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Estimates of Chinook Salmon Passage in the Kenai River at River Mile 8.6 Using Dual-Frequency Identification Sonar, 2012

by

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May 2015

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

FISHERY DATA SERIES NO. 15-09

ESTIMATES OF CHINOOK SALMON PASSAGE IN THE KENAI RIVER AT RIVER MILE 8.6 USING DUAL-FREQUENCY IDENTIFICATION SONAR, 2012

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TABLE OF CONTENTS

Page

TABLE OF CONTENTS (Continued)

Page

LIST OF TABLES

Table **Page**

LIST OF FIGURES

LIST OF APPENDICES

Appendix **Page**

LIST OF APPENDICES (Continued)

ABSTRACT

Kenai River Chinook salmon (*Oncorhynchus tshawytscha*) passage was estimated in 2012 using dual-frequency identification sonar (DIDSON). Estimates of midriver Chinook salmon passage between and at least 3 m from the transducers were 3,228 (SE 191) fish for the early run (16 May–30 June) and 21,613 (SE 667) fish for the late run (1 July–15 August). DIDSON units temporarily deployed shoreward of the left- and right-bank transducers recorded large Chinook salmon (equal to or greater than 75 cm) migrating outside the standard insonified zone. The efficacy of installing sonar at river mile 13.7 was investigated and confirmed.

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

INTRODUCTION

Chinook salmon (*Oncorhynchus tshawytscha*) returning to the Kenai River are managed as two distinct runs (Burger et al. 1985): early (16 May–30 June) and late (1 July–10 August). Early-run Chinook salmon are harvested primarily by sport anglers, and late-run Chinook salmon by commercial, sport, subsistence, and personal use fisheries. These fisheries may be restricted if the projected escapement falls below 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 2012 season, goals of 5,300–9,000 early-run and 17,800–35,700 late-run Chinook salmon were in effect. 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. Implementation of these management plans has been contentious and has attracted public scrutiny. Fishery restrictions were imposed to meet escapement goals during the early run in 1990–1992, 1997, 1998, 2000, 2002, and 2010–2012 and during the late run in 1990, 1992, 1998, 2011, and 2012.

PROJECT HISTORY

Mark–recapture

The first estimates of Kenai River Chinook salmon abundance were generated in 1984 for the late run using a mark–recapture project (Hammarstrom et al. 1985). This mark–recapture project produced estimates for both early- and late-run riverine abundance (Hammarstrom and Larson 1986; Conrad and Larson 1987; Conrad 1988; Carlon and Alexandersdottir 1989; Alexandersdottir and Marsh 1990). However, these mark–recapture estimates had low precision and failed to provide inseason information on Chinook salmon abundance, and they were discontinued after 1990.

Dual-beam Sonar

The current Chinook salmon sonar site at river mile (RM) 8.6 was established in 1985 (Eggers et al. 1995). Unlike the sockeye salmon (*O. nerka*) sonar site at RM 19, the RM 8.6 sonar site is located downstream of all Chinook salmon spawning habitat and downstream of nearly all sport fishing for Chinook salmon. The site originally deployed dual-beam sonar technology, chosen for its ability to estimate acoustic size (target strength). Target strength (TS) is a measure of the loudness of the echo returning from a fish, corrected for position of the fish in the beam. Because of the considerable size difference between large Chinook salmon and other fish species in the Kenai River, it was postulated that target-strength measurements could be used to distinguish Chinook salmon from smaller fish (primarily sockeye salmon) and to estimate their numbers returning to the river.

Early Kenai River sonar and gillnetting studies indicated that Chinook salmon could be distinguished from sockeye salmon based on target strength and spatial separation in the river (Eggers et al. 1995). A target-strength threshold was established to censor small fish. Sockeye salmon also were thought to migrate primarily near the bank, and therefore a range or distance threshold was also imposed. From 1987 through 2011, "TS-based estimates" based on these two criteria were the primary basis for monitoring the number of Chinook salmon returning to the Kenai River for comparison with established escapement goals.

Split-beam Sonar

A more advanced acoustic technology, known as split-beam sonar, was used to test assumptions and design parameters of the dual-beam configuration in 1994 (Burwen et al. 1995). The split-beam system provided advantages over the dual-beam system in its ability to determine the 3-dimensional position of an acoustic target in the sonar beam. Consequently, the direction of travel for each target and the 3-dimensional spatial distribution of fish in the acoustic beam could be determined for the first time. The split-beam system also operated at a lower frequency than the dual-beam system, providing a higher (improved) signal-to-noise ratio (SNR; Simmonds and MacLennan 2005). It also interfaced with improved fish-tracking software, which reduced the interference from boat wake and improved fish-tracking capabilities (Burwen and Bosch 1996). The split-beam system was deployed side by side with the dual-beam system and was run concurrently for much of the 1994 season (Burwen et al. 1995). Both systems detected comparable numbers of fish. The split-beam data confirmed earlier studies (Eggers et al. 1995) showing that most fish targets were strongly oriented to the river bottom. However, experiments conducted with the split-beam system could not confirm that Chinook salmon could be discriminated from sockeye salmon based on target strength. Modeling exercises performed by Eggers (1994) also questioned the feasibility of discriminating between Chinook and sockeye salmon using target strength. It was hypothesized that discrimination between the two species was primarily accomplished using range thresholds on the acoustic data that exploited the assumed spatial segregation of the species (sockeye salmon migrate near shore and Chinook salmon migrate midriver; Burwen et al. 1995; Eggers et al. 1995). In 1995, the dual-beam system was replaced with the split-beam system to take advantage of the additional information on direction of travel and spatial position of targets. TS-based estimates continued to be produced with the split-beam sonar to make comparisons across years.

Ancillary drift gillnetting and sonar studies conducted in 1995 (Burwen et al. 1998) were directed at providing definitive answers to remaining questions regarding 1) the degree to which sockeye and Chinook salmon are spatially separated at the RM-8.6 Chinook salmon sonar site and 2) the utility of using target strength and other acoustic parameters for species separation. These studies confirmed the potential for misclassifying sockeye salmon as Chinook salmon. The drift gillnetting study found that sockeye salmon were present in the middle insonified portion of the river. In addition, most sockeye salmon in the live tethered fish experiment had mean target strengths that exceeded the target-strength threshold.

Concurrent Studies to Verify and Improve Sonar Passage Estimates

Mark–recapture experiments using radiotelemetry were implemented in 1996 and 1997 to estimate the magnitude of bias introduced into the Chinook salmon passage estimates during periods of high sockeye salmon passage (Hammarstrom and Hasbrouck 1998-1999). These studies were designed to provide an independent and accurate estimate of inriver Chinook salmon passage during the late run, when the potential to misclassify sockeye salmon using sonar was thought to be greatest. Although the precision of radiotelemetry estimates and previous mark–recapture estimates were similar, the use of radiotelemetry avoided certain biases associated with the earlier mark–recapture studies. Sonar estimates of late-run Chinook salmon abundance were 26% greater in 1996 and 28% greater in 1997 than the corresponding telemetry estimates, assumed to be due to the misclassification of sockeye salmon as Chinook salmon (Hammarstrom and Hasbrouck 1998-1999).

An investigation in 1999 (Burwen et al. 2000) attempted to identify alternative sites above tidal influence with stronger bank orientation of sockeye salmon, where range thresholds would be more effective. The investigation concentrated on a site located at RM 13.2 that was upstream of tidal influence but downstream of major spawning areas. Gillnetting data indicated that there were fewer sockeye salmon in the offshore area at the alternative site than at the current site. However, there were still relatively large numbers of sockeye salmon present in the offshore area of the alternative site during peak migration periods as well as high numbers of Chinook salmon present in the nearshore area. The alternate sonar site also had disadvantages over the current site, including more boat traffic and less acoustically favorable bottom topography, both of which contributed to higher background noise and resulted in difficult fish-tracking conditions.

The inriver drift gillnetting program, originally designed to collect age, sex, and length (ASL) samples (Marsh 2000), was modified in 1998 to produce standardized estimates of Chinook salmon catch per unit effort (CPUE) for use as an index of Chinook salmon passage (Reimer et al. 2002). A drift zone was established just downstream from the sonar site, and crews fished relative to the tide cycles because gillnets could not be fished effectively during parts of the rising- and high-tide stages due to lack of river current. In addition, the schedule was intensified so that CPUE estimates could be generated daily. During subsequent years, inriver gillnet CPUE was compared with sonar passage estimates to detect periods when Chinook salmon passage estimates were potentially high because of inclusion of sockeye salmon or other species (Bosch and Burwen 2000; Miller and Burwen 2002; Miller et al. 2002-2005, 2007a-b, 2010-2012).

Analysis of the 1998–2000 standardized CPUE data suggested the gillnetting data were better suited for determining species apportionment of split-beam sonar counts than for passage estimates (Reimer et al. 2002). In 2002, the inriver gillnetting program was modified further. A 5-inch mesh gillnet was introduced, alternating with the existing 7.5-inch mesh to reduce size selectivity; nets were constructed of multi-monofilament (formerly cable-lay braided nylon); the color of the mesh was changed to more closely match that of the river; and drifts were shortened and constrained to more closely match the portion of the channel sampled by the sonar. These changes increased netting efficiency and decreased the effect of water clarity on gillnet catches (Reimer 2004).

In 2002, the species discrimination algorithm for TS-based estimates was refined in order to reduce sensitivity of the estimates to large bursts of migrating sockeye salmon. During hourly samples when sockeye salmon were abundant, as evidenced by aggregation of migrating fish into groups, the data were censored, and Chinook salmon passage was estimated from the remaining hourly samples.

Also in 2002, two experimental methods of estimating Chinook salmon passage were initiated. The first alternative estimate, referred to as the net-apportioned estimate, used the product of Chinook salmon catch proportions from the netting program (Eskelin 2010) and sonar upstream midriver fish passage estimates (see Methods). Net-apportioned estimates have been published annually since 2002 (Miller et al. 2004-2005, 2007a-b, 2010-2012) and have proven useful for tracking short-term trends in Chinook salmon abundance.

The second alternative estimate was based on split-beam measures of echo envelope length, which is a better predictor of fish length than target strength (Burwen and Fleischman 1998; Burwen et al. 2003). Statistical methods were developed that enable robust estimates of species composition even when species overlap in size (Fleischman and Burwen 2003). Echo length standard deviation (ELSD) information from the sonar was combined with fish length data from the netting program to estimate the species composition of fish passing the sonar site. The resulting estimated proportion of Chinook salmon was then multiplied by upstream fish passage estimates from the sonar. The resulting "ELSD-based" estimates, considered to be more accurate than the official TS-based estimates, were produced for the years 2002–2006. Because echo length measurements can be corrupted when 2 or more fish swim very close to one another, resulting in higher values of ELSD, only early-run estimates were published (Miller et al. 2004-2005, 2007a-b, 2010). The corresponding late-run estimates were suspected to be too high due to high sockeye salmon densities.

In 2007, the ELSD mixture model method was modified in an attempt to reduce the bias at high fish densities. Using split-beam measurements of 3-dimensional fish location, the distance between fish was calculated and fish within 1 meter of any other fish were censored before fitting the mixture model. Essentially, fish swimming close to other fish were assumed not to be Chinook salmon. This modification reduced estimates during high densities, but also had the potential to mistakenly censor Chinook salmon. ELSD-based estimates published in the 2007 report (Miller et al. 2011) supplanted the previously published early-run estimates. See Miller et al. (2014: Appendix F) for a complete record of daily ELSD-based estimates for 2002–2011. Split-beam sonar was discontinued after the 2011 season.

Dual-frequency Identification Sonar (DIDSON)

ADF&G began testing dual-frequency identification sonar (DIDSON[1]) in the Kenai River in 2002 (Burwen et al. 2007). DIDSON uses a lens system that provides high-resolution images that approach the quality achieved with conventional optics (Simmonds and MacLennan 2005), with the advantage that images can be obtained in dark or turbid waters. DIDSON imagery resembles somewhat pixelated video footage taken from a vantage point above the fish (see Appendices A6–A8). Fish size was immediately evident from DIDSON footage of migrating Kenai River salmon, suggesting that DIDSON had promise for improved discrimination of large Chinook salmon from smaller fish in the Kenai River. With ADF&G input, DIDSON developers designed custom software for manually measuring fish size directly from still images. Initial experiments using live tethered salmon showed that at ranges up to 12 m, precise estimates of fish length could be obtained by manually measuring fish images produced by a standard DIDSON unit

[1] DIDSON was designed by the University of Washington Applied Physics Laboratory, originally for military applications.

(Burwen et al. 2007). Ranges to 30 m are required to adequately insonify the Kenai River at the current sonar location (RM 8.6). The development of a comparatively long-range DIDSON model in 2004 extended the range of high-frequency operation to approximately 30 m, and a high-resolution lens developed in 2007 improved the resolution by nearly a factor of two. Tethered-fish experiments conducted in 2007 with the new equipment established that DIDSON-estimated fish length was closely related to true length at ranges up to 22 m (Burwen et al. 2010; Miller et al. 2011). Additional experiments conducted with multiple observers on the left bank during 2009 confirmed the 2007 results at ranges up to 32 m (Miller et al. 2012).

In the years 2007–2009, the long-range high-resolution DIDSON sonar was deployed on the left bank to sample 10 m of river cross section that was simultaneously sampled by the split-beam transducer (Miller et al. 2011-2012). Methods and equipment were developed to minimize accumulation of silt in the lens, which could result in degraded image resolution. A pilot study concluded that automated tracking and measuring of free-swimming fish were feasible and potentially advantageous under some circumstances. DIDSON exhibited multiple advantages over split-beam sonar with respect to detection, tracking, and species classification of passing fish. Frequency distributions of DIDSON length measurements, along with paired netting data, lent themselves well to mixture modeling, which enabled estimation of species composition of passing fish. Such estimates agreed well with corresponding split-beam estimates from the ELSD mixture model in 2009.

A second DIDSON system was acquired in 2010, and simultaneous coverage of both banks was achieved for 48 of 87 days (Miller et al. 2013). Comparisons of TS-based estimates with DIDSON estimates and other indices of Chinook salmon abundance showed that the assumptions underpinning TS-based estimates of Chinook salmon abundance were not valid. The DIDSON also detected large fish at short ranges that had not been sampled by the split-beam sonar or the onsite netting project.

Split-beam and DIDSON data were collected concurrently for a second full season in 2011 (Miller et al. 2014), confirming that DIDSON was better at distinguishing large from small salmon. Supplemental sampling behind the existing left-bank transducer in June confirmed the presence of large fish near shore.

Split-beam sonar was discontinued in 2012. In this report, we present daily and seasonal DIDSON-based estimates of Chinook salmon inriver abundance for 2012. We also document continued sampling efforts shoreward of existing transducers and an investigation of an alternative sonar site at river mile 13.7, approximately 5 miles upriver from the current site (RM 8.6).

OBJECTIVES

The primary objective of this project was to produce weekly and seasonal estimates of the inriver run of Chinook salmon to the Kenai River such that the seasonal estimate was within 10% of the true value 95% of the time. The precision criterion for passage estimates addresses sampling error and species classification, but not detection[2].

[2] Uncertainty due to incomplete spatial coverage is addressed in separate reports (Fleischman and McKinley 2013 and McKinley and Fleischman 2013).

A second objective was to test for the presence of large Chinook salmon (greater than or equal to 75 cm) shoreward of existing transducer placements.

A third objective was to investigate the feasibility of moving the sonar upstream of tidal influence where a larger fraction of migrating fish could be detected.

METHODS

STUDY AREA

The Kenai River drainage is approximately 2,150 square miles (Figure 1). It is glacially influenced, with discharge rates lowest during winter (<1,800 ft^3/s), increasing throughout the summer, and peaking in August (>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, Skilak, 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 (1971–2006) precipitation for the City of Kenai, located at the mouth of the Kenai River, is 48 cm (WRCC 2008). Average summer (June, July, and August) temperature for the City of Kenai is 12°C (WRCC 2008).

SITE DESCRIPTION

The sonar site was located 14 km (8.6 miles) from the mouth of the Kenai River (Figure 2). This site has been used since 1985 and was selected for its acoustic characteristics and its location downstream of the sport fishery and known Chinook salmon spawning habitat.

The river bottom in this area has remained stable for the past 27 years (Bosch and Burwen 1999). The slope from both banks is gradual and uniform, which allows a large proportion of the water column to be insonified without acoustic shadowing effects. On the right bank, the bottom is composed primarily of mud, providing an acoustically absorptive surface. This absorptive property improves the signal-to-noise ratio (SNR) when the beam is aimed along the river bottom. The left-bank bottom gradient is steeper and consists of more acoustically reflective small rounded cobble and gravel.

The sonar site is located downstream of the lowest suspected Chinook salmon spawning sites, yet far enough from the mouth that most of the fish counted are probably committed to the Kenai River (Alexandersdottir and Marsh 1990). Most sport fishing activity occurs upstream of the site (Eskelin 2007).

ACOUSTIC SAMPLING

A Sound Metrics Corporation[3] (SMC) DIDSON system was operated from 16 May to 10 August 2012. Components of the DIDSON system are listed in Table 1. Appendix A1 provides greater detail on DIDSON technology and theory.

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

Sonar System Configuration

A single long-range DIDSON (DIDSON-LR) equipped with an ultra-high resolution lens was deployed on each bank of the river, such that each remained submerged at low tide (Figure 3). The location of each DIDSON relative to the bank varied slightly throughout the summer because the units were occasionally pulled and redeployed for maintenance purposes or after being dislodged by floating debris. A detailed discussion of DIDSON configurations and DIDSON image resolution and a brief explanation of multibeam sonar can be found in Appendices A1–A8. More detailed theory can be found in Belcher et al. (2002).

Electronics were housed in a tent located on the right (north) bank of the river (Figure 3). The DIDSON units were mounted on remote pan-and-tilt systems (right bank: Remote Ocean Systems PT-25; left bank: Sound Metrics Corporation X2) for precise aiming in the horizontal and vertical axes. The combined sonar and rotators were deployed in the river on a tripod-style mount (Figure 4, photo A). 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 (Figure 3). Internal attitude sensors in the DIDSON provided measurements of compass heading, pitch, and roll. An AIM 2000 attitude sensor attached to the right bank mount provided depth measurements throughout the season.

Communication cables from the right bank DIDSON fed directly into the right-bank topside box and data collection computer. On the left bank, the DIDSON communication cable fed to a topside box staged on top of the bluff, and data was transmitted via a wireless bridge to a data collection computer on the right bank. Because silt deposition in the lens compartment can cause deterioration in both image quality and range capabilities, a custom-fit fabric enclosure was used to limit silt infiltration (Figure 4, photos B and C).

During 21–26 June 2012, a standard DIDSON unit (DIDSON-S) was deployed to insonify 10 m of range behind (shoreward of) the existing left-bank DIDSON-LR. During 31 July–7 August 2012, an Adaptive Resolution Imaging Sonar (ARIS 1200—the newest generation of DIDSON technology) was deployed to insonify 26 m of range behind (shoreward of) the existing right-bank DIDSON-LR.

River Profile Mapping and Coverage

A detailed profile of the river bottom and the area encompassed by the sonar beams was produced prior to acoustic sampling. Depth readings collected with a Lowrance X-16 were paired with range measurements taken from a Bushnell Laser Ranger (±1 m accuracy) aimed at a fixed target on shore. When bottom profile information is combined with vertical tilt information from the DIDSON's internal orientation sensor, a detailed visualization of how the acoustic beam insonifies the water column above the bottom substrate can be generated (Figure 5). Each time a transducer was moved, new measurements of the transducer height above the bottom substrate and its position relative to a fixed shore location were updated in a Microsoft Excel worksheet so that beam coverage at the new location could be evaluated.

Before 2001, the right- and left-bank transducers were deployed directly across the river from each other, and complete beam coverage for the entire middle portion of the river was accomplished by extending the counting range for both banks to the thalweg (the line delimiting the lowest points along the length of the river bed). Under these conditions, we could be relatively certain that the entire middle portion of the river was insonified. In 2001, river bottom profiles indicated improved beam coverage (in the vertical plane) could be attained on the left bank by moving the transducer approximately 35 m downstream of its original location (Miller et al. 2003). The left-bank transducer has been deployed at this location since 2001. Because of the offset deployment of the right- and left- bank transducers (Figure 3), it is difficult to determine whether there is complete beam coverage (Miller et al. 2004). For this reason it is possible that some fish migrating near the thalweg (accounting for a small fraction of the inriver run) are double-counted or missed entirely.

Sampling Procedure

A systematic sample design (Cochran 1977) was used to estimate fish passage between each transducer and the river thalweg. In 2012, four separate range strata were sampled on each bank (3.3–8.3 m, 8.3–13.3 m, 13.3–23.3 m, and 23.3–33.3 m; Figure 6). This differed from 2010 and 2011, when there were 3 strata and the first stratum covered 3.3–13.3 m. The DIDSON was programmed to sample each stratum systematically for 10 min per hour according to the schedule outlined in Figure 7. This routine was followed 24 hours per day and 7 days per week unless a transducer on one or both banks was inoperable.

A test of the systematic sample design 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 and have been found to provide accurate estimates of passage (Reynolds et al. 2007; Xie and Martens 2014).

Because fish passage rates are related to tides (Eggers et al. 1995), tide stage was recorded at the top of each hour and at 30 minutes past each hour. Tide stage was determined using water level measurements taken from an AIM 2000 depth sensor attached to the right-bank DIDSON mount.

Data Collection Parameters

The autofocus feature was enabled so that the sonar automatically set the lens focus to the midrange of the selected display window (e.g., for a window length of 10 m that started at 15 m, the focus range would be 20 m; Appendix A1). The frame rate (frame per second, or fps) differed by stratum: 10 fps for 3.3–8.3 m and 8.3–13.3 m strata, 7 fps for 13.3–23.3 m strata, and 5 fps for 23.3–33.3 m strata. Long-range strata require more time for the transmitted sound to return, necessitating slower frame rates.

Manual DIDSON Fish Length Measurements

Software included with the DIDSON system (Control and Display software Version 5.25) was used to count and measure fish from DIDSON images. Electronic echograms provided the means to manually count, track, and size individual fish (Figure 6). Noise from stationary structures was removed from the images using Sound Metric Corporation’s algorithm for dynamic background removal. Fish traces displayed on the echogram could also be displayed in video mode through a toggle function (Figure 6). In video mode, technicians used the manual measuring tools to estimate the DIDSON-based length (DL) for each fish. Date, time, frame number, range, and direction of travel were also recorded for each free-swimming fish. Details regarding which fish to measure and whether or not to record direction of travel differed depending upon rate of fish passage and level of staffing. On a given day, one of the following 3 sampling protocols was selected to guide processing and analysis of the data.

Standard (STD) Sampling Protocol

The standard sampling protocol, used 16 May–14 July, was as follows:

1) Length was measured from the DIDSON image for all salmon-shaped[4] fish greater than or equal to 40 cm (DL).
2) Direction of travel was recorded for each measured fish.

The 40 cm threshold approximately separates salmon from nonsalmon species. It also corresponds approximately to the smallest fish gilled in the inriver netting project (Perschbacher 2014).

Fast Track (FT) Sampling Protocol

During the peak of the sockeye salmon run (15 July–7 August), the following “Fast-Track” sampling protocol was used:

1) Length was measured for all large salmon-shaped fish greater than or equal to 75 cm DL.
2) Length was also measured for a subset of medium salmon-shaped fish greater than or equal to 40 cm and up to 75 cm DL.
3) Direction of travel was recorded for each measured fish.

Large Fish Only (LFO) Sampling Protocol

After 7 August, milling and holding pink salmon made it difficult to reliably assess direction of travel. Beginning on 8 August, fish 75 cm or greater were measured and shorter fish were ignored. The “Large Fish Only” sampling protocol was as follows:

1) Length was measured for all large salmon-shaped fish greater than or equal to 75 cm DL.
2) Direction of travel was recorded for each measured fish.
3) Fish less than 75 cm DL were not recorded in any way due to the difficulty in ascertaining direction of travel. Fish chosen for measurement that turned out to be less than 75 cm DL were *not* recorded.

Under all protocols, any fish appearing in a DIDSON image was a candidate for counting and measuring. That is, there was no requirement that the fish cross the center of the beam. Additional details on the procedures and software settings used to obtain manual fish length measurements can be found in Burwen et al. (2010) and in Appendices A5–A8.

Evaluation of Alternative Upriver Sonar Site

The current site at RM 8.6 was selected in part because of 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 (at this site, from the nearshore region to the thalweg). A primary disadvantage of the site is its location within tidal influence. The area shoreward of the transducers cannot be insonified as the tide rises and floods behind the transducers. Data collected in 2011 (Miller et al. 2014) indicated that significant numbers of Chinook salmon migrate shoreward of the transducers, undetected by the sonar. For this reason, ADF&G measured river bottom profiles at locations upriver from river mile 8.6 in 2011 and identified a potential alternative site at RM 13.7 (Figure 8). The RM 13.7 site is located outside of tidal influence, yet downstream of major Chinook salmon spawning grounds. A significant portion of

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[4] Flatfish, seals, and beluga whales were not recorded, and fish measured less than 40 cm were omitted from further calculations.

the Chinook salmon sport fishery occurs below RM 13.7, but harvest below the site can be accounted for if this site were to be used to generate estimates for inseason management.

Aquacoustics Inc. was contracted to conduct an extensive survey of the RM 13.7 site on 9 July 2012. Based on the survey and associated cross-river transects, a sonar was deployed on each bank of the main channel from 16 to 30 July (ARIS 1200 on the left bank and DIDSON-LR on the right bank; Figure 9). The DIDSON-LR was also deployed from 30 to 31 July in the minor channel. Deployment configurations were similar to those described for the RM 8.6 project, with high resolution lenses attached to the ARIS 1200 and DIDSON-LR and each mounted to a Sound Metrics Corporation X2 rotator and a steel tripod. The sonar systems were deployed to determine image quality at the site relative to bottom contour, and to determine the presence or absence of fish migrating upriver in the minor channel.

DATA ANALYSIS

DIDSON data were used to generate multiple estimates of fish passage, detailed below. Except where otherwise stated, all estimates apply to fish migrating *upstream* in a *midriver corridor* greater than 3 m from both the left- and right-bank transducers. Note that this corridor is 19 m wider than that formerly covered by split-beam sonar, which was greater than 15 m from the right-bank transducer and greater than 10 m from the left-bank transducer.

Fish longer than 40 cm are referred to generically as "salmon" in this report. A minimum threshold of 40 cm includes virtually all Chinook salmon and effectively excludes nonsalmon species. For example, none of 452 Chinook salmon caught in gillnets at RM 8.6 in 2012 were smaller than 40 cm (or 16 inches; Perschbacher 2014). The proportion of fish over 40 cm that were not salmon is not known because nonsalmon species were not measured; however, the proportion was very small.

Midriver Salmon Passage

The DIDSON generally operated 10 minutes per hour for each spatial stratum, 24 hours per day. The number of salmon-sized fish y passing upstream, midriver between the transducers, during day i was estimated as follows:

$$\hat{y}_i = 24\hat{\bar{y}}_i \tag{1}$$

where

$$\hat{\bar{y}}_i = \frac{1}{n_i}\sum_{j=1}^{n_i}\hat{y}_{ij}\ , \tag{2}$$

n_i is the number of hours (j) during which fish passage was estimated for day i, and

$$\hat{y}_{ij} = \sum_{k=1}^{2}\hat{y}_{ijk}\ . \tag{3}$$

The quantity $\hat{y}_{ijk}$ is upstream midriver fish passage on bank k during hour j of day i, estimated as

$$\hat{y}_{ijk} = \sum_{s=1}^{4}\hat{y}_{ijks}\ , \tag{4}$$

where y_{ijks} is upstream midriver fish passage for stratum s of bank k during hour j of day i, estimated as

$$\hat{y}_{ijks} = \frac{60}{m_{ijks}} c_{ijks} \tag{5}$$

and where

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

c_{ijks} = number of upstream bound fish greater than or equal to 40 cm in stratum s of bank k during hour j of day i.

When samples were missed due to equipment malfunction on one bank, passage on the nonfunctional bank k' was estimated from passage on the functional bank k as follows:

$$\hat{y}_{ijk'} = \hat{R}_{ikt}\hat{y}_{ijk} \tag{6}$$

where the estimated bank-to-bank ratio $\hat{R}_{ikt}$ for day i and tide stage t was calculated by pooling counts from all hours at tide stage t (set J_t) during the previous 2 days (to ensure adequate sample size) as follows:

$$\hat{R}_{ikt} = \frac{\sum_{j \in J_t} \hat{y}_{(i-2)jk'} + \sum_{j \in J_t} \hat{y}_{(i-1)jk'}}{\sum_{j \in J_t} \hat{y}_{(i-2)jk} + \sum_{j \in J_t} \hat{y}_{(i-1)jk}}. \tag{7}$$

The variance of the daily estimates $\hat{y}$, due to systematic sampling in time, was approximated (successive difference model, Wolter 1985) with adjustments for missing data as follows:

$$\hat{V}[\hat{y}_i] \cong 24^2(1-f)\frac{\sum_{j=2}^{24} \phi_{ij}\phi_{i(j-1)}\left(\hat{y}_{ij} - \hat{y}_{i(j-1)}\right)^2}{2\sum_{j=1}^{24}\phi_{ij}\sum_{j=2}^{24}\phi_{ij}\phi_{i(j-1)}} \tag{8}$$

where f is the sampling fraction (proportion of time sampled daily, usually 0.17), and ϕ_{ij} is 1 if $\hat{y}_{ij}$ exists for hour j of day i, or 0 if not. This variance is an assessment of the uncertainty due to subsampling (counting fish for 10 minutes per hour and expanding). It 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).

The estimate of total upstream midriver fish passage during the period of sonar operation, and its variance, was the sum of all daily estimates:

$$\hat{Y} = \sum_i \hat{y}_i \tag{9}$$

and

$$\hat{V}\left[\hat{Y}\right] = \sum_i \hat{V}\left[\hat{y}_i\right]. \quad (10)$$

Midriver Large Fish Passage

The estimated number of large fish passing upstream in midriver during day *i* was calculated following Equations 1–10 after redefining c_{ijks} in Equation 5 to be the number of upstream bound fish greater than 3 m from the right- and left-bank transducers and equal to or exceeding *X* cm in length as measured by the DIDSON for the sample of stratum *s* on bank *k* during hour *j* of day *i*, where *X* was 75, 80, or 90 cm.

Midriver Chinook Salmon Passage

The number of Chinook salmon passing upstream in midriver on day *i* was estimated by multiplying the sonar-based midriver salmon passage estimate by a sonar- and netting-based estimate of the proportion of salmon that were Chinook salmon:

$$\hat{z}_i = \hat{y}_i \hat{\pi}_{Ci}. \quad (11)$$

where y_i is upstream passage of salmon-sized fish between and at least 3 m from both the left-bank transducer and right-bank transducers (estimated using Equation 1), and $\hat{\pi}_{Ci}$ is the estimated proportion of salmon passing in midriver that were Chinook salmon, obtained by fitting a statistical mixture model to DIDSON length data, gillnet catches, and tethered fish data. The mixture model is described in Appendix B1–B3; WinBUGS code is provided in Appendices B4–B6, and technical details are summarized in Appendix B7.

Variance estimates follow Goodman (1960):

$$\hat{V}\left(\hat{z}_i\right) = \hat{y}_i^2 \hat{V}\left(\hat{\pi}_{Ci}\right) + \hat{\pi}_{Ci}^2 \hat{V}\left(\hat{y}_i\right) - \hat{V}\left(\hat{\pi}_{Ci}\right)\hat{V}\left(\hat{y}_i\right). \quad (12)$$

Cumulative estimates were obtained by summing daily estimates and variances.

Net-apportioned Chinook Salmon Index

The “net-apportioned” daily index of Chinook salmon passage is the product of a sonar-based passage estimate and a netting-derived estimate of species composition:

$$\hat{y}_{NETi} = \hat{y}_{SBi} \hat{\pi}_{NETi} \quad (13)$$

with variance

$$\hat{V}\left(\hat{y}_{NETi}\right) = \hat{y}_{SBi}^2 \hat{V}\left(\hat{\pi}_{NETi}\right) + \hat{\pi}_{NETi}^2 \hat{V}\left(\hat{y}_{SBi}\right) - \hat{V}\left(\hat{\pi}_{NETi}\right)\hat{V}\left(\hat{y}_{SBi}\right) \quad (14)$$

where y_{SBi} is upstream passage of salmon-sized fish greater than 10 m from the left-bank transducer and greater than 15 m from the right-bank transducer (formerly composing the split-beam sonar corridor), and $\hat{\pi}_{NETi}$ is the estimated proportion of drift gillnet catches that were Chinook salmon (Perschbacher 2014).

Large Fish Passage Shoreward of Existing Transducers

Data were collected in 2012 with an additional DIDSON transducer deployed behind (shoreward of) the existing left-bank transducer 21–26 June and the existing right-bank transducer 31 July–7 August. Fish equal to or exceeding 75 cm DIDSON length were tallied by direction of travel for comparison with midriver results.

RESULTS

Long-range high-resolution DIDSON units were deployed from both banks and sampled the midsection of the river for 92 days (16 May–15 August) in 2012. Salmon passage was successfully estimated in 98% and 95% of early-run and late-run samples, respectively.

SIZE DISTRIBUTION AND SPECIES COMPOSITION

Small fish predominated in both early and late runs as evidenced by large left-hand modes in the DIDSON length (DL) frequency distributions (Figure 10, top panels). The modes of the DL distributions line up well with distributions of mid eye to tail fork (METF) lengths from salmon measured by the inriver netting project (Figure 10, bottom panels). The DL distributions are broader than the corresponding METF distributions because there is greater error associated with measuring length from DIDSON images. The shapes of the frequency distributions suggest that fish measuring greater than approximately 75–80 cm are probably Chinook salmon. Of fish measuring 40 cm or longer between 16 May and 7 August, 3.8% were 75 cm or longer and 3.5% were 80 cm or longer. After 7 August, milling pink salmon prevented a full accounting of total salmon passage, and only large fish were recorded. In this report, “large Chinook salmon” are defined as fish greater than or equal to 75 cm DIDSON length. Although the species of individual fish cannot be determined with certainty from DIDSON images, probably very few fish greater than 75 cm DL were *not* Chinook salmon.

SPATIAL AND TEMPORAL DISTRIBUTION

During the early run, salmon of all sizes favored the left bank of the insonified zone (Figure 11). During the late run, large Chinook salmon continued to favor the left bank, but small salmon favored the right bank (Figure 11). During both the early and late runs, most (57–73%) upstream-bound large (DL $\geq$ 75 cm) Chinook salmon were observed from the left-bank transducer (Table 2).

Distribution by range strata (3–8 m, 8–13 m, 13–23 m, and 23–33 m) was 20%, 22%, 29%, and 29%, respectively, in the early run and 17%, 18%, 31%, and 34%, respectively, during the late run (derived from summed values for left and right banks in Table 2). The temporal distribution of large Chinook salmon among tide stages differed by run, from 39%, 38%, and 23% on the rising, falling, and low tides, respectively, during the early run to 47%, 39%, and 14%, respectively, during the late run (Table 2, last column). The natural distribution of tide stages was 32% rising, 44% falling, and 24% low. Comparing this to the tidal distribution of salmon (quoted above from Table 2) indicates that a disproportionately large fraction of Chinook salmon migrated past the site during the rising tide in both early and late runs.

The proportion of all upstream-bound salmon that were classified as large Chinook salmon (≥75 cm DL) varied by run, bank, range stratum, and tide stage (Table 3). A greater proportion of salmon were large Chinook salmon in the early run (7.0%) than in the late run (4.0%). The late run value applies to 1 July–7 August; after 7 August, milling pink salmon made it infeasible to count upstream passage of fish.

During the early run, the highest proportions of large fish occurred in the 8–13 m strata and in the center of the river (left and right bank 23–33 m strata; Table 3). During the late run, when small salmon favored the right bank (Figure 11), relatively more salmon were large Chinook salmon on the left bank (5.4%) than on the right bank (2.8%), with the lowest fraction (1.5%) occurring in the nearshore right-bank stratum.

During the early run, upstream-moving salmon that passed during rising tide had the highest fraction of large Chinook salmon (8.4%), followed by the low tide (7.8%) and the falling tide (5.6%; Table 3). The same pattern held during the late run; fish migrating during the rising tide were composed of 4.0% large Chinook salmon, followed by 2.2% during the low tide and 2.1% during the falling tide (Table 3).

Spatial and temporal patterns of migration of small, medium, and large salmon are displayed relative to tide stage in Appendices C1–C7. In general, Chinook salmon greater than or equal to 75 cm DL were interspersed throughout the sampled range and were only mildly clustered in space and time. Smaller salmon exhibited more clustering than did large Chinook salmon, and their migration timing was strongly influenced by the tide cycle.

DIRECTION OF TRAVEL

Among fish that were greater than or equal to 75 cm DL, 94.6% were upstream bound in the early run, and 94.2% were upstream bound in the late run (Appendices D1 and D2). Daily percentages of fish greater than or equal to 75 cm DL that were upstream bound ranged from 54% (26 May; 7 of 13 fish) to 100% (many days).

MIDRIVER SALMON PASSAGE

Daily DIDSON estimates of upstream salmon passage totaled 36,976 (SE 645) for the early run (Table 4) and 536,843 (SE 18,120) for 1 July–7 August of the late run (Table 5). After 7 August, when milling pink salmon became abundant and some small fish were not recorded, a full accounting of total upstream salmon passage was not possible.

MIDRIVER CHINOOK SALMON PASSAGE

Daily proportions of upstream-bound salmon that were Chinook salmon were estimated using a DL mixture model. These proportions were multiplied by DIDSON estimates of upstream salmon passage to produce DIDSON estimates of upstream Chinook salmon passage: 3,228 (SE 191) Chinook salmon during the early run (16 May–30 June; Table 4) and 21,613 (SE 667) during the late run (1 July–15 August; Table 5). The DL mixture model also produced daily estimates of Chinook salmon age composition (Tables 6 and 7). These estimates incorporated length information from DIDSON as well as from inriver gillnet catches. The DIDSON-based estimates are germane to a midriver water column located between and at least 3 m from the transducers at RM 8.6. They supplant the preliminary numbers reported by Fleischman and McKinley (2013: Table 4) and McKinley and Fleischman (2013: Table 5)[5].

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[5] Several technical modifications were made to mixture model methodology since preliminary estimates were published in 2013. A list of these modifications can be found in Appendix B7.

MIDRIVER LARGE FISH PASSAGE

Daily threshold estimates of fish equal or exceeding DIDSON lengths of 75 cm, 80 cm, and 90 cm are tabulated in Appendices E1 and E2. A DIDSON length of 90 cm is approximately midway between the average lengths of age-5 and age-6 Chinook salmon[6].

NET-APPORTIONED INDEX OF CHINOOK SALMON PASSAGE

Net-apportioned estimates of upstream Chinook salmon passage were 2,771 (SE 300) fish during the early run and 20,391 (SE 1,660) fish for 1 July through 7 August (Appendix F1 and F2). After 7 August, the presence of milling pink salmon made it impractical to count every small fish in every sample. Therefore, the quantity $\hat{y}_{SBi}$ and the net-apportioned index $\hat{y}_{NETi}$ (see Equation 13) could not be produced for 8–15 August.

It is important to note that DIDSON generally detects and resolves more fish than split-beam sonar. Therefore, the net-apportioned estimates, based on DIDSON counts, are greater than what would have been obtained in 2002–2011 with split-beam sonar. Any comparison between 2012 and 2002–2011 versions of net-apportioned estimates must take this difference into account. See Miller et al. (2013: Figure 26), and Miller et al. (2014: Figure 16) for a quantification of this difference. Finally, comparability with past years will be imperfect because, in 2012, the inriver netting program sampled the river corridor insonified by the DIDSON (Perschbacher 2014), rather than the corridor formerly insonified by the split-beam sonar.

LARGE FISH PASSAGE SHOREWARD OF EXISTING TRANSDUCERS

During 21–26 July 2012, an additional DIDSON transducer was positioned to insonify 10 m of range behind (shoreward of) the existing left-bank transducer. Relative to large fish detected midriver using the standard configuration, the extra coverage for the 6-day trial period resulted in detecting 29% more fish greater than or equal to 75 cm DL and 12% more fish greater than or equal to 90 cm DL. Downstream-bound fish accounted for 10% of total fish greater than or equal to 75 cm behind the transducer, compared to 0% in midriver. Spatial and temporal distribution of fish during the trial period is depicted in Figure 12.

During 31 July–7 August, an ARIS transducer was positioned to insonify 26 m of range behind (shoreward of) the existing right-bank DIDSON transducer. Relative to large fish detected midriver using the standard configuration, the extra coverage for the 8-day trial period resulted in detecting 3% more fish greater than or equal to 75 cm DL and 2% more fish greater than or equal to 90 cm DL. Downstream-bound fish made up 31% of total fish greater than or equal to 75 cm behind the transducer, compared to 9% in midriver. Spatial and temporal distribution of fish during the trial period is depicted in Figure 13.

EVALUATION OF ALTERNATIVE UPRIVER SONAR SITE

Bathymetric surveys conducted at RM 13.7 on 9 July 2012 by Aquacoustics, Inc. showed that this section of river has a nearly ideal bottom profile for sonar deployment. A total of 9 cross-river transects were conducted in the area (Figures 9 and 14). Transect 5 (right bank) and Transect 6 (left bank) were chosen as the preferred locations for sonar deployment.

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[6] Ages are total age from spawning event to spawning migration.

On 16 July 2012, an ARIS 1200 with a high-resolution lens was deployed on the left bank in the vicinity of Transect 6 and a DIDSON-LR with a high-resolution lens was deployed on the right bank in the vicinity of Transect 5. Image quality was sufficient at both locations for estimating salmon passage. The width of the main channel at RM 13.7 is approximately 90 m at ordinary high water. The range capabilities of the ARIS 1200 and the DIDSON-LR with high-resolution lenses are limited to approximately 33 m for the purpose of accurately estimating fish length. For this reason, a total of 4 sonars would be required to provide near-complete coverage of the cross section of the main channel at RM 13.7 (a nearshore and offshore sonar on each bank).

On 30 July, the DIDSON-LR was moved to the minor channel and deployed on the left bank of the channel near the downriver end of the island (Figure 9). This location was unsuitable for sonar deployment for 2 reasons: 1) the width of the channel at this location (approximately 40 m) would require more than 1 sonar to cover the entire channel; and 2) low river current in this section of the channel resulted in extensive fish milling behavior, making fish difficult to count and measure. On 31 July, the DIDSON-LR was relocated to the upriver end of the island (Figure 9) where the minor channel is more narrow (approximately 30 m) and milling activity is minimal due to increased river current at this location. Image quality at this second location was good, and many fish were observed actively migrating upstream near the far (right) bank.

DISCUSSION AND RECOMMENDATIONS

In 2012, daily values of inriver gillnetting CPUE, net-apportioned estimates, and sport fishery CPUE exhibited varying degrees of (visually compared but unmeasured) congruity with DIDSON estimates of Chinook salmon passage (Figures 15, 16, and 17). As more index data are collected concurrent with DIDSON data, it will be possible to more thoroughly evaluate their strengths and weaknesses and to identify confounding influences.

During a 6-day trial in June 2012, an additional 29% of large (greater than or equal to 75 cm DL) Chinook salmon migrated shoreward of the left-bank transducer, exceeding the 9% observed in July 2011 (Miller et al. 2014). These results, which are germane to only a fraction of the river not sampled by sonar and were obtained during a limited time period, are consistent with indirect estimates of 55% during the early run (McKinley and Fleischman 2013) and 28% during the late run (Fleischman and McKinley 2013), based on modeling of 1986–2012 abundance data.

Bathymetric surveys and sonar deployment using ARIS and DIDSON indicate that RM 13.7 is an effective location for operating an experimental sonar site for the purpose of estimating Chinook salmon passage. The favorable bottom contour at RM 13.7 combined with the proper sonar deployment configuration (4 sonars in the main channel and 1 sonar in the minor channel) would allow nearly complete cross-river coverage.

RECOMMENDATIONS

1) As soon as practicable, develop new escapement goals based on DIDSON estimates of abundance.
2) Continue to operate the inriver netting project at RM 8.6 in the same standardized protocol as has been practiced since 2002. Consistent data produced by this project may continue to prove valuable for reconstructing historical abundance.
3) Consider deploying additional nets behind the standard transducer placements in order to confirm the presence of large Chinook salmon and to investigate the feasibility of sampling behind the transducers.

4) In 2013, install an experimental sonar site upstream of tidal influence at RM 13.7, compare Chinook salmon passage at the two sites, and assess the feasibility of relocating all sonar operations to the new site in the near future.

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TABLES

Table 1.–Components of the DIDSON sonar system used in 2012.

System component	Description
Sounder	DIDSON-LR operating at 1.2 MHz (one for each bank)
Orientation sensor	Honeywell Truepoint Compass (internal)
Lens	High Resolution Lens Assembly with ~3°×15° beam pattern
Data collection computer	Dell Latitude E6500 laptop computer (one for each sonar)
Remote pan-and-tilt aiming controller	Remote Ocean Systems Model PTC-1 Pan-and-tilt Controller (right bank)
Remote pan-and-tilt aiming unit	Remote Ocean Systems Model P-25 Remote Pan-and-tilt Unit (right bank) Sound Metrics X2 rotator – controlled via DIDSON software (left bank)
Heading and angular measurement device	JASCO Research Ltd. AIM-2000 (provided depth and temperature readings – right bank)

Table 2.–Percentage of upstream-bound large Chinook salmon (DIDSON length ≥ 75 cm) by riverbank, range stratum (distance from transducer), and tide stage sampled by DIDSON for the 2012 early and late runs.

		Left bank					Right bank					
		Range stratum					Range stratum					
Run	Tide stage	3–8 m	8–13 m	13–23 m	23–33 m	All strata	3–8 m	8–13 m	13–23 m	23–33 m	All strata	Both banks
Early												
	Rising	5	7	8	5	25	1	2	4	7	14	39
	Falling	6	5	8	9	29	1	1	2	5	9	38
	Low	6	5	6	2	19	1	1	1	1	4	23
	All stages	17	17	22	16	73	3	5	7	13	27	100
Late												
	Rising	4	4	8	8	25	3	4	7	8	22	47
	Falling	4	5	7	8	23	2	3	5	6	16	39
	Low	2	2	2	3	9	1	1	2	2	5	14
	All stages	10	11	18	18	57	7	7	13	16	43	100

Note: Due to rounding, sums of values across individual cells may not sum to marginal totals.

Table 3.–Percentage of upstream-bound salmon that were classified as large Chinook salmon (DIDSON length ≥ 75cm) by riverbank, range stratum (distance from transducer), and tide stage for the 2012 early and late runs.

		Left bank					Right bank					
		Range stratum					Range stratum					
Run	Tide stage	3–8 m	8–13 m	13–23 m	23–33 m	All strata	3–8 m	8–13 m	13–23 m	23–33 m	All strata	Both banks
Early												
	Rising	6.1	11.5	7.9	8.3	8.3	5.7	9.9	6.5	11.6	8.7	8.4
	Falling	5.5	5.3	4.5	7.6	5.6	5.4	7.1	3.1	7.4	5.7	5.6
	Low	7.3	9.7	8.6	4.4	7.6	10.0	10.7	10.3	6.1	8.3	7.8
	All stages	6.2	8.2	6.3	7.2	6.8	6.1	8.9	5.5	8.8	7.4	7.0
Late												
	Rising	6.1	5.3	7.2	6.2	6.3	2.1	2.9	4.2	6.4	4.0	5.0
	Falling	4.2	4.3	4.7	5.2	4.7	1.0	1.6	2.4	3.3	2.1	3.2
	Low	6.4	6.9	5.0	5.5	5.8	1.6	1.6	2.6	3.3	2.2	3.9
	All stages	5.2	5.0	5.6	5.6	5.4	1.5	2.1	3.2	4.5	2.8	4.0

Table 4.–DIDSON-based estimates of upstream salmon passage, DL mixture model (DLMM) proportion of salmon that were Chinook salmon, and DLMM-estimated upstream Chinook salmon passage, RM 8.6 Kenai River, early run, 2012.

	DIDSON upstream salmon		DLMM Chinook salmon		DLMM Chinook salmon		
Date	Passage	SE	Proportion	SE	Passage	SE	CV
16 May	72	17	0.181	0.118	13	9	0.68
17 May	54	17	0.354	0.227	19	13	0.69
18 May	90	18	0.137	0.086	12	8	0.67
19 May	78	14	0.422	0.129	33	12	0.35
20 May	103	18	0.291	0.124	30	14	0.46
21 May	173	35	0.112	0.060	19	11	0.58
22 May	145	28	0.123	0.067	18	10	0.56
23 May	187	37	0.261	0.147	49	29	0.58
24 May	300	45	0.106	0.056	32	17	0.54
25 May	398	63	0.091	0.039	36	17	0.46
26 May	283	38	0.161	0.060	46	18	0.39
27 May	742	71	0.035	0.017	26	13	0.48
28 May	876	77	0.126	0.032	110	30	0.27
29 May	510	59	0.071	0.077	36	39	1.08
30 May	754	74	0.070	0.024	52	19	0.36
31 May	513	71	0.103	0.037	53	20	0.38
1 Jun	629	70	0.105	0.031	66	21	0.31
2 Jun	470	53	0.167	0.069	78	33	0.43
3 Jun	609	79	0.133	0.035	81	23	0.29
4 Jun	826	93	0.088	0.028	73	25	0.34
5 Jun	766	102	0.063	0.025	49	20	0.41
6 Jun	767	145	0.107	0.032	82	29	0.35
7 Jun	1,152	103	0.040	0.015	46	18	0.39
8 Jun	555	56	0.156	0.039	86	23	0.27
9 Jun	1,224	156	0.104	0.025	127	34	0.27
10 Jun	1,080	87	0.129	0.031	139	35	0.25
11 Jun	887	101	0.074	0.028	66	26	0.39
12 Jun	917	109	0.116	0.031	106	31	0.29
13 Jun	1,044	83	0.104	0.032	109	34	0.31
14 Jun	851	76	0.073	0.027	62	23	0.37
15 Jun	941	77	0.118	0.034	111	33	0.30
16 Jun	772	64	0.098	0.032	76	26	0.34
17 Jun	700	63	0.101	0.041	70	29	0.41
18 Jun	543	76	0.189	0.057	103	34	0.33
19 Jun	646	73	0.145	0.046	94	31	0.33
20 Jun	808	107	0.154	0.046	125	40	0.32

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Table 4.–Page 2 of 2.

	DIDSON upstream salmon		DLMM Chinook salmon		DLMM Chinook salmon		
Date	Passage	SE	Proportion	SE	Passage	SE	CV
21 Jun	833	62	0.083	0.031	69	27	0.39
22 Jun	688	68	0.096	0.036	66	26	0.39
23 Jun	634	74	0.157	0.058	99	38	0.38
24 Jun	875	66	0.038	0.023	33	20	0.60
25 Jun	793	74	0.094	0.043	75	35	0.46
26 Jun	790	87	0.075	0.037	60	30	0.49
27 Jun	1,972	198	0.067	0.029	132	59	0.45
28 Jun	2,818	206	0.031	0.012	89	33	0.37
29 Jun	3,664	253	0.031	0.011	113	39	0.35
30 Jun	2,444	176	0.065	0.018	159	46	0.29
Total	36,976	645			3,228	191	0.06

Note: All estimates are of upstream-bound fish in midriver between and at least 3 m from the transducers.

Table 5.–DIDSON-based estimates of upstream salmon passage, DL mixture model (DLMM) proportion of salmon that were Chinook salmon, and DLMM-estimated upstream Chinook salmon passage, RM 8.6 Kenai River, late run, 2012.

	DIDSON upstream salmon		DLMM Chinook salmon		DLMM Chinook salmon		
Date	Passage	SE	Proportion	SE	Passage	SE	CV
1 Jul	4,910	325	0.044	0.014	218	68	0.31
2 Jul	5,321	478	0.023	0.008	121	41	0.34
3 Jul	5,305	377	0.024	0.008	127	42	0.33
4 Jul	4,525	364	0.013	0.006	60	26	0.44
5 Jul	4,377	318	0.012	0.006	52	27	0.51
6 Jul	2,991	248	0.031	0.010	92	31	0.33
7 Jul	4,245	352	0.027	0.008	114	35	0.31
8 Jul	4,776	495	0.023	0.006	110	32	0.29
9 Jul	4,551	510	0.054	0.012	247	62	0.25
10 Jul	6,123	745	0.086	0.014	530	106	0.20
11 Jul	7,077	722	0.066	0.011	464	89	0.19
12 Jul	8,909	866	0.043	0.007	383	75	0.20
13 Jul	14,044	1,242	0.047	0.007	662	118	0.18
14 Jul	30,950	5,771	0.019	0.003	589	151	0.26
15 Jul	64,268	14,161	0.003	0.001	222	80	0.36
16 Jul	42,329	3,492	0.010	0.001	428	70	0.16
17 Jul	13,032	935	0.063	0.006	827	100	0.12
18 Jul	15,611	1,269	0.030	0.004	463	72	0.16
19 Jul	14,677	1,326	0.023	0.004	331	59	0.18
20 Jul	27,132	2,782	0.023	0.003	628	99	0.16
21 Jul	41,057	4,922	0.007	0.001	304	65	0.21
22 Jul	30,246	2,244	0.022	0.004	668	130	0.20
23 Jul	16,998	2,154	0.015	0.003	252	61	0.24
24 Jul	14,851	1,245	0.035	0.006	522	98	0.19
25 Jul	14,521	2,004	0.039	0.006	573	113	0.20
26 Jul	8,382	851	0.093	0.012	776	127	0.16
27 Jul	4,398	343	0.190	0.019	834	107	0.13
28 Jul	2,857	278	0.292	0.028	835	114	0.14
29 Jul	2,809	286	0.221	0.025	621	94	0.15
30 Jul	6,294	511	0.080	0.010	503	74	0.15
31 Jul	8,647	565	0.089	0.009	767	92	0.12

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Table 5.–Page 2 of 2.

Date	DIDSON upstream salmon		DLMM Chinook salmon		DLMM Chinook salmon		
	Passage	SE	Proportion	SE	Passage	SE	CV
1 Aug	10,402	843	0.052	0.006	540	78	0.14
2 Aug	18,934	1,360	0.030	0.004	570	79	0.14
3 Aug	29,419	3,305	0.020	0.002	580	97	0.17
4 Aug	13,787	519	0.047	0.006	650	84	0.13
5 Aug	11,445	1,612	0.024	0.004	272	58	0.21
6 Aug	11,977	2,482	0.047	0.005	560	133	0.24
7 Aug	4,666	1,410	0.228	0.017	1,063	331	0.31
8 Aug					638	74	0.12
9 Aug					666	73	0.11
10 Aug					996	80	0.08
11 Aug					562	71	0.13
12 Aug					415	147	0.35
13 Aug					359	101	0.28
14 Aug					296	51	0.17
15 Aug					123	28	0.22
Total							
1 July–7 Aug	536,843	18,120					
1 July–15 Aug					21,613	667	0.031

Note: All estimates are of upstream-bound fish in midriver between and at least 3 m from the transducers. Estimates of upstream salmon passage were not available after 7 August. DLMM estimate was not available for 15 August (value shown is a simple expansion of the daily DIDSON length threshold estimate from Appendix E2).

Table 6.–Daily estimates of Chinook salmon age composition derived from fitting a mixture model to length measurements from DIDSON and inriver gillnet catches, RM 8.6 Kenai River, early run, 2012.

	Ages 3 and 4		Age 5		Ages 6 and 7	
Date	Proportion	SE	Proportion	SE	Proportion	SE
16 May	0.10	0.12	0.11	0.13	0.79	0.17
17 May	0.07	0.09	0.16	0.14	0.77	0.15
18 May	0.05	0.06	0.08	0.08	0.88	0.10
19 May	0.04	0.05	0.08	0.09	0.88	0.10
20 May	0.05	0.07	0.11	0.11	0.83	0.13
21 May	0.04	0.05	0.10	0.10	0.86	0.11
22 May	0.04	0.05	0.08	0.09	0.88	0.10
23 May	0.04	0.05	0.09	0.10	0.87	0.11
24 May	0.04	0.06	0.15	0.13	0.80	0.14
25 May	0.06	0.08	0.12	0.11	0.82	0.13
26 May	0.07	0.09	0.17	0.14	0.76	0.15
27 May	0.04	0.05	0.33	0.18	0.63	0.18
28 May	0.06	0.07	0.41	0.17	0.53	0.17
29 May	0.05	0.07	0.44	0.18	0.51	0.18
30 May	0.04	0.05	0.52	0.16	0.45	0.16
31 May	0.04	0.06	0.51	0.13	0.45	0.13
1 Jun	0.04	0.05	0.58	0.13	0.39	0.12
2 Jun	0.03	0.04	0.42	0.17	0.55	0.17
3 Jun	0.03	0.04	0.61	0.14	0.36	0.14
4 Jun	0.03	0.04	0.56	0.14	0.41	0.14
5 Jun	0.03	0.04	0.57	0.12	0.40	0.12
6 Jun	0.03	0.03	0.61	0.14	0.37	0.14
7 Jun	0.03	0.04	0.60	0.14	0.38	0.14
8 Jun	0.03	0.04	0.63	0.14	0.34	0.14
9 Jun	0.14	0.09	0.54	0.11	0.32	0.10
10 Jun	0.13	0.08	0.70	0.11	0.18	0.09
11 Jun	0.14	0.09	0.60	0.13	0.26	0.12
12 Jun	0.18	0.10	0.53	0.15	0.29	0.14
13 Jun	0.23	0.12	0.54	0.15	0.23	0.12
14 Jun	0.22	0.12	0.51	0.18	0.27	0.16
15 Jun	0.23	0.12	0.62	0.14	0.15	0.10
16 Jun	0.17	0.10	0.48	0.14	0.36	0.12
17 Jun	0.27	0.12	0.52	0.14	0.22	0.11
18 Jun	0.25	0.11	0.52	0.14	0.23	0.12
19 Jun	0.26	0.10	0.52	0.12	0.22	0.09
20 Jun	0.27	0.11	0.49	0.12	0.24	0.10

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Table 6.–Page 2 of 2.

	Ages 3 and 4		Age 5		Ages 6 and 7	
Date	Proportion	SE	Proportion	SE	Proportion	SE
21 Jun	0.31	0.11	0.48	0.12	0.22	0.10
22 Jun	0.34	0.11	0.33	0.14	0.33	0.13
23 Jun	0.40	0.13	0.46	0.14	0.13	0.10
24 Jun	0.35	0.13	0.23	0.15	0.42	0.14
25 Jun	0.33	0.12	0.48	0.15	0.18	0.12
26 Jun	0.38	0.12	0.50	0.13	0.12	0.09
27 Jun	0.41	0.13	0.39	0.13	0.20	0.10
28 Jun	0.33	0.12	0.43	0.12	0.24	0.10
29 Jun	0.32	0.11	0.38	0.12	0.31	0.11
30 Jun	0.28	0.11	0.32	0.11	0.40	0.11
Weighted mean	0.18	0.02	0.46	0.04	0.35	0.03

Note: Estimates apply to upstream-bound fish in midriver between and at least 3 m from the transducers. In the mixture model, ages 3 and 4 are pooled, as are ages 6 and 7. Means are weighted by daily DLMM estimates.

Table 7.–Daily estimates of Chinook salmon age composition derived from fitting a mixture model to length measurements from DIDSON and inriver gillnet catches, RM 8.6 Kenai River, late run, 2012.

	Ages 3 and 4		Age 5		Ages 6 and 7	
Date	Proportion	SE	Proportion	SE	Proportion	SE
1 Jul	0.35	0.12	0.36	0.10	0.28	0.09
2 Jul	0.32	0.11	0.33	0.12	0.35	0.11
3 Jul	0.25	0.11	0.38	0.12	0.37	0.12
4 Jul	0.22	0.10	0.33	0.13	0.44	0.13
5 Jul	0.25	0.11	0.53	0.12	0.22	0.09
6 Jul	0.21	0.09	0.50	0.10	0.28	0.08
7 Jul	0.19	0.09	0.49	0.10	0.32	0.09
8 Jul	0.13	0.07	0.50	0.12	0.37	0.11
9 Jul	0.24	0.09	0.55	0.12	0.21	0.10
10 Jul	0.25	0.08	0.48	0.18	0.27	0.17
11 Jul	0.24	0.08	0.36	0.13	0.40	0.13
12 Jul	0.21	0.08	0.39	0.09	0.39	0.09
13 Jul	0.24	0.08	0.32	0.10	0.44	0.10
14 Jul	0.16	0.06	0.30	0.08	0.54	0.09
15 Jul	0.18	0.07	0.27	0.11	0.56	0.11
16 Jul	0.08	0.05	0.33	0.09	0.59	0.09
17 Jul	0.05	0.04	0.36	0.11	0.59	0.12
18 Jul	0.05	0.05	0.48	0.09	0.47	0.09
19 Jul	0.06	0.05	0.33	0.16	0.62	0.16
20 Jul	0.09	0.06	0.46	0.15	0.45	0.15
21 Jul	0.11	0.08	0.36	0.14	0.53	0.14
22 Jul	0.20	0.08	0.33	0.11	0.47	0.11
23 Jul	0.22	0.08	0.27	0.12	0.51	0.12
24 Jul	0.23	0.08	0.21	0.11	0.56	0.11
25 Jul	0.24	0.07	0.34	0.11	0.42	0.11
26 Jul	0.21	0.06	0.32	0.10	0.46	0.10
27 Jul	0.17	0.05	0.22	0.14	0.61	0.15
28 Jul	0.17	0.05	0.51	0.09	0.32	0.08
29 Jul	0.16	0.05	0.35	0.19	0.49	0.19
30 Jul	0.13	0.04	0.41	0.21	0.46	0.21
31 Jul	0.12	0.04	0.45	0.25	0.43	0.25

-continued-

Table 7.–Page 2 of 2.

	Ages 3 and 4		Age 5		Ages 6 and 7	
Date	Proportion	SE	Proportion	SE	Proportion	SE
1 Aug	0.08	0.04	0.48	0.12	0.44	0.12
2 Aug	0.10	0.04	0.56	0.10	0.34	0.10
3 Aug	0.12	0.05	0.15	0.12	0.73	0.12
4 Aug	0.07	0.04	0.48	0.15	0.45	0.15
5 Aug	0.04	0.03	0.48	0.12	0.47	0.12
6 Aug	0.05	0.03	0.37	0.10	0.58	0.10
7 Aug	0.03	0.02	0.30	0.11	0.66	0.12
8 Aug	0.03	0.03	0.41	0.11	0.55	0.11
9 Aug	0.03	0.03	0.24	0.09	0.73	0.09
10 Aug	0.03	0.02	0.30	0.12	0.67	0.12
11 Aug	0.04	0.03	0.31	0.09	0.64	0.09
12 Aug	0.02	0.02	0.34	0.09	0.64	0.10
13 Aug	0.02	0.03	0.31	0.10	0.67	0.10
14 Aug	0.02	0.03	0.40	0.15	0.57	0.15
15 Aug	0.00	0.00	0.00	0.00	0.00	0.00
Weighted mean	0.12	0.01	0.36	0.02	0.51	0.02

Note: Estimates apply to upstream-bound fish in midriver between and at least 3 m from the transducers. In the mixture model, ages 3 and 4 are pooled, as are ages 6 and 7. Means are weighted by daily DLMM estimates.

FIGURES

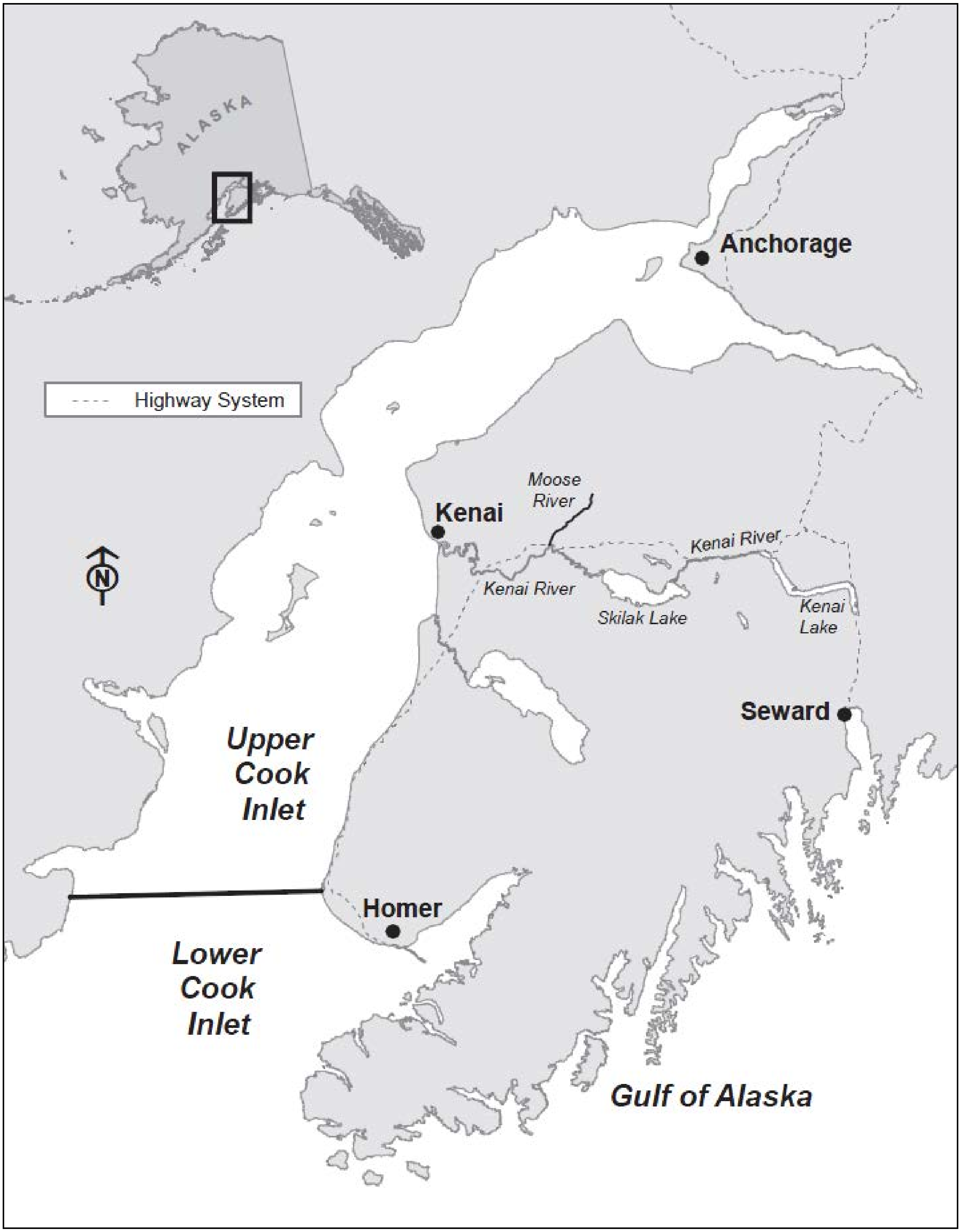


Figure 1.–Cook Inlet showing location of Kenai River.

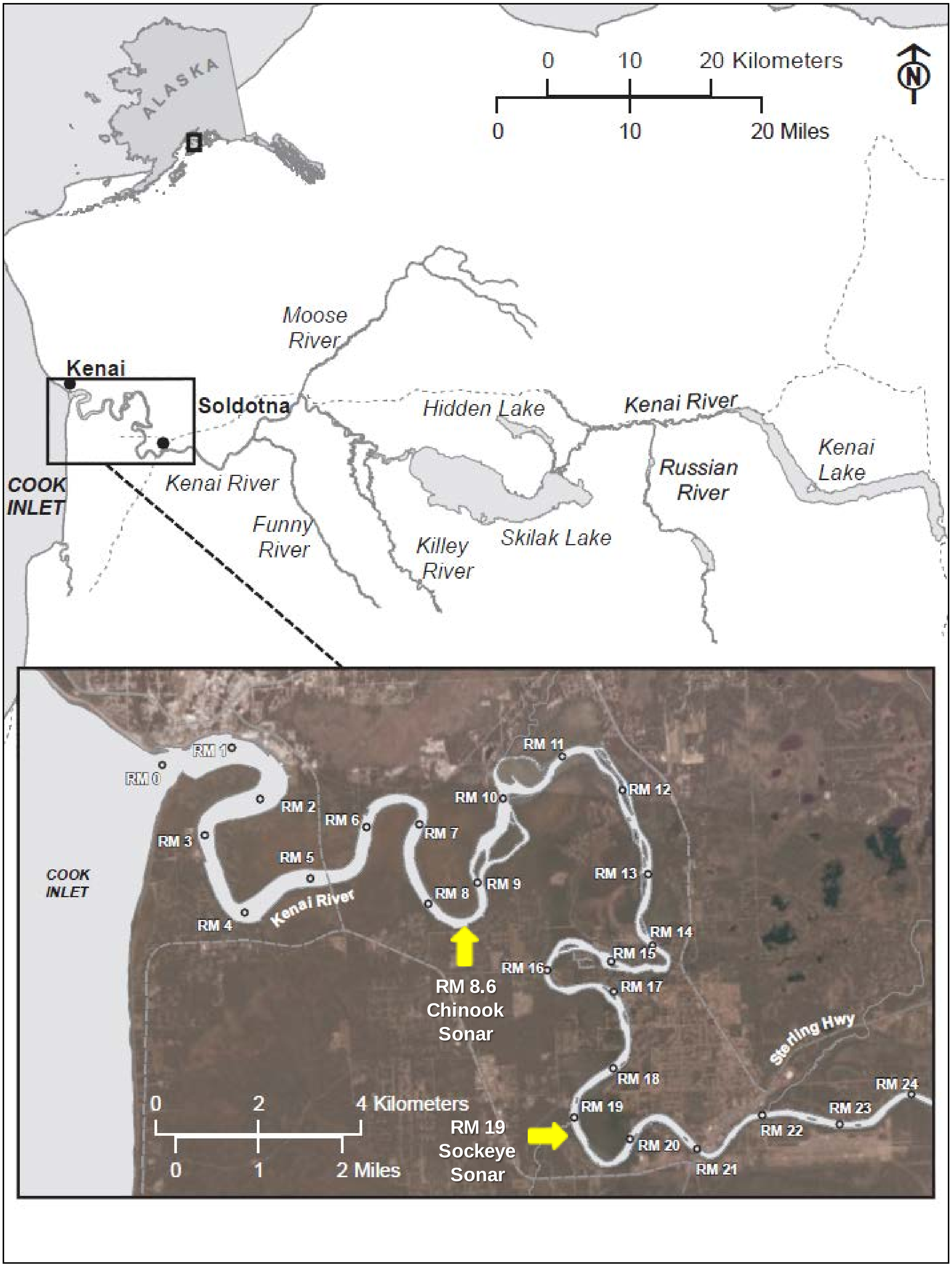
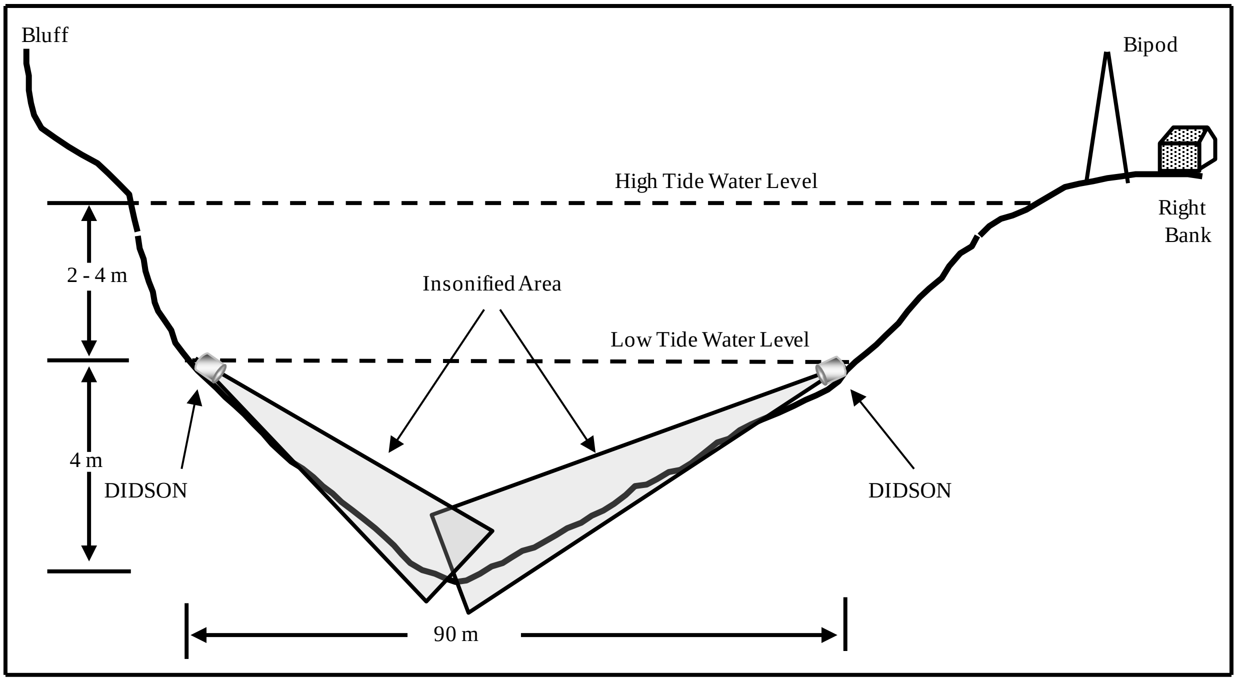


Figure 2.–Kenai River sonar site locations, 2012.



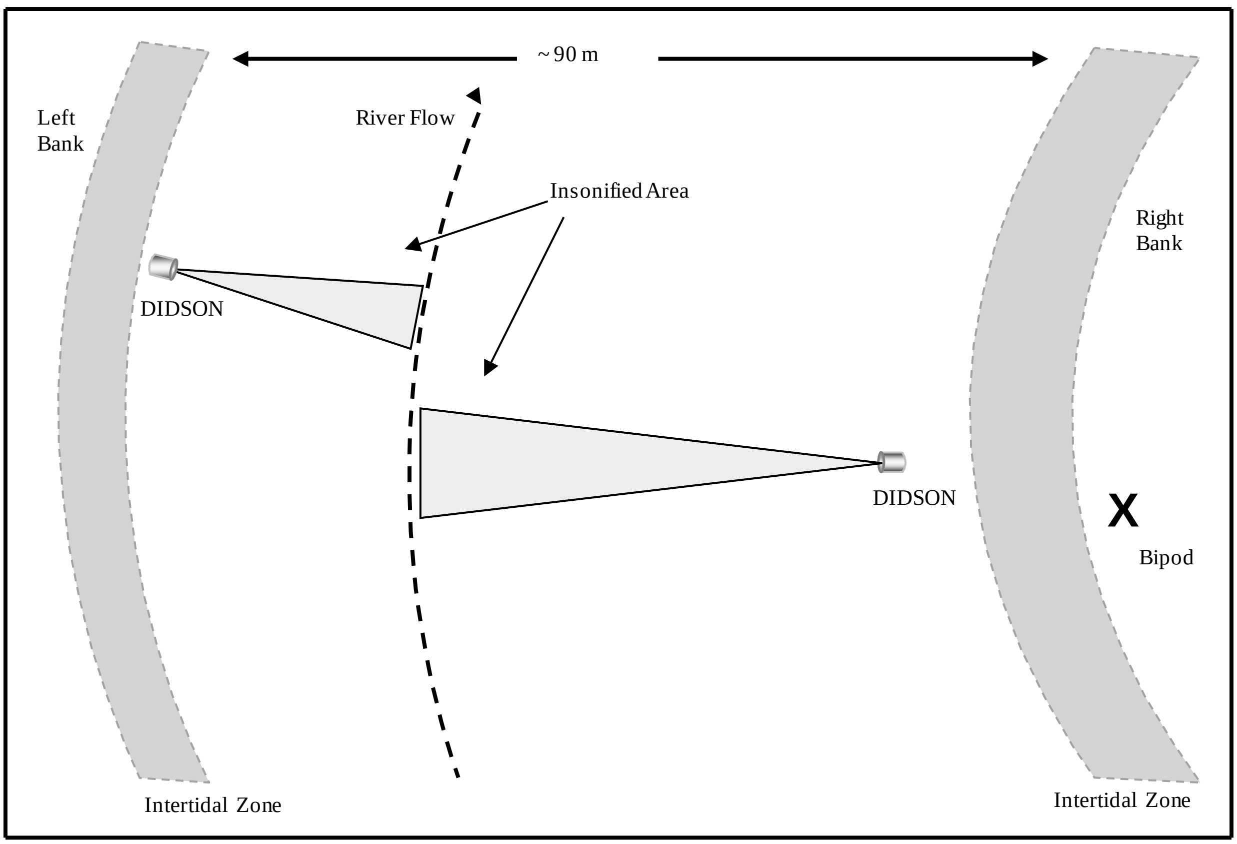


Figure 3.–Cross-sectional (top) and aerial (bottom) diagrams of sonar site illustrating insonified portions of RM 8.6 of the Kenai River, 2012.

Note: Distance from bipod to thalweg (shown as dashed line depicting lowest course of the river) is approximately 88 m.

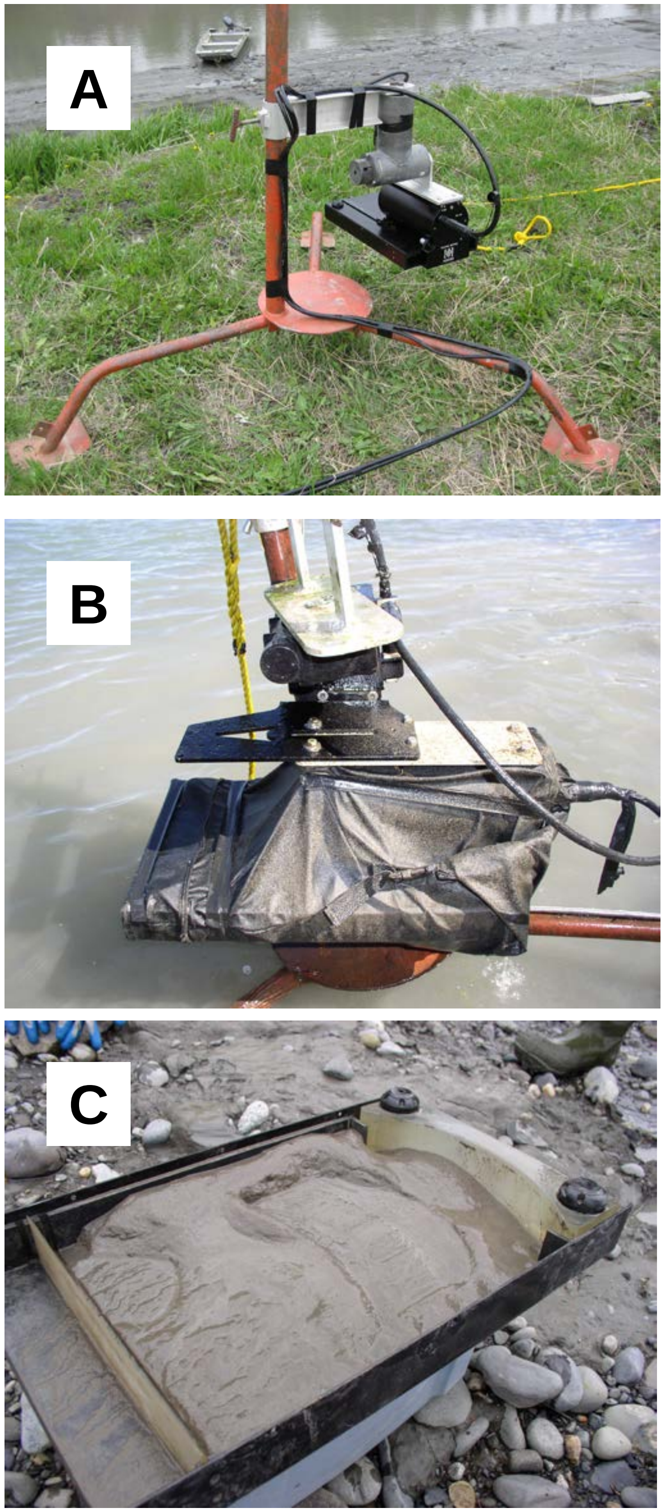


Figure 4.–A DIDSON-LR with a high-resolution lens is mounted on a steel tripod (photo A, top) and fitted with a custom fabric enclosure (photo B, middle), which protects against silt buildup in front of the lens (photo C, bottom).

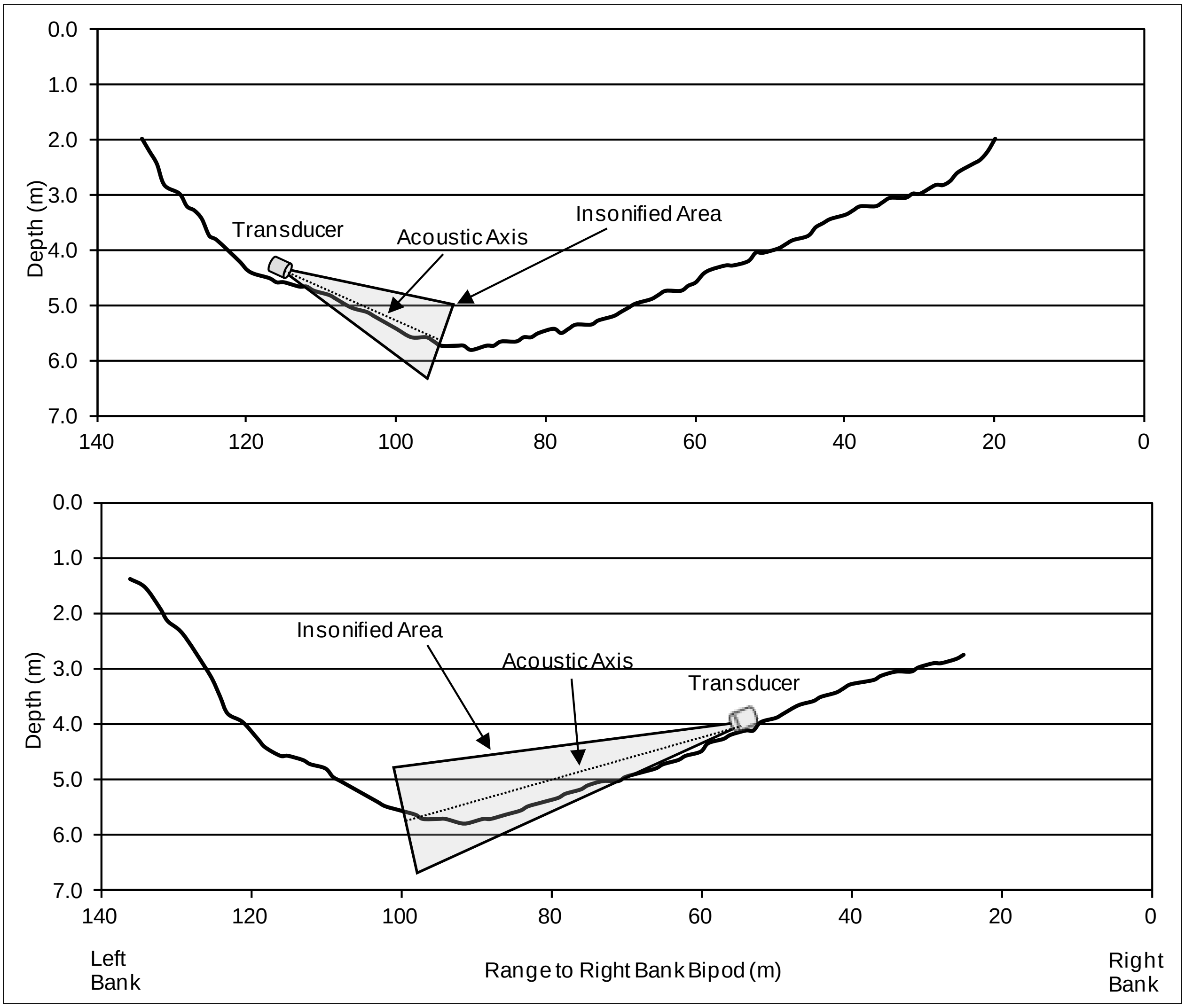


Figure 5.–Bottom profiles for the left-bank transducer (top) and right-bank transducer (bottom) at the Kenai River Chinook salmon sonar site with approximate transducer placement and sonar beam coverage for 16 May 2012.

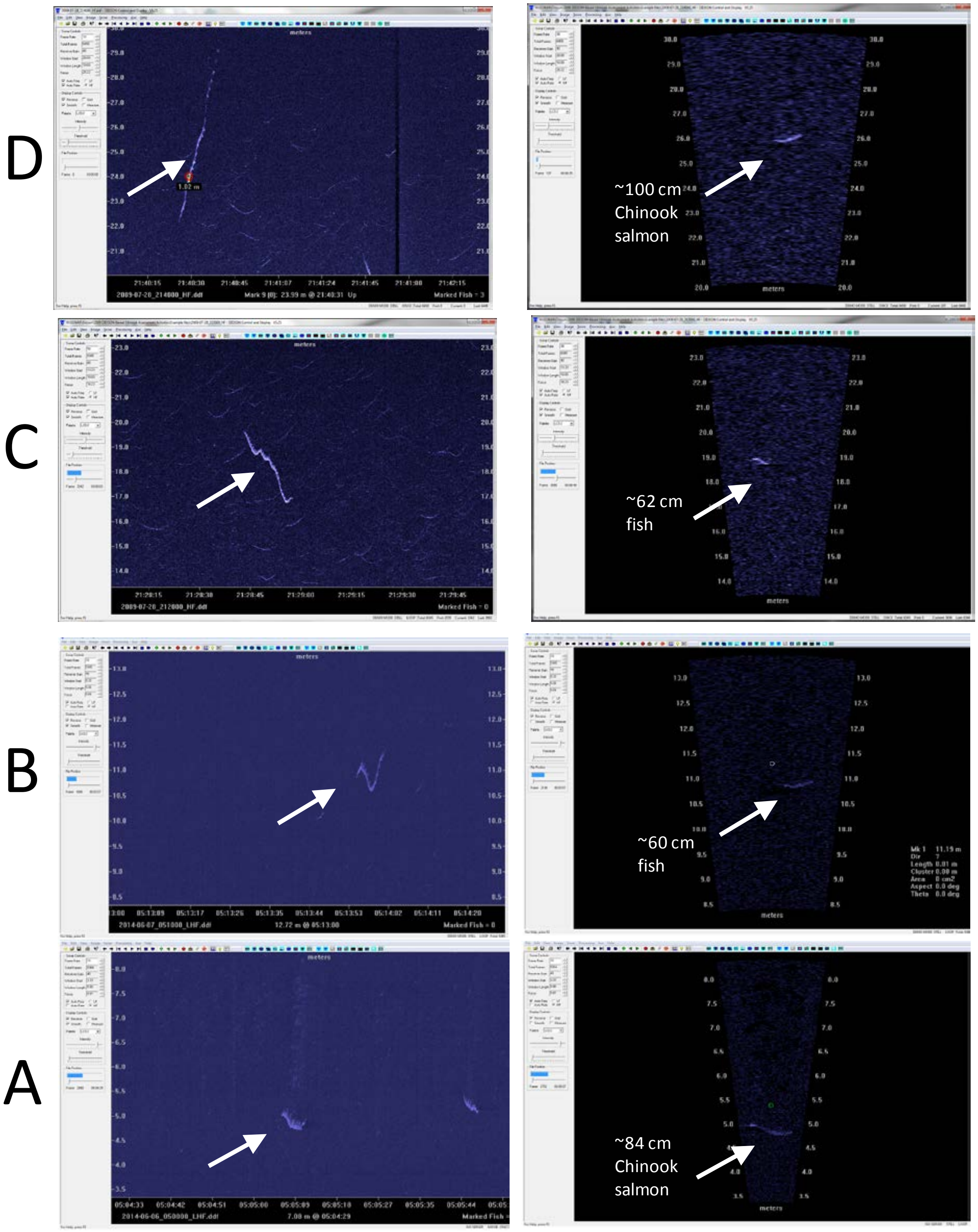


Figure 6.–Example fish traces with their measured sizes are shown on DIDSON echogram (at left) and video (at right) displays for each of the 4 range strata: 3.3–8.3 m (panel A), 8.3–13.3 m (panel B), 13.3–23.3 m (panel C), and 23.3–33.3 m (panel D).

Note: The echograms display approximately 800 frames, whereas the video displays the single frame on which the measurement was taken.

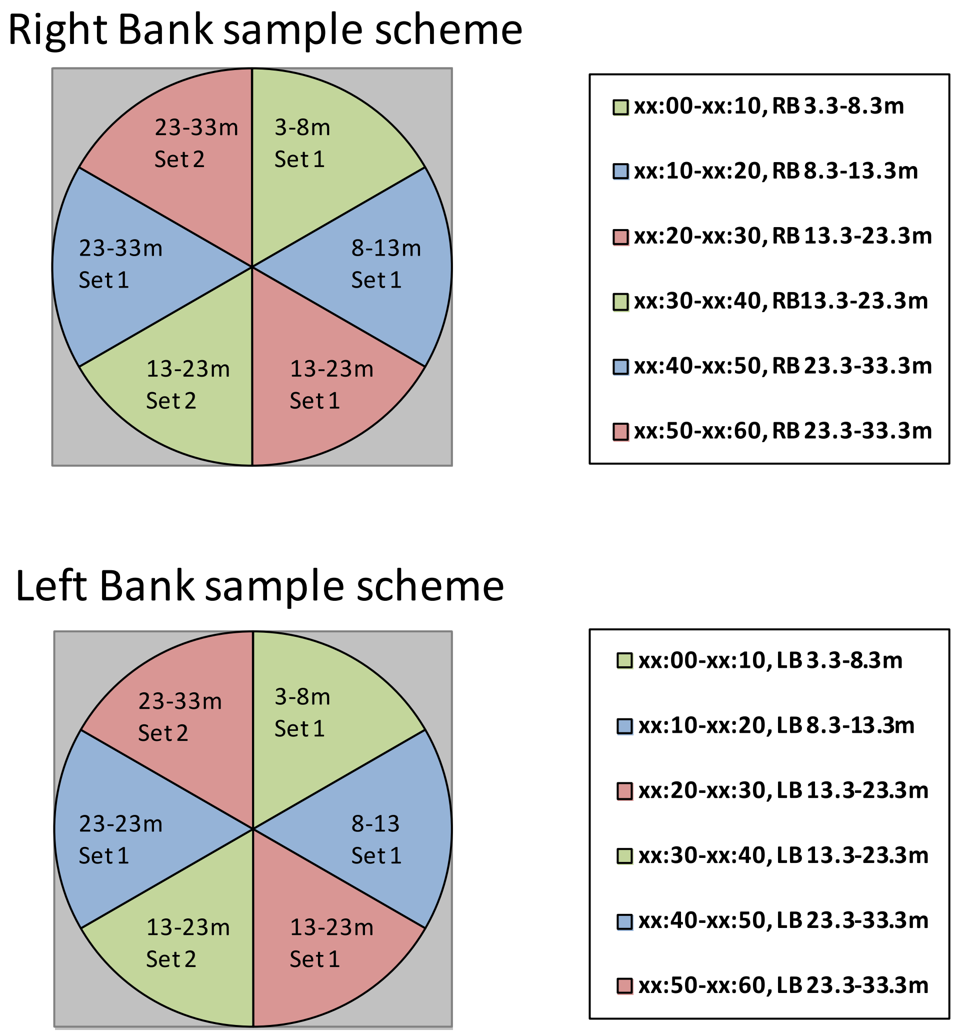


Figure 7.–Right (top) and left (bottom) bank range strata sampling schedules for 2012.

Note: Time presented in hours and minutes (hh:mm) format.

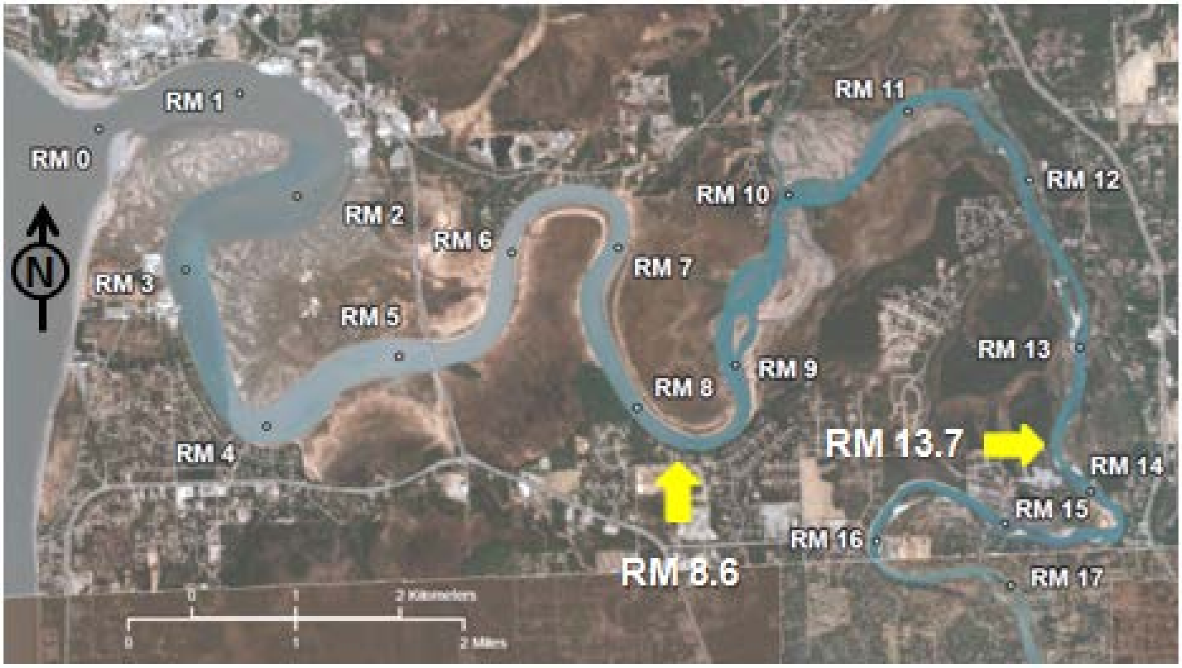


Figure 8.–Location of RM 13.7 site relative to RM 8.6 sonar site.

Figure 9.–Locations of 9 transects conducted at Kenai River RM 13.7 on 9 July 2012. Yellow arrows indicate preferred locations where sonars were deployed on each bank of the main channel. Red arrows indicate sonar deployment locations in the minor channel.

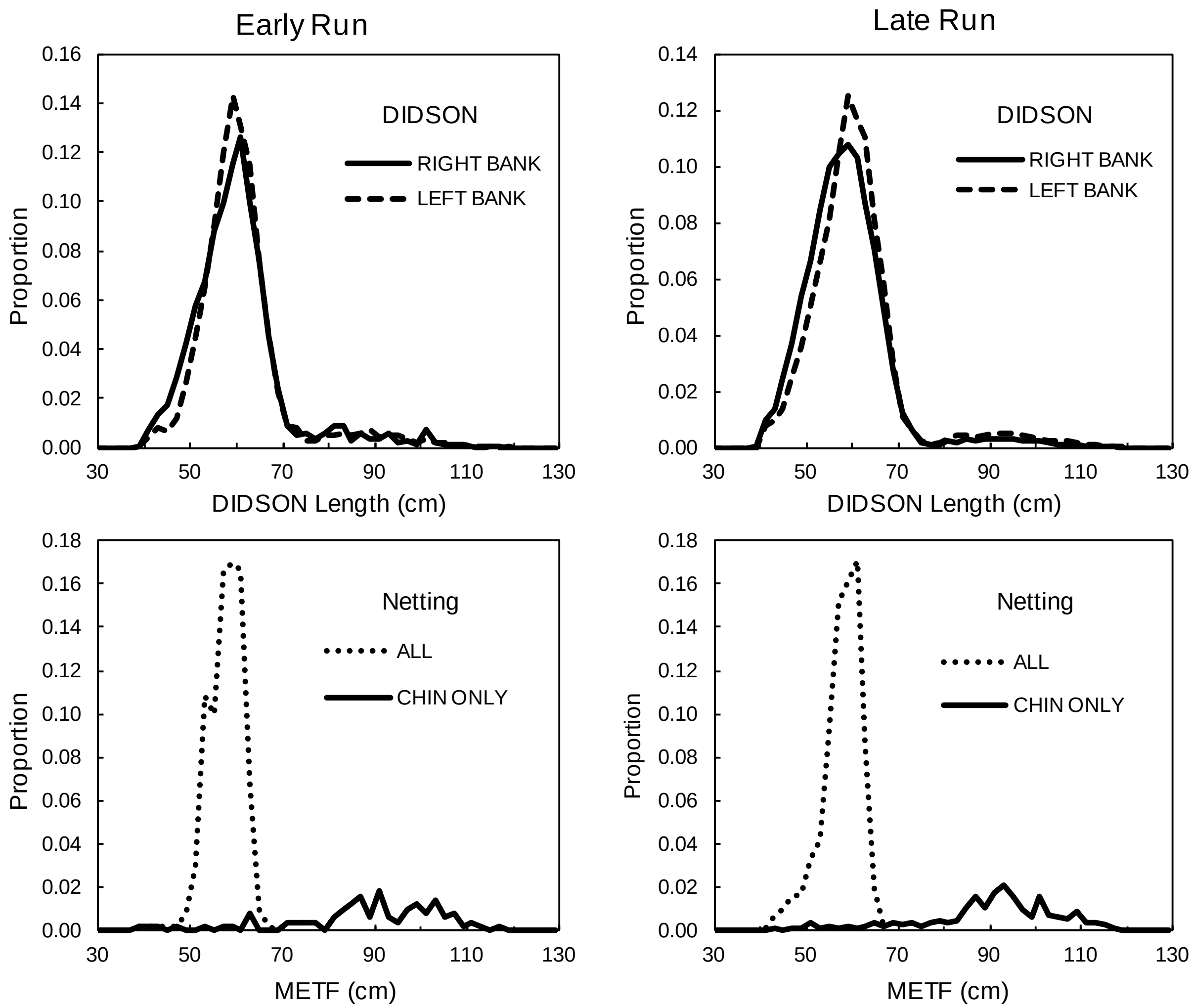


Figure 10.–Frequency distributions of fish length as measured by the DIDSON (top, by bank) and measurements from mid eye to tail fork (METF) from an onsite netting project (bottom, all species vs. Chinook salmon only), Kenai River RM 8.6, early and late runs, 2012.

Note: Data were not filtered by direction of travel. Non-Chinook salmon were sampled (measured) at less than one-half the rate of Chinook salmon by the netting project, so Chinook salmon are overrepresented in the netting length data.

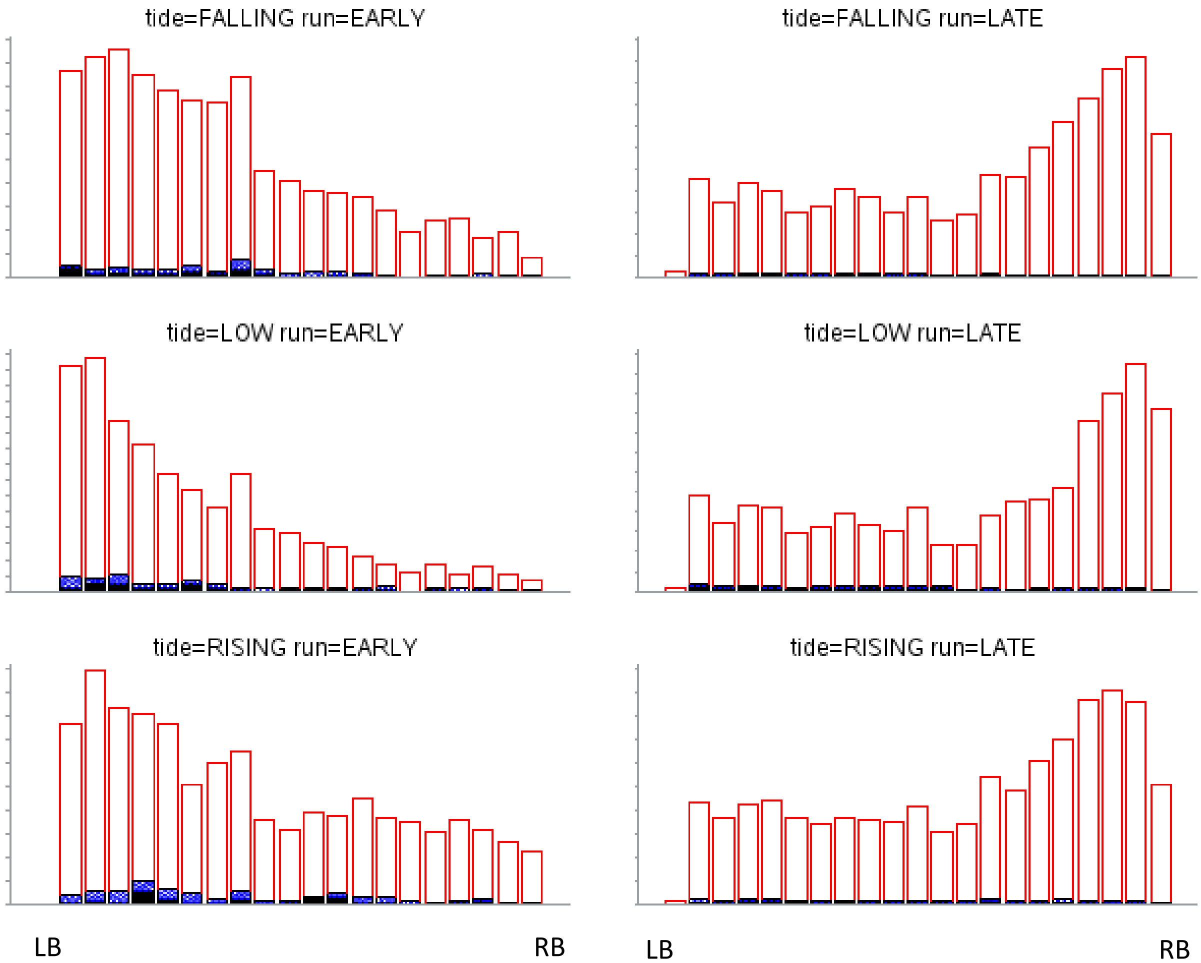


Figure 11.–Relative frequency distributions of horizontal (cross-river) position of upstream bound fish by tide stage and DIDSON length class (black solid ≥ 90 cm, blue hatched = 75–90 cm, red open < 75 cm), Kenai River RM 8.6, early and late runs, 2012.

Note: Vertical axis shows percent relative frequency by run and tide stage. Approximately 60 meters separates the left-bank (LB) and right-bank (RB) transducers.

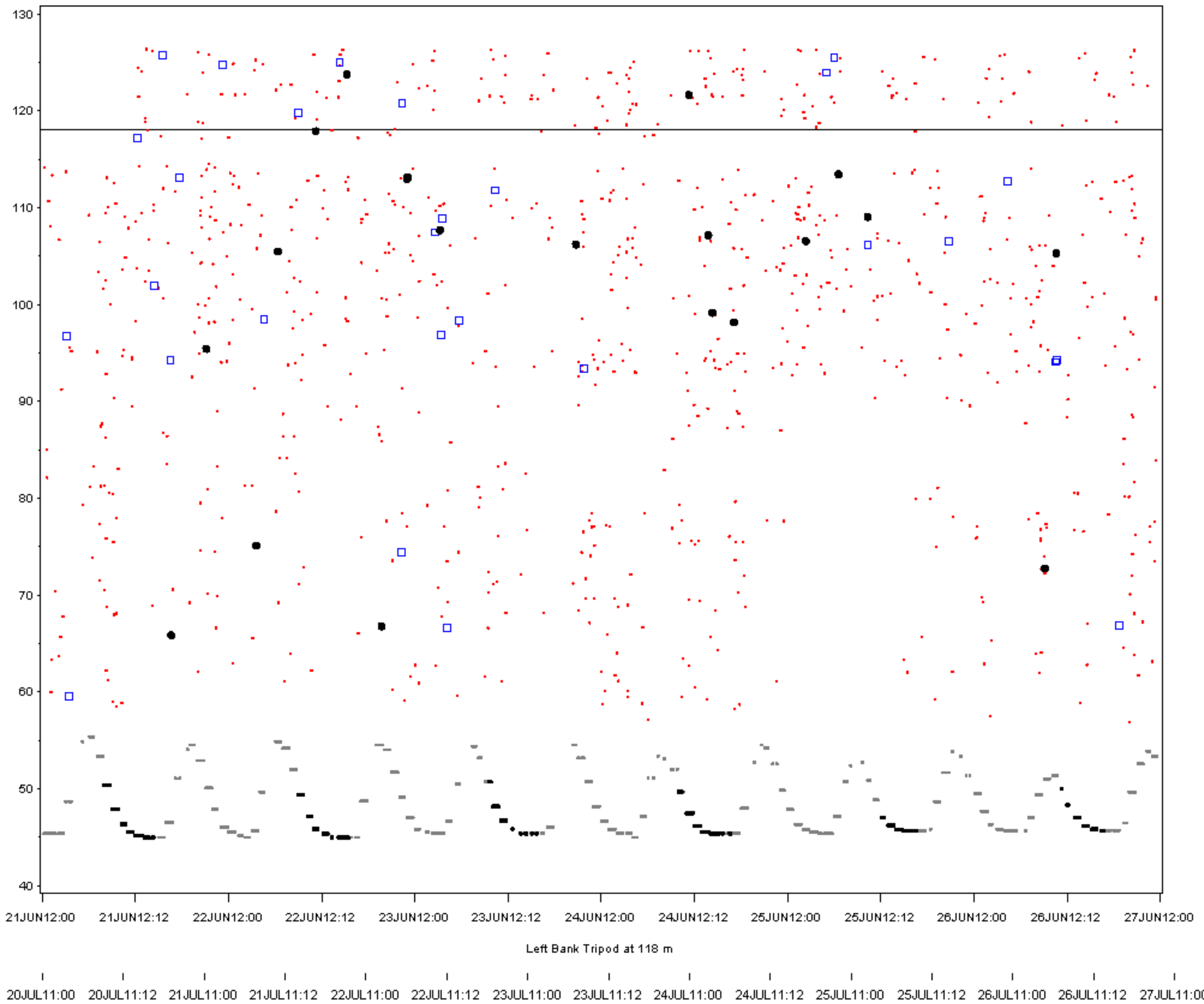
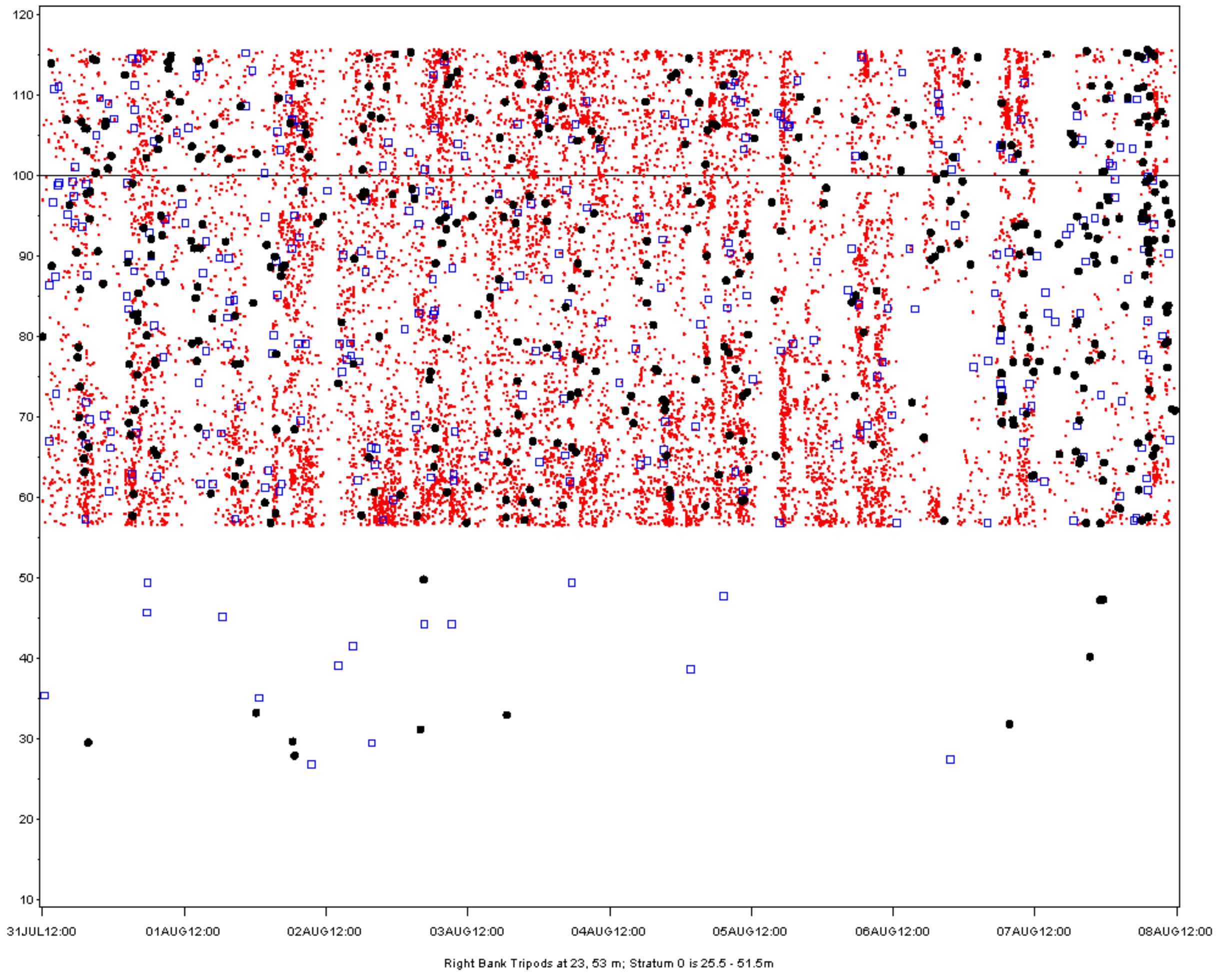


Figure 12.–Spatial and temporal distribution of small (DIDSON length DL < 75 cm; small red symbols), medium (75 cm ≤ DL < 90 cm; larger blue squares), and large fish (DL ≥ 90 cm; large black symbols), RM 8.6 Kenai River, 21–26 July 2012.

Note: Vertical axis is distance (m) from benchmark on right-bank shore, except that relative water level is plotted at bottom (small grey symbols), with netting periods in black. This is the same representation as in Appendix C3, except that additional data from behind the left-bank transducer (above solid black line) are also displayed, and the X axis ranges is not identical.



Right Bank Tripods at 23, 53 m; Stratum 0 is 25.5 - 51.5m

Figure 13.–Spatial and temporal distribution of small (DIDSON length DL < 75 cm; small red symbols), medium (75 cm ≤ DL < 90 cm; larger blue squares), and large fish (DL ≥ 90 cm; large black symbols), RM 8.6 Kenai River, 31 July–7 August 2012.

Note: Vertical axis is distance (m) from benchmark on right-bank shore. This is the same representation as in Appendix C6, except that medium and large fish detected behind the right-bank transducer (25.5–51.5 m) are also displayed, and the X axis range is not identical.

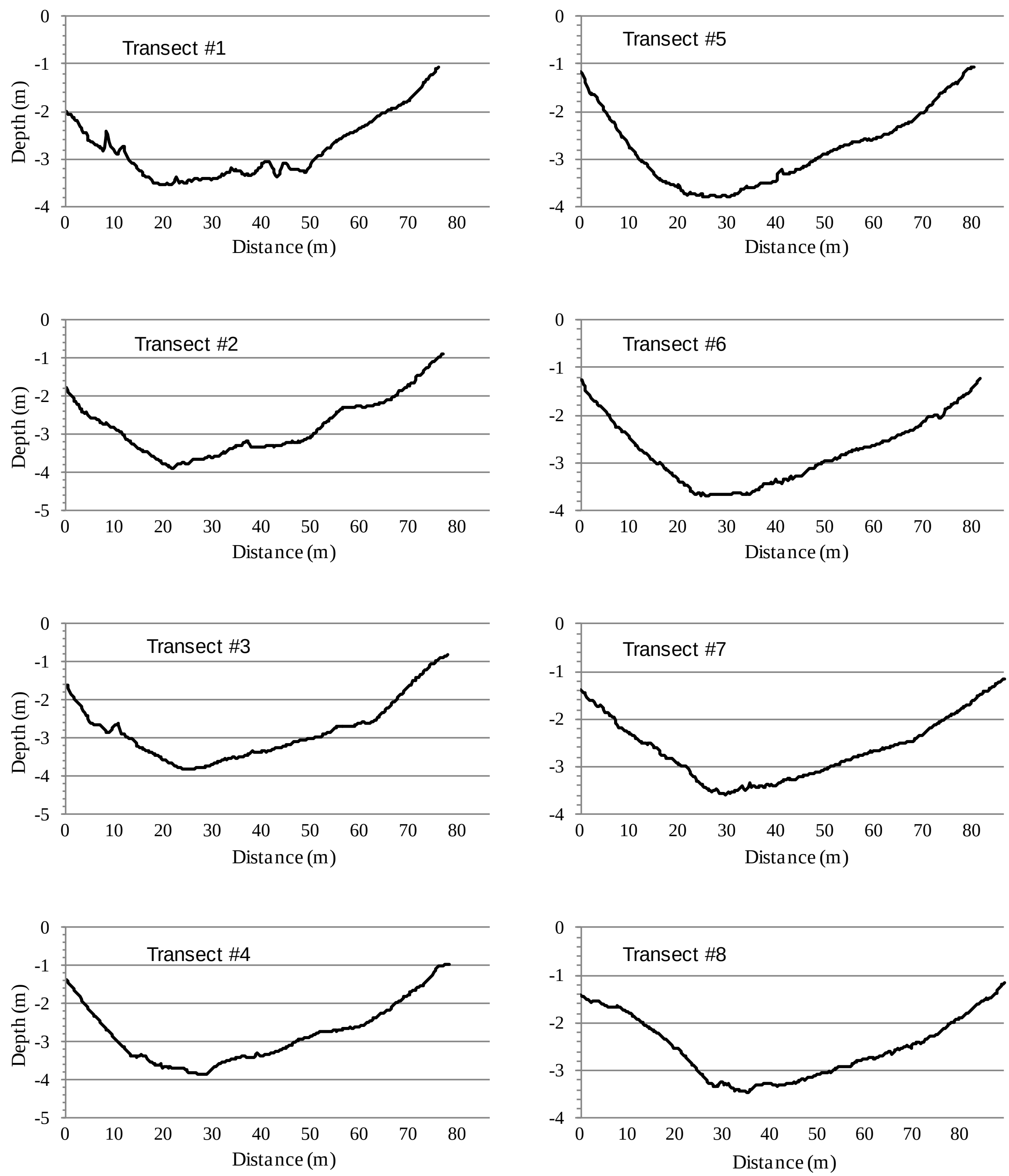


Figure 14.–Profiles for 8 of 9 transects (see Figure 9 for corresponding numbers) conducted at Kenai River RM 13.7 on 9 July 2012.

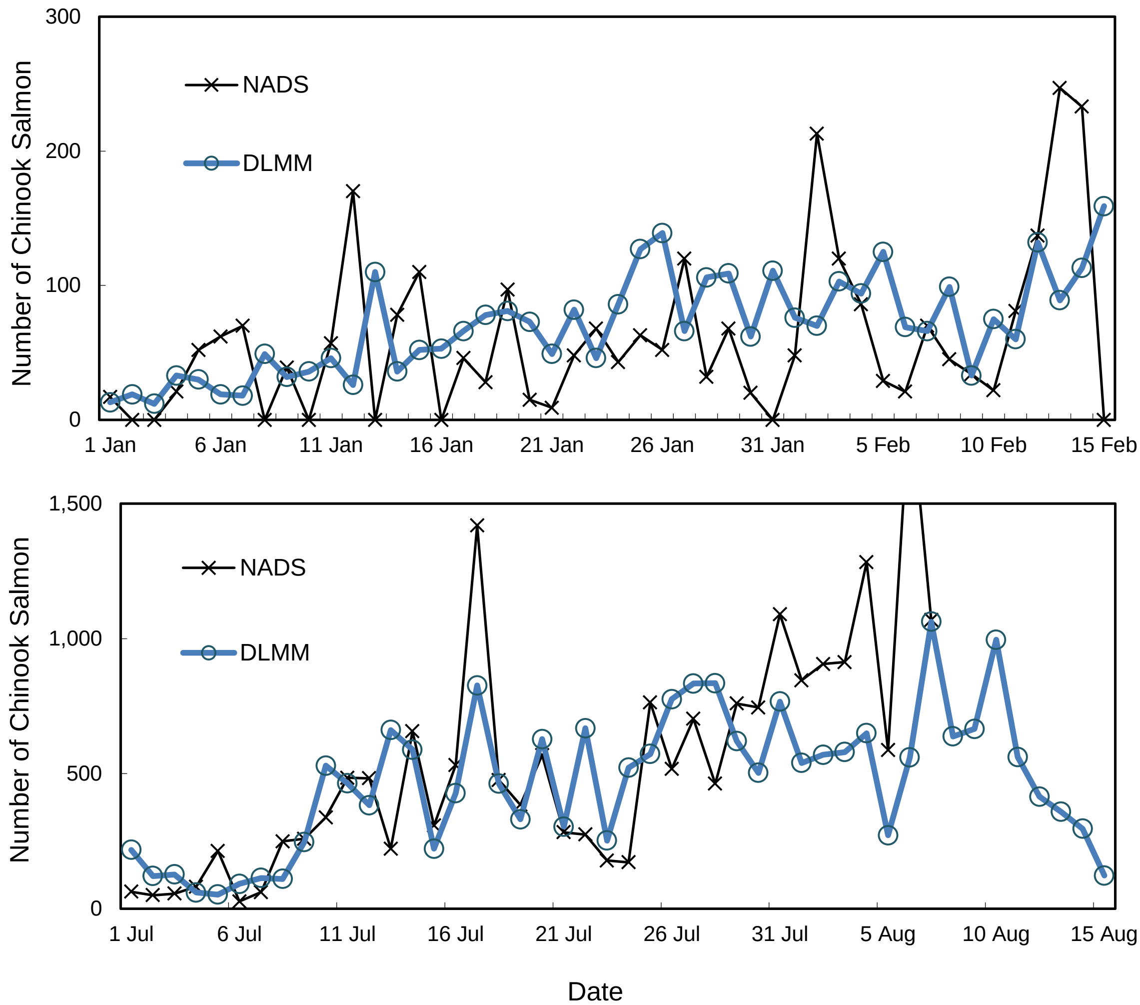


Figure 15.–Estimated upstream-bound fish passage based on net-apportioned DIDSON (NADS), and DIDSON-length mixture model (DLMM), for early- (top) and late-run (bottom) Kenai River Chinook salmon, 2012.

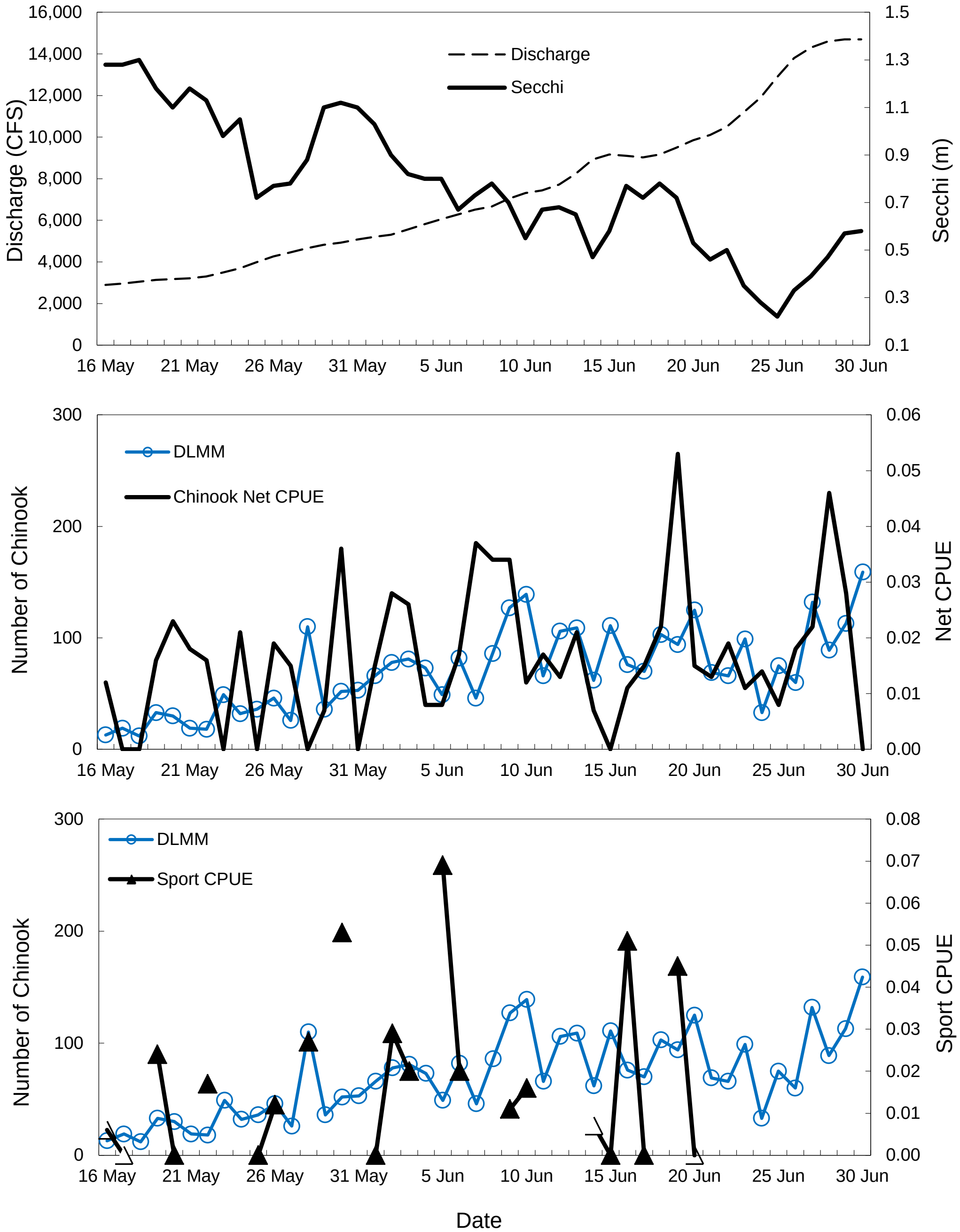


Figure 16.–Daily discharge rates collected at the Soldotna Bridge and Secchi disk readings taken from the sonar site (top), DIDSON-length mixture model (DLMM) estimates of Chinook salmon passage and inriver gillnet Chinook salmon CPUE (middle), and DLMM estimates compared to Chinook salmon sport fishery CPUE (bottom), Kenai River, early run 2012.

Note: River discharge taken from USGS[7]. Net CPUE and sport fish CPUE taken from Perschbacher (2014). Open triangles represent days on which only unguided anglers were allowed to fish. The sport fishery closed after 21 June.

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7 USGS Water resource data, Alaska, water year 2012. Website Daily Streamflow for Alaska, Soldotna gauging station, site #15266300, http://water.usgs.gov/ak/nwis/discharge (Accessed December 11, 2013).

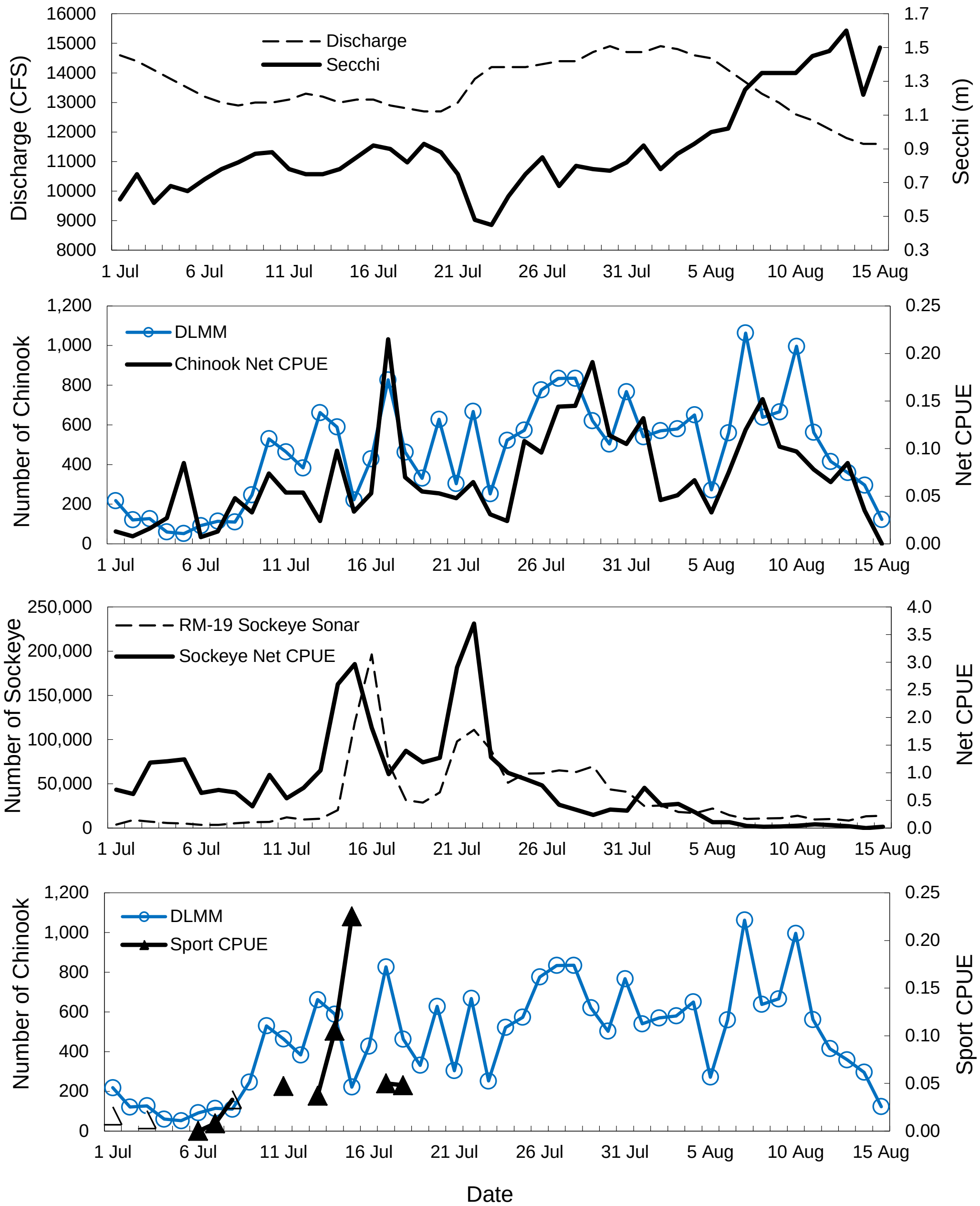

Figure 17.–Daily discharge rates collected at the Soldotna Bridge and Secchi disk readings taken at the RM 8.6 sonar site (top), DIDSON-length mixture model (DLMM) estimates of Chinook salmon passage and inriver gillnet Chinook salmon CPUE (top middle), RM 19 sockeye salmon sonar passage and inriver gillnet sockeye salmon CPUE (bottom middle), and DLMM estimates compared to Chinook salmon sport fishery CPUE (bottom), Kenai River, late run, 2012.

Note: River discharge taken from USGS[8]. Net CPUE and sport fish CPUE taken from Perschbacher (2014). Open triangles represent days on which only unguided anglers were allowed to fish. RM 19 sonar from Westerman and Willette (2013). The sport fishery closed after 18 July.

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8 . USGS Water resource data, Alaska, water year 2012. Website Daily Streamflow for Alaska, Soldotna gauging station, site #15266300, http://water.usgs.gov/ak/nwis/discharge (Accessed December 11, 2013).

APPENDIX A: DIDSON CONFIGURATION FOR KENAI RIVER CHINOOK SONAR STUDY, 2012

Selection of the appropriate DIDSON hardware configuration and operating parameters is primarily determined by the range and resolution needs of a specific application. Because resolution generally decreases as the insonified range increases, the need to balance and optimize these parameters determined the configuration used at the Kenai River RM 8.6 site.

Frequency

DIDSON sonars operate at 2 frequencies: a higher frequency that produces higher resolution images and a lower frequency that can detect 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-S) operates at 1.8 MHz to approximately 15 m and 1.1 MHz to approximately 30 m and produces higher-resolution images than the long-range model. The long-range model (DIDSON-LR) operates at 1.2 MHz to approximately 30 m and 0.7 MHz to ranges exceeding 100 m but produces images with approximately half the resolution of the DIDSON-S (see explanation below). A long-range model (DIDSON-LR) was used in this study to insonify the required range and was operated in high-frequency mode (1.2 MHz) to achieve maximum image resolution.

Beam Dimensions and Lens Selection

The DIDSON-LR used in this study was fitted with a high-resolution lens to further enhance the image resolution of the DIDSON-LR system (DIDSON-LR+HRL).The high-resolution lens has a larger aperture that increases the image resolution by approximately a factor of 2 over the standard lens by reducing the width of the individual beams and spreading them across a narrower field of view (Appendices D2 and D3). Overall nominal beam dimensions for a DIDSON-LR with a standard lens are approximately 29° in the horizontal axis and 14° in the vertical axis. Operating at 1.2 MHz, the 29° horizontal axis is a radial array of 48 beams that are nominally 0.54° 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 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. The combined concentration of horizontal and vertical beam widths also increases the returned signal from a given target by 10 dB, which increases the range capability of the DIDSON-LR from 25 m to at least 30 m (Appendix A2). After adding the high-resolution lens, the DIDSON-LR has equivalent resolution and twice the range capabilities as the DIDSON-S. However, the reduction in beam dimensions could potentially reduce detection capabilities, particularly at very close range (e.g., at ranges less than 5 m).

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Resolution

The resolution of a DIDSON image is defined in terms of down-range and cross-range resolution, where cross-range resolution refers to the width and down-range resolution refers to the height of the individual pixels that make up the DIDSON image (Appendix A4). Each image pixel in a DIDSON 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 down-range resolution and the pixel width defines the cross-range resolution of the image. Appendix A4 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.

"Window length" is the range interval sampled by the sonar, and it controls the down-range resolution of the DIDSON image. Because the DIDSON image is composed of 512 samples (pixels) in range, images with shorter window lengths are better resolved (i.e., down-range resolution = window length/512). Window length can be set to 2.5, 5.0, 10.0, or 20.0 m for the DIDSON-LR+HRL at 1.2 MHz. Shorter window lengths have higher resolution but require more individual strata to cover the desired range. However, dividing the total range covered into too many discrete strata increases the data-processing time. For this study, a window length of 5 m was used to minimize the bias associated with close-range targets for the first two range strata. When sampling at close range (less than about 8 m with a long-range lens), a shorter range window (i.e., 5 m) for the first range stratum minimizes the effect of poor focal resolution at close range (Bill Hanot, Sound Metrics Corporation, personal communication). A window length of 10 m was used for each of the two subsequent range strata, a compromise that allowed a relatively high resolution while allowing a reasonable distance to be covered by each stratum. The down-range resolution (or pixel height) for a 5 m range window is 1 cm (500 cm/512) and for a 10 m window length is 2 cm (1,000 cm/512).

The cross-range resolution is primarily determined by the individual beam spacing and beam width, both of which are approximately 0.3° for the DIDSON LR+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:

$$X = 2R\tan\left(\theta/2\right) \tag{A1}$$

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°).

Other Settings

The transmit power of the DIDSON sonar is fixed, but the receiver gain is user-configurable. The maximum receiver gain (−40 dB) was used during all data collection. The autofocus feature was enabled so that the sonar automatically set the lens focus to the midrange of the selected display window (e.g., for a window length of 15 m that started at 10 m, the focus range would be 10 m + [15 m/2] = 17.5 m).

Appendix A2.–Summary of manufacturer specifications for maximum range, individual beam dimensions, and spacing for a DIDSON-S and a DIDSON-LR with and without the addition of a high-resolution lens (specifications from Sound Metrics Corporation).

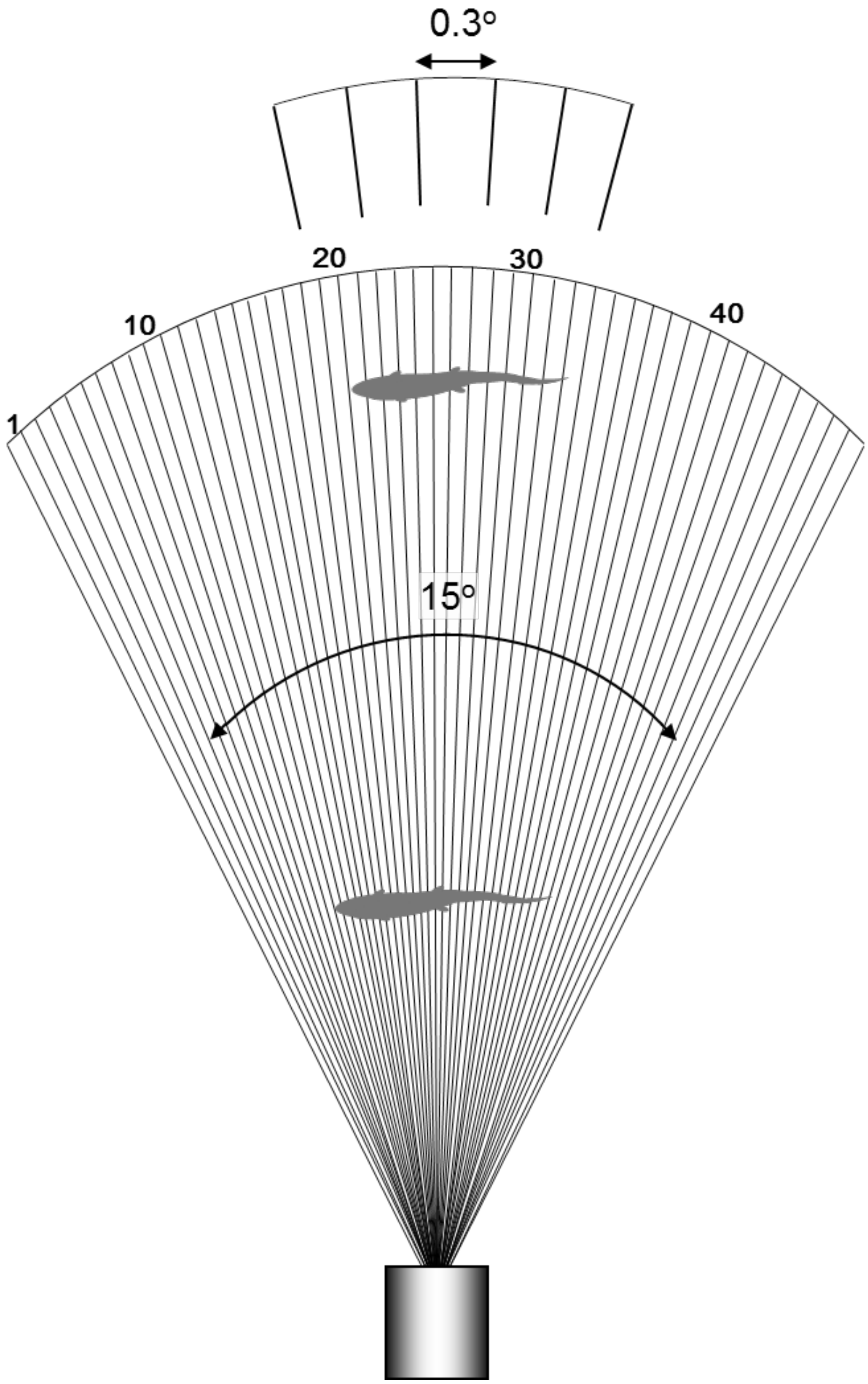
System	Maximum range (m)[a]	Horizontal beam width	Vertical beam width	Number of beams	Individual beam width[b,c]	Individual beam spacing[b,c]
DIDSON-S (1.8 MHz)	15	29°	14°	96	0.30°	0.30°
DIDSON-S (1.1 MHz)	30	29°	14°	48	0.40°	0.60°
DIDSON-S (1.8 MHz) +HRL	20	15°	3°	96	0.17°	0.15°
DIDSON-S (1.1 MHz) +HRL	40	15°	3°	48	0.22°	0.30°
DIDSON-LR (1.2 MHz)	25	29°	14°	48	0.40°	0.30°
DIDSON-LR (0.7 MHz)	80	29°	14°	48	0.60°	0.60°
DIDSON-LR (1.2 MHz) +HRL	30	15°	3°	48	0.27°	0.30°
DIDSON-LR (0.7 MHz) +HRL	100	15°	3°	48	0.33°	0.60°

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

[b] Beam width values are for 2-way transmission at the −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-S 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 standard (but not large) lens.

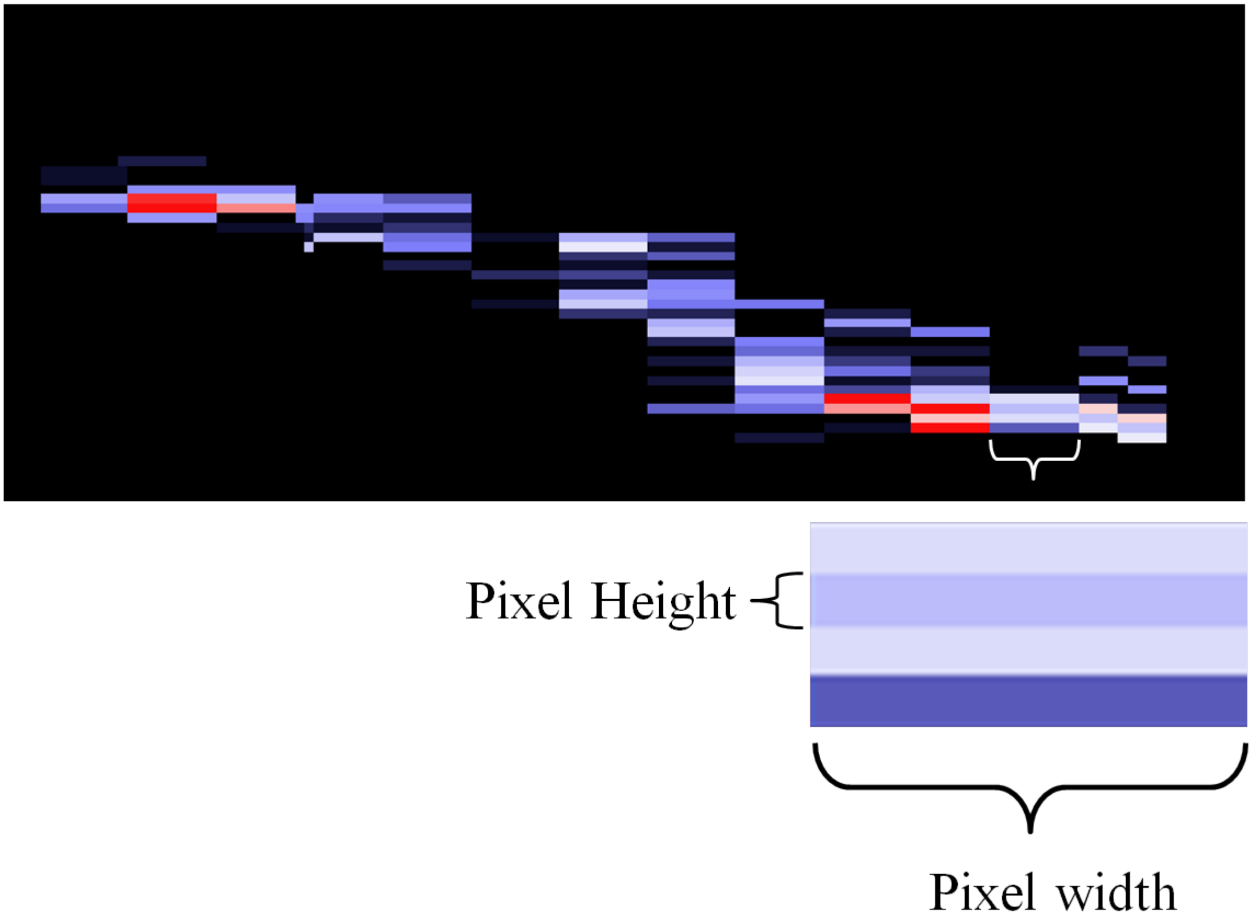
Appendix A3.–Diagram showing the horizontal plane of a DIDSON-LR sonar with a high-resolution lens (DIDSON-LR+HRL). The overall horizontal beam width of 15° is composed of 48 sub-beams with approximately 0.3° beam widths.



Source: Adapted from Burwen et al. 2007.

Note: Because the beam widths grow wider with range, fish at close range are better resolved than fish at far range.

Appendix A4.–An enlargement of a tethered Chinook salmon showing the individual pixels that make up the image. Each image pixel in a DIDSON frame has (x, y) rectangular coordinates that are mapped back to a beam and sample number defined by polar coordinates range.



Source: Adapted from Burwen et al. 2010.

Appendix A5.–Instructions and settings used for manual length measurements from DIDSON images in 2012 using Sound Metrics Software Version 5.25.28.

Parameter setup prior to beginning measurements

Step 1. Set the number of frames displayed (i.e., when right-clicking on a fish in echogram mode to display in movie mode) from the default of plus-minus one second to plus-minus any number of frames:

1) Select **<image><playback><set endpoints>**.
2) [√] Loop on still for +/- N frames.
3) Enter the number of frames (suggestion: 20–30).

Step 2. Select **<Processing><Echogram><Use Cluster Data>** to use ALL the beams when creating the echogram (we generally do). Use fewer beams by unchecking this option and selecting the number of beams.

Step 3. Set up **processing parameters** (last Icon on right) for **<u>File Creation</u>** as follows:

1) Auto Countfile Name
2) Binary CountFile (.dat)
3) New Countfile on Open
4) Echogram File (.ech)

Step 4. Echogram counts can be reloaded to finish or review at a later time if the Echogram file has been checked as follows:

1) Select **<File><Open> then Files of type .ech** from drop-down menu.
2) Open desired file.
3) The Echogram file should reload showing previous measurements.

Or this option will work as long as the .dat file has been saved (as shown above):

1) Open the file and bring up the echogram (follow instructions below).
2) Select **<Processing><Echogram><Import Echogram Counts>**.
3) Select the **.dat** file with saved counts. The file should reload, showing previous measurements (the filename for the .dat file will begin with **FC_**).

Step 5. Make sure **<Image><Configure><Auto Threshold/Intensity>** is UNCHECKED. This will keep the threshold and intensity settings from changing when switching between Echogram and Movie mode.

Step 6. Uncheck the 'Display Raw Data' toolbar icon (first button on left in Combined toolbar). (If you are in Movie mode and it is displaying the raw image data, it is because 'Display Raw Data' is enabled by default).

Instructions for manual echogram-based length measurements

***Note that these settings may already be active because some of them have "memory" and are saved until changed.**

1) Select **<BS>** (background subtraction) from toolbar or under **<Processing><Background><Background Subtraction>**.
2) Select **<Processing><Background><Fixed Background>**.
3) Select threshold and range settings given in Table 1. To adjust these settings, use the slider bars under Display Controls to the left of the echogram.
4) Select the threshold and intensity settings for each range stratum as indicated below. To adjust these settings, use slider bars under the Display Controls to the left side of the Echogram or Movie window.

	3-8m	8-13 m	13–23 m	23–33 m
Threshold	11	11	10	9
Intensity	50	50	45	40

-continued-

5) Select **<EG>** (for view echogram) from toolbar or under **<Processing><Echogram><View echogram**>.
6) **<left click>** on the echogram near or on the fish trace of interest to “mark” it. A white circle should be visible.
7) **<right click>** INSIDE the white circle to switch to Movie mode (Movie mode will play the 16 frames encompassing this circle continuously).
8) Press **<space bar>** to pause the movie.
9) Step through the movie frames using the right or left arrows until finding a frame that displays the entire length of the fish well (see section below for selecting optimal images).
10) **<right mouse click drag>** will magnify the area in the rectangle.
11) **<left click>** on the FISH SNOUT and continue to <left click> along the body to create a “segmented measurement.” ***The segments should follow the midline of the body of the fish*** ending with the tail. Try not to use more than 3 or 4 segments to define the fish (see section below for selecting optimal images).
12) **<double left click>** or select **<f>** key to add measurement to file.
13) **<right click>** to unzoom.
14) **<right click>** to return to the echogram.

Hot keys

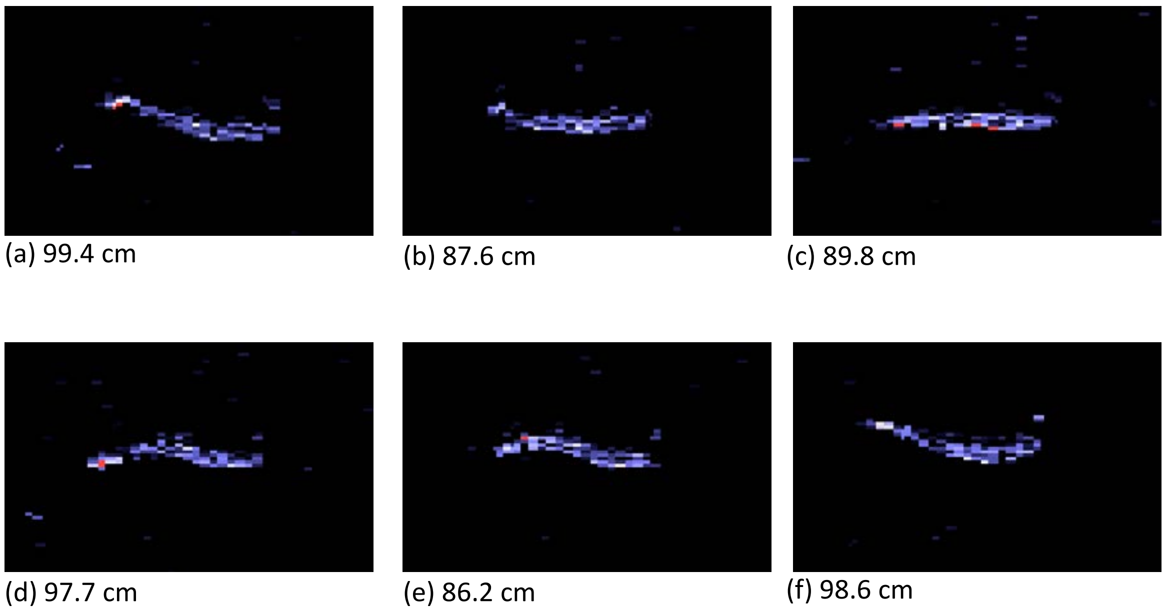
1) **<e>** to save all echogram measurements to file
2) **<f>** to “fish it” (to accept the measurement and display it on the echogram)
3) **<u>** to undo the last segment
4) **<d>** to delete all segments
5) **<space bar>** to pause in Movie mode (if this doesn’t work, click in the black area of the display)
6) **<right arrow>** forward direction when selecting play or advances frame one at a time if the pause button is on (pause button = blue square on the toolbar)
7) **<left arrow>** opposite of above
8) **Left Click Drag** to show movie over the selected time
9) **Right Click Drag** zooms the selected area

Selecting optimal images to measure

Measurements should be taken from frames where contrast between the fish image and background are high and where the fish displays its full length (e.g., panels *a*, *d*, and *f* in Appendix A6). In general, the best images are obtained when the fish is sinusoidal in shape, rather than linear (e.g., panel *c* in Appendix A6), because it is easier to identify the snout and tail and to assess whether the entire length of the fish is visible when there is some curvature to the fish body (e.g., Appendices A6 and A7). Images that appear distorted or truncated should not be measured. For example, under some conditions where a fish is highly reflective or near range, the image will appear “smeared” out into adjacent beams. This condition, also referred to as “arcing,” most often occurs when the target is both linear and perpendicular relative to the sonar beams as in shown in Appendix A8.

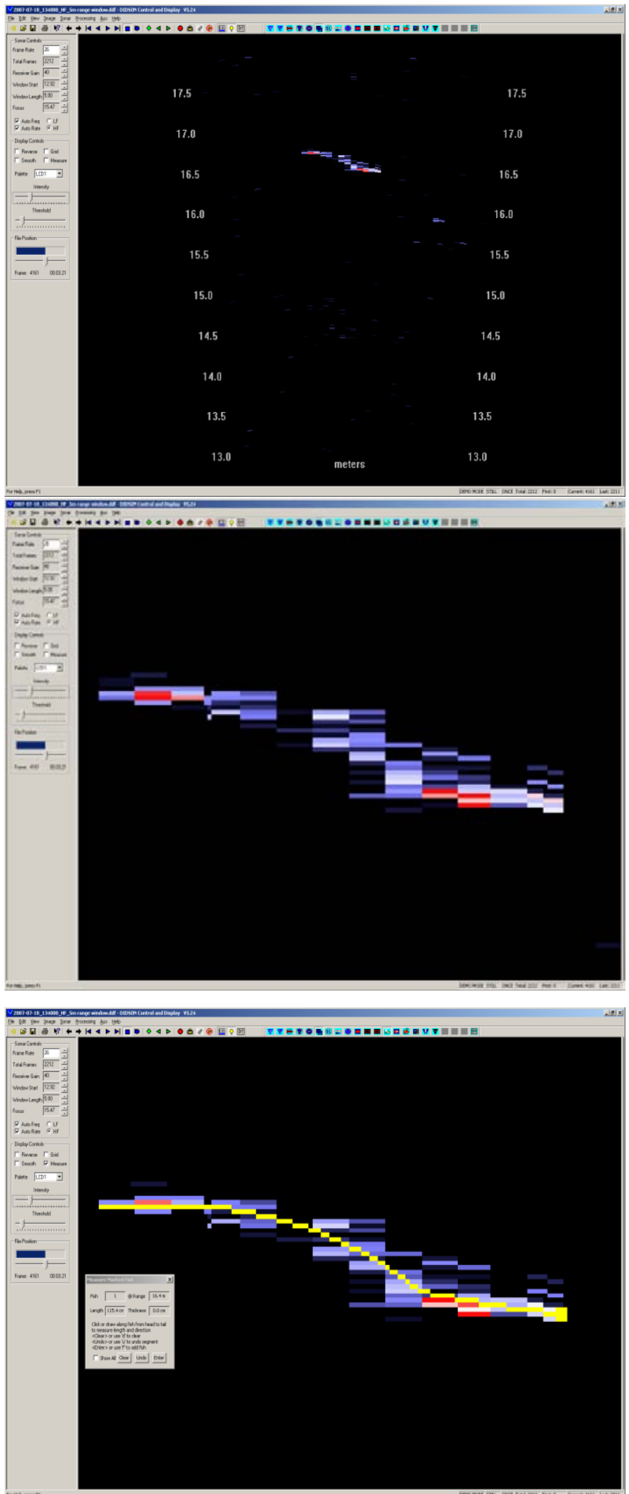
Appendix A7 demonstrates the process of measuring a fish using the manual measuring tool. The user pauses the DIDSON movie (top), zooms in on the fish of interest (middle), and measures the fish length with a segmented line created by mouse clicks along the center axis of the fish (bottom). The user selects the leading pixel edge of the snout to start the measurement (yellow start pixel extends beyond snout) and clicks just before the trailing edge of the pixel(s), defining the tail such that the “yellow measurement line” is flush with the trailing pixel edge.

Appendix A6.–Panels *a–f* show the variability in length measurements from DIDSON images of a tethered Chinook salmon during one full tail-beat cycle.



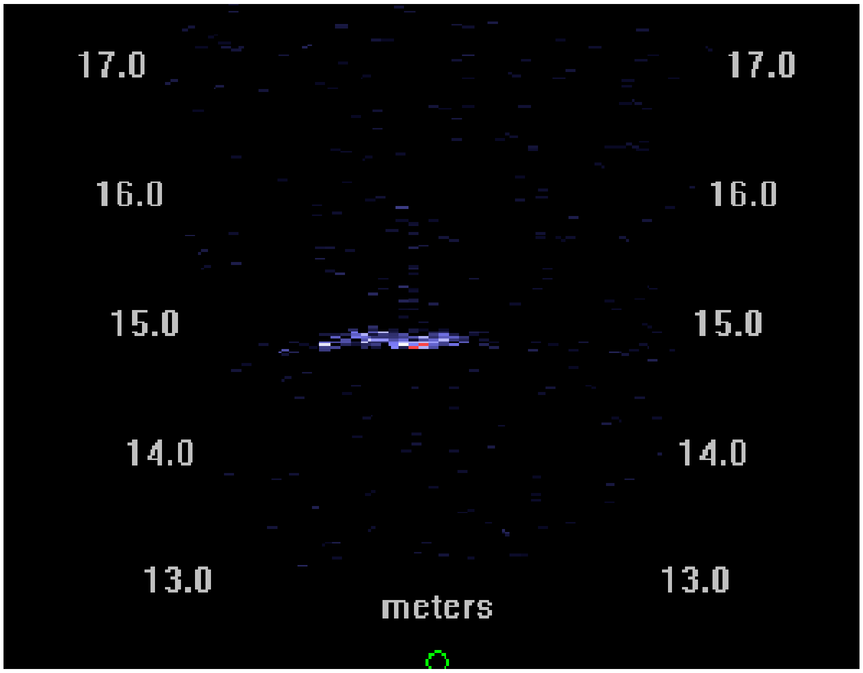
Source: Adapted from Burwen et al. 2010.

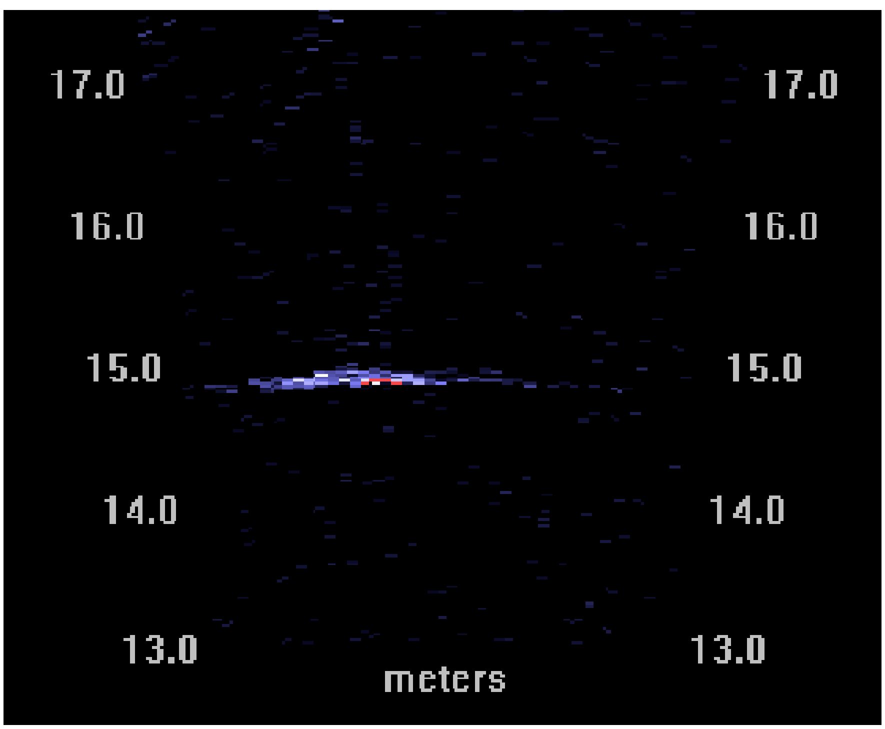
Appendix A7.–DIDSON images from a tethered Chinook salmon showing the original DIDSON image (top), the zoomed image (middle), and the segmented lines that result when the observer clicks along the length of the fish to mark its length (bottom).



Source: Adapted from Burwen et al. 2010.

Appendix A8.–DIDSON images from a Chinook salmon showing a well-defined image of the fish swimming through the beam (top) and a "smeared" image of the same fish (bottom).

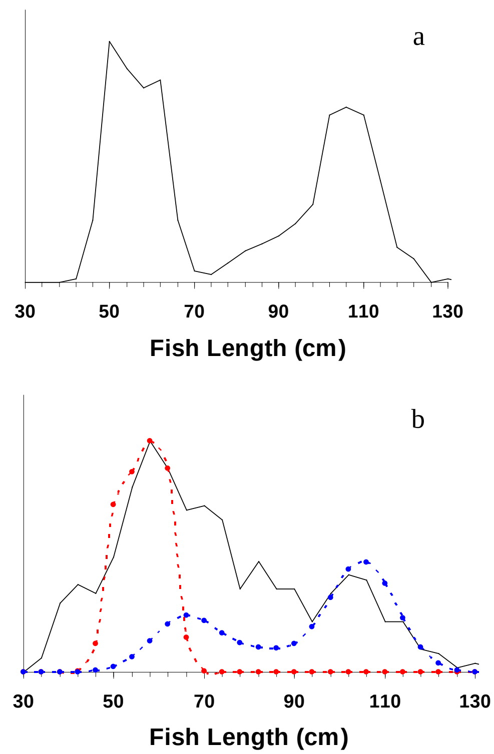




APPENDIX B: STATISTICAL MIXTURE MODEL USED TO ESTIMATE SPECIES COMPOSITION OF PASSING FISH

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 realistic assessments of uncertainty.



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

-continued-

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

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

$$f(w) = \pi_S f_S(w) + \pi_C f_C(w) \tag{B1}$$

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 flow chart in Appendix B2.

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

$$w_i = \beta_0 + \beta_1 x_i + \varepsilon_i \tag{B2}$$

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 B3–B4) 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 (Perschbacher 2014) immediately downstream of the sonar site. In 2012, the netting program was designed to sample the river corridor insonified by DIDSON. Length data from the nets were paired with hydroacoustic data from the same time periods.

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:

$$f_S(x) = \theta_{S1} f_{S1}(x) + \theta_{S2} f_{S2}(x) + \theta_{S3} f_{S3}(x) \text{ and} \tag{B3}$$

$$f_C(x) = \theta_{C1} f_{C1}(x) + \theta_{C2} f_{C2}(x) + \theta_{C3} f_{C3}(x) \tag{B4}$$

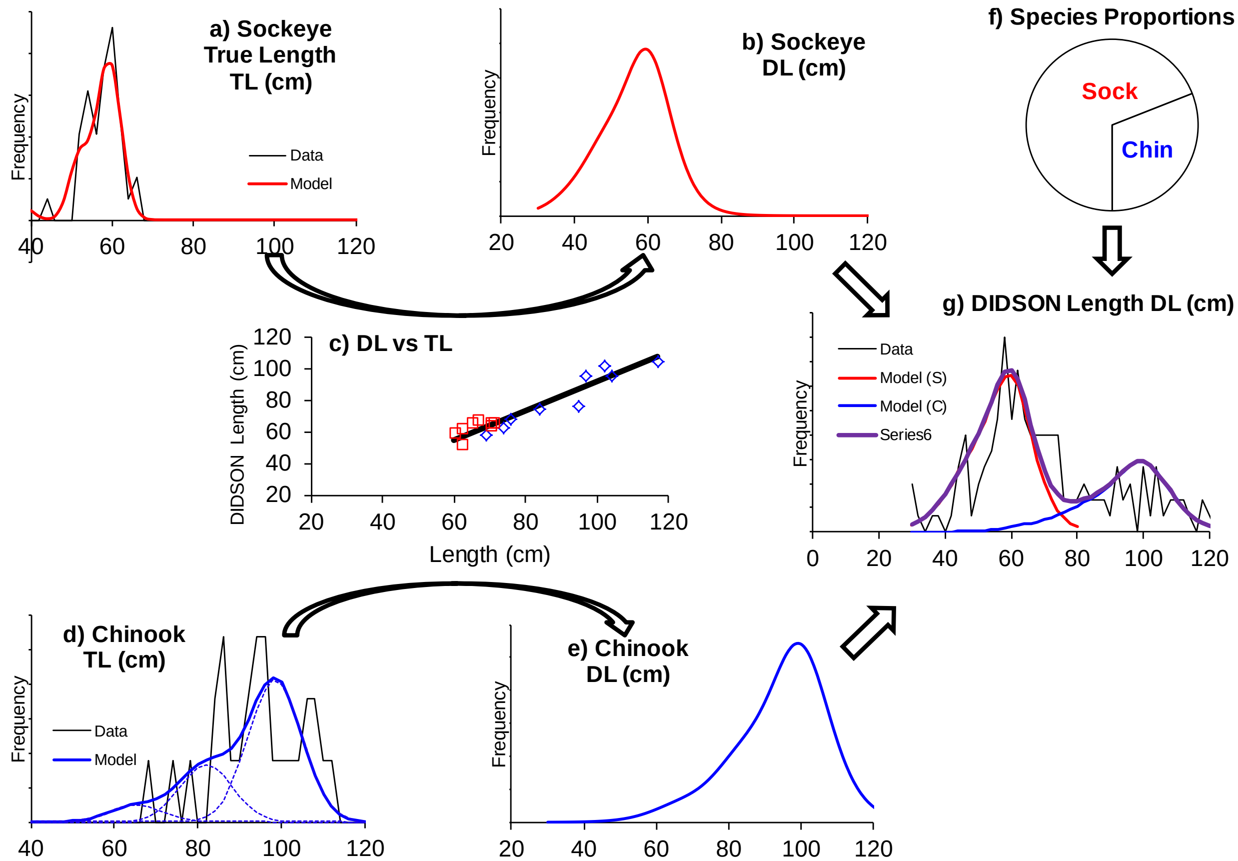
where θ_{Ca} and θ_{Sa} are the proportions of sockeye and Chinook salmon belonging to age component a and the distributions

$$f_{Sa}(x) \sim N(\mu_{Sa},, \tau^2_{Sa}), \text{ and} \tag{B5}$$

$$f_{Ca}(x) \sim N(\mu_{Ca},, \tau^2_{Ca}) \tag{B6}$$

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 DIDSON length (w), each component of which is transformed from a 3-component normal age mixture of fish length (x).

Appendix B2.–Flow chart of a mixture model. The frequency distribution of DIDSON length (DL, panel *g*) is modeled as a weighted mixture of species-specific DL distributions (panels *b* and *e*), which in turn are the products of species-specific size distributions (panels *a* and *d*) and the relationship between DL and true fish length (panel *c*). The weights (species proportions, panel *f*) are the parameters of interest.



Bayesian statistical methods were employed to fit the mixture model to the data. Bayesian methods were chosen because they provide realistic estimates of uncertainty and the ability to incorporate diverse sources of auxiliary information. We implemented the Bayesian mixture model in WinBUGS (Bayes Using Gibbs Sampler; Gilks et al. 1994). Bayesian methods require that prior probability distributions be formulated for all unknowns in the model (Gelman et al. 2004). Species proportions π_S and π_C were assigned an uninformative Dirichlet (0.1,0.9) prior. Age proportions $\{\theta_{Sa}\}$ and $\{\theta_{Ca}\}$ were assigned informative Dirichlet priors based on a hierarchical analysis of historical data (Appendix B4). Likewise, informative normal priors based on historical data were used for the length-at-age means μ and standard deviations τ (Appendix B5). A linear statistical model of tethered fish data (Burwen et al. 2003) was integrated into the mixture model (Appendix B5) to provide information on regression parameters β_0, β_1, and σ^2.

WinBUGS uses Markov chain Monte Carlo methods to sample from the joint posterior distribution of all unknown quantities in the model. A single Markov chain[9] was initiated for each daily run of the hierarchical age composition model, samples were thinned 20 to 1, and history plots were monitored to confirm convergence and mixing. The first 4,000 or more "burn-in" samples were discarded, and at least 10,000 additional samples were drawn from the posterior distribution.

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

Mixture model results were more robust to length measurement error if only a minimal number of tethered fish data points were used, so a subset of tethered fish data from 2007 DIDSON experiments (Burwen et al. 2010) provided a mildly informative prior for the β_0 and β_1 parameters. Species proportions π_C and π_S were assigned a Dirichlet (0.1,0.9) prior. This is a very mildly informative prior distribution, equivalent to a single additional observation and centered on 10% Chinook salmon rather than 50% for the noninformative beta (0.5, 0.5). Prior distributions for age proportions $\{\theta_{Ca}\}$ and $\{\theta_{Sa}\}$ were constructed with nested beta (0.5, 0.5) prior distributions. Netting probability of capture was assumed to be equal for all three age classes. Netting length data (Perschbacher 2012) from days $d-3$ through $d+3$ were paired with DIDSON length data from day d.

After 14 July, "Fast-Tracked" fish judged to be less than 75 cm, but not included in the measured subset of medium-sized fish, were modeled as having come from a censored sample. A test conducted on 2010 data found extremely good agreement between Chinook salmon proportions estimated with standard vs. fast-track protocols. Between 4 July and 4 August 2010, 29 days with uncensored data were censored and reanalyzed with fast-track protocol, yielding a 0.9994 to 1.0 relationship with a coefficient of determination of 0.998.

-continued-

[9] During initial development of the model, multiple chains were used to assess convergence (Gelman et al. 2004). This was not necessary during subsequent annual updates.

A single Markov chain[10] was initiated for each daily run of the DIDSON-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.

WinBUGS code for the DIDSON length mixture model is in Appendix B5. Model statements for censored observations under fast-track protocol are in the last paragraph of Appendix B6.

Posterior means are reported herein as point estimates and posterior standard deviations as standard errors.

See Fleischman and Burwen (2003) for an application of these methods to split-beam sonar data. Some of the methodological details used for this report differ from those used to produce preliminary 2010–2012 mixture model estimates that were reported elsewhere (Fleischman and McKinley 2013: Table 4; and McKinley and Fleischman 2013: Table 5). These modifications are summarized in Appendix B7.

[10] 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 B4.–WinBUGS code for hierarchical age-composition model used to develop prior distributions for DIDSON-length mixture model.

```
# Age Mixture.odc  version 6a:

model  {
 #Overall means and std deviations
 for  ( a in 1:A)    {
  sigma[a] ~ dnorm  ( 0,1.0E-4)  I ( 0,)
  tau[a] <- 1 / sigma[a] / sigma[a]
  mu[a] ~ dnorm  ( 0,1.0E-12)  I ( 0,)
  }
 #Dirichlet distributed age proportions across years within weeks
 D.scale ~ dunif  ( 0,1)
 D.sum <- 1 /  ( D.scale * D.scale)
 for  ( w in 1:W)    {
  pi[w,1] ~ dbeta  ( 0.2,0.4)
  pi.2p[w] ~ dbeta  ( 0.2,0.2)
  pi[w,2] <- pi.2p[w] *  ( 1 - pi[w,1])
  pi[w,3] <- 1 - pi[w,1] - pi[w,2]
  for  ( y in 1:Y)    {
   for  ( a in 1:A)    {
    D[w,y,a] <- D.sum * pi[w,a]
    g[w,y,a] ~ dgamma  ( D[w,y,a],1)
    pi.wy[w,y,a] <- g[w,y,a]/sum  ( g[w,y,])
    }
   }
  }
 for  ( i in 1:nfish)    {
  age[i] ~ dcat  ( pi.wy[week[i],year[i],1:A])
  length[i] ~ dnorm  ( mu[age[i]],tau[age[i]])
  }
}
```

Appendix B5.–WinBUGS code for DIDSON-length mixture model, standard protocol. Prior distributions in green font, likelihoods in blue.

```
model{
 beta0 ~ dnorm(75,0.0025)
 beta1 ~ dnorm(0.8,25)
 sigma.DL ~ dunif(0,20)
 tau.DL  <- 1 / sigma.DL / sigma.DL
 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] * ntgts
 p.large <- ps[1] * (1 - pa[1,1])
 n.large <- p.large * ntgts
  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) {
   TL.cm.75[k] <- TL.cm[k] - 75
   mu.DL1[k] <- beta0 + beta1 * TL.cm.75[k]
   DL1[k] ~ dnorm(mu.DL1[k],tau.DL)
   }
 for (i in 1:nfish) {
   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:ntgts) {
   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]])
   TL2.cm.75[j] <- (1.1*mefl.mm.2[j] + 2) / 10 - 75    # CONVERT TO TL -NUSHAGAK 2001 DATA
   mu.DL2[j] <- beta0 + beta1 * TL2.cm.75[j]
   DL2[j] ~ dnorm(mu.DL2[j],tau.DL)
   }
 }
```

Appendix B6.–Substitute WinBUGS code for DIDSON-length mixture model, fast-track protocol. Statements replace last paragraph of Appendix B5. Likelihoods in blue. Data DL3 are unmeasured fish judged to be less than 75 cm.

```
 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]])
  TL2.cm.75[j] <- (1.1*mefl.mm.2[j]) / 10 - 75
  mu.DL2[j] <- beta0 + beta1 * TL2.cm.75[j]
  DL2[j] ~ dnorm(mu.DL2[j],tau.DL)I(40,)
  }
for (k in 1:n_small) {
  species3[k] ~ dcat(ps[])
  age3[k] ~ dcat(pa[species3[k],1:3])
  mefl.mm.3[k] ~ dnorm(mu[species3[k],age3[k]],Ltau[species3[k],age3[k]])
  TL3.cm.75[k] <- (1.1*mefl.mm.3[k] + 2) / 10 - 75
  mu.DL3[k] <- beta0 + beta1 * TL3.cm.75[k]
  DL3[k] ~ dnorm(mu.DL3[k],tau.DL)I(,75)
  }
 }
```

Appendix B7.–Methodological details differing from previously published estimates.

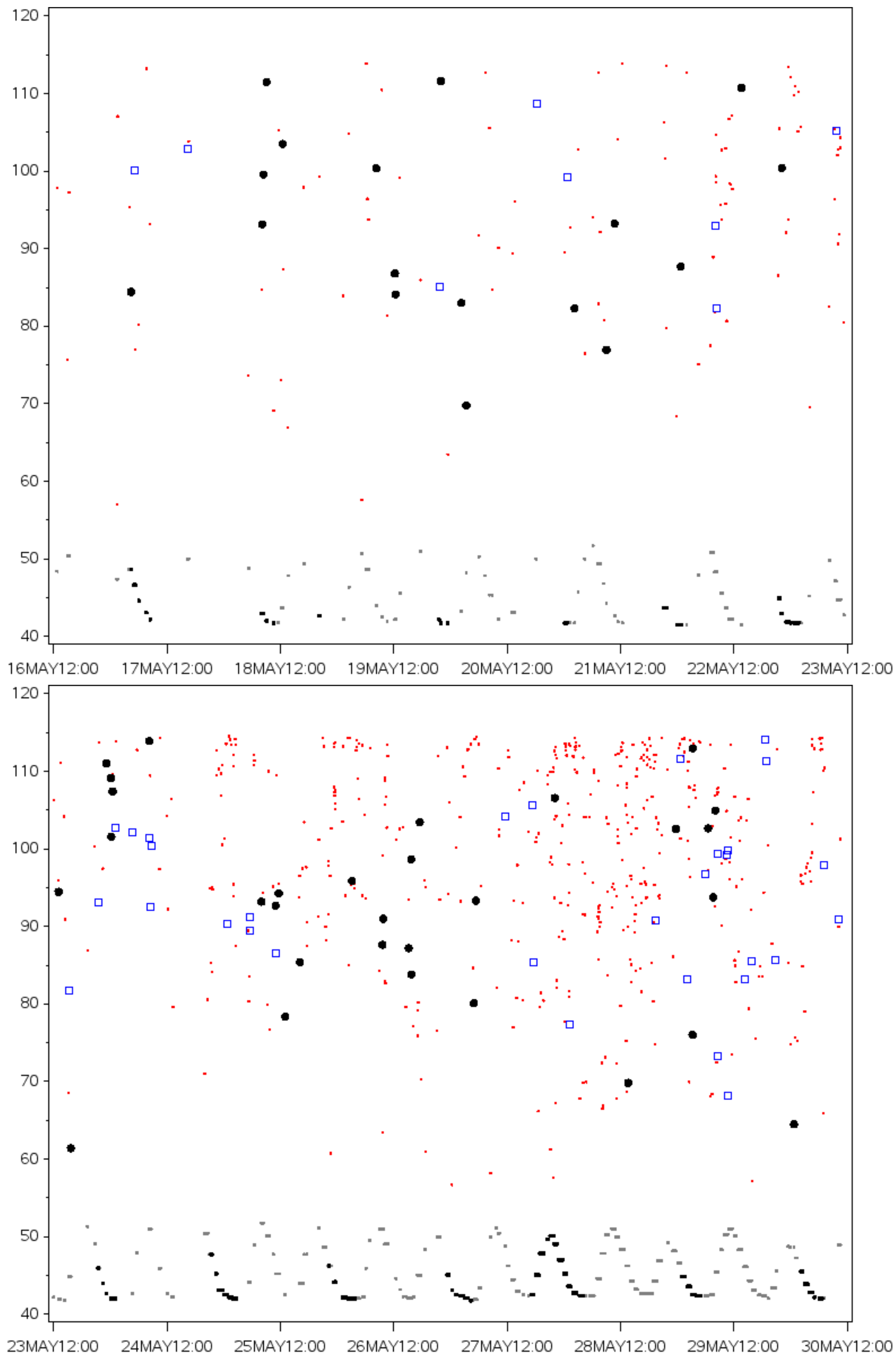
Preliminary values of some of the estimates in this report were published by Fleischman and McKinley (2013: Table 4, for late-run Chinook salmon) and McKinley and Fleischman (2013: Table 5, for early-run Chinook salmon). Technical methodological details that differed between preliminary and final estimates for 2010 and 2011 are summarized here.

	Preliminary[a]		Final[b]
Modification	2010	2011–2012	2010–2012
Age composition prior	informative[c]	informative[c]	noninformative[d]
Species composition prior	Dirichlet(0.5,0.5)	Dirichlet(0.5,0.5)	Dirichlet(0.1,0.9)
Days of netting data pooled and paired with day *d* of sonar data	*d−1 to d*	*d−6 to d*	*d−3 to d+3*
Chinook salmon size selectivity by age class	0.61, 0.57, 0.41	0.61, 0.57, 0.41	1, 1, 1

[a] Used to produce results reported in McKinley and Fleischman (2013: Table 5) and Fleischman and McKinley (2013: Table 4).
[b] Used to produce results reported herein, in Miller et al. (2013) and in Miller et al. (2014).
[c] Informative priors differed by week, as developed from the hierarchical age composition model in Appendix B4.
[d] Noninformative nested beta priors (see Appendix B5).

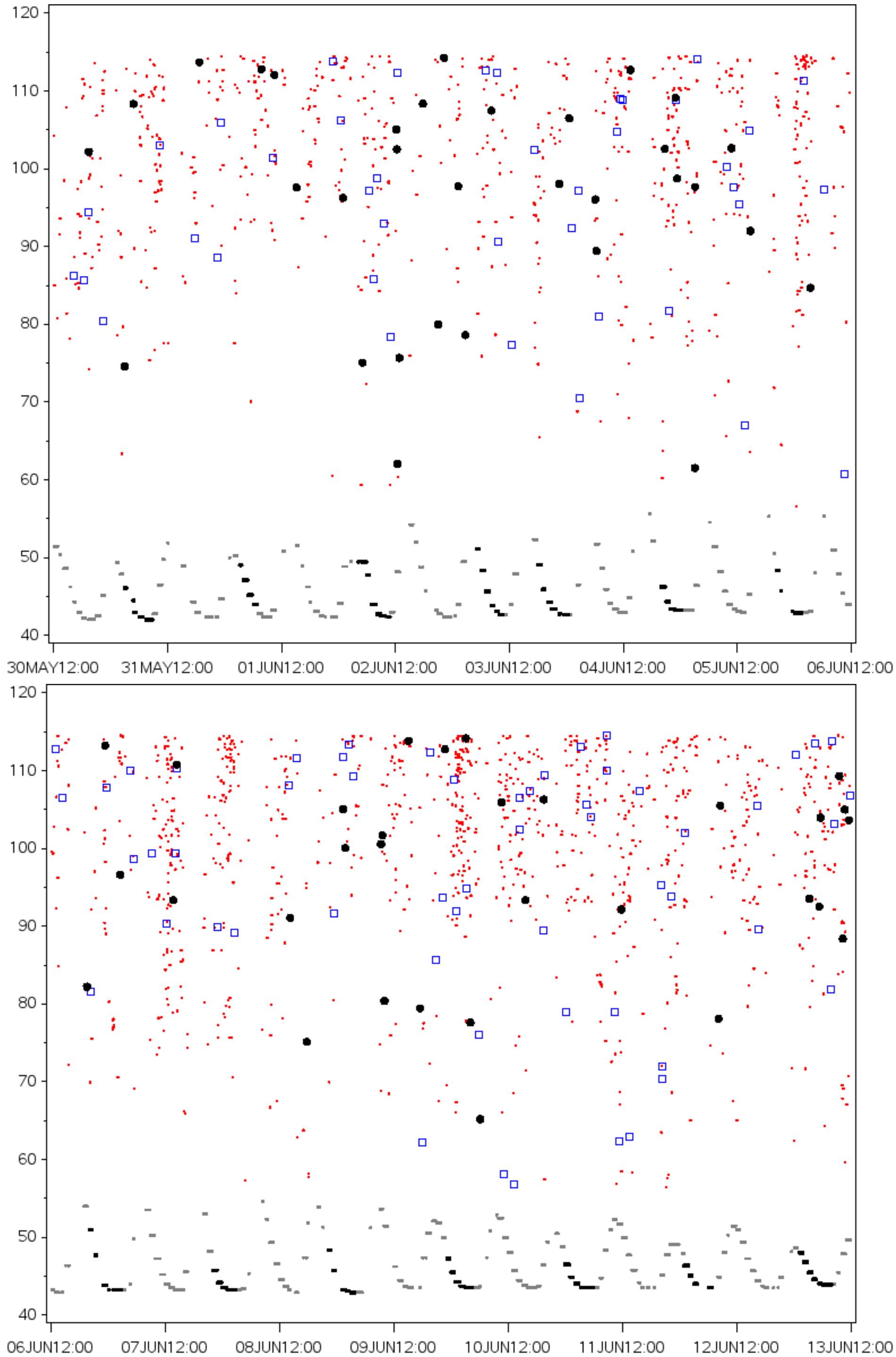
APPENDIX C: SPATIAL AND TEMPORAL DISTRIBUTION OF FISH BY SIZE AS MEASURED BY DIDSON, RM 8.6 KENAI RIVER, 2012

Appendix C1.–Spatial and temporal distribution of small (DIDSON length DL < 75 cm; small red symbols), medium (75 cm ≤ DL < 90 cm; larger blue squares), and large fish (DL ≥ 90 cm; large black symbols), RM 8.6 Kenai River, 16–22 May (top) and 23–29 May (bottom) 2012.



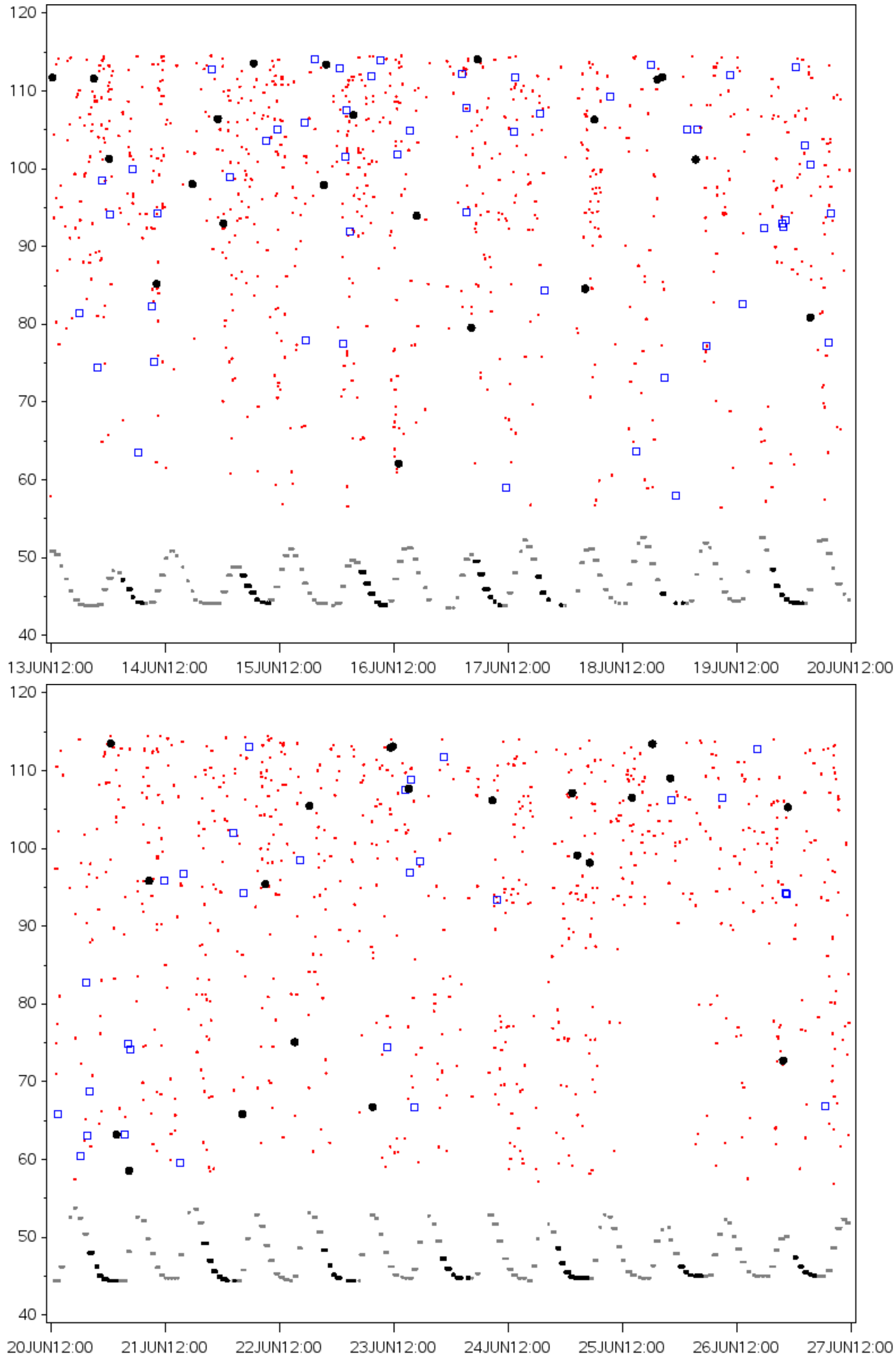
Note: Vertical axis is distance (m) from benchmark on right-bank shore, except that relative water level is plotted at bottom (small grey symbols), with netting periods in black.

Appendix C2.–Spatial and temporal distribution of small (DIDSON length DL < 75 cm; small red symbols), medium (75 cm ≤ DL < 90 cm; larger blue squares), and large fish (DL ≥ 90 cm; large black symbols), RM 8.6 Kenai River, 30 May–5 June (top) and 6–12 June (bottom) 2012.



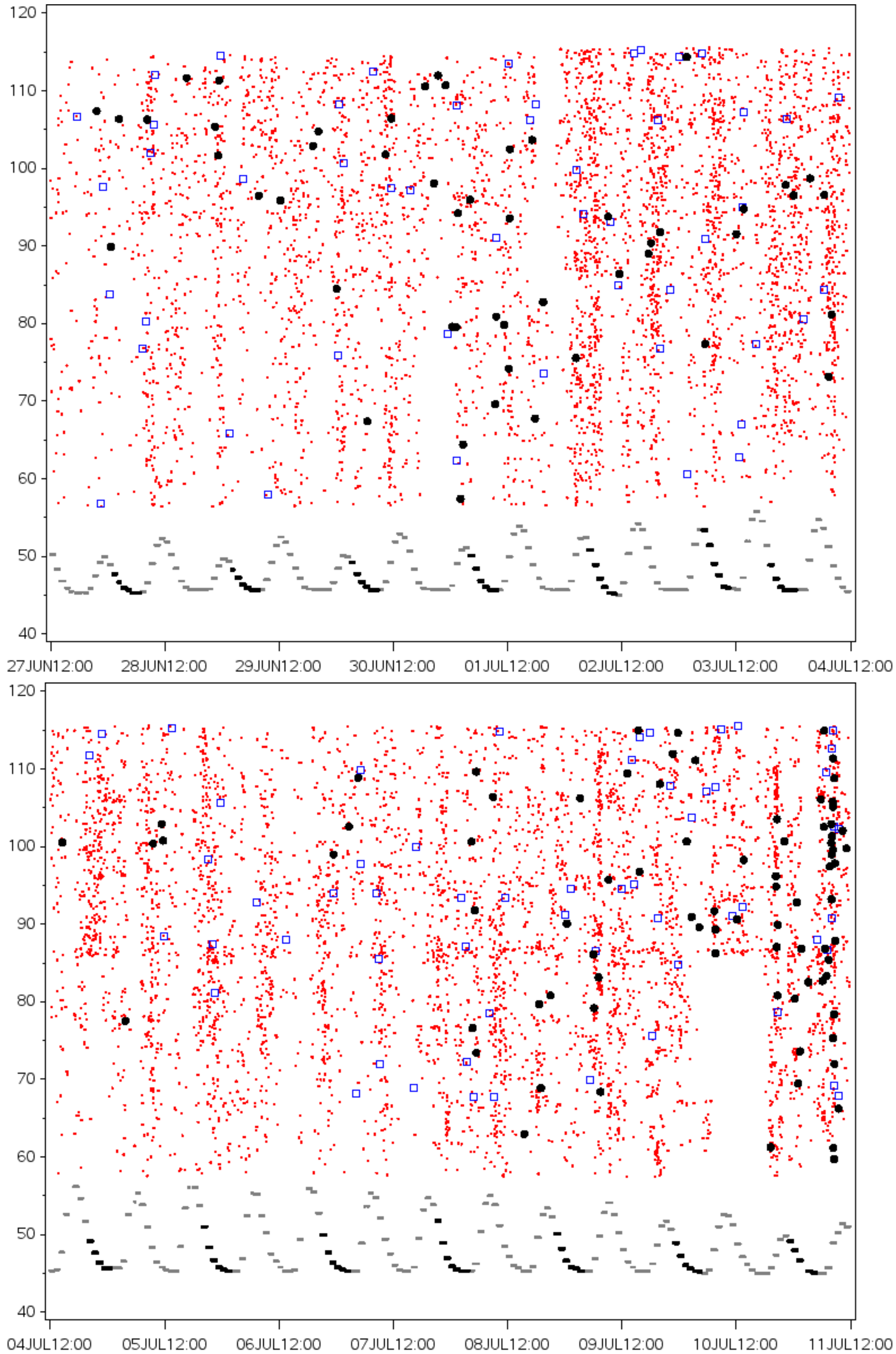
Note: Vertical axis is distance (m) from benchmark on right-bank shore, except that relative water level is plotted at bottom (small grey symbols), with netting periods in black.

Appendix C3.–Spatial and temporal distribution of small (DIDSON length DL < 75 cm; small red symbols), medium (75 cm ≤ DL < 90 cm; larger blue squares), and large fish (DL ≥ 90 cm; large black symbols), RM 8.6 Kenai River, 13–19 June (top) and 20–26 June (bottom) 2012.



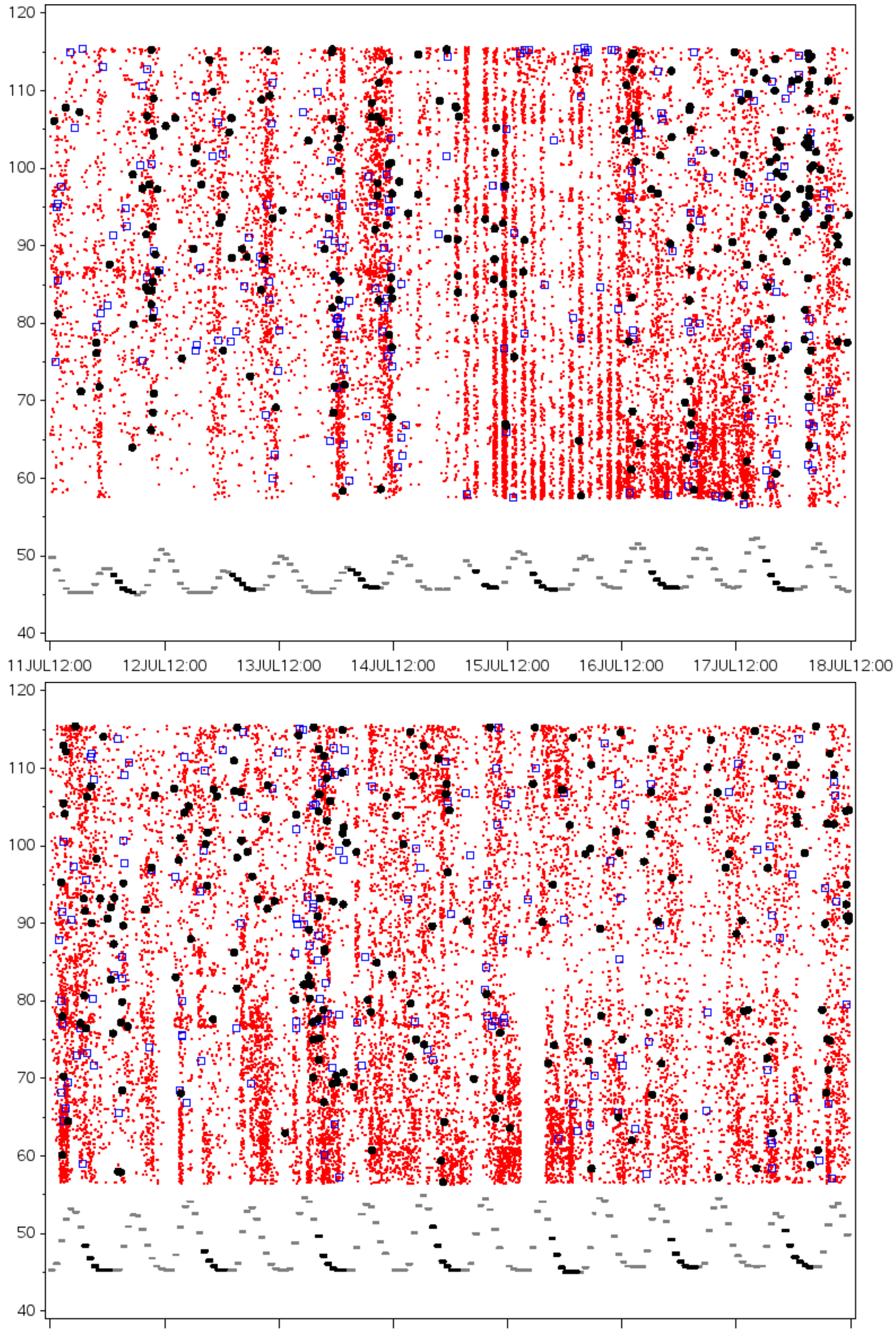
Note: Vertical axis is distance (m) from benchmark on right bank shore, except that relative water level is plotted at bottom (small grey symbols), with netting periods in black.

Appendix C4.–Spatial and temporal distribution of small (DIDSON length DL < 75 cm; small red symbols), medium (75 cm ≤ DL < 90 cm; larger blue squares), and large fish (DL ≥ 90 cm; large black symbols), RM 8.6 Kenai River, 27 June–3 July (top) and 4–10 July (bottom) 2012.



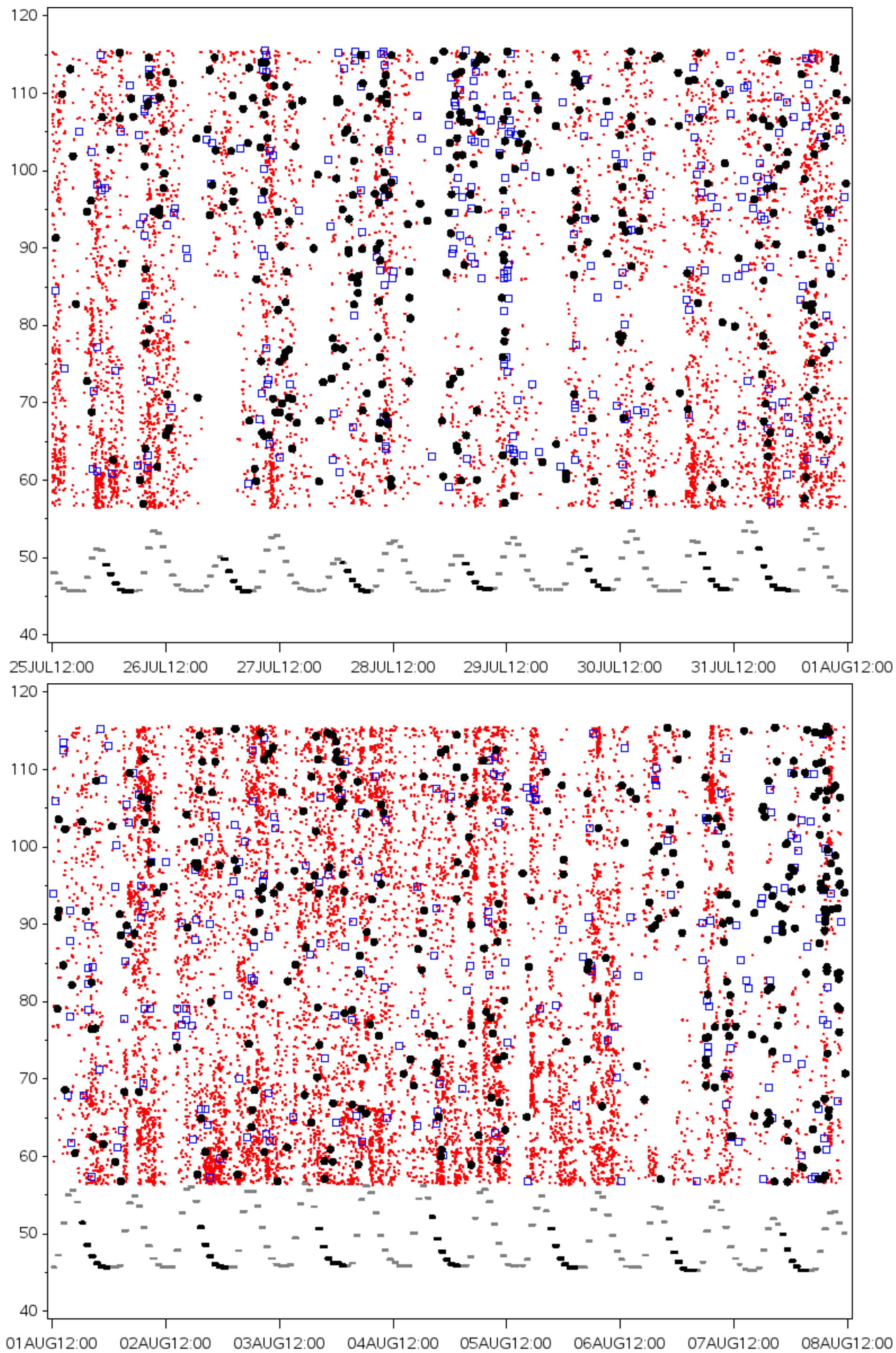
Note: Vertical axis is distance (m) from benchmark on right bank shore, except that relative water level is plotted at bottom (small grey symbols), with netting periods in black.

Appendix C5.–Spatial and temporal distribution of small (DIDSON length DL < 75 cm; small red symbols), medium (75 cm ≤ DL < 90 cm; larger blue squares), and large fish (DL ≥ 90 cm; large black symbols), RM 8.6 Kenai River, 11–17 July (top) and 18–24 July (bottom) 2012.



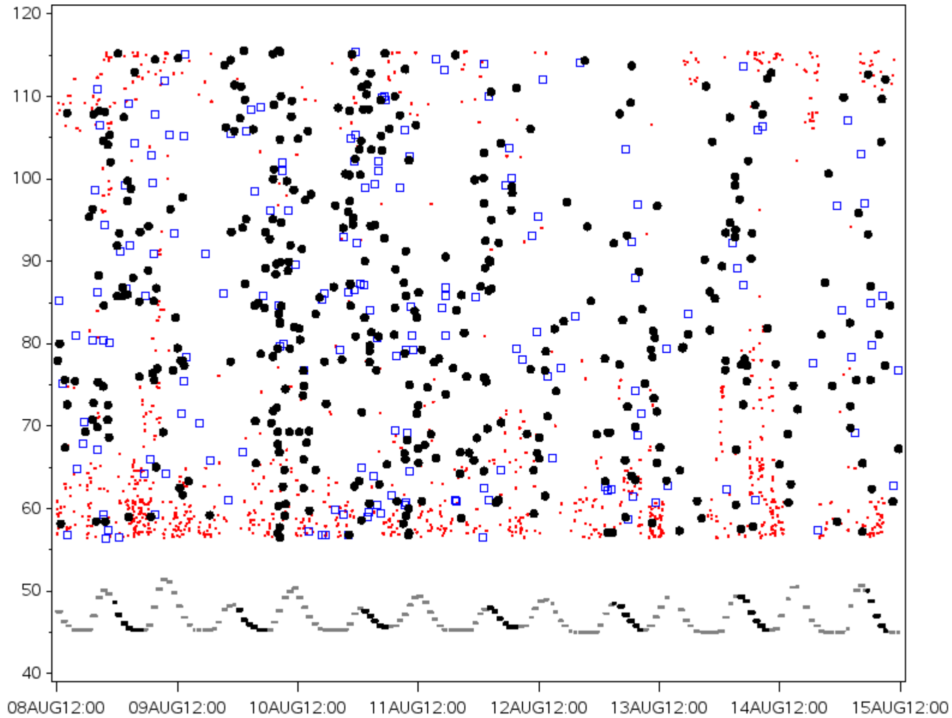
Note: Vertical axis is distance (m) from benchmark on right bank shore, except that relative water level is plotted at bottom (small grey symbols), with netting periods in black. On 14–15 July, only 12 hours per day were sampled.

Appendix C6.–Spatial and temporal distribution of small (DIDSON length DL < 75 cm; small red symbols), medium (75 cm ≤ DL < 90 cm; larger blue squares), and large fish (DL ≥ 90 cm; large black symbols), RM 8.6 Kenai River, 25–31 July (top) and 1–7 August (bottom) 2012.



Note: Vertical axis is distance (m) from benchmark on right bank shore, except that relative water level is plotted at bottom (small grey symbols), with netting periods in black.

Appendix C7.–Spatial and temporal distribution of small (DIDSON length DL < 75 cm; small red symbols), medium (75 cm ≤ DL < 90 cm; larger blue squares), and large fish (DL ≥ 90 cm; large black symbols), RM 8.6 Kenai River, 8–14 August 2012.



Note: Vertical axis is distance (m) from benchmark on right bank shore, except that relative water level is plotted at bottom (small grey symbols), with netting periods in black. Beginning on 8 August, only medium and large fish were measured in some samples.

APPENDIX D: DIRECTION OF TRAVEL OF LARGE FISH DETECTED BY DIDSON, RM 8.6 KENAI RIVER, 2012.

Appendix D1.–Daily numbers and proportions of upstream- and downstream-moving fish greater than or equal to 75 cm DIDSON length for the early run, RM 8.6 Kenai River, 2012.

Date	Total fish sampled	Number moving downstream	Number moving upstream	Percent moving downstream	Percent moving upstream
16 May	2	0	2	0%	100%
17 May	4	0	4	0%	100%
18 May	2	0	2	0%	100%
19 May	7	1	6	14%	86%
20 May	5	0	5	0%	100%
21 May	4	1	3	25%	75%
22 May	4	1	3	25%	75%
23 May	14	0	14	0%	100%
24 May	8	1	7	13%	88%
25 May	5	0	5	0%	100%
26 May	13	6	7	46%	54%
27 May	4	0	4	0%	100%
28 May	19	3	16	16%	84%
29 May	8	0	8	0%	100%
30 May	8	0	8	0%	100%
31 May	7	0	7	0%	100%
1 Jun	12	2	10	17%	83%
2 Jun	14	0	14	0%	100%
3 Jun	13	0	13	0%	100%
4 Jun	13	1	12	8%	92%
5 Jun	8	0	8	0%	100%
6 Jun	12	2	10	17%	83%
7 Jun	7	0	7	0%	100%
8 Jun	14	1	13	7%	93%
9 Jun	17	1	16	6%	94%
10 Jun	17	0	17	0%	100%
11 Jun	10	1	9	10%	90%
12 Jun	16	1	15	6%	94%
13 Jun	13	0	13	0%	100%
14 Jun	8	0	8	0%	100%
15 Jun	13	0	13	0%	100%
16 Jun	10	0	10	0%	100%
17 Jun	7	0	7	0%	100%
18 Jun	12	1	11	8%	92%
19 Jun	11	0	11	0%	100%
20 Jun	13	0	13	0%	100%

-continued-

Appendix D1.–Page 2 of 2.

Date	Total fish sampled	Number moving downstream	Number moving upstream	Percent moving downstream	Percent moving upstream
21 Jun	7	0	7	0%	100%
22 Jun	7	0	7	0%	100%
23 Jun	9	0	9	0%	100%
24 Jun	4	1	3	25%	75%
25 Jun	5	0	5	0%	100%
26 Jun	6	0	6	0%	100%
27 Jun	13	0	13	0%	100%
28 Jun	9	0	9	0%	100%
29 Jun	12	0	12	0%	100%
30 Jun	18	0	18	0%	100%
Total	444	24	420	5.4%	94.6%

Appendix D2.–Daily numbers and proportions of upstream and downstream moving fish greater than or equal to 75 cm DIDSON length for the late run, RM 8.6 Kenai River, 2012.

Date	Total fish sampled	Number moving downstream	Number moving upstream	Percent moving downstream	Percent moving upstream
1 Jul	17	0	17	0%	100%
2 Jul	14	0	14	0%	100%
3 Jul	17	0	17	0%	100%
4 Jul	8	0	8	0%	100%
5 Jul	7	1	6	14%	86%
6 Jul	11	0	11	0%	100%
7 Jul	16	0	16	0%	100%
8 Jul	17	2	15	12%	88%
9 Jul	27	0	27	0%	100%
10 Jul	60	2	58	3%	97%
11 Jul	57	0	57	0%	100%
12 Jul	50	1	49	2%	98%
13 Jul	82	0	82	0%	100%
14 Jul	41	1	40	2%	98%
15 Jul	27	0	27	0%	100%
16 Jul	68	1	67	2%	99%
17 Jul	121	0	121	0%	100%
18 Jul	71	1	70	1%	99%
19 Jul	48	0	48	0%	100%
20 Jul	95	3	92	3%	97%
21 Jul	51	1	50	2%	98%
22 Jul	40	0	40	0%	100%
23 Jul	32	0	32	0%	100%
24 Jul	59	0	59	0%	100%
25 Jul	70	0	70	0%	100%
26 Jul	75	1	74	1%	99%
27 Jul	117	4	113	3%	97%
28 Jul	124	10	114	8%	92%
29 Jul	87	4	83	5%	95%
30 Jul	81	10	71	12%	88%
31 Jul	121	12	109	10%	90%

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Appendix D2.–Page 2 of 2.

Date	Total fish sampled	Number moving downstream	Number moving upstream	Percent moving downstream	Percent moving upstream
1 Aug	97	20	77	21%	79%
2 Aug	89	7	82	8%	92%
3 Aug	89	6	83	7%	93%
4 Aug	80	3	77	4%	96%
5 Aug	47	5	42	11%	89%
6 Aug	83	7	76	8%	92%
7 Aug	155	5	150	3%	97%
8 Aug	107	7	100	6%	94%
9 Aug	113	8	105	7%	93%
10 Aug	160	11	149	7%	93%
11 Aug	101	19	82	19%	81%
12 Aug	78	14	64	18%	82%
13 Aug	56	1	55	2%	98%
14 Aug	53	6	47	11%	89%
15 Aug	16	2	14	13%	88%
Total	3,035	175	2,860	5.8%	94.2%

APPENDIX E: DIDSON-LENGTH THRESHOLD ESTIMATES OF LARGE CHINOOK SALMON, RM 8.6 KENAI RIVER, 2012

Appendix E1.–Daily DIDSON length (DL) threshold estimates of large Chinook salmon passage (DL ≥ X cm) at RM 8.6 in the Kenai River, early run 2012.

	DL ≥ 75 cm		DL ≥ 80 cm		DL ≥ 90 cm	
Date	Passage	SE	Passage	SE	Passage	SE
16 May	12	5	12	5	6	5
17 May	24	10	18	9	18	9
18 May	12	6	12	6	12	6
19 May	36	10	36	10	30	10
20 May	30	10	30	10	18	7
21 May	20	13	20	13	7	6
22 May	18	9	18	9	12	7
23 May	85	27	60	25	42	16
24 May	31	13	24	10	18	9
25 May	30	13	30	13	30	13
26 May	44	20	38	20	38	20
27 May	24	12	24	12	6	5
28 May	97	25	91	22	42	13
29 May	82	32	74	31	15	13
30 May	48	13	42	12	18	7
31 May	42	13	30	10	18	9
1 Jun	57	11	57	11	13	8
2 Jun	84	22	84	22	60	17
3 Jun	72	21	66	21	24	12
4 Jun	72	23	48	17	42	17
5 Jun	48	12	36	14	12	7
6 Jun	60	15	60	15	18	9
7 Jun	42	15	36	14	12	5
8 Jun	78	19	66	21	42	15
9 Jun	88	17	76	18	38	12
10 Jun	103	21	84	16	18	8
11 Jun	54	21	42	19	12	10
12 Jun	84	17	72	16	42	13
13 Jun	78	18	60	17	24	9
14 Jun	48	12	42	11	24	9
15 Jun	78	18	66	17	18	11
16 Jun	91	30	79	27	36	15
17 Jun	42	14	36	13	12	7
18 Jun	66	17	48	14	18	7
19 Jun	66	18	54	14	6	5
20 Jun	79	18	60	18	24	9

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Appendix E1.–Page 2 of 2.

	DL ≥ 75 cm		DL ≥ 80 cm		DL ≥ 90 cm	
Date	Passage	SE	Passage	SE	Passage	SE
21 Jun	42	15	36	13	12	7
22 Jun	42	10	30	11	30	11
23 Jun	54	13	54	13	12	7
24 Jun	18	7	18	7	18	7
25 Jun	32	14	32	14	18	9
26 Jun	36	15	24	13	12	5
27 Jun	78	16	54	15	24	10
28 Jun	54	17	42	13	30	11
29 Jun	72	16	66	16	42	10
30 Jun	109	25	103	24	78	16
Total	2,562	116	2,190	108	1,101	71

Note: All estimates are of upstream-bound fish in midriver between and greater than 3 m from the transducers.

Appendix E2.–Daily DIDSON length (DL) threshold estimates of large Chinook salmon passage (DL ≥ X cm) at RM 8.6 in the Kenai River, late run 2012.

	DL ≥ 75 cm		DL ≥ 80 cm		DL ≥ 90 cm	
Date	Passage	SE	Passage	SE	Passage	SE
1 Jul	175	71	163	70	85	32
2 Jul	94	18	81	20	30	10
3 Jul	103	23	72	15	48	11
4 Jul	53	17	36	14	30	11
5 Jul	38	11	25	11	0	0
6 Jul	78	23	42	13	18	9
7 Jul	96	17	72	18	36	14
8 Jul	90	18	90	18	66	16
9 Jul	216	50	173	50	107	38
10 Jul	482	131	451	127	381	107
11 Jul	344	60	313	56	199	49
12 Jul	295	35	259	33	157	22
13 Jul	494	57	434	56	247	45
14 Jul	463	80	425	82	316	80
15 Jul	229	55	145	40	84	29
16 Jul	404	71	356	67	235	52
17 Jul	769	117	739	108	509	78
18 Jul	422	61	356	56	229	35
19 Jul	289	35	264	33	171	25
20 Jul	555	63	488	56	314	41
21 Jul	304	38	243	29	157	26
22 Jul	288	60	244	53	178	43
23 Jul	193	40	169	36	133	32
24 Jul	393	59	367	57	252	41
25 Jul	449	62	412	62	262	43
26 Jul	505	65	479	60	319	39
27 Jul	710	59	674	51	513	40
28 Jul	717	90	682	87	392	61
29 Jul	525	70	492	68	261	38
30 Jul	430	51	412	51	231	42
31 Jul	657	61	615	57	380	39

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Appendix E2.–Page 2 of 2.

	DL ≥ 75 cm		DL ≥ 80 cm		DL ≥ 90 cm	
Date	Passage	SE	Passage	SE	Passage	SE
1 Aug	464	35	416	33	229	26
2 Aug	494	60	476	64	241	38
3 Aug	501	51	488	51	350	33
4 Aug	493	50	467	43	316	37
5 Aug	253	36	229	34	121	29
6 Aug	582	90	557	86	381	54
7 Aug	919	106	895	107	637	92
8 Aug	603	61	585	60	368	43
9 Aug	633	96	621	94	482	76
10 Aug	898	75	868	80	603	61
11 Aug	494	66	464	66	356	52
12 Aug	386	39	374	39	271	32
13 Aug	332	31	320	30	265	29
14 Aug	287	27	287	27	197	16
15 Aug	113	25	113	25	105	22
Total	18,312	413	16,933	397	11,262	302

Note: All estimates are of upstream-bound fish in midriver between and greater than 3 m from the transducers.

APPENDIX F: NET-APPORTIONED ESTIMATES, KENAI RIVER, 2012

Appendix F1.–DIDSON-based upstream fish passage (all species) at split-beam ranges (>10 m from left-bank transducer and >15 m from right-bank transducer), proportion of fish that were Chinook salmon in the inriver netting project, and daily net-apportioned estimates of Chinook salmon passage at RM 8.6 in the Kenai River, early run 2012.

	DIDSON upstream salmon at split beam ranges		Proportion Chinook salmon in inriver gillnets		Net-apportioned Chinook salmon estimates		
Date	Passage	SE	Proportion	SE	Passage	SE	CV
16 May	60	16	0.290	0.226	17	14	0.82
17 May	48	17	zero fish caught				
18 May	66	18	0.000	0.000	0	0	
19 May	60	14	0.354	0.218	21	14	0.65
20 May	90	18	0.581	0.166	52	18	0.35
21 May	154	35	0.404	0.114	62	22	0.36
22 May	109	28	0.639	0.174	70	26	0.37
23 May	115	37	0.000	0.000	0	0	
24 May	180	45	0.219	0.064	39	15	0.38
25 May	265	63	0.000	0.000	0	0	
26 May	195	38	0.290	0.247	57	49	0.85
27 May	471	71	0.360	0.143	170	71	0.42
28 May	580	77	0.000	0.000	0	0	
29 May	374	59	0.208	0.241	78	90	1.15
30 May	543	74	0.203	0.145	110	79	0.72
31 May	296	71	0.000	0.000	0	0	
1 Jun	397	70	0.117	0.074	46	30	0.65
2 Jun	284	53	0.099	0.044	28	13	0.48
3 Jun	404	79	0.239	0.086	97	39	0.40
4 Jun	537	93	0.028	0.026	15	14	0.93
5 Jun	464	102	0.020	0.014	9	7	0.74
6 Jun	503	145	0.096	0.050	48	28	0.58
7 Jun	766	103	0.089	0.055	68	43	0.63
8 Jun	314	56	0.136	0.038	43	14	0.33
9 Jun	674	156	0.094	0.025	63	22	0.35
10 Jun	700	87	0.074	0.035	52	25	0.48
11 Jun	621	101	0.194	0.115	120	73	0.61
12 Jun	671	109	0.047	0.045	32	30	0.94
13 Jun	706	83	0.097	0.027	68	21	0.30
14 Jun	621	76	0.033	0.033	20	20	1.02
15 Jun	627	77	0.000	0.000	0	0	
16 Jun	528	64	0.091	0.034	48	19	0.39
17 Jun	477	63	0.447	0.041	213	34	0.16
18 Jun	332	76	0.360	0.198	120	70	0.58
19 Jun	465	73	0.185	0.046	86	25	0.29
20 Jun	504	107	0.058	0.038	29	20	0.68

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Appendix F1.–Page 2 of 2.

	DIDSON upstream salmon at split beam ranges		Proportion Chinook salmon in inriver gillnets		Net-apportioned Chinook salmon estimates		
Date	Passage	SE	Proportion	SE	Passage	SE	CV
21 Jun	549	62	0.038	0.027	21	15	0.71
22 Jun	428	68	0.164	0.047	70	23	0.33
23 Jun	465	74	0.097	0.042	45	21	0.46
24 Jun	615	66	0.055	0.033	34	21	0.60
25 Jun	529	74	0.042	0.049	22	26	1.18
26 Jun	567	87	0.142	0.075	81	44	0.54
27 Jun	1,443	198	0.095	0.042	137	63	0.46
28 Jun	1,943	206	0.127	0.059	247	117	0.47
29 Jun	2,565	253	0.091	0.059	233	152	0.65
30 Jun	1,859	176	0.000	0.000	0	0	
Total	25,164	645			2,771	300	0.11

Note: All estimates are germane to upstream-bound fish in midriver (>10 m from left-bank transducer and >15 m from right-bank transducer) for purposes of comparability with historical net-apportioned estimates based on split-beam sonar. See Net-apportioned Index sections in Methods and Results.

Appendix F2.–DIDSON-based upstream fish passage (all species) at split-beam ranges (>10 m from left-bank transducer and > 15 m from right-bank transducer), proportion of fish that were Chinook salmon in the inriver netting project, and daily net-apportioned estimates of Chinook salmon passage at RM 8.6 in the Kenai River, late run 2012.

	DIDSON upstream salmon at split beam ranges		Proportion Chinook salmon in inriver gillnets		Net-apportioned Chinook salmon estimates		
Date	Passage	SE	Proportion	SE	Passage	SE	CV
1 Jul	3,516	283	0.018	0.011	63	39	0.62
2 Jul	4,141	385	0.012	0.012	50	50	0.99
3 Jul	4,309	342	0.013	0.008	56	35	0.62
4 Jul	3,679	283	0.022	0.007	81	26	0.33
5 Jul	3,348	243	0.064	0.034	214	115	0.54
6 Jul	2,426	234	0.011	0.011	27	27	0.99
7 Jul	3,202	260	0.019	0.011	61	35	0.58
8 Jul	3,606	374	0.069	0.030	249	111	0.44
9 Jul	3,316	413	0.078	0.021	259	76	0.29
10 Jul	4,693	614	0.072	0.029	338	142	0.42
11 Jul	5,335	529	0.091	0.014	485	89	0.18
12 Jul	6,902	730	0.070	0.020	483	146	0.30
13 Jul	10,100	783	0.022	0.017	222	172	0.77
14 Jul	18,247	3,654	0.036	0.012	657	252	0.38
15 Jul	28,003	5,776	0.011	0.007	308	202	0.66
16 Jul	18,995	2,272	0.028	0.030	532	569	1.07
17 Jul	7,840	588	0.181	0.052	1,419	420	0.30
18 Jul	9,912	658	0.048	0.016	476	161	0.34
19 Jul	8,744	890	0.044	0.015	385	136	0.35
20 Jul	14,221	1,460	0.040	0.015	569	220	0.39
21 Jul	17,665	1,785	0.016	0.015	283	265	0.94
22 Jul	16,193	1,385	0.017	0.003	275	54	0.20
23 Jul	7,410	776	0.024	0.009	178	69	0.39
24 Jul	7,475	504	0.023	0.014	172	105	0.61
25 Jul	7,078	980	0.108	0.031	764	242	0.32
26 Jul	4,750	487	0.109	0.012	518	78	0.15
27 Jul	2,758	206	0.255	0.089	703	250	0.36
28 Jul	1,574	147	0.294	0.060	463	103	0.22
29 Jul	1,689	200	0.450	0.083	760	166	0.22
30 Jul	3,448	227	0.216	0.038	745	140	0.19
31 Jul	4,764	291	0.229	0.071	1,091	344	0.32

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Appendix F2.–Page 2 of 2.

Date	DIDSON upstream salmon at split beam ranges		Proportion Chinook salmon in inriver gillnets		Net-apportioned Chinook salmon estimates		
	Passage	SE	Proportion	SE	Passage	SE	CV
1 Aug	6,313	478	0.134	0.024	846	164	0.19
2 Aug	10,293	626	0.088	0.025	906	263	0.29
3 Aug	15,467	1,572	0.059	0.028	913	441	0.48
4 Aug	7,966	525	0.161	0.073	1,283	586	0.46
5 Aug	5,988	860	0.098	0.051	587	314	0.53
6 Aug	8,126	2,188	0.234	0.084	1,901	833	0.44
7 Aug	2,742	836	0.390	0.045	1,069	347	0.32
1 July–7 Aug	296,234	8,677			20,391	1,660	0.081

Note: All estimates are germane to upstream-bound fish in midriver (>10 m from left-bank transducer and > 15 m from right-bank transducer) for purposes of comparability with historical net-apportioned estimates based on split-beam sonar. See Net-apportioned Index sections in Methods and Results. Unbiased estimates of upstream passage not available after 7 August.