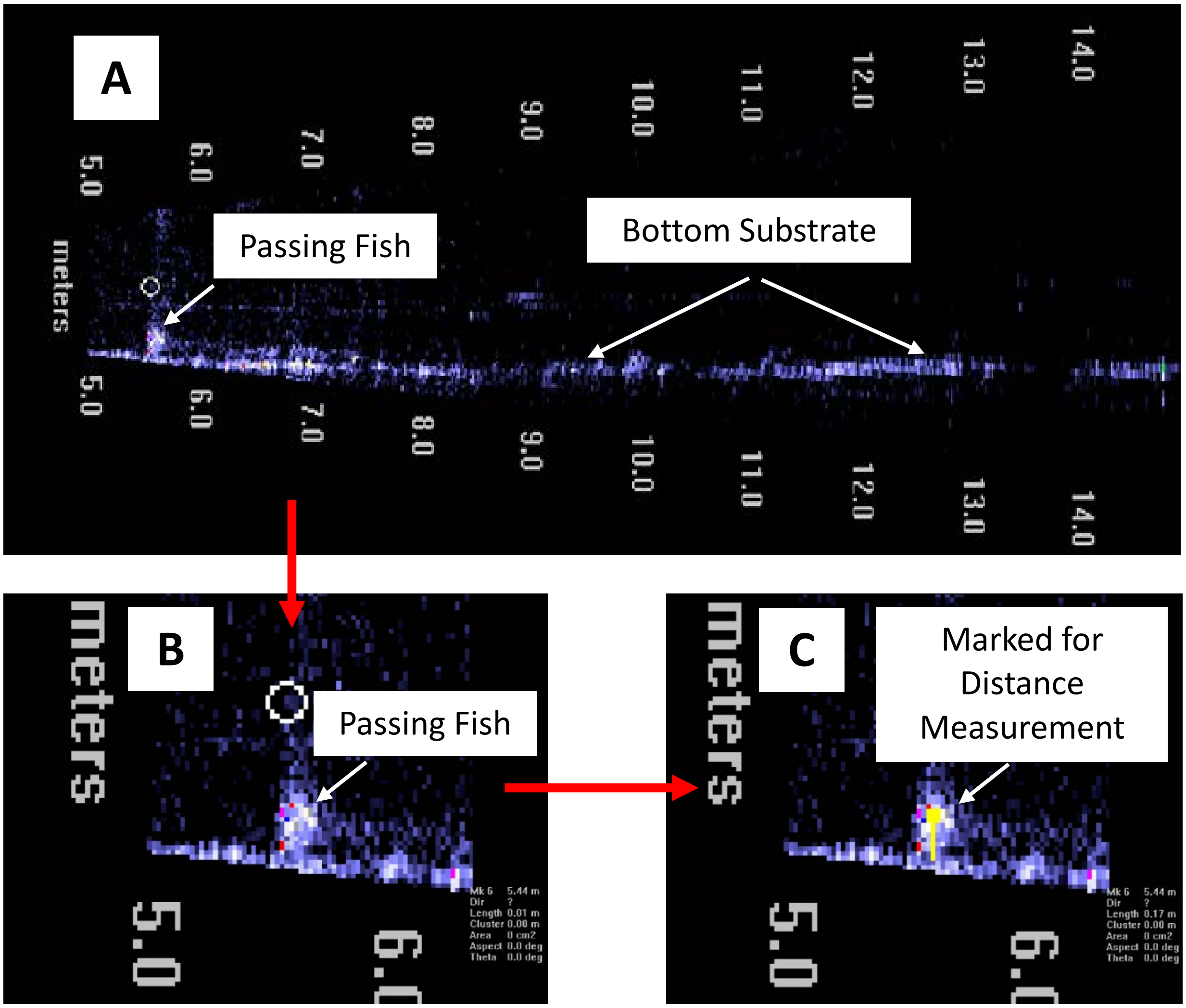

Figure 16.–Images taken from vertically oriented DIDSON-LR showing bottom substrate and passing fish (Panel A), a zoomed image of the passing fish (Panel B), and the yellow mark showing the distance measurement from center of the fish to the bottom substrate (Panel C), Kenai River mile 13.7 sonar project, 2015.

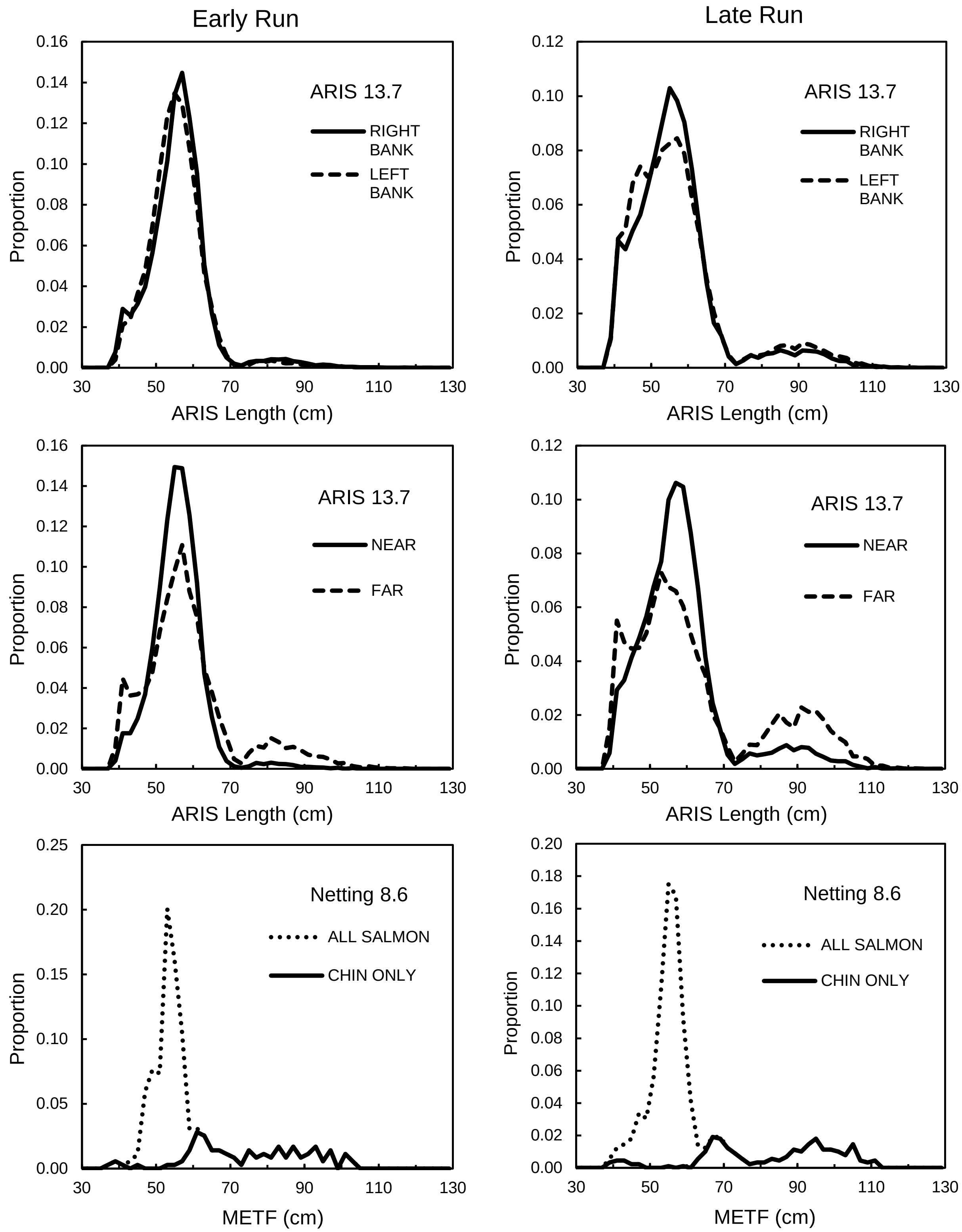

Figure 17.–Frequency distributions of ARIS lengths by bank at RM 13.7 (top), ARIS lengths by near and far transducers (middle), and mid eye to tail fork (METF) lengths by species (all salmon vs. Chinook salmon only) from an inriver netting project at RM 8.6 (bottom), Kenai River early and late runs, 2015.

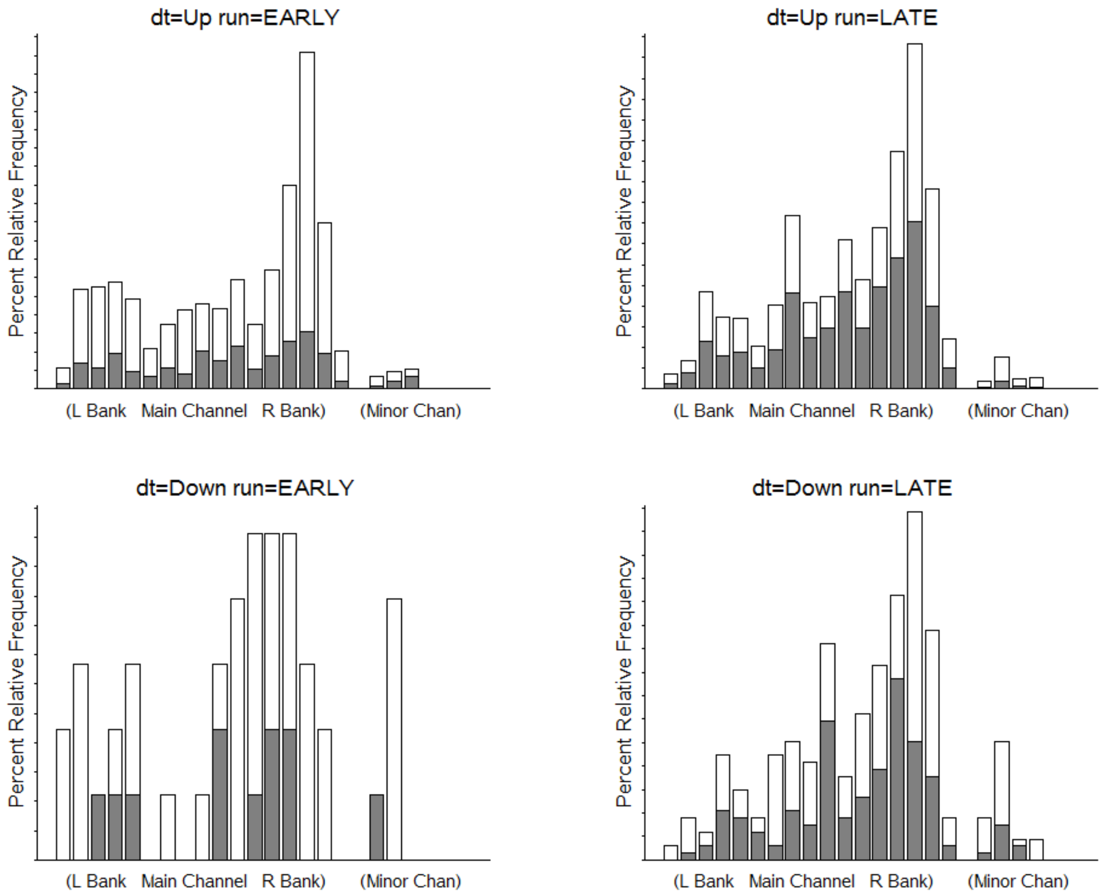

Figure 18.–Horizontal distribution, in 5 m increments from the left-bank main channel shore to the right-bank minor channel shore, of medium (75 cm ≤ AL < 90 cm, open bars) and large (AL ≥ 90 cm, solid bars) early- and late-run fish measured from ARIS, RM 13.7 Kenai River, 2015.

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

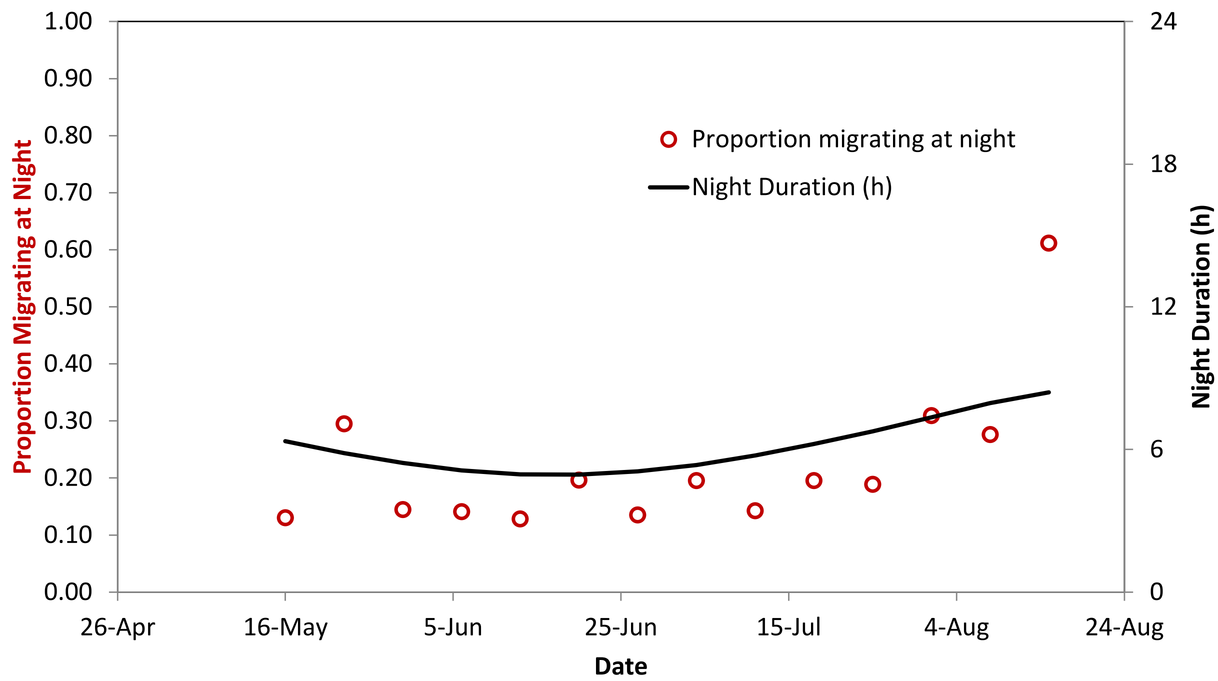

Figure 19.–Weekly proportions of fish greater than 75 cm AL migrating upstream at night (between sunset and sunrise; red circles), compared to relative night duration (solid line) in Kenai, Alaska.

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.

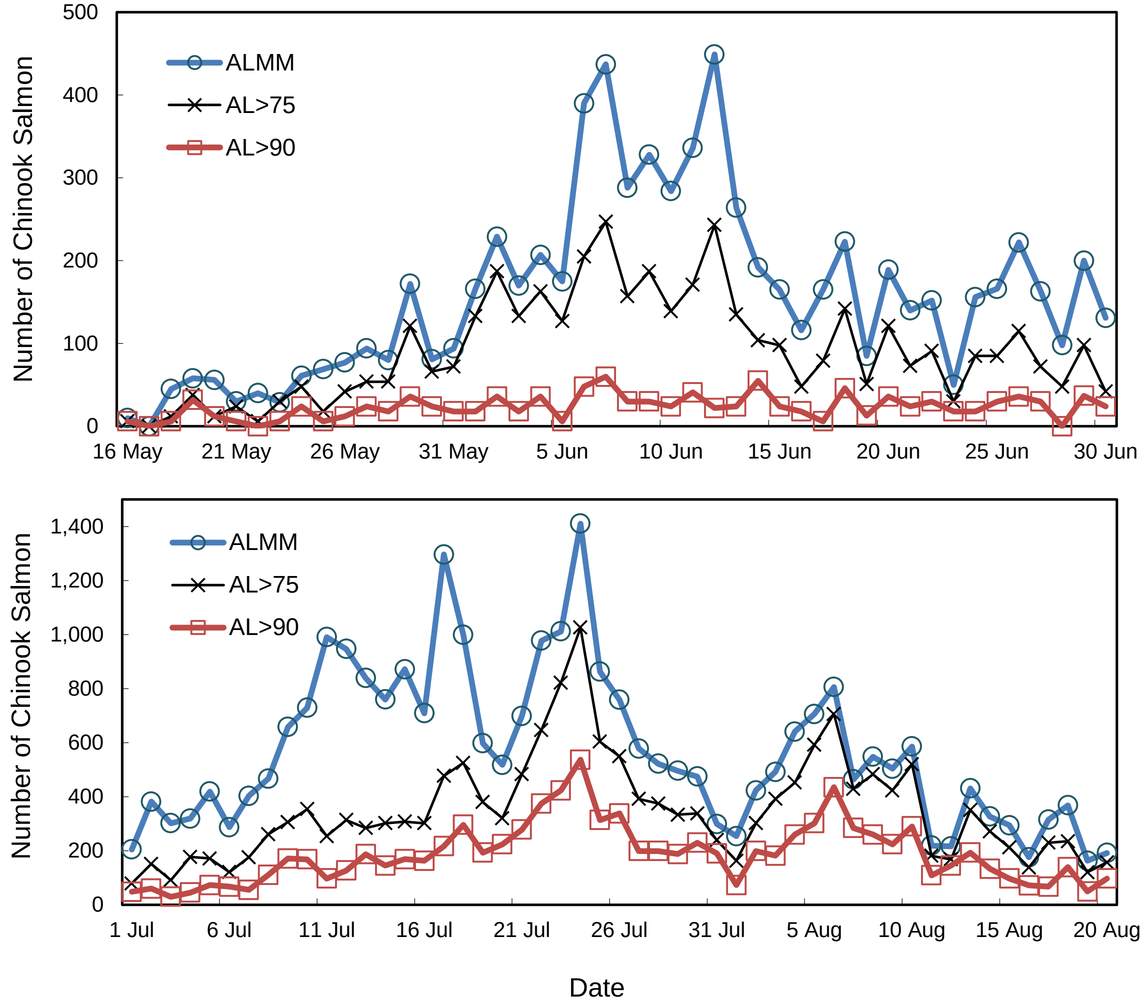

Figure 20.–Estimated net upstream passage of Chinook salmon based on an ARIS-length mixture model (ALMM) and estimated net upstream passage of medium and large Chinook salmon greater than or equal to 75 cm ARIS length (AL $\geq$ 75) and large Chinook salmon greater than or equal to 90 cm (AL $\geq$ 90) for early- (top) and late-run (bottom) Kenai River Chinook salmon, 2015.

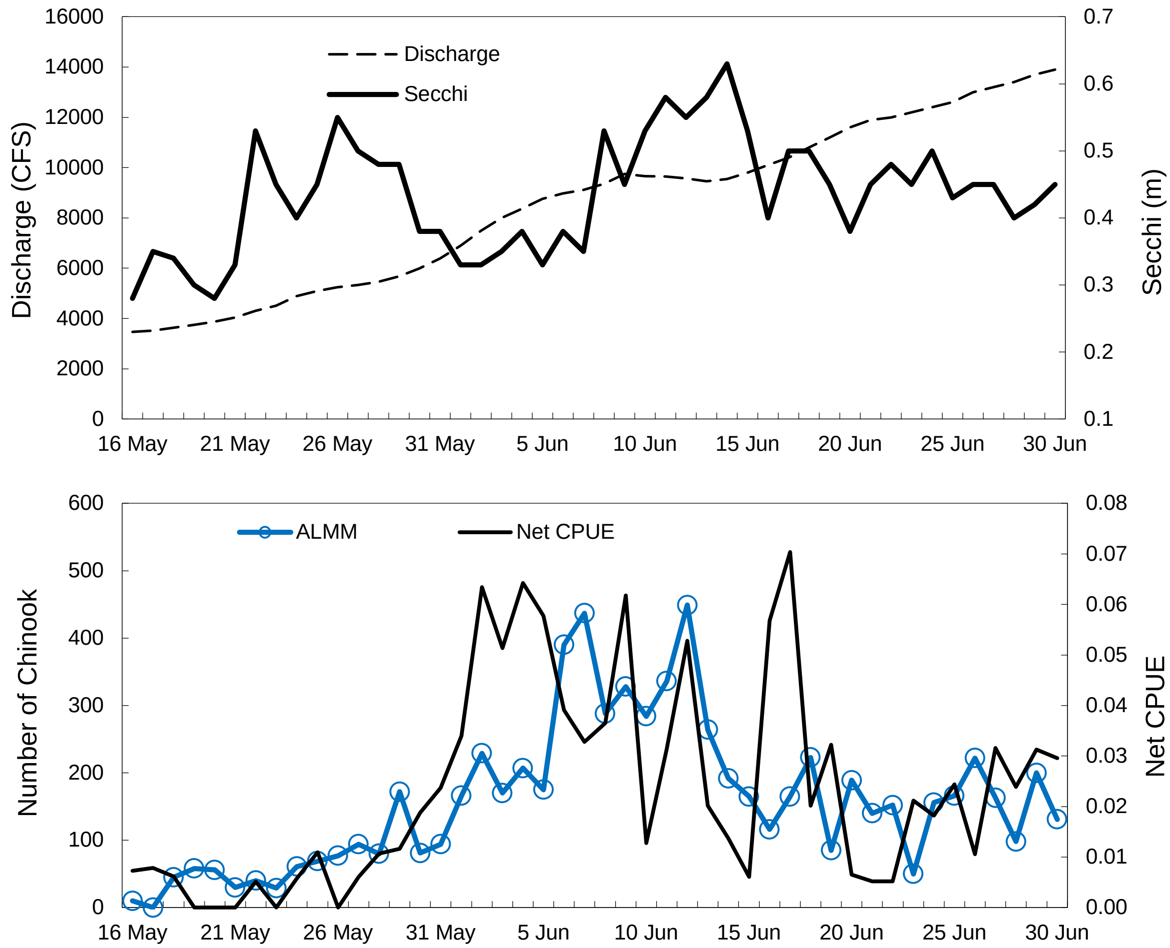

Figure 21.–Daily discharge rates collected at the Soldotna Bridge and Secchi disk readings taken at the RM 13.7 sonar site (top); and ARIS-length mixture model (ALMM) estimates of net upstream Chinook salmon passage at RM 13.7 and inriver gillnet Chinook salmon CPUE at RM 8.6 (bottom), early run 2015.

Note: River discharge taken from USGS[10]. Net CPUE and sport fish CPUE from Perschbacher (*In prep*)[11]. The sport fishery was closed during the entire 2015 early run.

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[10] USGS Water resource data, Alaska, water year 2015. Website Daily Streamflow for Alaska, Soldotna gauging station, site #15266300, accessed September 16, 2016. http://water.usgs.gov/ak/nwis/discharge.

[11] Perschbacher, J. *In prep*. Chinook salmon creel survey and inriver gillnetting study, lower Kenai River, Alaska, 2015. Alaska Department of Fish and Game, Fishery Data Series, Anchorage.

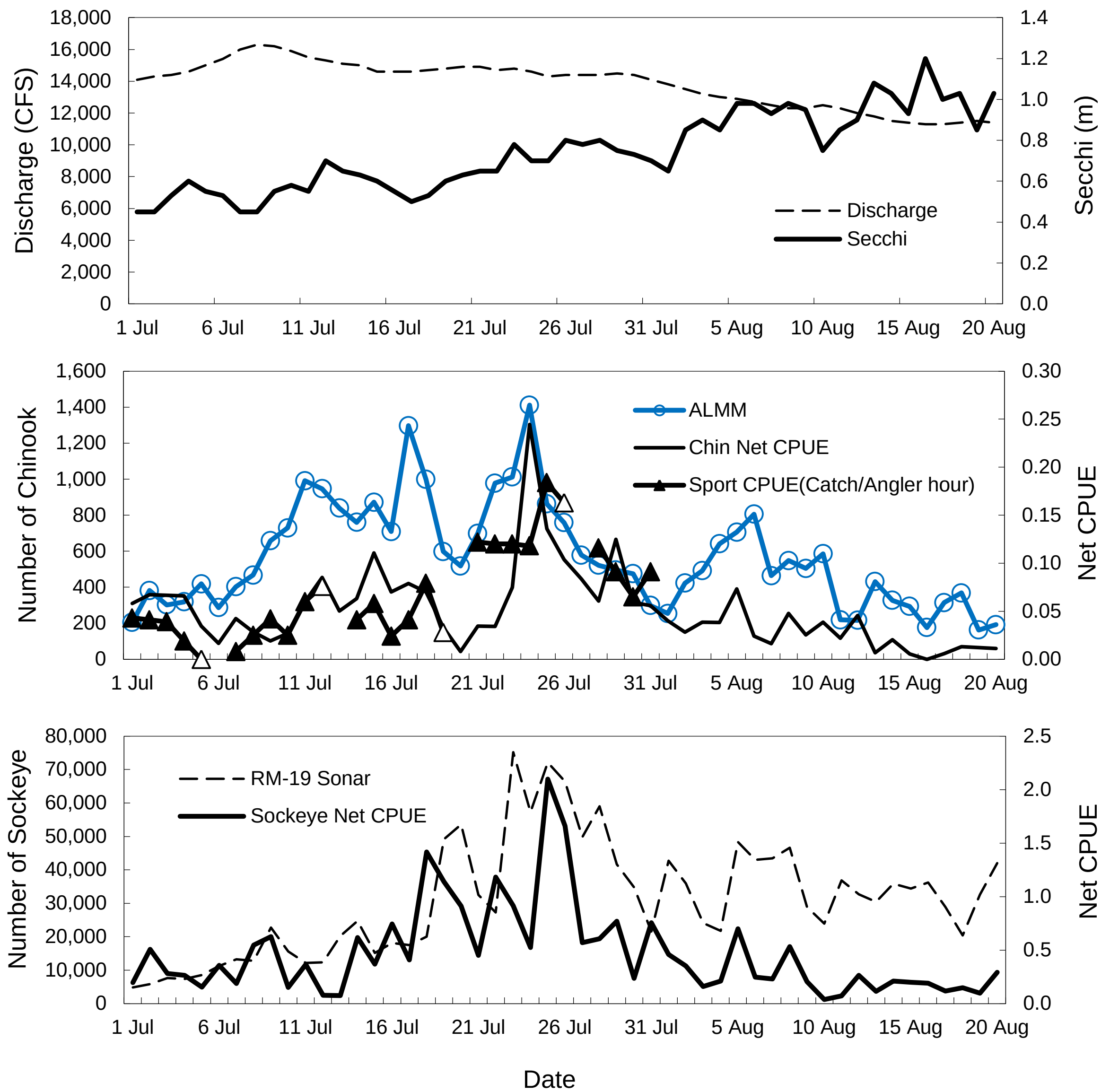

Figure 22.–Daily discharge rates collected at the Soldotna Bridge and Secchi disk readings taken at the RM 8.6 netting site (top); ARIS-length mixture model (ALMM) estimates of net upstream Chinook salmon passage at RM 13.7, inriver gillnet Chinook salmon CPUE at RM 8.6, and Chinook salmon sport fishery CPUE (middle); RM 19 sockeye salmon sonar passage and inriver gillnet sockeye salmon CPUE at RM 8.6 (bottom), Kenai River late run, 2015.

Note: River discharge taken from USGS[12]. Net CPUE and sport fish CPUE from Perschbacher (*In prep*)[13]. RM 19 sonar estimates from Glick and Willette. Open triangles represent days on which only unguided anglers were allowed to fish. The sport fishery closed after 31 July.

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[12] USGS Water resource data, Alaska, water year 2015. Website Daily Streamflow for Alaska, Soldotna gauging station, site #15266300, accessed September 16, 2016. http://water.usgs.gov/ak/nwis/discharge.

[13] Perschbacher, J. *In prep*. Chinook salmon creel survey and inriver gillnetting study, lower Kenai River, Alaska, 2015. Alaska Department of Fish and Game, Fishery Data Series, Anchorage.

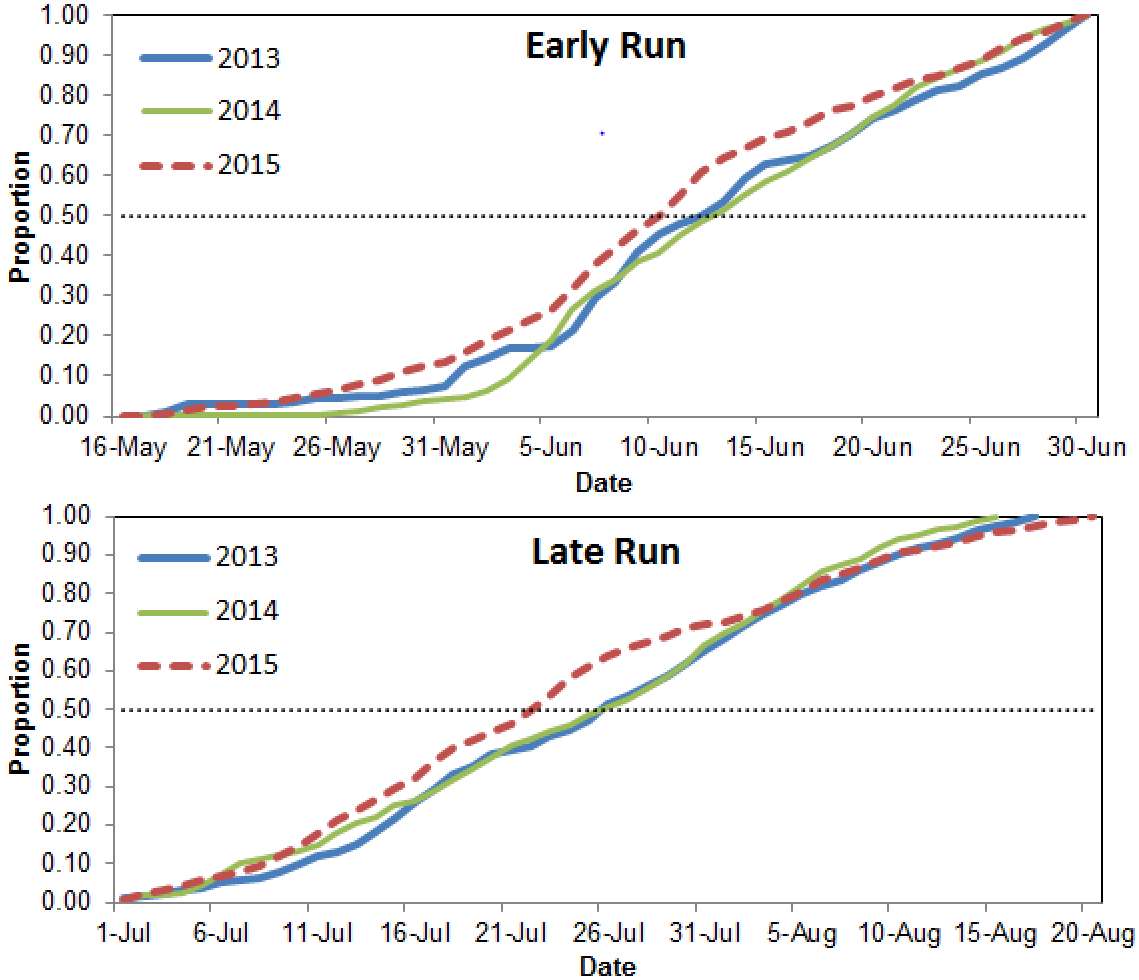

Figure 23.–Cumulative proportion of passage by day for all Chinook salmon (regardless of size) during the early (top) and late (bottom) run based on ARIS length mixture model analysis, Kenai River RM 13.7, 2013–2015.

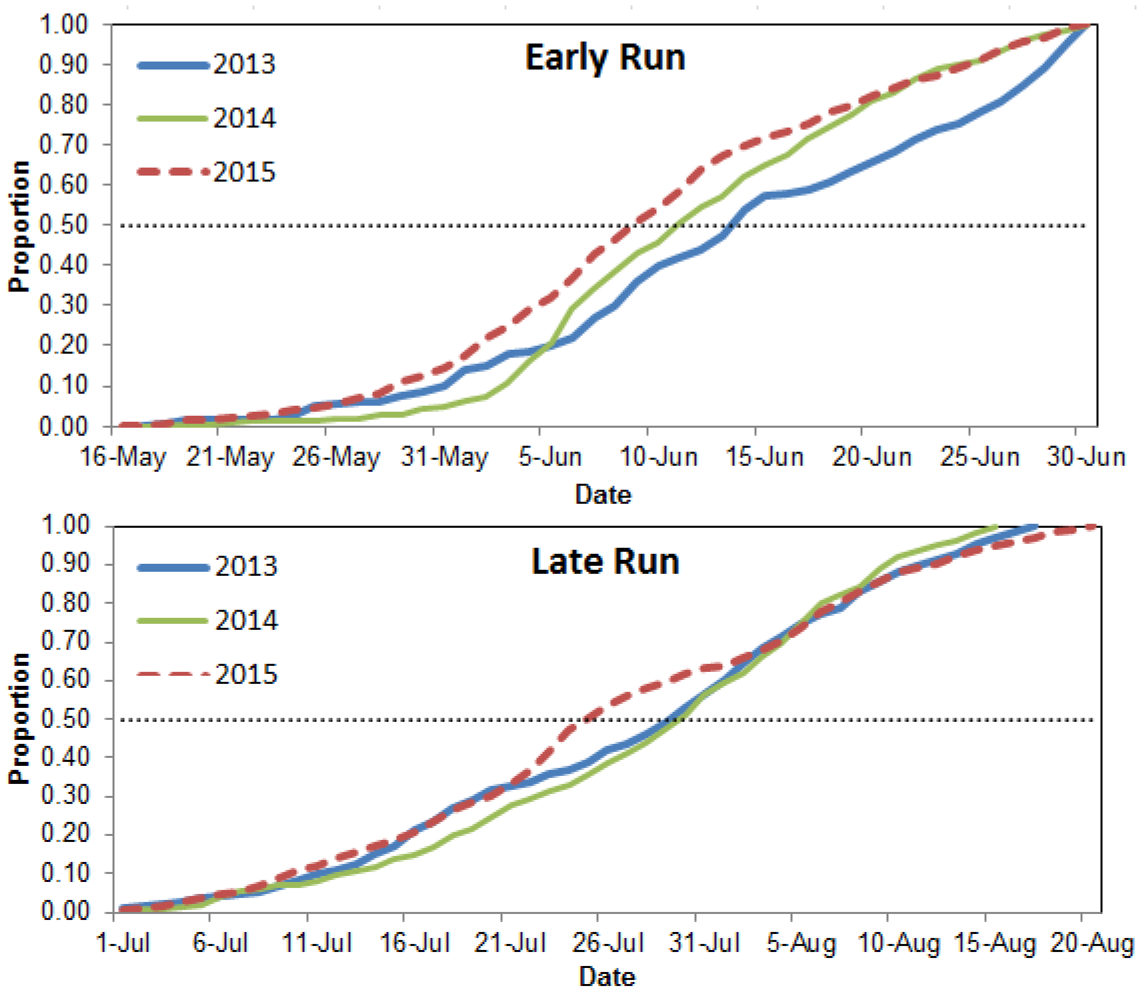

Figure 24.–Cumulative proportion of passage by day for Chinook salmon ≥75 cm AL during the early (top) and late (bottom) run, Kenai River RM 13.7, 2013–2015.

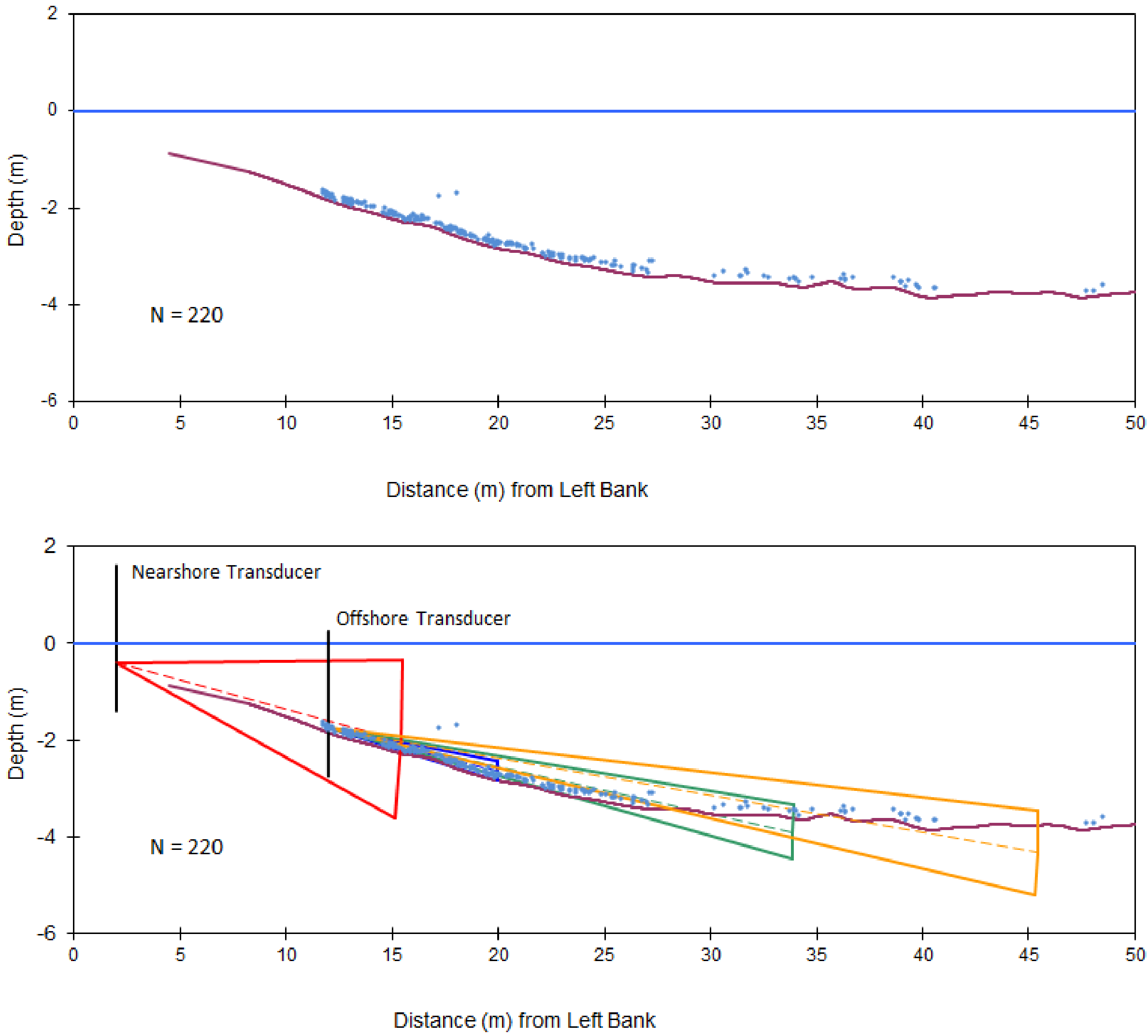

Figure 25.–Fish target distribution relative to the river bottom (top) and the inshore and offshore ARIS insonified zones (bottom), collected from the left bank of Kenai River at RM 13.7 from 11 to 13 June, 2015 using vertically-oriented DIDSON-LR.

Note: An ARIS 1800 with a standard lens and a 14° vertical field of view was deployed nearshore (red beam) and a ARIS 1200 with a high-resolution lens and a 3° vertical field of view was deployed offshore (blue, green, and yellow beams). Vertical DIDSON-LR data collection began approximately 11 m from the left bank; hence any fish passing inside of this range were not detected by the vertically oriented DIDSON-LR.

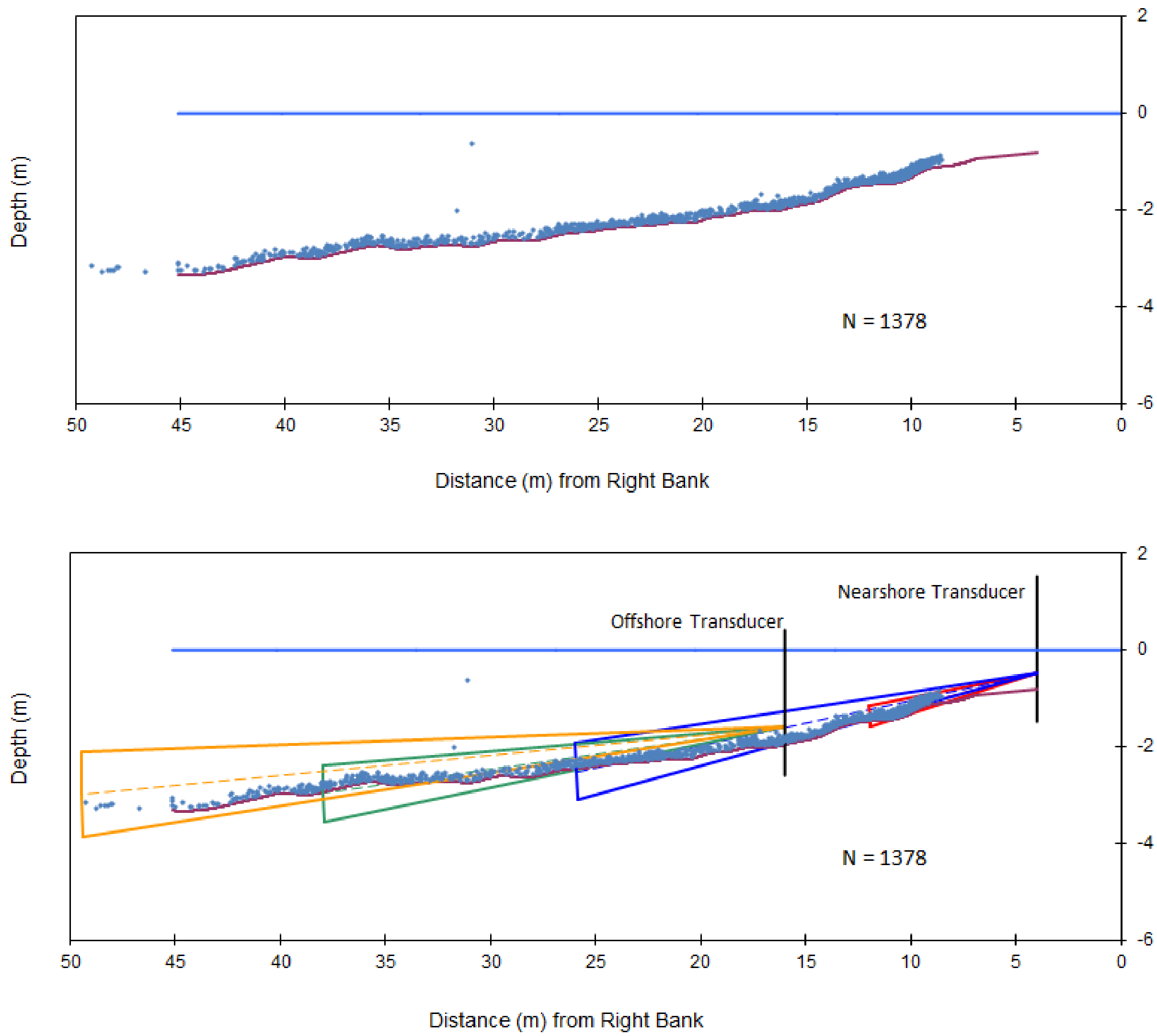

Figure 26.–Fish target distribution relative to the river bottom (top panel) and the inshore and offshore ARIS insonified zones (bottom panel), collected from the right bank of the Kenai River at RM 13.7 from 9 to 11 July and 18 to 19 July, 2015 using vertically-oriented DIDSON-LR.

Note: An ARIS 1200 with a high-resolution lens and a 3° vertical field of view was deployed both nearshore (red and blue beams) and offshore (green and yellow beams). Vertical DIDSON-LR data collection began approximately 8 m from the right bank; hence any fish passing inside of this range were not detected by the vertically-oriented DIDSON-LR.

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 following formula:

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

where

W = window length (cm), and

N = number of range samples (or pixels).

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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

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ARIS 1200 Specifications (continued)

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

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

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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

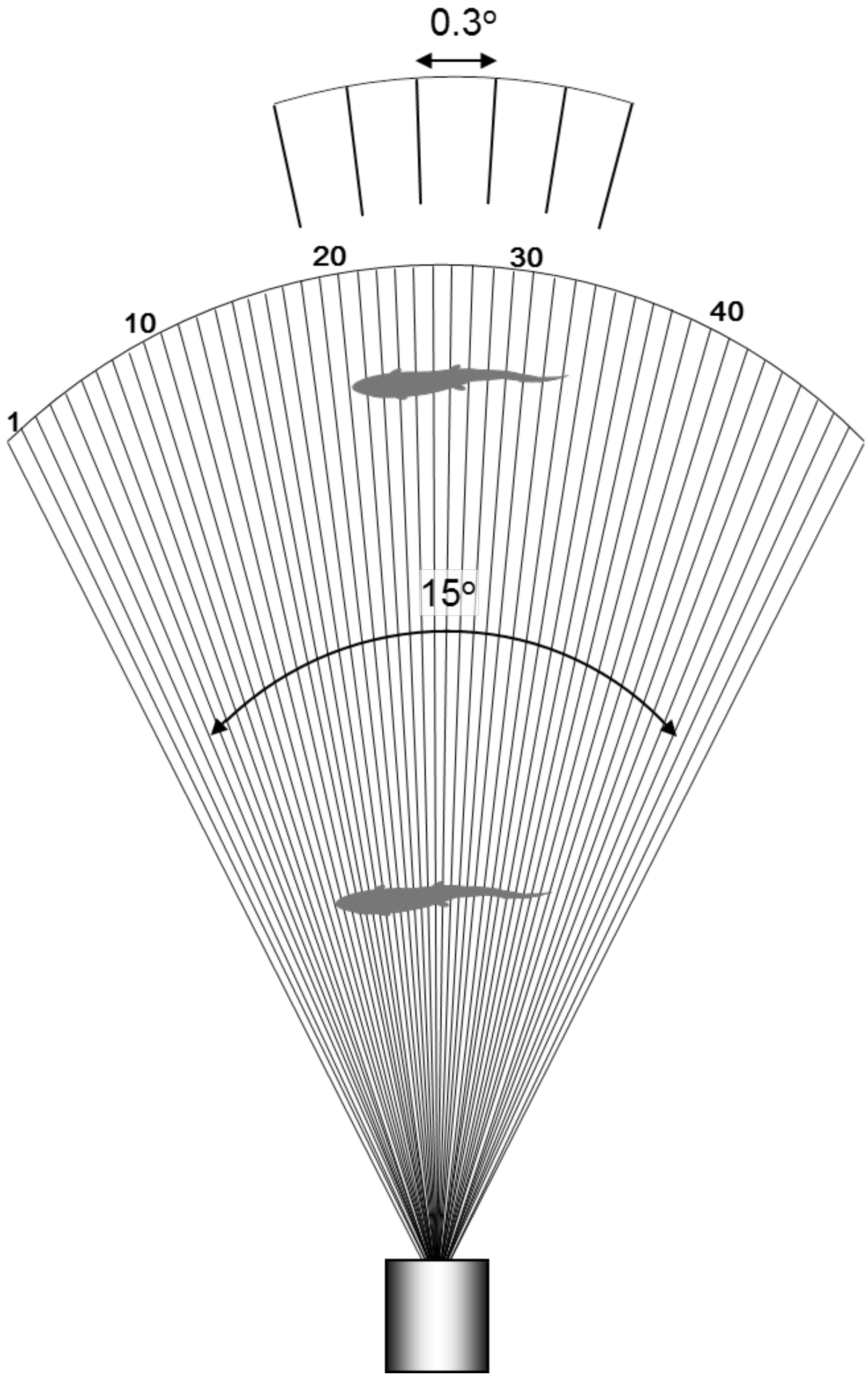
Weight in Air 7.9 kg (17.4 lb)

Weight in Sea Water 1.0 kg (2.2 lb)

Dimensions 31.0 cm × 20.6 cm × 17.1 cm

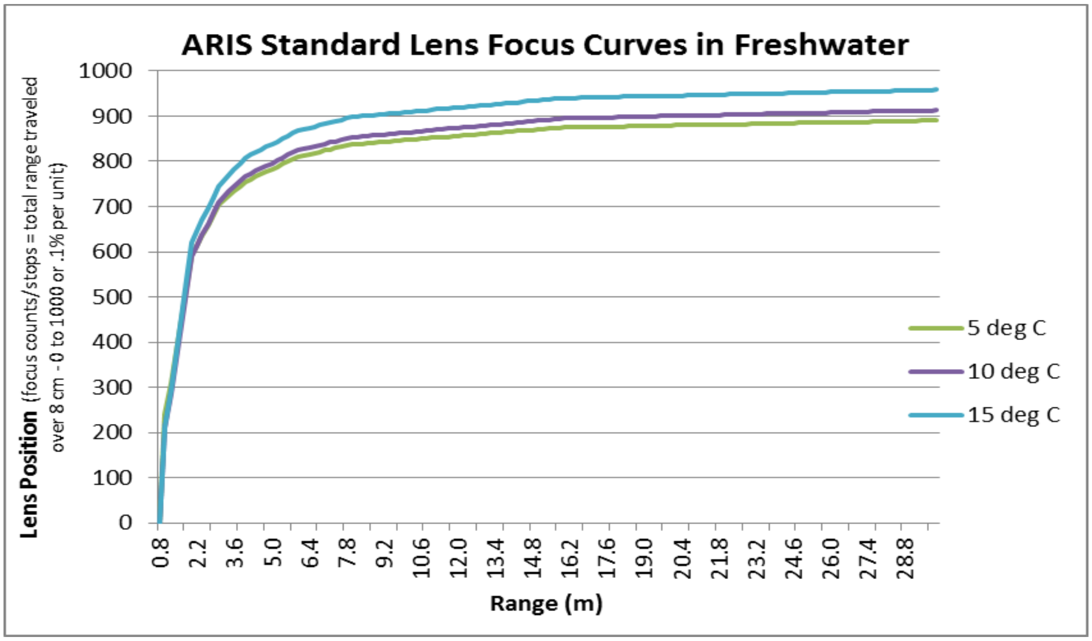
Topside PC Requirements Windows (XP, Vista, 7), Ethernet

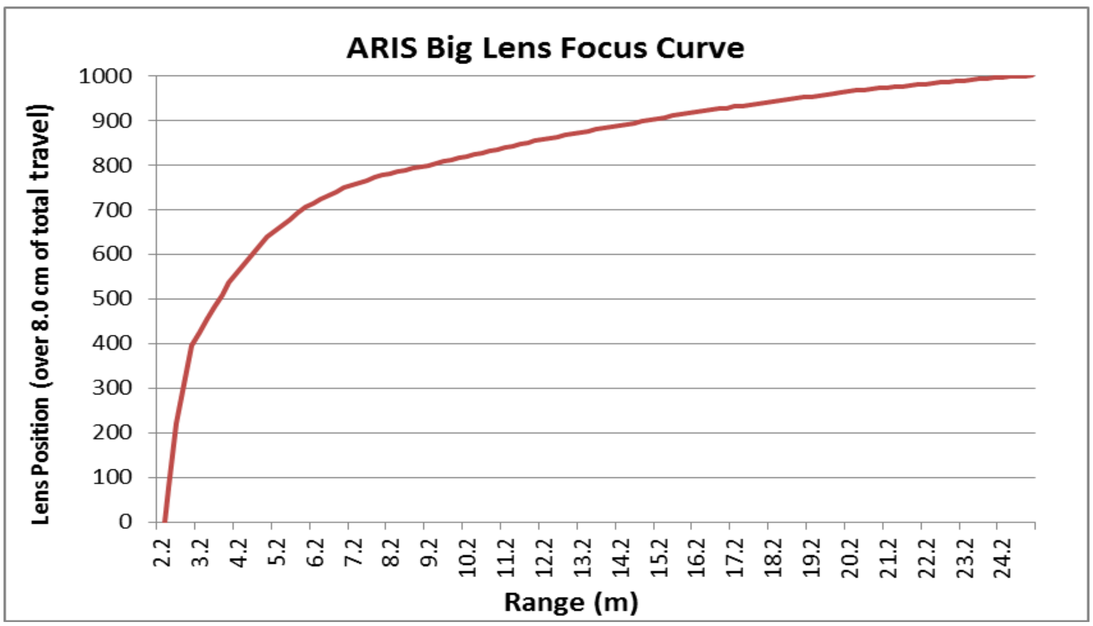
Optional NTSC video monitor



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

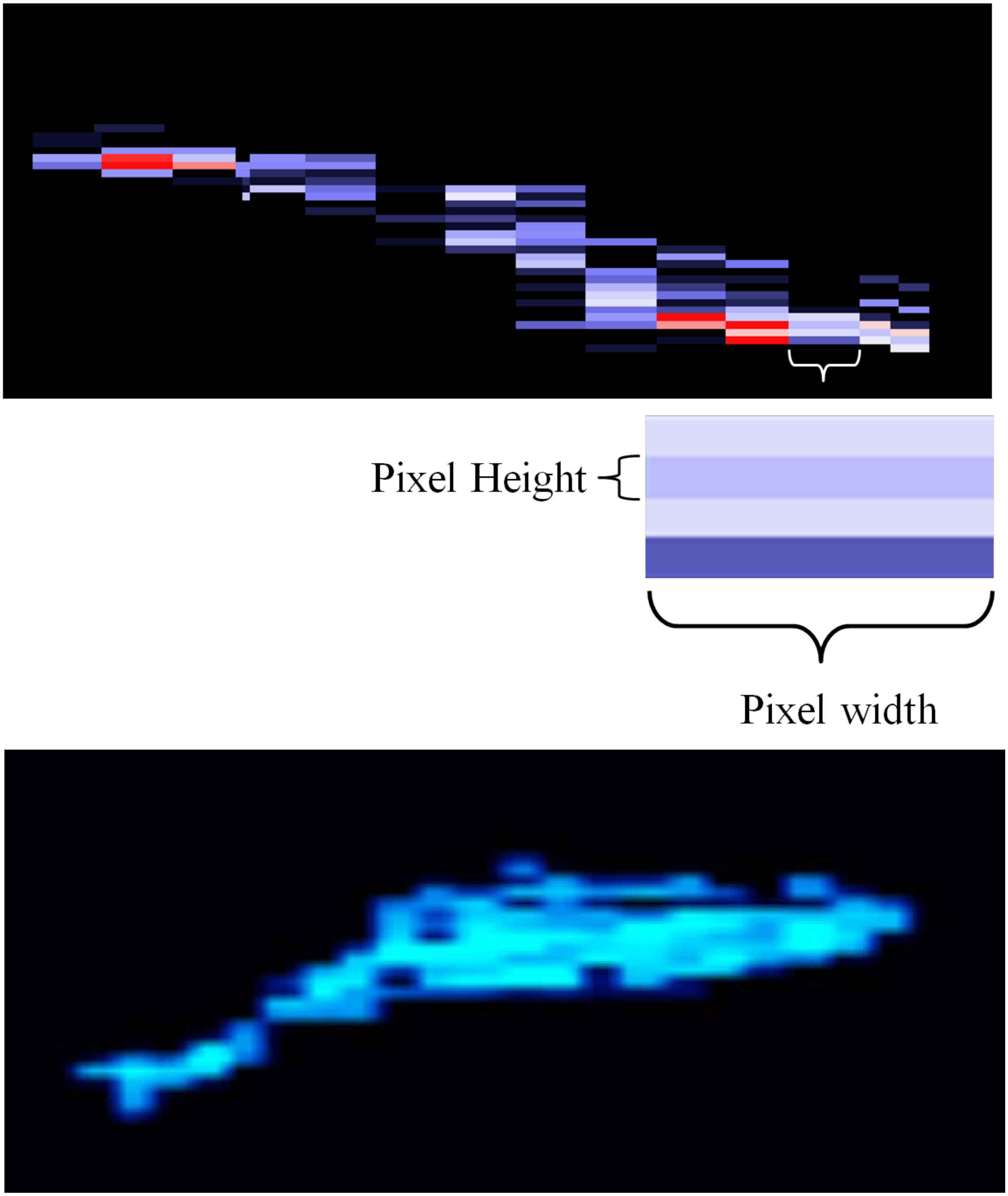
Note: The overall horizontal beam width of 15° is composed of 48 sub-beams with approximately 0.3° beam widths. Because sub-beams grow wider with range, fish at close range are better resolved than fish at far range (adapted from Burwen et al. [2007]).



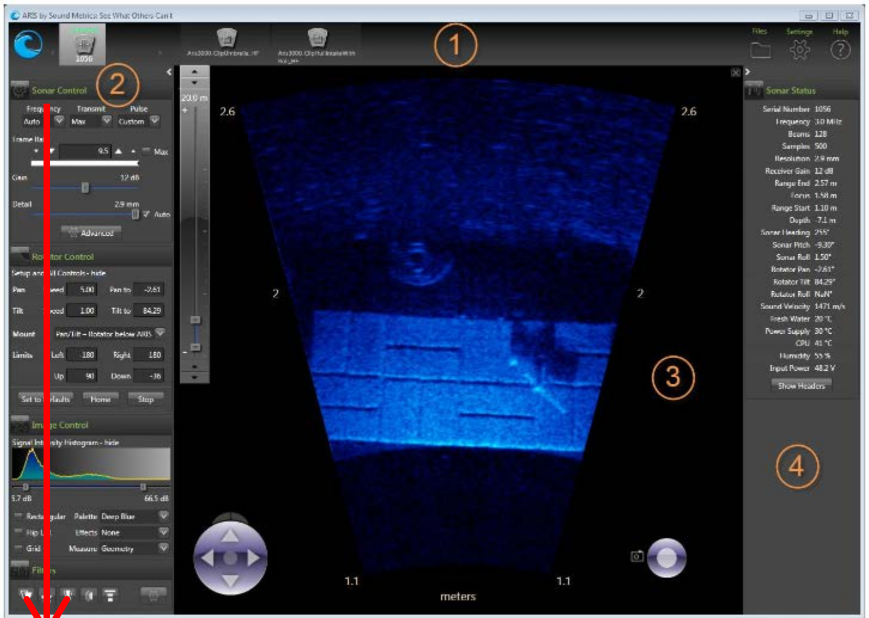


Appendix A5.–Relationships between focal length and lens position for ARIS standard lens (top) and high-resolution lens (bottom).

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



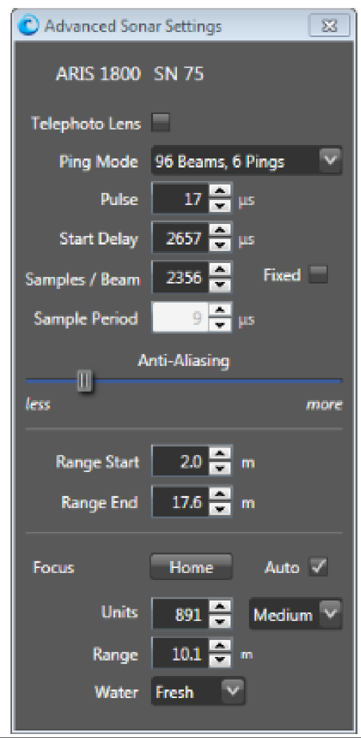
Appendix A6.–An enlargement of a tethered Chinook salmon showing the individual pixels that compose a DIDSON image (top) contrasted with an ARIS image of a free-swimming Chinook salmon (bottom).



Control Panel Menu

Expanded Sonar Control Window

Advanced Settings dialog



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

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

Appendix 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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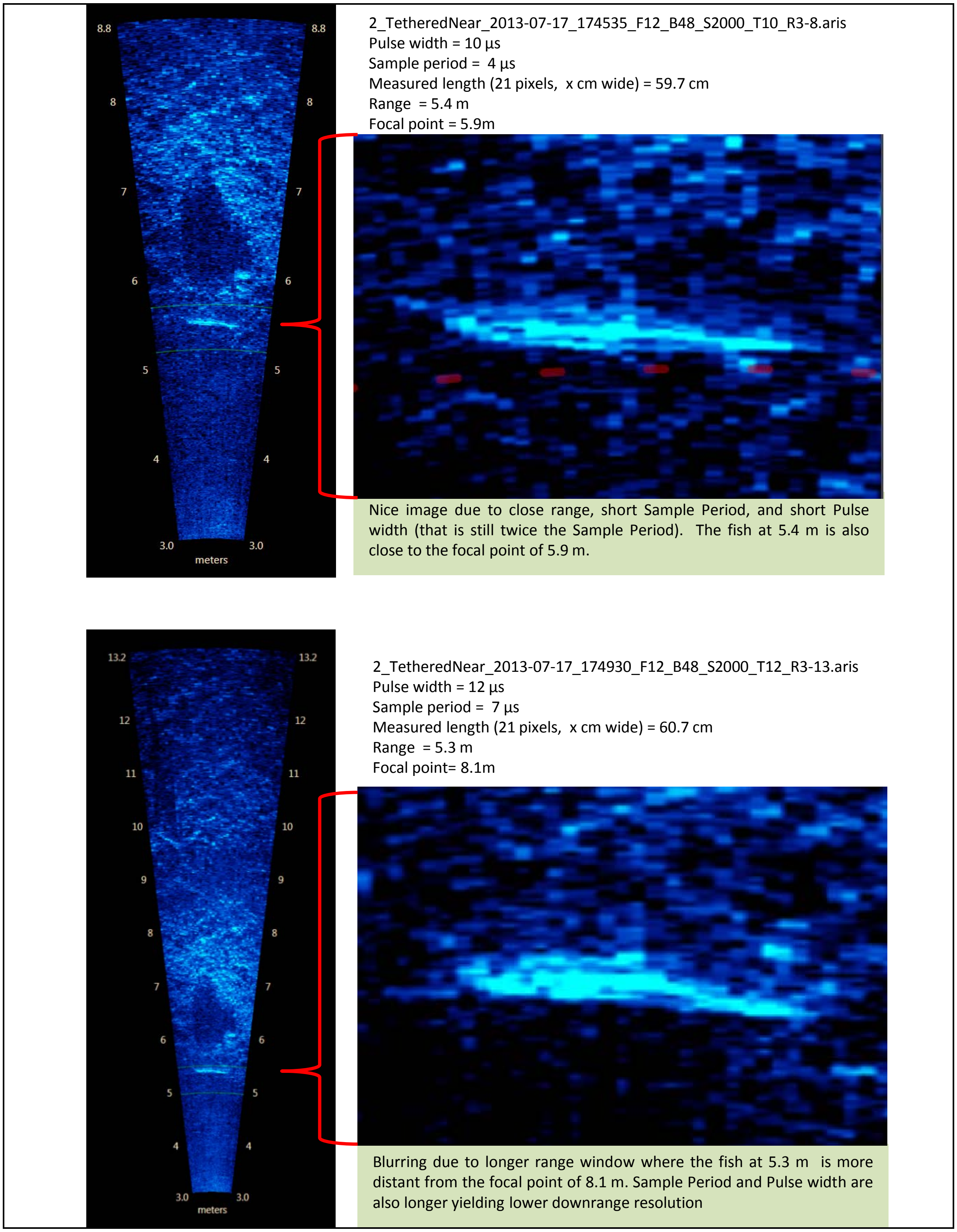
Appendix A8.–Page 2 of 2.

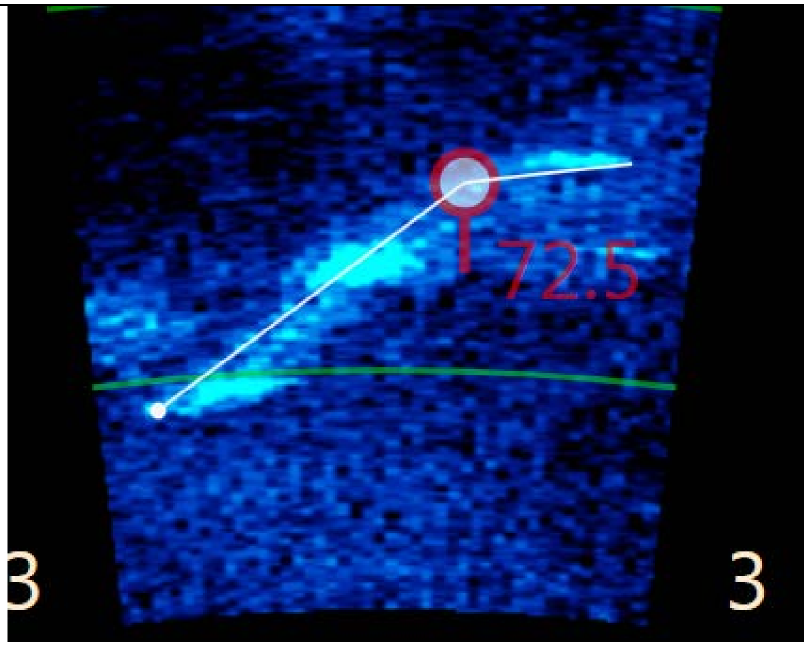
Parameter	Description
Sample Period (µs)	The <**Sample Period**> parameter sets the image data sample period within a beam in microseconds. Shorter values provide higher downrange resolution at the expense of larger frame sizes and potentially restricted frame rates. <**Sample Period**> can be set with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

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

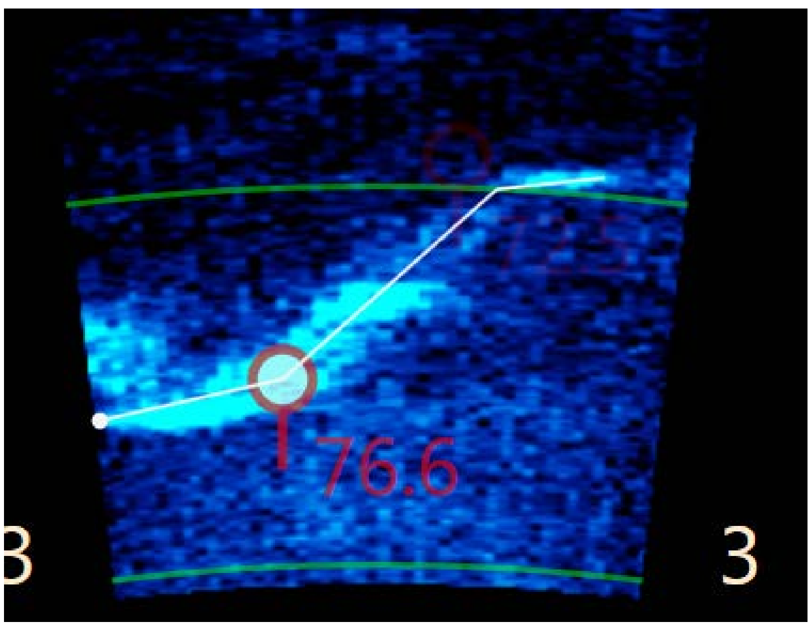


Appendix A9.–Images from a close-range tethered fish at 2 different range windows demonstrate the advantage of a shorter range window and higher sample period for close-range sampling.

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.

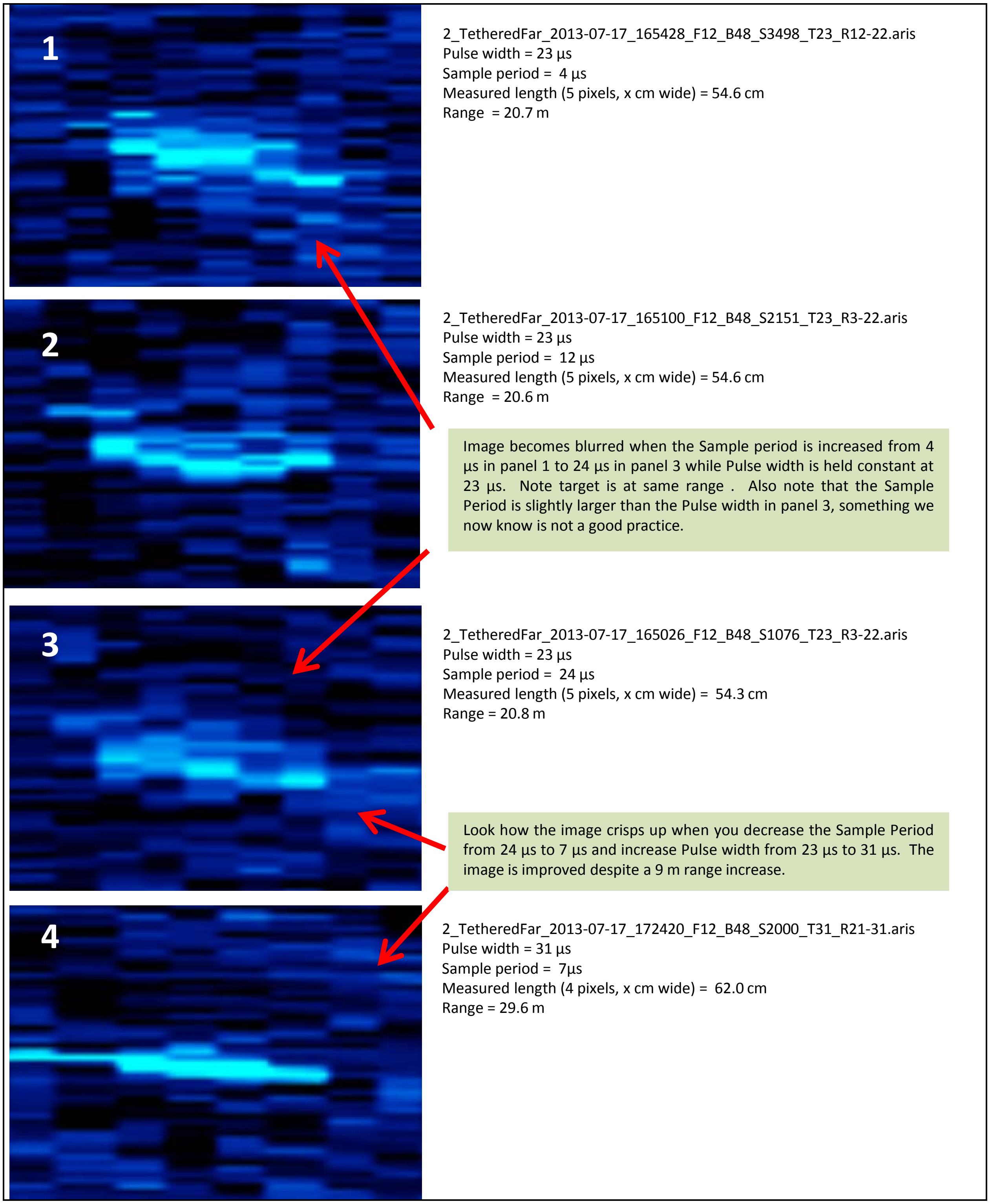


3_TetheredNear_2013-07-17_182746_F12_B48_S1724_T08_R3-8.aris
Fish Range: 3.35 m
Frame 2498
Fish size 72.5 cm



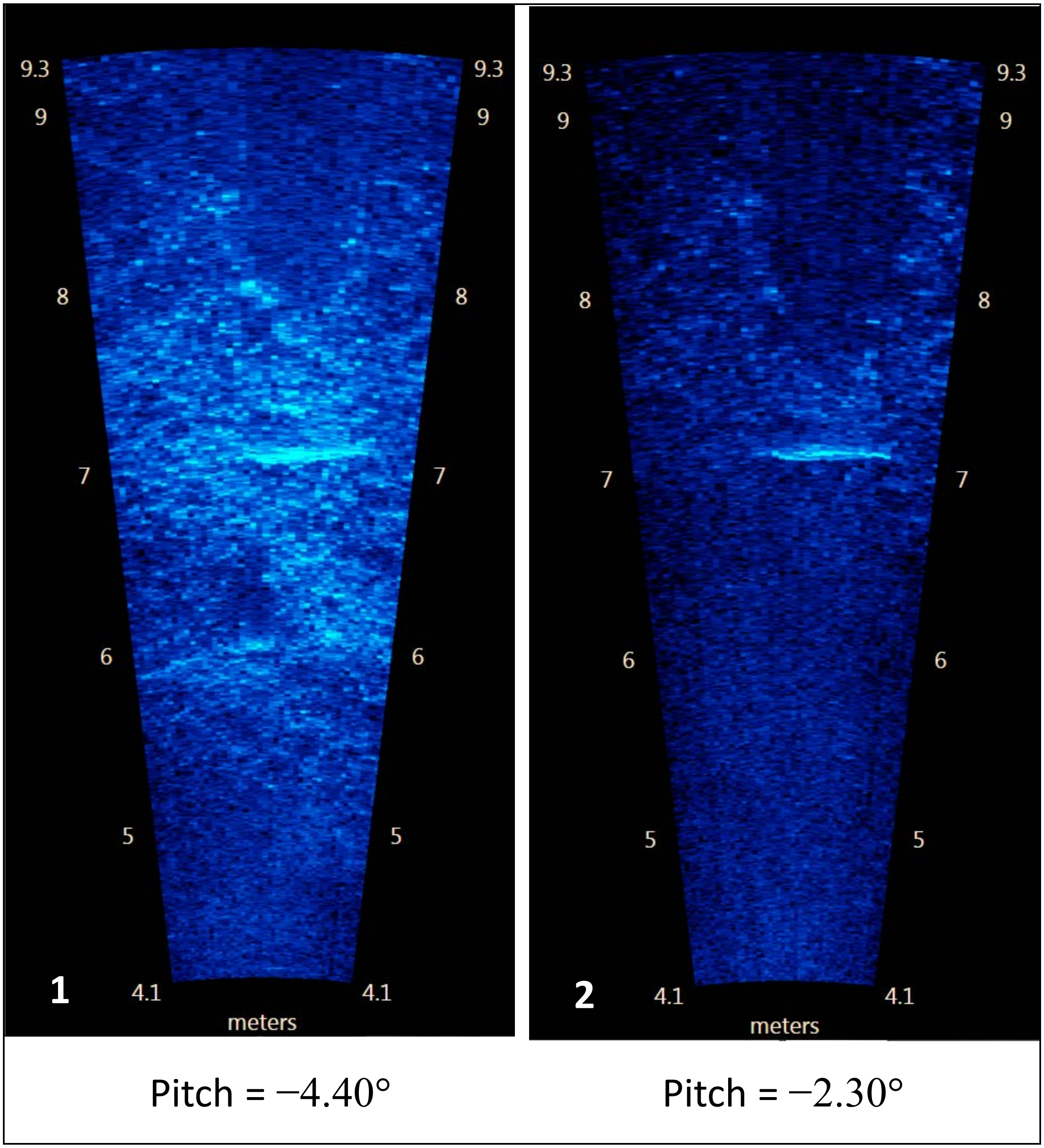
3_TetheredNear_2013-07-17_182746_F12_B48_S1724_T08_R3-8.aris
Fish Range: 3.17 m
Frame 1896
Fish size 76.6 cm

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.

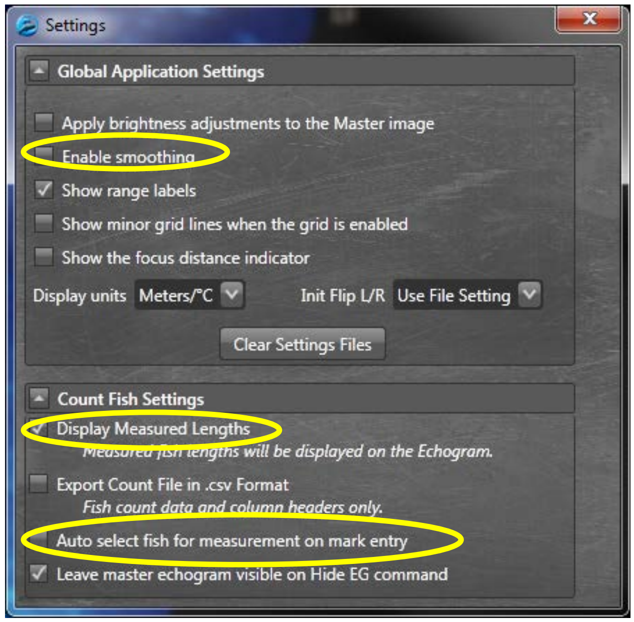
Note: Aiming the sonar farther into the bottom than required to cover the near-bottom region can cause unnecessary loss of vertical beam width and water column coverage and degrade the fish image.

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:

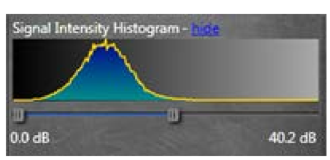


2. **<Enable smoothing>** is off.
3. **<Display Measured Lengths>** is on.
4. **<Auto select fish for measurement ….>** can be either on or off, as desired.

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

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

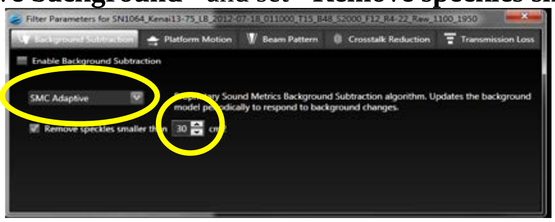
2. Navigate to the appropriate directory and open file (or simply **<double click>** on the file).
3. Set **<Signal Intensity Histogram>** sliders to 0.0 and 40.2 dB (or other recommended values for a specific stratum).



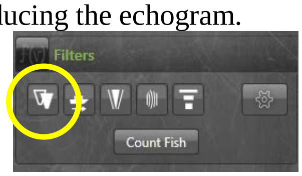
-continued-

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

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

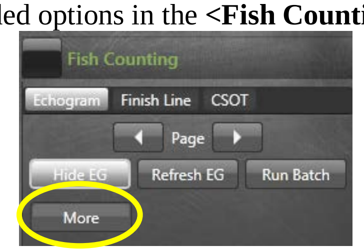


6. Select the **<Background Subtraction>** icon on the **<Filters>** menu (toggle); this will enable background subtraction for producing the echogram.



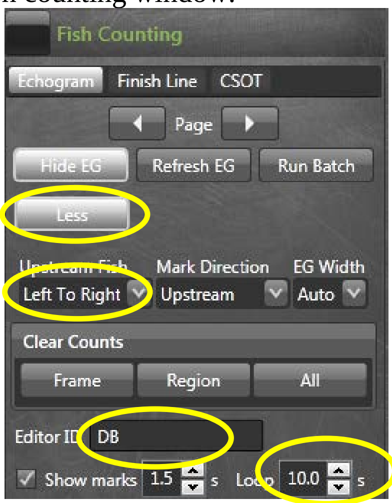
7. Select **<Echogram**> **<Show EG>** from the **<Fish Counting>** menu to display the echogram.

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

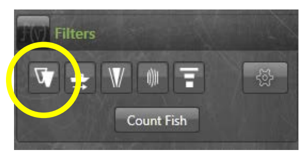


-continued-

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



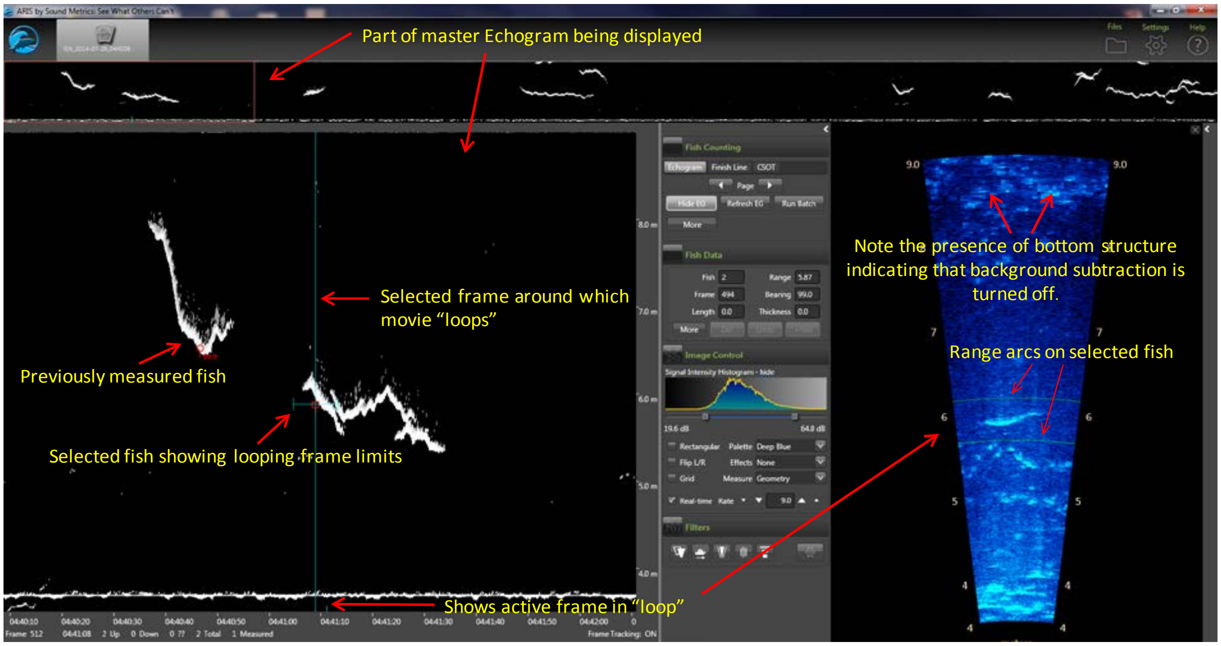
Now select the **<Background Subtraction>** icon on the **<Filters>** menu (toggle) to turn the background subtraction “off” on the video image. Failing to turn background subtraction off prior to measuring the fish image length may result in an underestimate of actual fish length [14].



-continued-

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

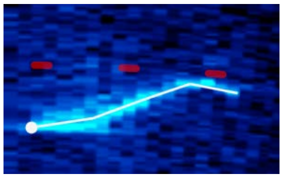
10. The overall display should look similar to the following image:



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

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

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



-continued-

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

Hot keys

<e> to “save” all echogram measurements to file

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

<u> to “undo” the last segment

<d> to “delete” 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

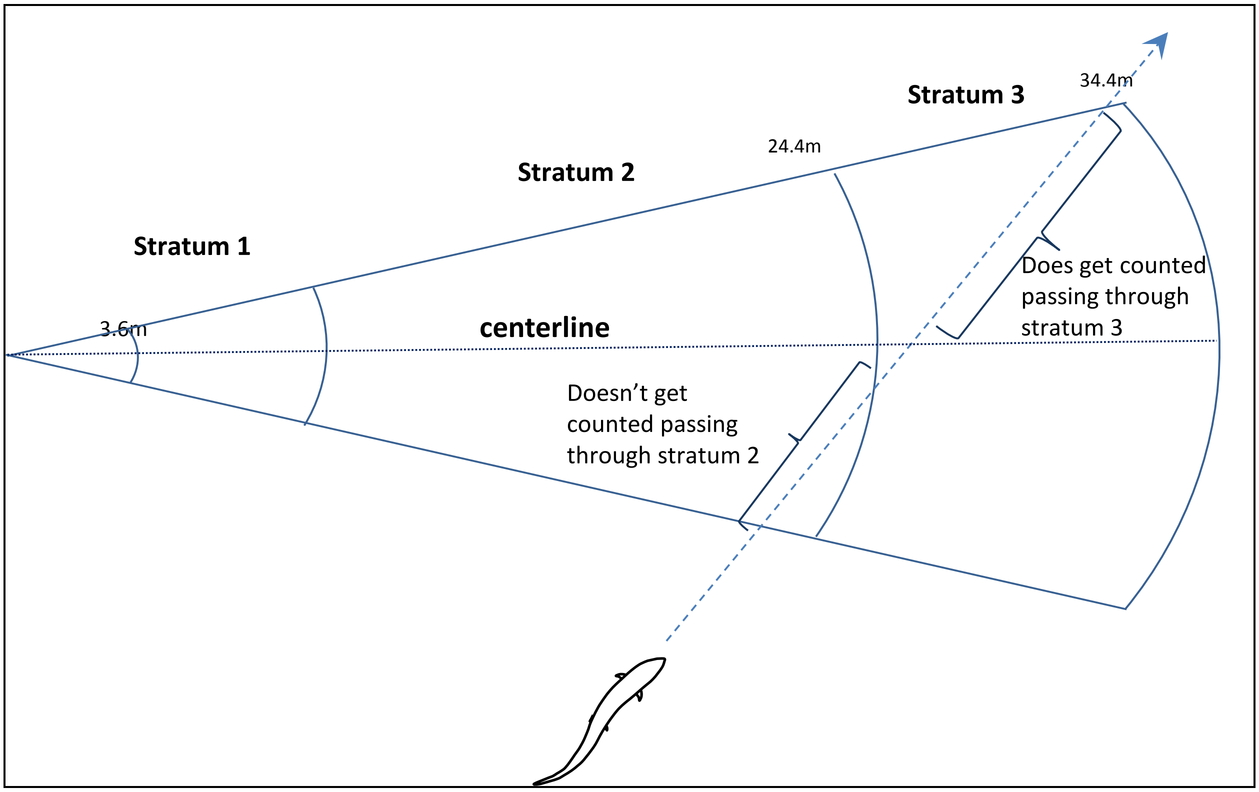
In order to optimize the aim of the sonar beams relative to the river bottom, the insonified zone is often divided into individual range strata that are sampled separately. In order to avoid overcounting fish as they cross stratum boundaries, we apply the “centerline rule” where a fish is not counted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

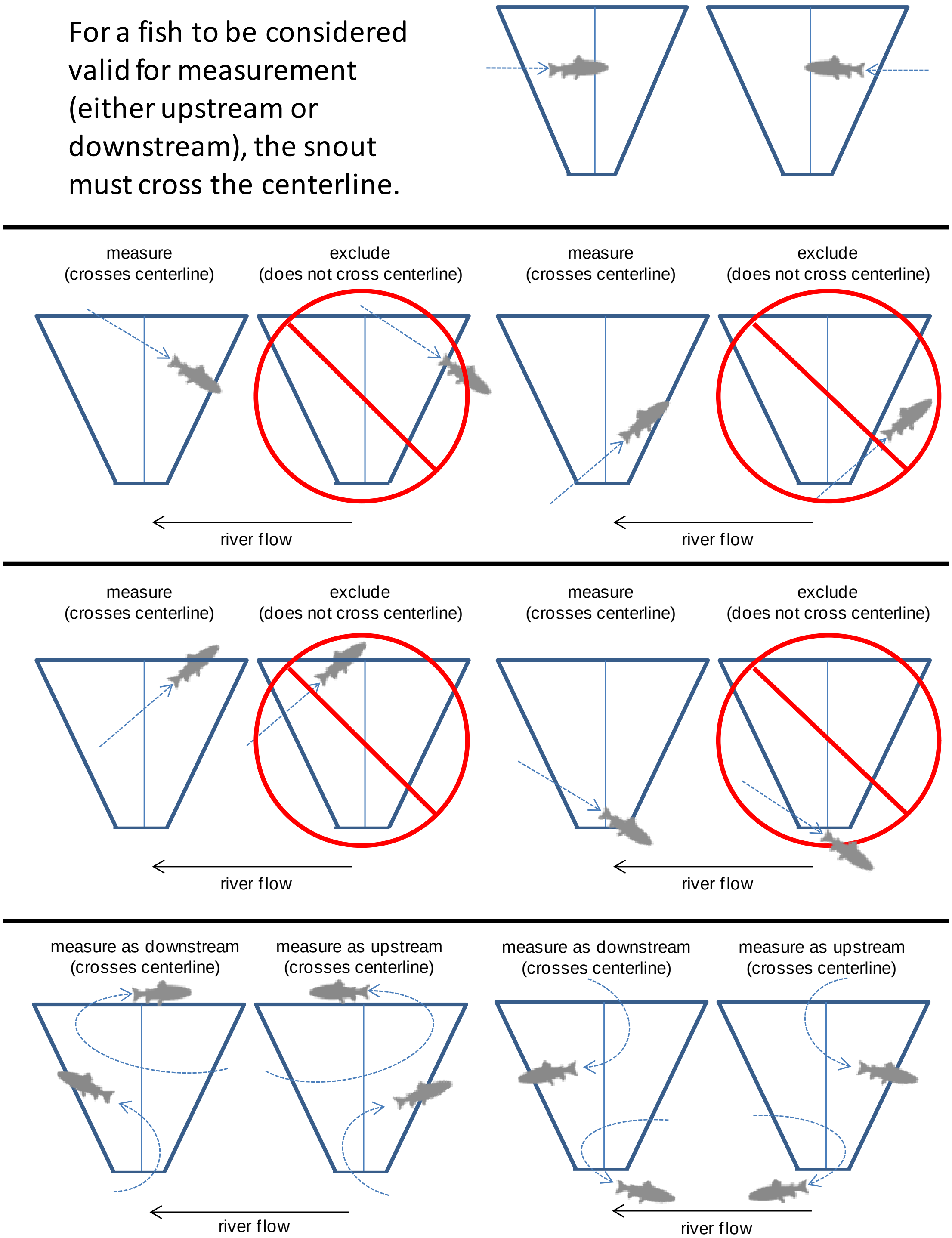
-continued-

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.



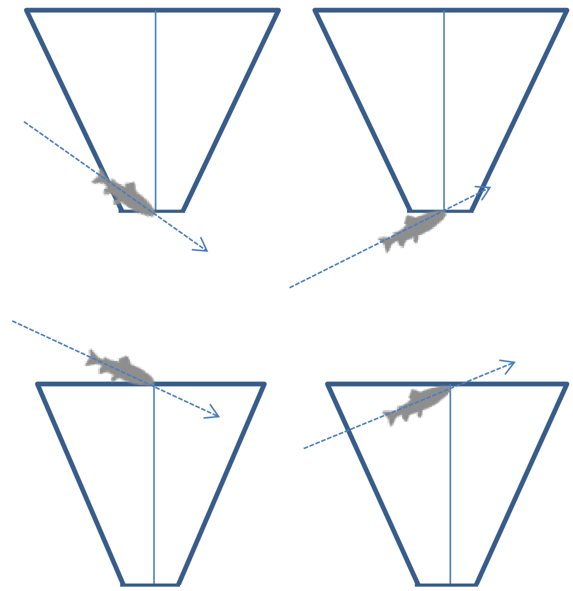
Appendix B2.–To avoid counting this fish in both Stratum 2 and Stratum 3, the fish will only be counted in Stratum 3 where it crosses the centerline of the beam.

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

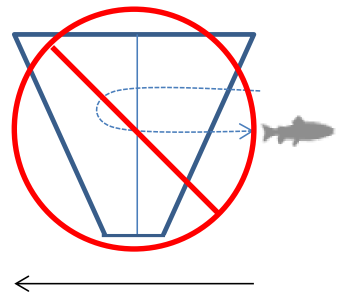


-continued-

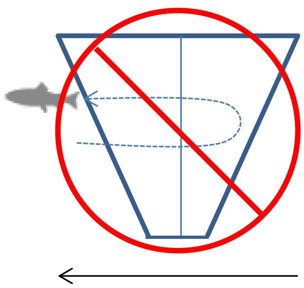
If the snout of the fish enters the near- or far-range boundary right on the centerline, the fish should be considered valid for measurement.



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

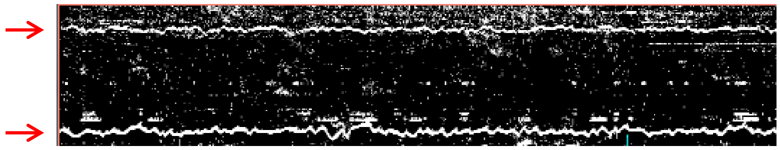


Exclude fish that enter the beam from downstream, then exit the beam downstream (do not measure even if they cross the centerline).



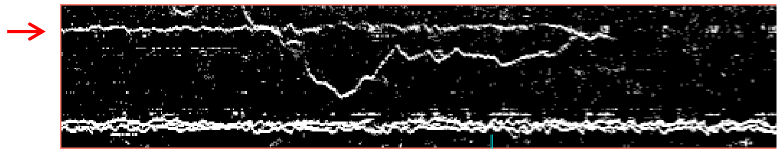
-continued-

Exclude fish that hold throughout the length of the sample.

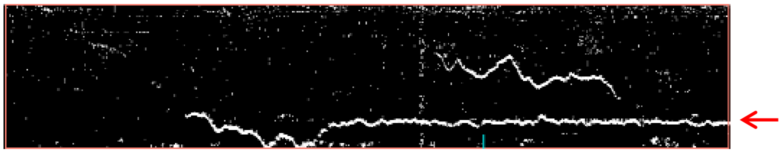


Two fish hold throughout the entire file. Exclude both fish.

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

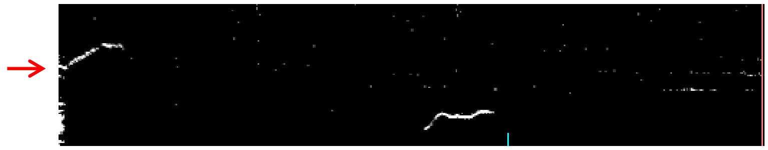


Fish holding as sample begins, then exits the beam about ¾ of the way through the sample. Exclude this fish.



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

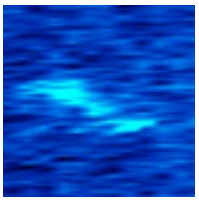
Fish that are actively migrating (not holding) as the sample begins or ends should be considered valid targets for measurement as long as they cross the centerline.

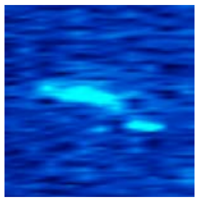


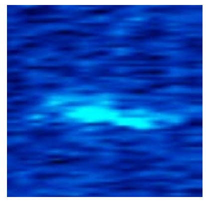
Fish is actively migrating through the beam as the sample starts. It crosses the center line and exits upstream so should be measured.

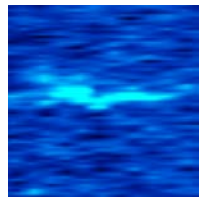
-continued-

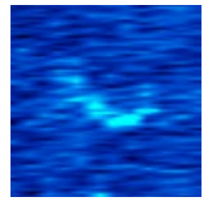
A fish passing through the beam that turns perpendicular to the axis and disappears should be excluded unless there is other evidence to indicate direction of travel.

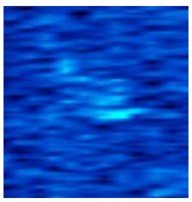

Frame #2353

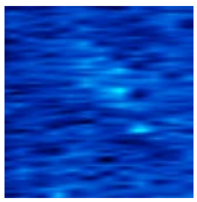

Frame #2354

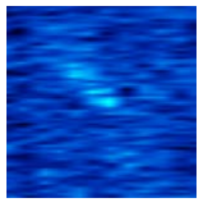

Frame #2355

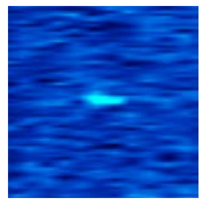

Frame #2356

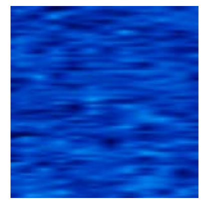

Frame #2357


Frame #2358


Frame #2359


Frame #2360

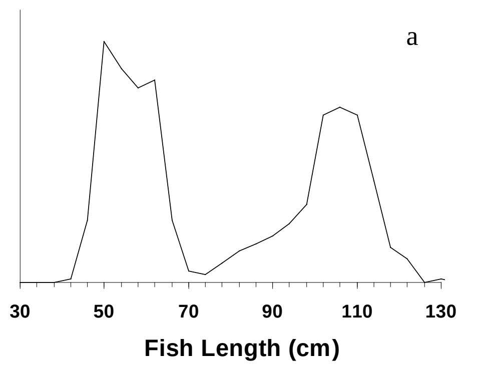

Frame #2361

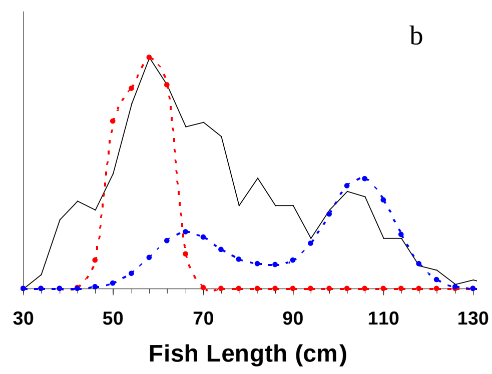

Frame #2362

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

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

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





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

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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:

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

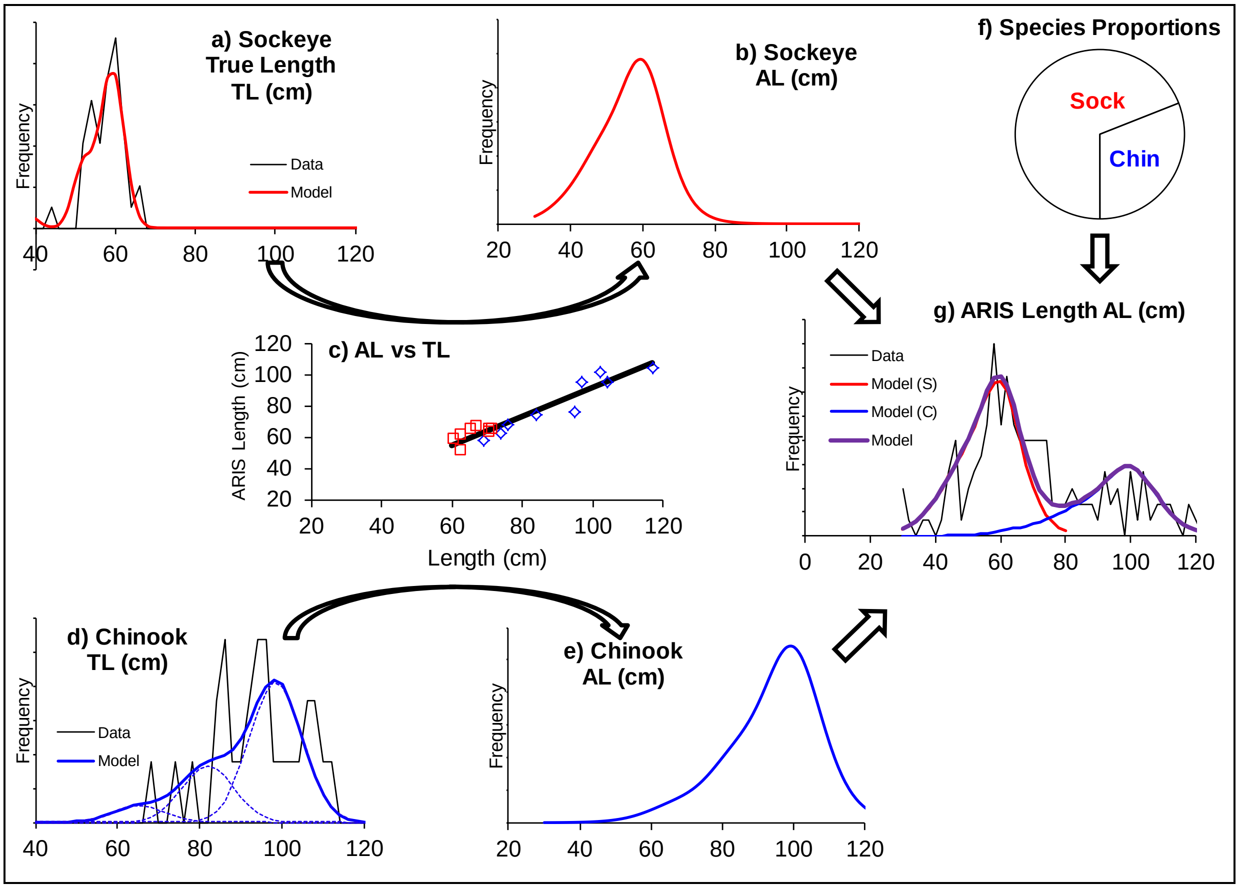
$$f_C(x) = \theta_{C1} f_{C1}(x) + \theta_{C2} f_{C2}(x) + \theta_{C3} f_{C3}(x) \tag{C4}$$

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

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

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

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.

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

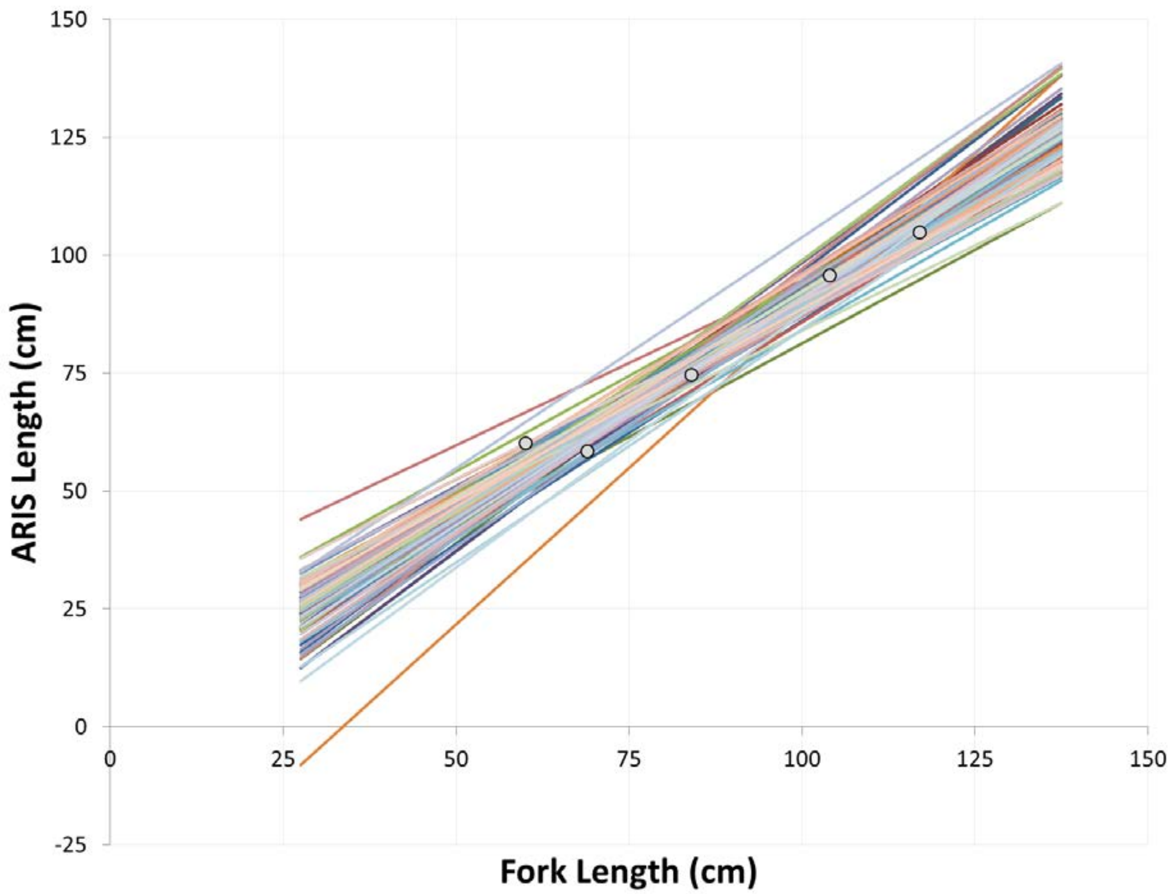
Appendix C4.–WinBUGS code for ARIS length mixture model.

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

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

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

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



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

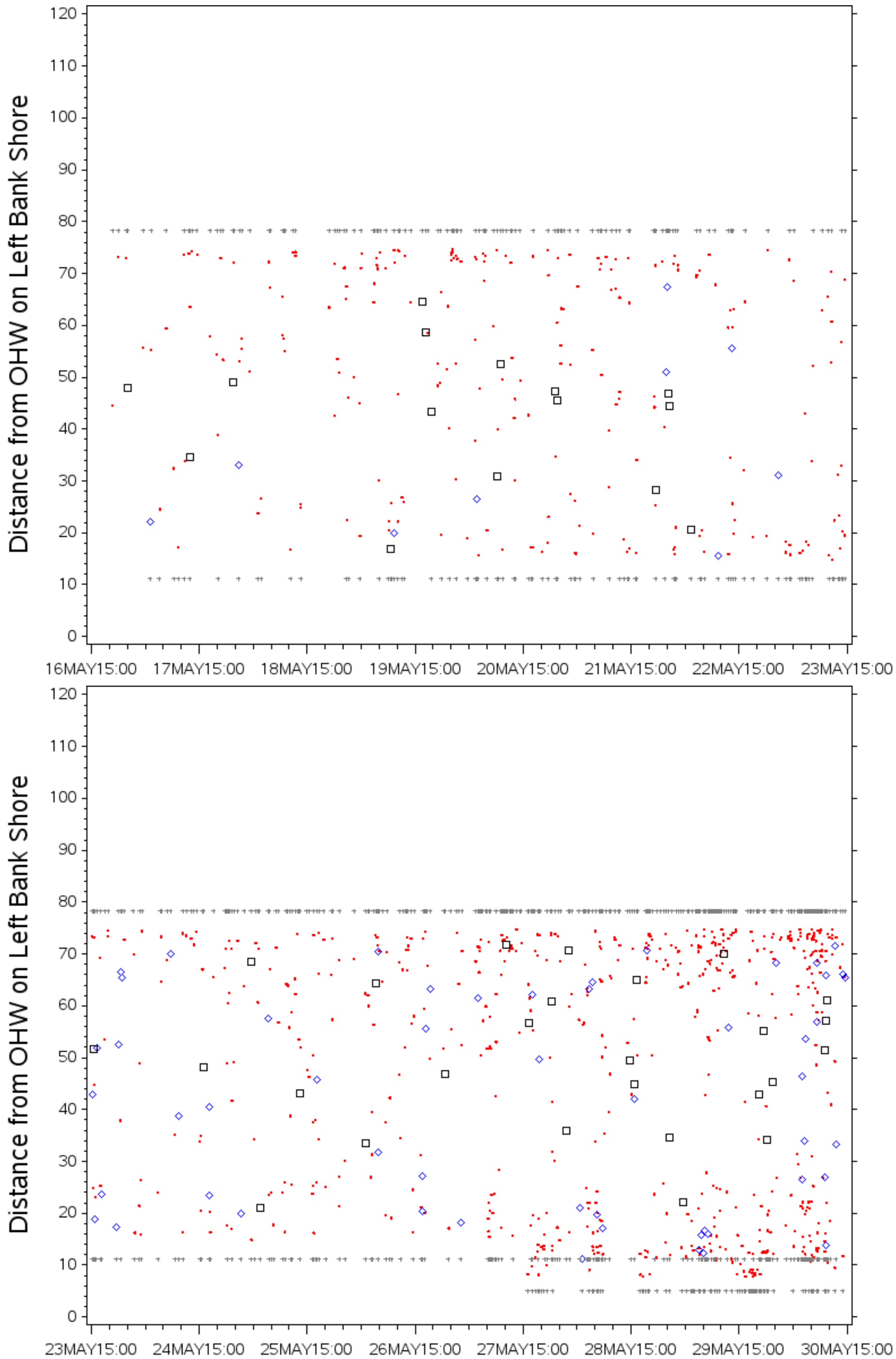
Appendix C6.–Differences in methodology between inseason and final ARIS-length mixture model estimates.

Modification	Inseason	Final [b]
Age composition prior	informative[a]	noninformative [b]
Species composition prior	Dirichlet(0.5,0.5)	Dirichlet(0.1,0.9)
Netting data	Midriver only	Midriver and nearshore
Chinook salmon size selectivity by age class	0.61, 0.57, 0.41	1, 1, 1

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

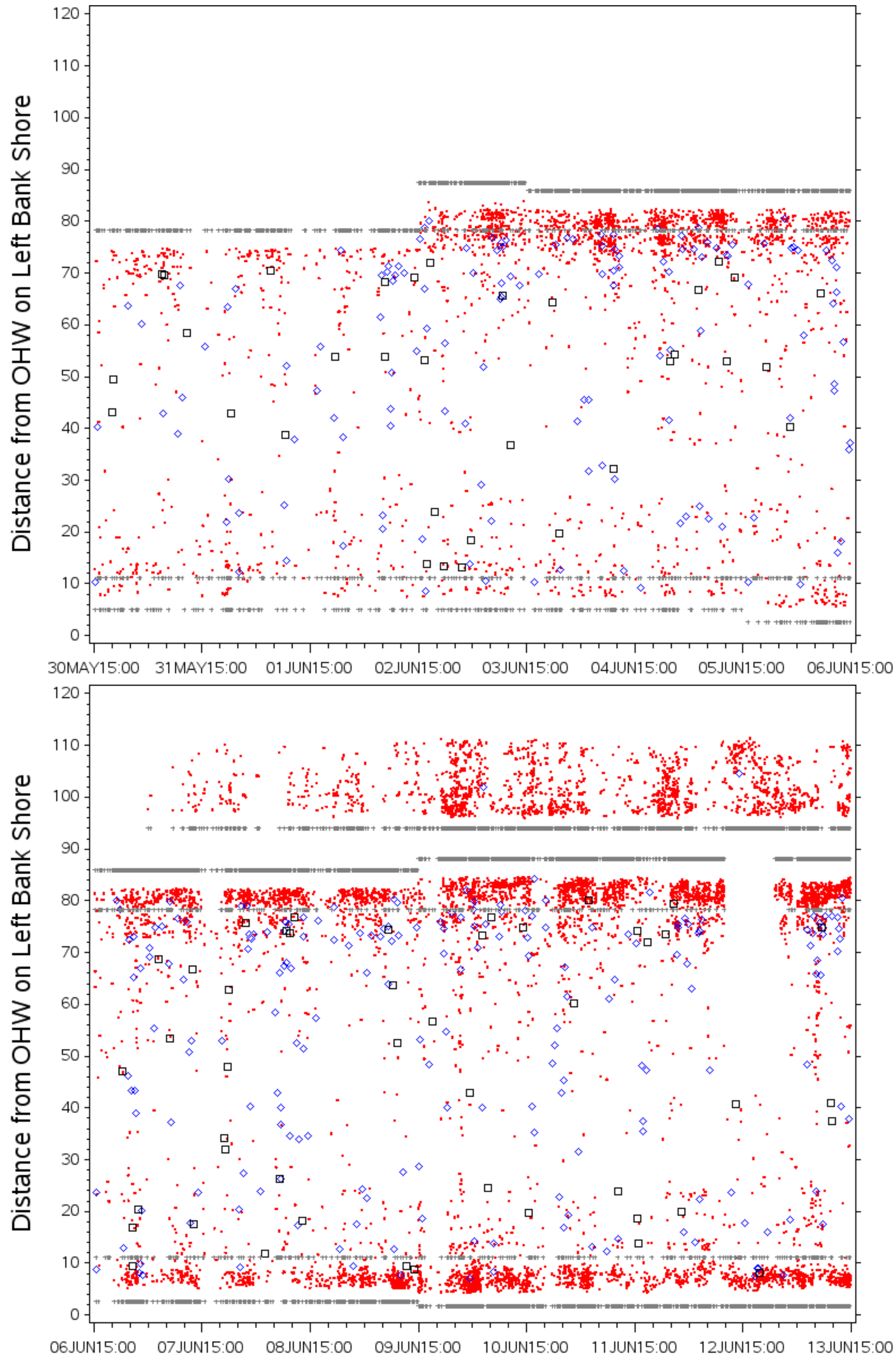
[b] Non-informative nested beta priors (see Appendix C4).

APPENDIX D: SPATIAL AND TEMPORAL DISTRIBUTION OF FISH BY SIZE AS MEASURED BY ARIS, RM 13.7 KENAI RIVER, 2015



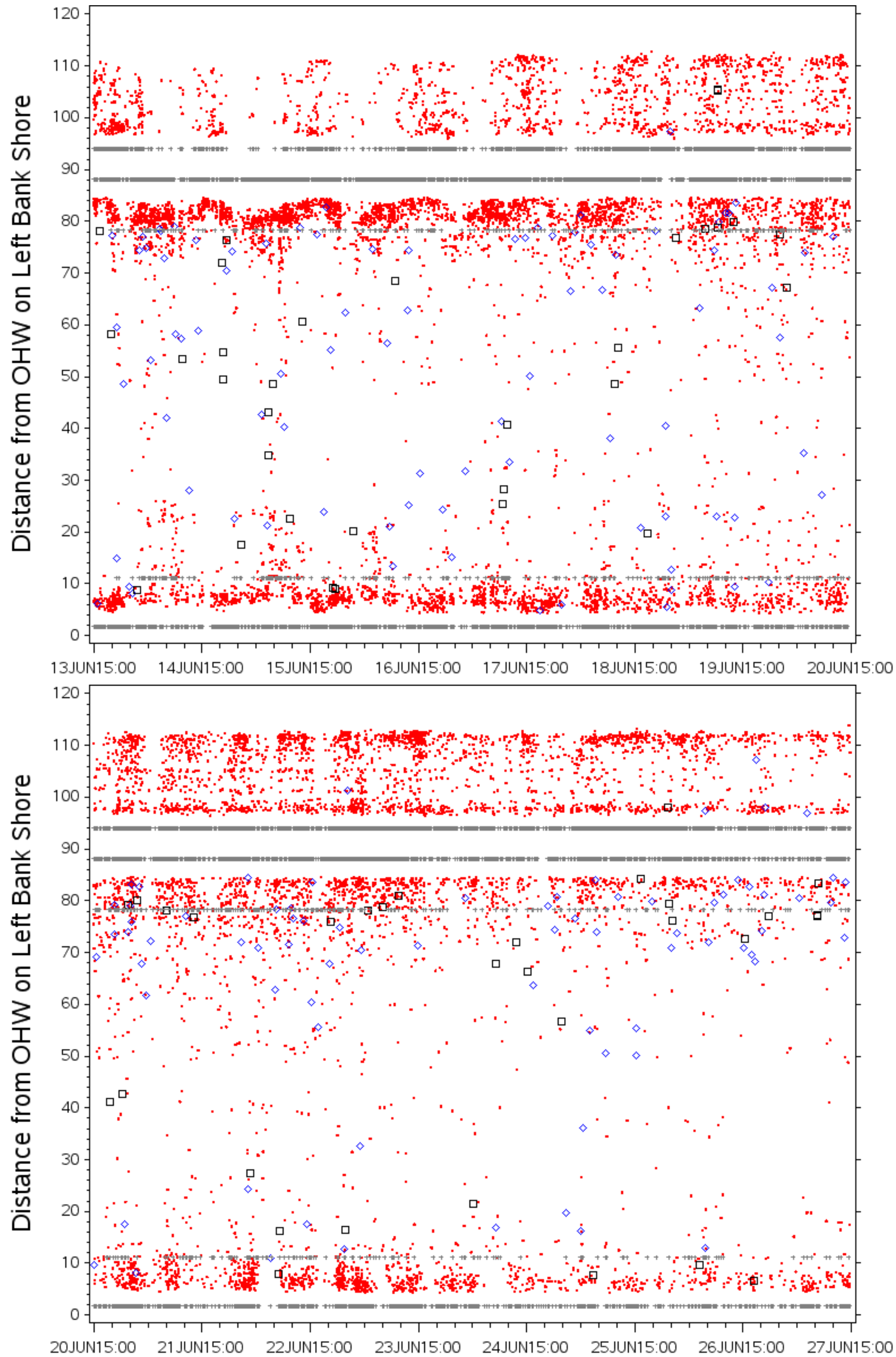
Appendix D1.–Spatial and temporal distribution of small (ARIS length [AL] < 75 cm; small red dots), medium (75 cm ≤ AL < 90 cm; larger blue diamonds), and large fish (AL ≥ 90 cm; large black squares), RM 13.7 Kenai River, 16–29 May 2015.

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



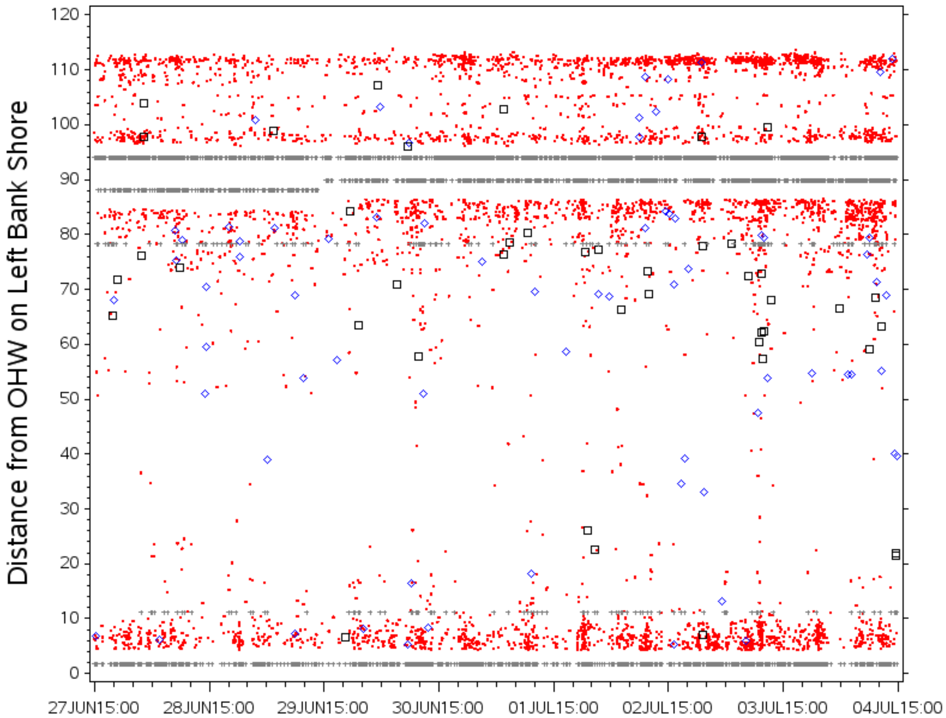
Appendix D2.–Spatial and temporal distribution of small (ARIS length [AL] < 75 cm; small red dots), medium (75 cm ≤ AL < 90 cm; larger blue diamonds), and large fish (AL ≥ 90 cm; large black squares), RM 13.7 Kenai River, 30 May–12 June 2015.

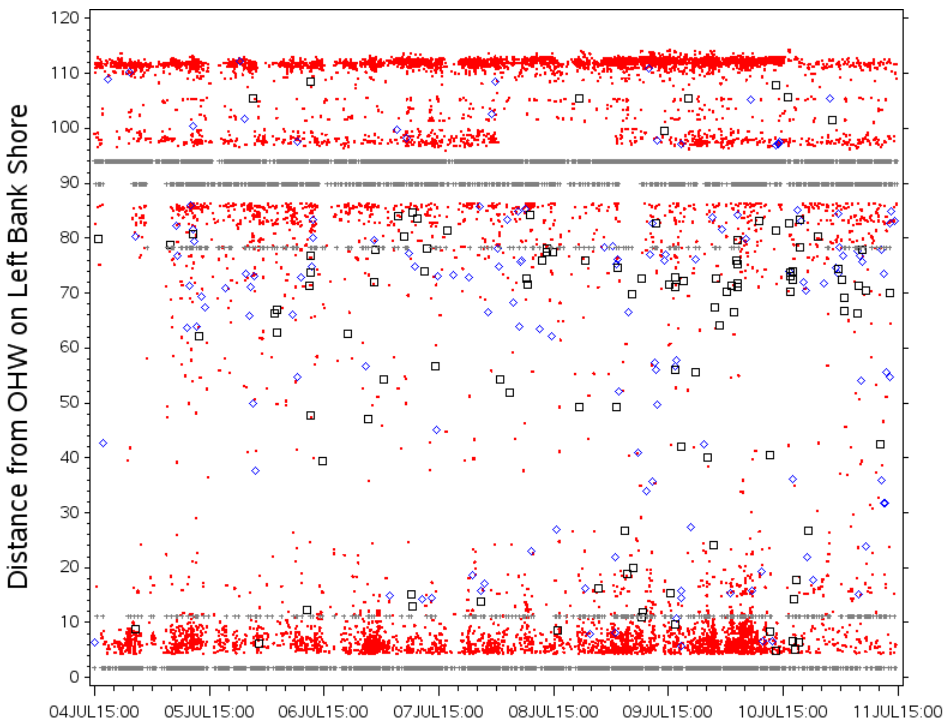
Note: Small fish can be underrepresented in the sample. Transducer locations are plotted as small grey crosses, one per fish. For the main channel, the vertical axis is the distance from a reference point near the ordinary high water level on the left bank. The side channel transducer was arbitrarily 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 2015.

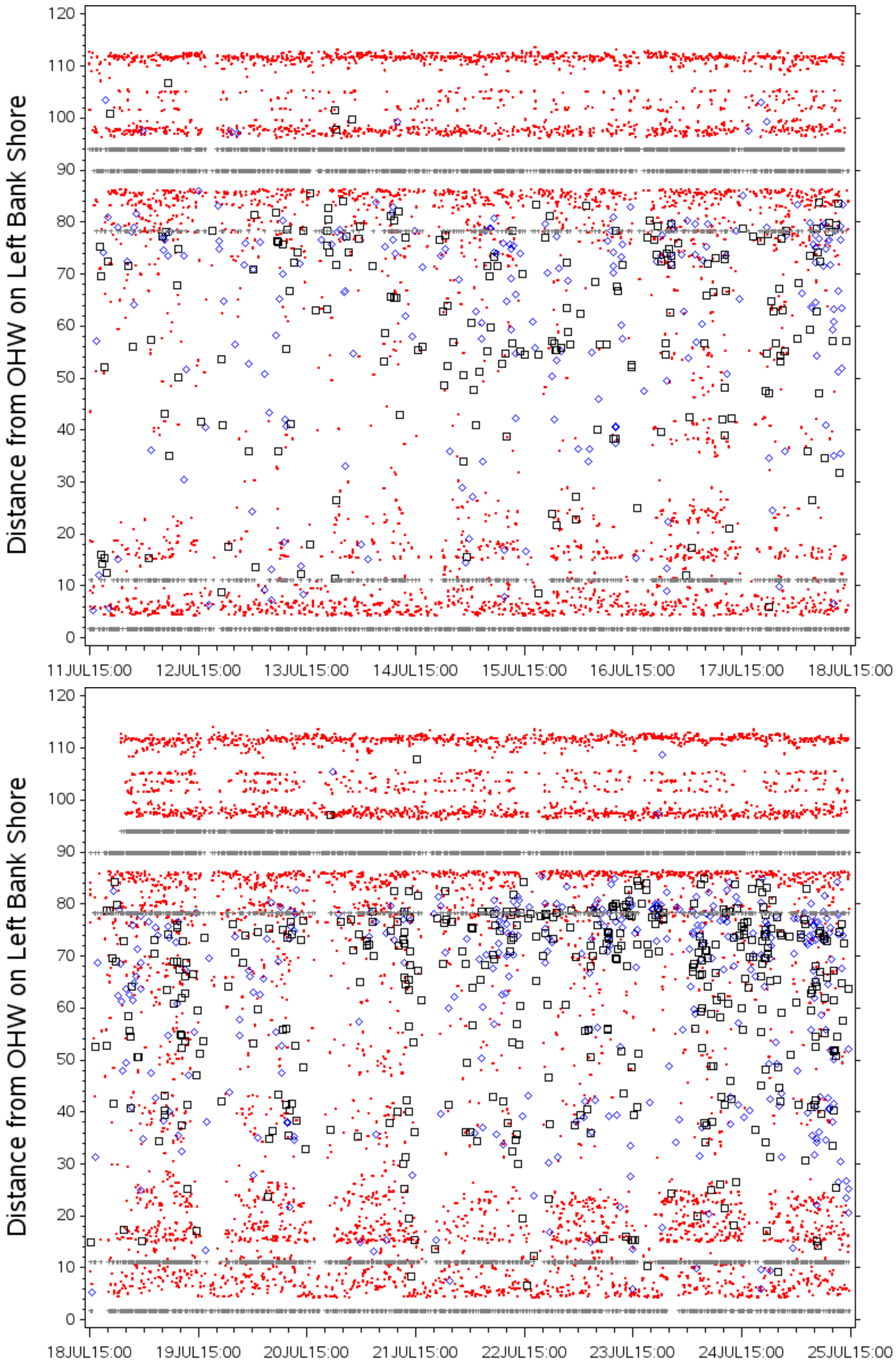
Note: Small fish can be underrepresented in the sample. Transducer locations are plotted as small grey crosses, one per fish. For the main channel, the vertical axis is the distance from a reference point near the ordinary high water level on the left bank. The side channel transducer was arbitrarily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





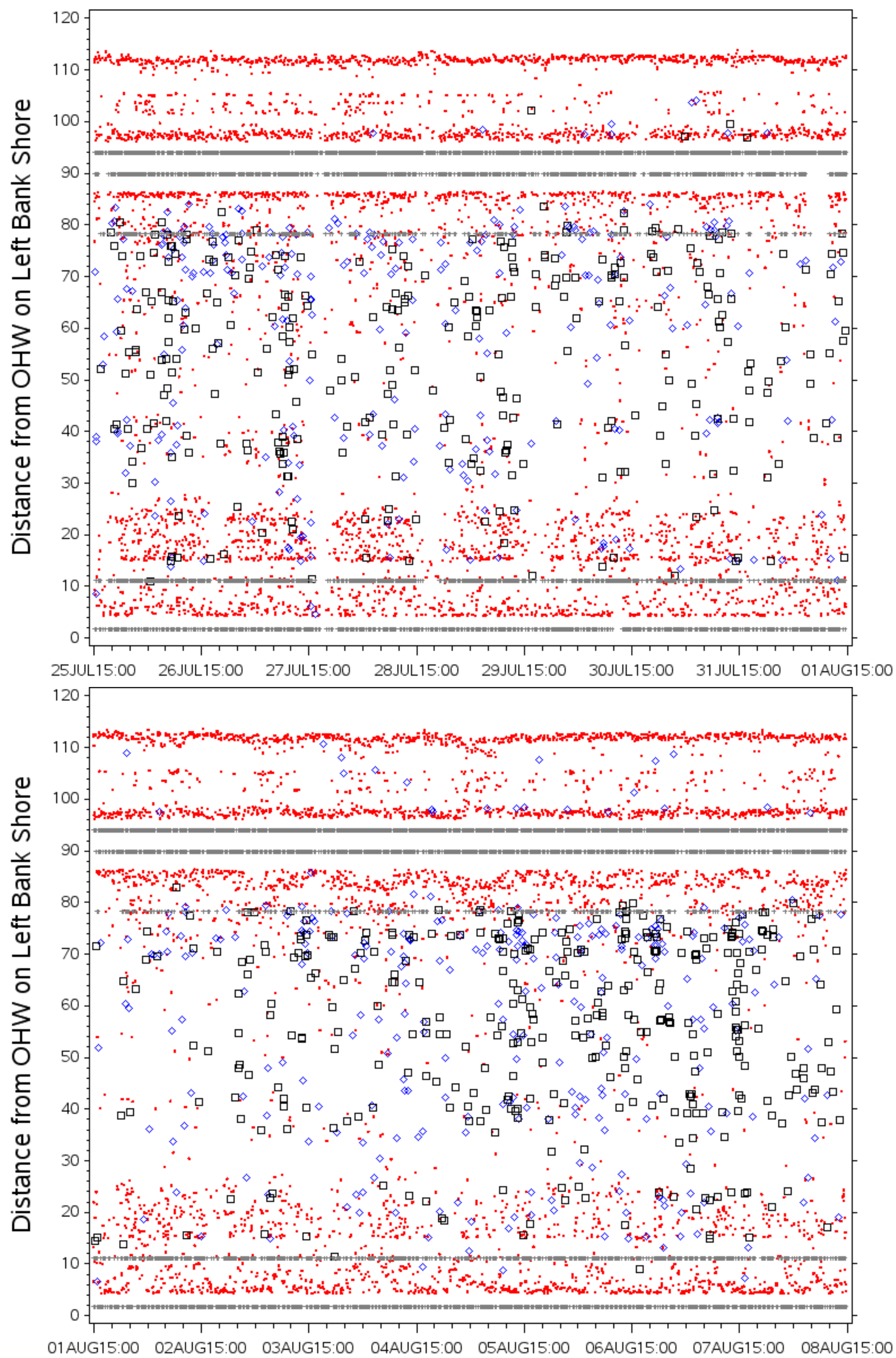
Appendix D4.–Spatial and temporal distribution of small (ARIS length [AL] < 75 cm; small red dots), medium (75 cm ≤ AL < 90 cm; larger blue diamonds), and large fish (AL ≥ 90 cm; large black squares), RM 13.7 Kenai River, 27 June–10 July 2015.

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



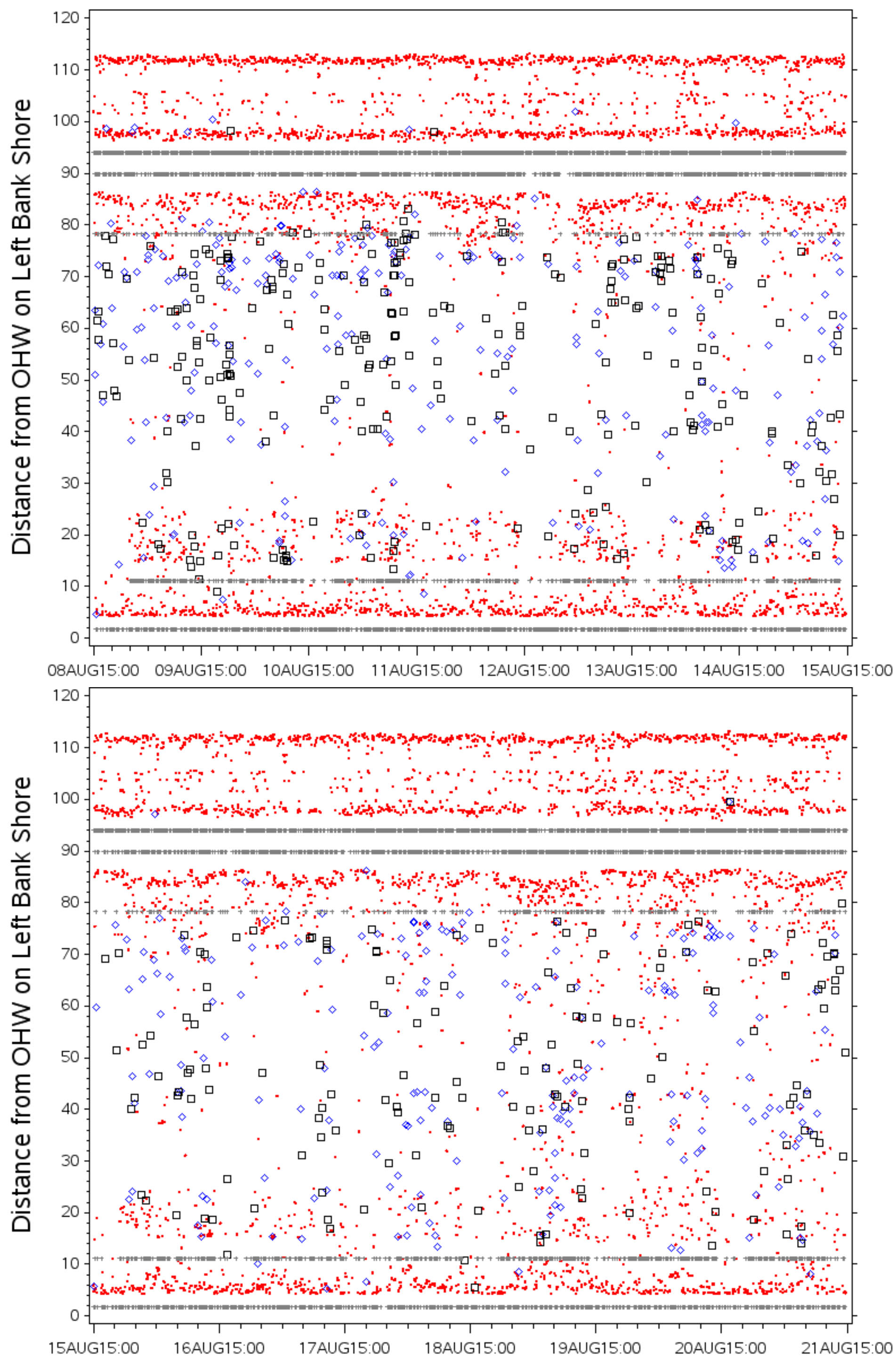
Appendix D5.–Spatial and temporal distribution of small (ARIS length [AL] < 75 cm; small red dots), medium (75 cm ≤ AL < 90 cm; larger blue diamonds), and large fish (AL ≥ 90 cm; large black squares), RM 13.7 Kenai River, 11–24 July 2015.

Note: Small fish can be underrepresented in the sample. Transducer locations are plotted as small grey crosses, one per fish. For the main channel, the vertical axis is distance 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 2015.

Note: Small fish can be underrepresented in the sample. Transducer locations are plotted as small grey crosses, one per fish. For the main channel, 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, 8–20 August 2015.

Note: Small fish can be underrepresented in the sample. Transducer locations are plotted as small grey crosses, one per fish. For the main channel, the vertical axis is distance 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, 2015

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, 2015.

	Downstream		Upstream		Total number
Date	Number	Percent	Number	Percent	sampled
16 May	1	33%	2	67%	3
17 May	1	33%	2	67%	3
18 May	0	0%	2	100%	2
19 May	0	0%	6	100%	6
20 May	0	0%	2	100%	2
21 May	4	33%	8	67%	12
22 May	0	0%	1	100%	1
23 May	3	23%	10	77%	13
24 May	0	0%	8	100%	8
25 May	0	0%	5	100%	5
26 May	0	0%	8	100%	8
27 May	2	13%	13	87%	15
28 May	2	13%	13	87%	15
29 May	0	0%	21	100%	21
30 May	0	0%	12	100%	12
31 May	1	7%	14	93%	15
1 Jun	0	0%	24	100%	24
2 Jun	3	8%	36	92%	39
3 Jun	1	4%	25	96%	26
4 Jun	2	6%	29	94%	31
5 Jun	5	16%	26	84%	31
6 Jun	2	5%	39	95%	41
7 Jun	2	4%	45	96%	47
8 Jun	2	6%	30	94%	32
9 Jun	1	3%	34	97%	35
10 Jun	1	3%	30	97%	31
11 Jun	2	6%	30	94%	32
12 Jun	1	3%	33	97%	34
13 Jun	0	0%	24	100%	24
14 Jun	0	0%	19	100%	19
15 Jun	0	0%	16	100%	16
16 Jun	1	8%	11	92%	12
17 Jun	0	0%	14	100%	14
18 Jun	2	8%	24	92%	26
19 Jun	1	10%	9	90%	10
20 Jun	0	0%	20	100%	20
21 Jun	3	17%	15	83%	18
22 Jun	0	0%	15	100%	15
23 Jun	0	0%	5	100%	5
24 Jun	0	0%	16	100%	16
25 Jun	1	6%	16	94%	17
26 Jun	0	0%	20	100%	20
27 Jun	0	0%	14	100%	14
28 Jun	1	9%	10	91%	11
29 Jun	0	0%	18	100%	18
30 Jun	0	0%	7	100%	7
Total	45	5.4%	781	94.6%	826

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, 2015.

	Downstream		Upstream		
Date	Number	Percent	Number	Percent	Total number sampled
1 Jul	3	16%	16	84%	19
2 Jul	0	0%	28	100%	28
3 Jul	1	5%	18	95%	19
4 Jul	0	0%	20	100%	20
5 Jul	0	0%	29	100%	29
6 Jul	1	4%	25	96%	26
7 Jul	1	3%	32	97%	33
8 Jul	0	0%	39	100%	39
9 Jul	2	4%	53	96%	55
10 Jul	1	2%	58	98%	59
11 Jul	1	2%	47	98%	48
12 Jul	1	2%	54	98%	55
13 Jul	1	2%	52	98%	53
14 Jul	3	5%	61	95%	64
15 Jul	3	4%	64	96%	67
16 Jul	5	8%	61	92%	66
17 Jul	3	4%	82	96%	85
18 Jul	2	2%	91	98%	93
19 Jul	1	2%	65	98%	66
20 Jul	5	8%	61	92%	66
21 Jul	3	3%	97	97%	100
22 Jul	4	3%	123	97%	127
23 Jul	3	2%	145	98%	148
24 Jul	0	0%	190	100%	190
25 Jul	3	3%	109	97%	112
26 Jul	3	3%	107	97%	110
27 Jul	3	4%	79	96%	82
28 Jul	9	10%	79	90%	88
29 Jul	8	10%	73	90%	81
30 Jul	7	9%	71	91%	78
31 Jul	6	12%	43	88%	49
1 Aug	7	14%	43	86%	50
2 Aug	9	12%	66	88%	75
3 Aug	11	12%	82	88%	93
4 Aug	15	12%	112	88%	127
5 Aug	11	8%	124	92%	135
6 Aug	10	7%	140	93%	150
7 Aug	2	3%	76	97%	78
8 Aug	9	9%	91	91%	100
9 Aug	10	10%	93	90%	103
10 Aug	9	8%	104	92%	113
11 Aug	11	18%	49	82%	60
12 Aug	10	18%	46	82%	56

-continued-

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	Downstream		Upstream		
Date	Number	Percent	Number	Percent	Total number sampled
13 Aug	11	13%	77	88%	88
14 Aug	7	11%	58	89%	65
15 Aug	12	17%	58	83%	70
16 Aug	14	24%	45	76%	59
17 Aug	24	26%	70	74%	94
18 Aug	19	21%	70	79%	89
19 Aug	24	32%	52	68%	76
20 Aug	29	32%	63	68%	92
Total	337	9%	3,591	91%	3,928