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Estimates of Chinook Salmon Passage in the Kenai River at River Mile 8.6 Using Dual-Frequency Identification Sonar, 2014

by

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April 2016

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

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Weights and measures (metric)

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

Weights and measures (English)

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

Time and temperature

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

Physics and chemistry

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

General

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

Mathematics, statistics

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

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ESTIMATES OF CHINOOK SALMON PASSAGE IN THE KENAI RIVER AT RIVER MILE 8.6 USING DUAL-FREQUENCY IDENTIFICATION SONAR, 2014

by

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TABLE OF CONTENTS

Page

TABLE OF CONTENTS (Continued)

LIST OF TABLES

Table **Page**

LIST OF FIGURES

Figure **Page**

LIST OF FIGURES (Continued)

LIST OF APPENDICES

LIST OF APPENDICES (Continued)

ABSTRACT

Kenai River Chinook salmon (*Oncorhynchus tshawytscha*) passage was estimated in 2014 at RM 8.6 using dual-frequency identification sonar (DIDSON). Estimates of midriver Chinook salmon passage between and at least 3 m from the transducers were 4,862 (SE 338) fish for the early run (16 May–30 June) and 13,952 (SE 492) fish for the late run (1 July–15 August). Methods and result from a second experimental sonar site located above tidal influence at RM 13.7 are presented in a separate report.

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 2 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 2014, an optimal escapement goal (OEG) range of 5,300–9,000 Chinook salmon was in effect for the early run, and a sustainable escapement goal (SEG) range of 15,000–30,000 Chinook salmon for the late run (Begich et al. 2013). Sonar estimates of midriver Chinook salmon passage as described in this report, after applying expansions for incomplete spatial coverage, provided the basis for estimating spawning escapement and managing sport and commercial fisheries for this stock.

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 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 2 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 and run concurrently with the dual-beam system for much of the 1994 season (Burwen et al. 1995). The two 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 to 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 precisions 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 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 alternative 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 "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 2. 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, 2015), confirming that DIDSON was better at distinguishing large from small salmon. Split-beam sonar was discontinued in 2012. Supplemental sampling behind the existing transducer placements in 2011 and 2012 confirmed the presence of large fish near shore

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

In this report, we present daily and seasonal DIDSON-based estimates of Chinook salmon midriver abundance for 2014. Passage estimates in this report have not been expanded for incomplete spatial coverage. Methods and results from deploying sonar at an experimental site above tidal influence at RM 13.7 are presented in a separate report (Miller et al. *In prep*).

OBJECTIVE

The primary objective of this project was to produce weekly and seasonal estimates of the midriver 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. Uncertainty due to incomplete spatial coverage is addressed in separate reports (Fleischman and McKinley 2013; McKinley and Fleischman 2013).

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 (1981–2010) precipitation for the City of Kenai, located at the mouth of the Kenai River, is 47 cm (WRCC 2016). Average summer (June, July, and August) minimum and maximum temperatures for the City of Kenai range from 8°C to 16°C (WRCC 2016).

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 28 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 (e.g., Perschbacher 2012).

ACOUSTIC SAMPLING

A Sound Metrics Corporation (SMC[2]) DIDSON system was operated from 16 May to 11 August 2014. Components of the DIDSON system are listed in Table 1. Appendices A1–A8 provide greater detail on DIDSON technology and theory.

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

Sonar System Configuration

A single DIDSON long-range (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 as 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 were 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).

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 an 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 if there is complete beam coverage (Miller et al. 2004). For this reason it is possible that some fish migrating near the thalweg (making up 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 2014, 4 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). 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 (frames 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. 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 (STD) sampling protocol, used 16 May–07 July, was as follows:

1) Length was measured from the DIDSON image for all salmon-shaped 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). Fish measuring less than 40 cm were omitted from further calculations. Flatfish, seals, and beluga whales (*Delphinapterus leucas*) were not recorded.

Fast Track (FT) Sampling Protocol

During much of the sockeye salmon run (8–27 July), the following "fast track" (FT) 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. The remaining fish greater than or equal to 40cm and less than 75 cm were counted but not measured.
3) Direction of travel was recorded for each measured fish.

All Large Fish (ALF) Sampling Protocol

During the end of the sockeye salmon run and the peak of the pink salmon run (28 July–11 August), the following "All Large Fish" (ALF) 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. Other than this subset, medium fish were not counted.
3) Direction of travel was recorded for each measured fish.

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.

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 the vast majority of Chinook salmon and effectively excludes nonsalmon species. For example, 9 of 466 Chinook salmon caught in gillnets at RM 8.6 in 2014 were smaller than 40 cm (16 inches; Perschbacher *In prep*). 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

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

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

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

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

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

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

$$\hat{V}[\hat{Y}] = \sum_i \hat{V}[\hat{y}_i]. \tag{10}$$

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 is 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:

$$\hat{z}_i = \hat{y}_i \hat{\pi}_{Ci} \tag{11}$$

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 DIDSON length mixture model (DLMM) is described in Appendices B1–B3 and WinBUGS code is provided in Appendices B4–B6. Some methodological details used to produce the DLMM estimates in this report differ from those used to produce daily estimates for fisheries management during the 2014 season. Such details are summarized in Appendix B7.

Variance estimates follow Goodman (1960):

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

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:

$$\hat{y}_{NETi} = \hat{y}_{SBi} \hat{\pi}_{NETi} \tag{13}$$

with variance

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

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 *In prep*[3]).

Daily DIDSON-equivalent estimates of Chinook salmon passage

DLMM estimates of inriver abundance could not be produced after 11 August due to logistical problems that necessitated early removal of the sonar equipment from the river. However, DLMM estimates were correlated with catch rates of Chinook salmon in the inriver netting project (Perschbacher *In prep*; available through 15 August). By fitting a daily abundance model (Appendix G1) to sonar and netting data, this relationship was leveraged to produce DIDSON-equivalent (DSEQ) estimates for 12–15 August.

Gillnet catches C on day d were modeled as an over-dispersed Poisson process:

$$C_d \sim Pois(\lambda_d) \tag{15}$$

in which the expected catch λ was a function of true abundance N and effort E:

$$\lambda_d = N_d (1 - \exp(-qE_d)) \exp(\varepsilon_{ODd}) \tag{16}$$

where ε_{OD} is a normally distributed error term with over-dispersion variance σ^2_{OD}.

Each daily DLMM estimate was modeled as having a lognormal distribution with median N_d and variances from Equation 12.

Parameters N, q, and σ^2_{OD} were estimated from the data. Model fitting was implemented in the Bayesian software program OpenBUGS (Lunn et al. 2009). After confirming that mixing and convergence were adequate, a single chain of 20,000 samples was used to approximate the posterior distribution of the model parameters. As with the results of other Bayesian analyses in this report, posterior means are reported as point estimates, and posterior standard deviations as

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[3] Perschbacher, J. *In prep*. Chinook salmon creel survey and inriver gillnetting study, Lower Kenai River, Alaska, 2014. Alaska Department of Fish and Game, Fishery Data Series, Anchorage.

standard errors. See Kery and Schaub (2012) for a description of similar models. OpenBUGS code for the daily abundance model is in Appendix G1.

RESULTS

Long-range high-resolution DIDSON units were deployed from both banks and sampled the midsection of the river for 88 days (16 May–11 August) in 2014. Salmon passage was successfully estimated in 99% of early-run and 98% of late-run samples.

SIZE DISTRIBUTION AND SPECIES COMPOSITION

Small fish predominated in both the early and late runs as evidenced by large left-hand modes in the DIDSON length (DL) frequency distributions (Figure 8, top panels). The modes of the DL distributions line up well with mid eye to tail fork (METF) length distributions from salmon measured by the inriver netting project (Figure 8, 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 in Figure 8 suggest that fish measuring greater than approximately 75 cm DL are probably Chinook salmon. Thus, from these data, "large Chinook salmon" can be defined as fish greater than or equal to 75 cm DL. 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 9). During the late run, large Chinook salmon continued to favor the left bank, but the relative number of small salmon on the right bank increased, especially during the rising tide (Figure 9). During both the early and late runs, most (79% and 71% respectively) 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 18%, 16%, 28%, and 39%, respectively in the early run and 15%, 16%, 33%, and 36%, 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 27%, 49%, and 24% on the rising, falling, and low tides, respectively during the early run to 43%, 38%, and 20%, respectively during the late run (Table 2, last column). During 16 May to 11 August, the natural distribution of tide stages was 33% rising, 41% falling, and 25% low. Comparing this to the tidal distribution of large salmon (Table 2) indicates that disproportionately large fractions of Chinook salmon migrated past the site during the falling tide in the early run, and during the rising tide in the late run.

The proportion of all upstream-bound salmon that were classified as large Chinook salmon ($\geq$75 cm DL) varied by run, bank, range stratum, and tide stage (Table 3). A smaller proportion of salmon were large Chinook salmon in the early run (2.2%) than in the late run (3.1%).

During the early run, the highest proportions of large fish occurred near shore in both left- and right-bank 3–8 m strata, but high proportions also occurred near river center in the 23–33 m strata (Table 3). During the late run, relatively more salmon were large Chinook salmon on the left bank (3.8%) than on the right bank (2.0%), with the lowest fraction (1.1%) occurring in the 8–13 m stratum on the right bank.

During the early run, the fraction of large Chinook salmon did not vary greatly by tide stage (2.0–2.4%; Table 3). During the late run, fish migrating during rising tide were composed of the highest fraction of large Chinook salmon (4.0%), followed by 3.1% during low tide and 2.4% during 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, 95.2% were upstream bound in the early run, and 96.0% 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 50% (23 May; 1 of 2 fish) to 100% (many days).

MIDRIVER SALMON PASSAGE

Daily DIDSON estimates of upstream salmon passage totaled 105,969 (SE 1,830) for the early run (Table 4) and 286,666 (SE 7,658) for 1–27 July of the late run (Table 5). After 27 July, when milling pink salmon became abundant and most small fish were not recorded, a full accounting of upstream salmon passage was not possible.

MIDRIVER CHINOOK SALMON PASSAGE

Daily proportions of upstream-bound salmon that were Chinook salmon were estimated using the DLMM (Appendices B1–B7). These proportions were multiplied by DIDSON estimates of upstream salmon passage to produce DIDSON estimates of upstream Chinook salmon passage: 4,862 (SE 338) Chinook salmon during the early run (16 May–30 June; Table 4) and 13,952 (SE 492) during the late run (1 July–15 August; Table 5). The latter number includes 102 (SE 57) fish expanded from inriver gillnet catches on 11–15 August when the DIDSON was not operating (see Daily DIDSON-equivalent estimates of Chinook salmon passage).

The DLMM also produced daily estimates of Chinook salmon age composition (Tables 6 and 7). These estimates incorporated length information from DIDSON as well 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.

MIDRIVER LARGE FISH PASSAGE

Daily "threshold" estimates of fish equal to 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 (total age from spawning event) Chinook salmon.

NET-APPORTIONED INDEX OF CHINOOK SALMON PASSAGE

Net-apportioned estimates of upstream Chinook salmon passage were 3,565 (SE 351) fish during the early run (Appendix F1) and 10,323 (SE 916) fish during 1–27 July of the late run (Appendix F2).

DISCUSSION

MIDRIVER CHINOOK SALMON PASSAGE

Estimates of midriver Chinook salmon passage presented here differ from preliminary estimates produced during the 2014 season for fisheries management. For the early run, the difference was large (the final estimate was 42% higher than the preliminary) due partly to methodological details that differ between preliminary and final estimates (Appendix B7), but also because the 2014 early run was composed of an anomalously large fraction of young fish. Preliminary estimates can rely heavily on "prior" historical age composition information when current data are sparse (Appendices B4 and B7). Because few fish were caught by the inriver netting project in May and June 2014, and because the age composition was very different than normal (much younger), the prior information received a great deal of weight and skewed the estimates away from what the (few) current data were saying.

In the past, historical average age composition has served as a good inseason proxy, and ultimately, preliminary and final DLMM estimates have differed by only a small amount (−3 to +14%; Appendix B7). For instance, the 2014 late run estimate was revised upward by 6%. Although it is not possible to produce final estimates inseason because of data availability and time constraints related to fishery management, in 2015 we will take measures to reduce the influence of prior historical information on the preliminary estimates. This should reduce the probability of having such a large revision to preliminary inseason estimates.

NET-APPORTIONED INDEX OF CHINOOK SALMON PASSAGE

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 estimated using the 2002–2011 versions of net-apportioned estimates based on split-beam sonar. Any comparison between 2014 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, comparisons of net-apportioned estimates from 2012 to 2014 versus 2002 to 2011 will be imperfect because in 2012–2014 the inriver netting program sampled the river corridor insonified by the DIDSON (Perschbacher 2014, 2015, *In prep*), rather than the corridor formerly insonified by the split-beam sonar.

COMPARISON OF DIDSON WITH OTHER DAILY INDICES OF CHINOOK SALMON PASSAGE

In 2014, daily values of inriver gillnetting CPUE, net-apportioned estimates, and sport fishery CPUE tracked DIDSON estimates of Chinook salmon passage with varying degrees of (visually compared but unmeasured) congruity (Figures 10, 11, and 12). 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.

EARLY RUN SONAR COMPARED TO WEIR COUNTS ON UPRIVER TRIBUTARIES

During the 2013 early run, the expanded DLMM estimate of Chinook salmon passage was less than weir counts at Funny and Killey tributaries, when it should have been significantly greater (Key et al. 2016). The shortfall was due almost entirely to small Chinook salmon migrating behind the transducers at RM 8.6. This explanation is consistent with the results of 2013 experimental netting (Perschbacher 2015).

During the 2014 early run, there was no such shortfall at the RM 8.6 sonar. The expanded estimate of Chinook salmon passing RM 8.6 (7,536; Table 4 sum multiplied by 1/0.65 = 1.55; Fleischman and McKinley 2013; McKinley and Fleischman 2013) was more than double the total of 3,021 (<74 cm METF length) Chinook salmon passing the Funny and Killey river weirs (derived from data reported by Gates and Boersma 2014b; Gates and Boersma 2014a). During both early and late runs, relatively few Chinook salmon were netted near shore in 2014, and they were similar in size to those migrating in midriver (Perschbacher *In prep*). Apparently, early-run migratory behavior of Chinook salmon at RM 8.6 of the Kenai River can differ greatly from one year to the next.

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TABLES

Table 1.–Components of the DIDSON sonar system used in 2014.

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 2014 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	4	5	7	6	21	0	1	2	3	6	27
	Falling	5	7	11	16	39	2	0	2	6	10	49
	Low	6	2	5	6	19	1	0	1	3	5	24
	All stages	14	14	23	27	79	4	1	5	12	21	100
Late												
	Rising	4	5	11	9	29	1	2	4	6	13	43
	Falling	4	5	9	9	26	2	1	4	5	12	38
	Low	3	3	6	4	16	1	1	1	2	4	20
	All stages	11	13	25	23	71	3	4	9	13	29	100

Note: Columns may not sum due to rounding.

Table 3.–Percentage of all upstream-bound salmon that were classified as large Chinook salmon (DIDSON length ≥75 cm) by riverbank, range stratum (distance from transducer), and tide stage for the 2014 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	2.5	2.8	2.0	2.7	2.5	2.1	2.1	1.9	2.4	2.1	2.4
	Falling	2.0	1.8	1.6	2.8	2.0	3.0	0.4	1.2	2.7	2.0	2.0
	Low	4.4	1.3	1.8	2.5	2.3	5.4	1.2	2.0	2.9	2.7	2.4
	All stages	2.8	1.9	1.8	2.7	2.2	3.2	1.0	1.6	2.6	2.2	2.2
Late												
	Rising	3.1	4.2	5.7	4.8	4.6	1.7	2.2	3.2	4.3	3.0	4.0
	Falling	2.3	2.8	3.2	3.8	3.1	1.5	0.5	1.6	2.0	1.4	2.4
	Low	3.6	3.5	4.3	3.5	3.8	1.4	0.7	1.4	2.7	1.6	3.1
	All stages	2.9	3.4	4.3	4.1	3.8	1.5	1.1	2.1	2.9	2.0	3.1

Note: Columns may not sum due to rounding.

Table 4.–DIDSON-based estimates (without spatial expansion) of upstream midriver 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, 2014.

	DIDSON upstream salmon		DLMM Chinook salmon		DLMM Chinook salmon		
Date	Passage	SE	Proportion	SE	Passage	SE	CV
16 May	6	5	0.538	0.294	3	3	
17 May	12	7	0.380	0.281	5	4	0.76
18 May	12	7	0.069	0.165	1	2	1.68
19 May	36	16	0.368	0.252	13	10	0.77
20 May	66	16	0.361	0.233	24	16	0.67
21 May	84	23	0.345	0.261	29	23	0.78
22 May	54	15	0.137	0.229	7	12	1.72
23 May	163	26	0.106	0.112	17	18	1.07
24 May	223	31	0.014	0.034	3	7	2.47
25 May	356	45	0.078	0.074	28	27	0.95
26 May	766	66	0.073	0.052	56	40	0.71
27 May	1,321	123	0.075	0.055	99	73	0.73
28 May	911	86	0.024	0.018	22	16	0.75
29 May	941	122	0.030	0.023	28	22	0.78
30 May	995	129	0.073	0.036	73	37	0.50
31 May	1,176	126	0.054	0.033	64	39	0.61
1 Jun	1,158	103	0.041	0.025	47	29	0.62
2 Jun	3,443	279	0.009	0.007	32	24	0.75
3 Jun	7,068	743	0.036	0.013	258	92	0.36
4 Jun	7,418	424	0.046	0.011	341	84	0.25
5 Jun	9,000	967	0.028	0.008	253	77	0.30
6 Jun	4,939	300	0.054	0.013	267	64	0.24
7 Jun	3,124	224	0.020	0.011	63	34	0.55
8 Jun	3,154	228	0.029	0.012	91	39	0.43
9 Jun	3,202	248	0.082	0.021	262	70	0.27
10 Jun	1,990	163	0.048	0.019	96	38	0.39
11 Jun	2,346	247	0.084	0.023	196	58	0.30
12 Jun	2,267	194	0.127	0.032	287	75	0.26
13 Jun	1,073	123	0.113	0.037	121	42	0.35
14 Jun	754	85	0.071	0.038	54	29	0.54
15 Jun	1,459	138	0.061	0.023	89	35	0.39
16 Jun	1,031	99	0.098	0.039	101	42	0.41
17 Jun	1,188	110	0.141	0.051	167	62	0.37
18 Jun	1,785	153	0.122	0.044	218	80	0.37
19 Jun	2,949	171	0.030	0.015	87	43	0.49

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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
20 Jun	2,756	232	0.068	0.022	188	63	0.34
21 Jun	2,460	411	0.061	0.029	149	74	0.50
22 Jun	2,894	192	0.036	0.019	103	56	0.54
23 Jun	3,063	326	0.051	0.024	155	76	0.49
24 Jun	2,454	202	0.043	0.020	106	49	0.46
25 Jun	3,690	225	0.032	0.013	118	50	0.42
26 Jun	6,040	457	0.023	0.011	139	65	0.47
27 Jun	3,998	277	0.020	0.014	82	55	0.67
28 Jun	3,479	214	0.018	0.011	63	40	0.63
29 Jun	2,826	215	0.027	0.015	77	43	0.56
30 Jun	5,839	428	0.031	0.011	180	67	0.37
Total	105,969	1,830			4,862	338	0.07

Table 5.–DIDSON-based estimates (without spatial expansion) 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, 2014.

	DIDSON upstream salmon		DLMM Chinook salmon		DLMM Chinook salmon		
Date	Passage	SE	Proportion	SE	Passage	SE	CV
1 Jul	4,866	292	0.036	0.018	175	87	0.49
2 Jul	6,767	387	0.026	0.012	174	79	0.45
3 Jul	7,708	858	0.024	0.008	184	65	0.35
4 Jul	5,540	501	0.014	0.006	79	36	0.45
5 Jul	9,997	738	0.024	0.006	237	61	0.26
6 Jul	11,390	915	0.031	0.008	350	95	0.27
7 Jul	7,230	613	0.056	0.013	406	97	0.24
8 Jul	5,389	455	0.049	0.016	264	86	0.33
9 Jul	8,200	840	0.029	0.009	234	74	0.31
10 Jul	5,243	310	0.037	0.013	193	68	0.35
11 Jul	7,352	463	0.030	0.009	217	68	0.32
12 Jul	7,710	641	0.027	0.009	206	73	0.36
13 Jul	9,277	888	0.025	0.007	230	68	0.30
14 Jul	9,495	835	0.014	0.004	131	43	0.33
15 Jul	8,537	927	0.016	0.004	140	37	0.27
16 Jul	5,576	597	0.033	0.008	184	49	0.26
17 Jul	12,168	1,319	0.033	0.006	407	80	0.20
18 Jul	9,869	1,361	0.047	0.007	464	92	0.20
19 Jul	15,652	1,983	0.044	0.006	693	126	0.18
20 Jul	13,848	1,806	0.060	0.007	832	145	0.17
21 Jul	9,044	1,444	0.036	0.007	323	79	0.24
22 Jul	12,843	711	0.031	0.005	397	71	0.18
23 Jul	10,188	1,452	0.056	0.008	575	116	0.20
24 Jul	16,099	1,750	0.045	0.007	731	132	0.18
25 Jul	21,026	2,317	0.035	0.005	744	130	0.17
26 Jul	23,758	2,747	0.017	0.003	412	80	0.19
27 Jul	21,894	4,457	0.009	0.002	208	61	0.29
28 Jul					478	76	0.16
29 Jul					673	85	0.13
30 Jul					523	69	0.13
31 Jul					666	73	0.11

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Table 5.–Page 2 of 2.

	DIDSON upstream salmon		DLMM Chinook salmon		DLMM Chinook salmon		
Date	Passage	SE	Proportion	SE	Passage	SE	CV
1 Aug					525	64	0.12
2 Aug					428	56	0.13
3 Aug					241	40	0.17
4 Aug					222	37	0.17
5 Aug					280	43	0.15
6 Aug					127	29	0.23
7 Aug					158	32	0.20
8 Aug					111	28	0.25
9 Aug					105	27	0.25
10 Aug					59	21	0.36
11 Aug					55	21	0.38
12 Aug					14	20	1.43
13 Aug					11	17	1.55
14 Aug					30	29	0.97
15 Aug					56	39	0.70
Total	286,666	7,658			13,952	492	0.04

Note: All estimates are of upstream-bound fish in midriver between and at least 3 m from the transducer. "Fast Track" sampling protocol began 8 July. "All Large Fish" sampling protocol began 28 July (estimates of upstream salmon passage were not available). Sonar operations ended on 11 August. DLMM Chinook salmon passage estimates for 12–15 August were expanded from netting catch rates (Appendix F1).

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, 2014.

	Ages 3 and 4		Age 5		Ages 6 and 7	
Date	Proportion	SE	Proportion	SE	Proportion	SE
16 May	0.26	0.26	0.37	0.27	0.37	0.24
17 May	0.30	0.28	0.45	0.30	0.25	0.23
18 May	0.45	0.35	0.39	0.32	0.16	0.20
19 May	0.30	0.27	0.40	0.30	0.30	0.25
20 May	0.33	0.27	0.39	0.28	0.29	0.22
21 May	0.60	0.26	0.28	0.24	0.12	0.14
22 May	0.80	0.23	0.11	0.16	0.10	0.16
23 May	0.67	0.26	0.21	0.22	0.13	0.17
24 May	0.53	0.25	0.13	0.16	0.34	0.23
25 May	0.54	0.25	0.13	0.16	0.33	0.22
26 May	0.48	0.24	0.30	0.22	0.23	0.19
27 May	0.73	0.23	0.11	0.15	0.16	0.15
28 May	0.31	0.19	0.46	0.22	0.23	0.18
29 May	0.44	0.19	0.32	0.19	0.24	0.15
30 May	0.47	0.16	0.25	0.14	0.28	0.12
31 May	0.60	0.15	0.38	0.15	0.03	0.04
1 Jun	0.62	0.13	0.34	0.13	0.03	0.04
2 Jun	0.56	0.13	0.39	0.13	0.05	0.05
3 Jun	0.59	0.12	0.34	0.11	0.06	0.04
4 Jun	0.51	0.11	0.44	0.10	0.05	0.03
5 Jun	0.53	0.11	0.41	0.11	0.06	0.05
6 Jun	0.53	0.09	0.39	0.09	0.08	0.04
7 Jun	0.58	0.10	0.34	0.09	0.08	0.05
8 Jun	0.54	0.09	0.37	0.09	0.09	0.05
9 Jun	0.55	0.08	0.41	0.09	0.03	0.03
10 Jun	0.52	0.09	0.45	0.09	0.03	0.03
11 Jun	0.51	0.09	0.45	0.09	0.04	0.03
12 Jun	0.51	0.08	0.46	0.08	0.03	0.03
13 Jun	0.47	0.09	0.51	0.09	0.02	0.03
14 Jun	0.42	0.11	0.54	0.11	0.04	0.05
15 Jun	0.37	0.12	0.55	0.13	0.08	0.08
16 Jun	0.39	0.14	0.53	0.14	0.09	0.06
17 Jun	0.60	0.10	0.35	0.10	0.05	0.04
18 Jun	0.64	0.10	0.33	0.10	0.03	0.03
19 Jun	0.64	0.10	0.30	0.10	0.06	0.05
20 Jun	0.63	0.09	0.27	0.09	0.09	0.05

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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	0.67	0.11	0.22	0.12	0.11	0.07
22 Jun	0.65	0.11	0.28	0.11	0.06	0.05
23 Jun	0.63	0.11	0.32	0.1	0.05	0.04
24 Jun	0.59	0.1	0.34	0.1	0.07	0.05
25 Jun	0.6	0.1	0.34	0.1	0.06	0.04
26 Jun	0.7	0.09	0.2	0.09	0.1	0.07
27 Jun	0.73	0.09	0.24	0.09	0.02	0.03
28 Jun	0.71	0.09	0.27	0.09	0.02	0.03
29 Jun	0.7	0.09	0.24	0.09	0.06	0.04
30 Jun	0.68	0.1	0.22	0.09	0.1	0.05
Weighted mean	0.57		0.36		0.07	

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, 2014.

	Ages 3 and 4		Age 5		Ages 6 and 7	
Date	Proportion	SE	Proportion	SE	Proportion	SE
1 Jul	0.71	0.11	0.20	0.11	0.09	0.05
2 Jul	0.67	0.12	0.26	0.12	0.07	0.04
3 Jul	0.59	0.11	0.30	0.10	0.11	0.05
4 Jul	0.55	0.09	0.28	0.10	0.17	0.07
5 Jul	0.53	0.09	0.30	0.08	0.17	0.06
6 Jul	0.66	0.09	0.18	0.08	0.17	0.05
7 Jul	0.65	0.08	0.20	0.08	0.15	0.05
8 Jul	0.68	0.08	0.22	0.08	0.10	0.05
9 Jul	0.63	0.07	0.24	0.08	0.13	0.06
10 Jul	0.61	0.09	0.28	0.09	0.10	0.05
11 Jul	0.59	0.08	0.28	0.11	0.12	0.09
12 Jul	0.60	0.09	0.35	0.10	0.05	0.06
13 Jul	0.48	0.09	0.31	0.09	0.21	0.08
14 Jul	0.35	0.09	0.50	0.10	0.16	0.08
15 Jul	0.33	0.09	0.46	0.09	0.21	0.07
16 Jul	0.32	0.09	0.47	0.09	0.21	0.08
17 Jul	0.28	0.07	0.52	0.08	0.20	0.06
18 Jul	0.26	0.07	0.57	0.08	0.17	0.06
19 Jul	0.28	0.06	0.52	0.08	0.20	0.07
20 Jul	0.29	0.06	0.49	0.08	0.22	0.07
21 Jul	0.30	0.07	0.42	0.08	0.29	0.07
22 Jul	0.27	0.07	0.42	0.08	0.31	0.08
23 Jul	0.25	0.07	0.47	0.07	0.28	0.06
24 Jul	0.25	0.08	0.48	0.08	0.27	0.06
25 Jul	0.28	0.07	0.37	0.09	0.35	0.10
26 Jul	0.20	0.08	0.48	0.09	0.32	0.10
27 Jul	0.18	0.08	0.46	0.09	0.37	0.10
28 Jul	0.24	0.07	0.42	0.10	0.34	0.10
29 Jul	0.22	0.06	0.47	0.09	0.31	0.09
30 Jul	0.17	0.06	0.37	0.10	0.46	0.11
31 Jul	0.12	0.06	0.43	0.07	0.45	0.08

-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	0.14	0.05	0.50	0.11	0.35	0.11
2 Aug	0.08	0.05	0.47	0.10	0.45	0.10
3 Aug	0.06	0.04	0.50	0.13	0.45	0.13
4 Aug	0.02	0.03	0.39	0.11	0.59	0.11
5 Aug	0.03	0.04	0.38	0.11	0.59	0.12
6 Aug	0.03	0.04	0.26	0.16	0.72	0.16
7 Aug	0.03	0.04	0.44	0.31	0.53	0.31
8 Aug	0.03	0.04	0.25	0.14	0.71	0.14
9 Aug	0.04	0.05	0.28	0.17	0.68	0.17
10 Aug	0.05	0.07	0.45	0.17	0.50	0.17
11 Aug	0.06	0.07	0.13	0.13	0.82	0.14
Weighted mean	0.29		0.41		0.29	

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

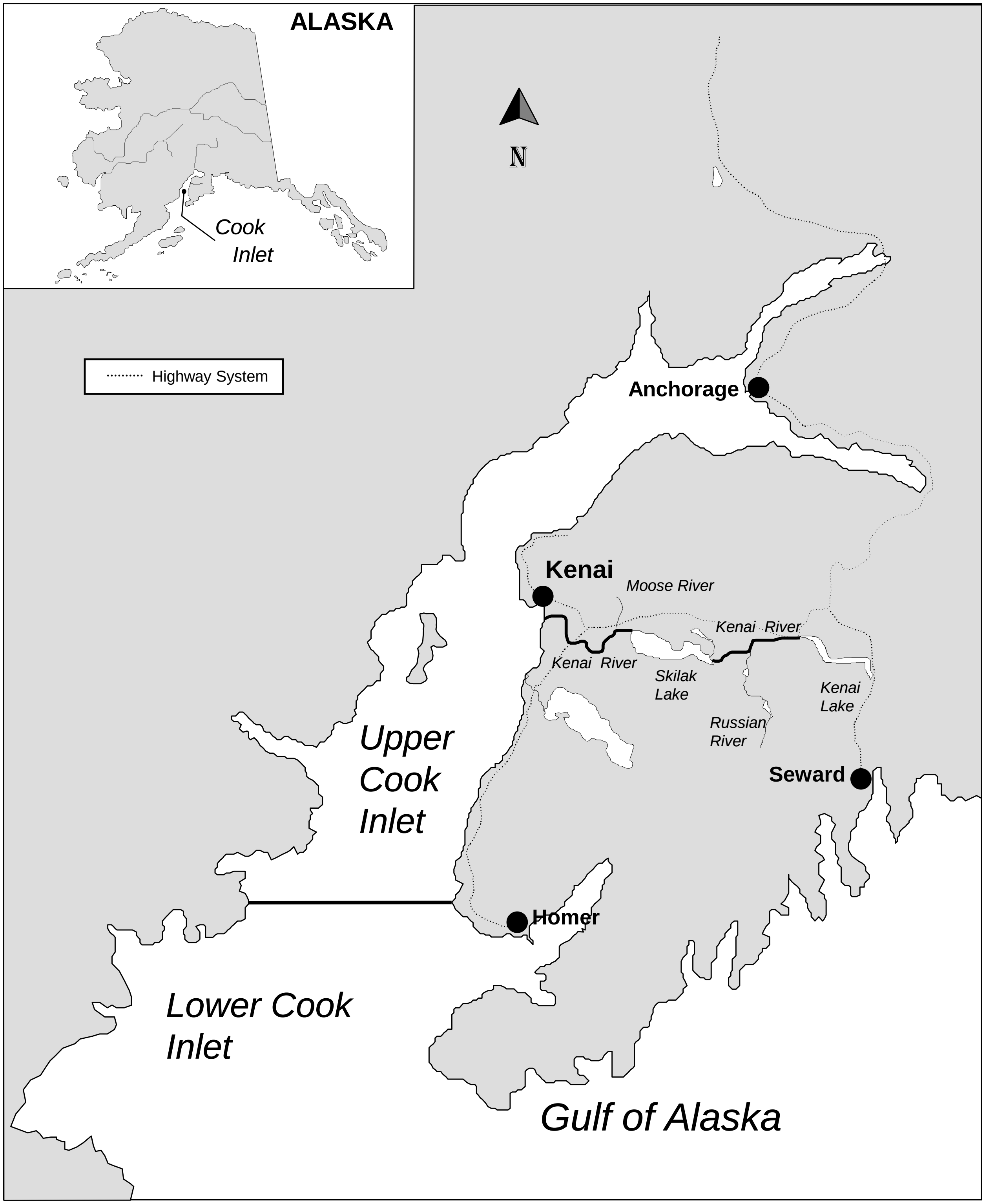


Figure 1.–Cook Inlet showing location of Kenai River.

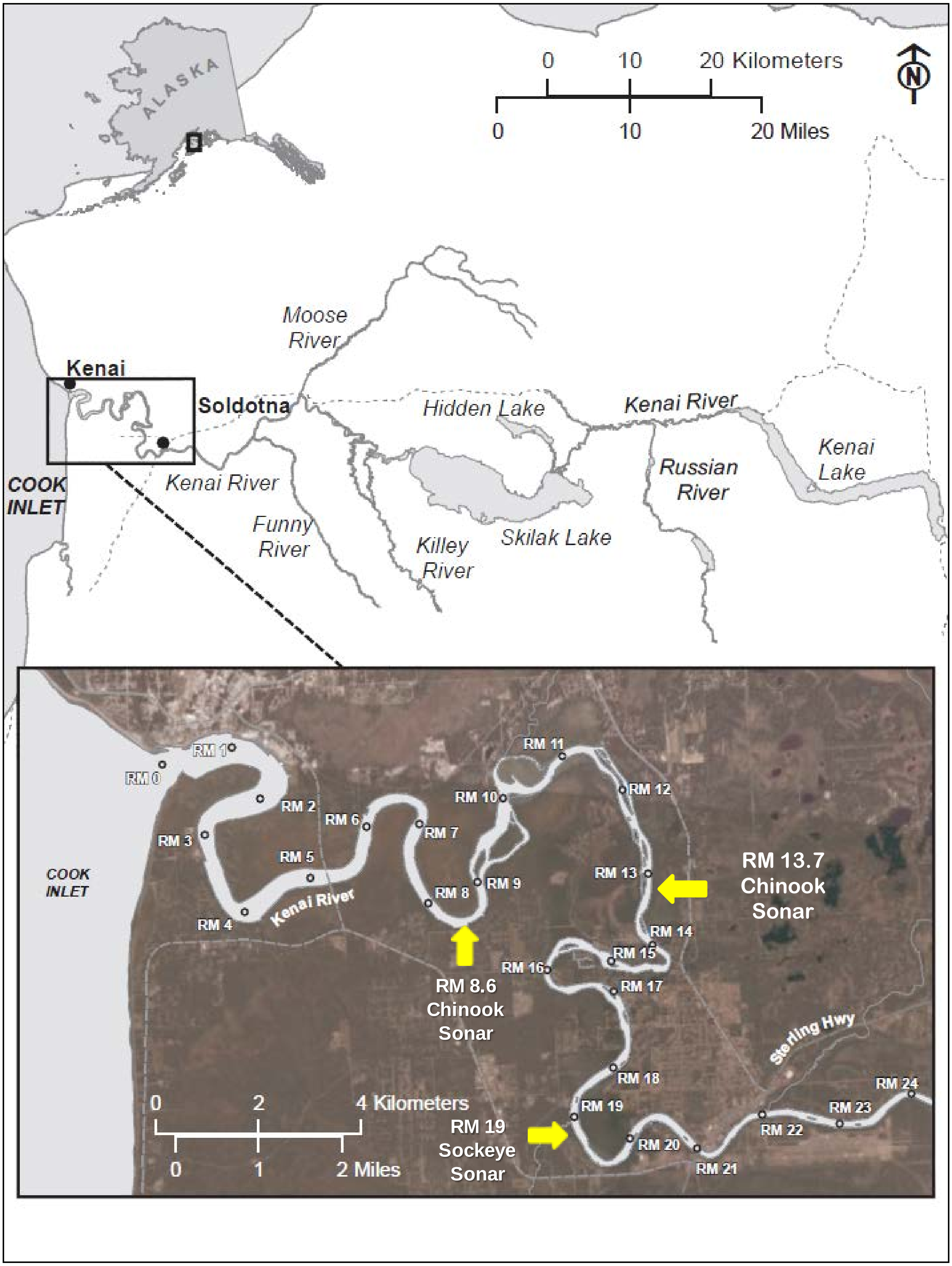


Figure 2.–Kenai River sonar site locations, 2014; this report documents findings from the RM 8.6 site.

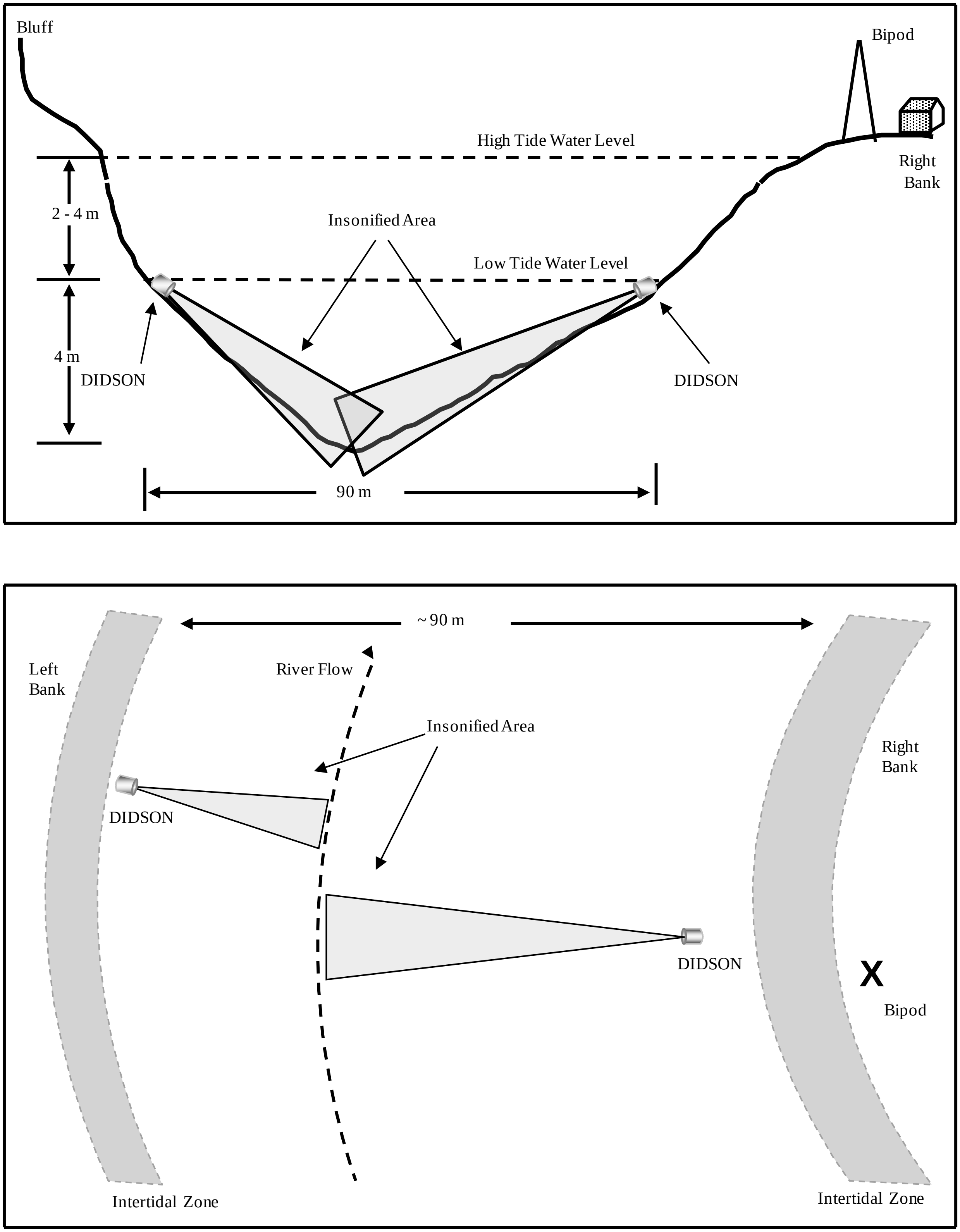


Figure 3.–Cross-sectional (top) and aerial (bottom) diagrams of sonar site illustrating insonified portions of RM 8.6 of the Kenai River, 2014.

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

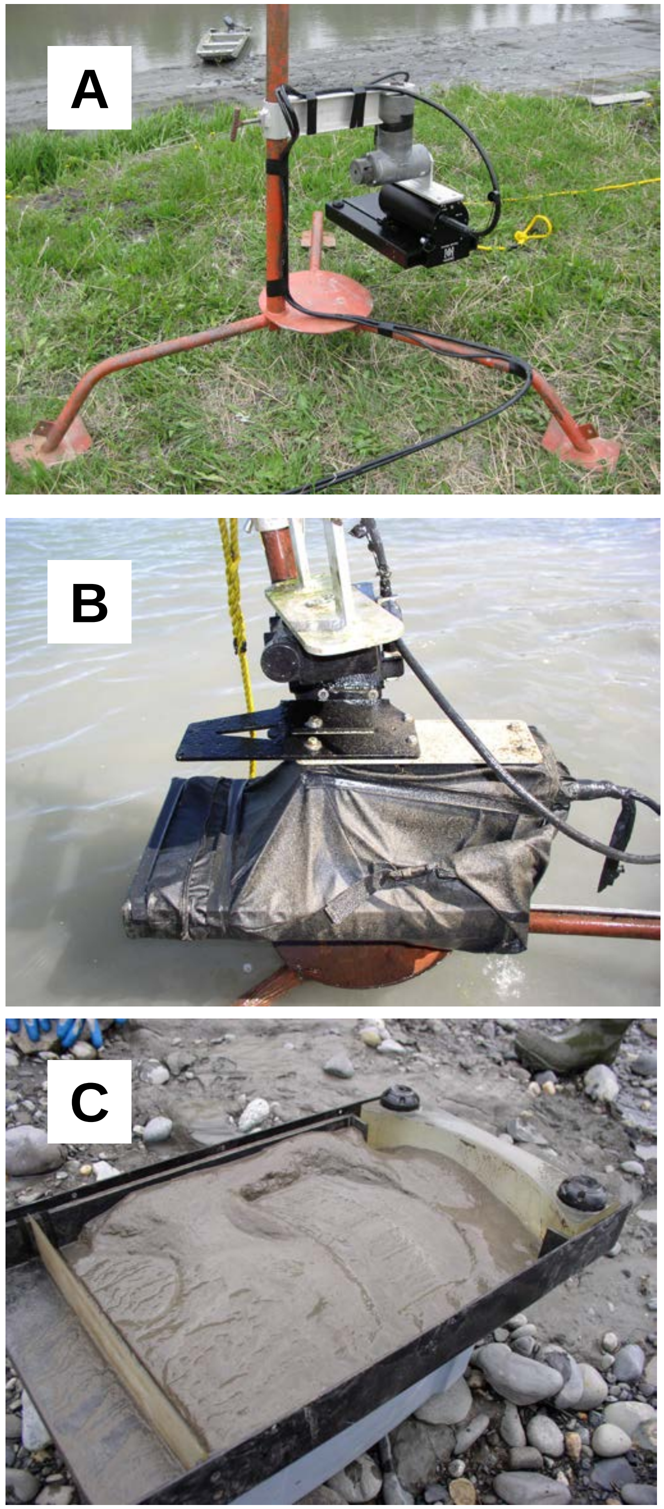


Figure 4.–A DIDSON-LR with a high-resolution lens is mounted on a steel tripod (photo A, top) and fitted with a custom fabric enclosure (photo B, middle), which protects against silt buildup in front of the lens (photo C, bottom).

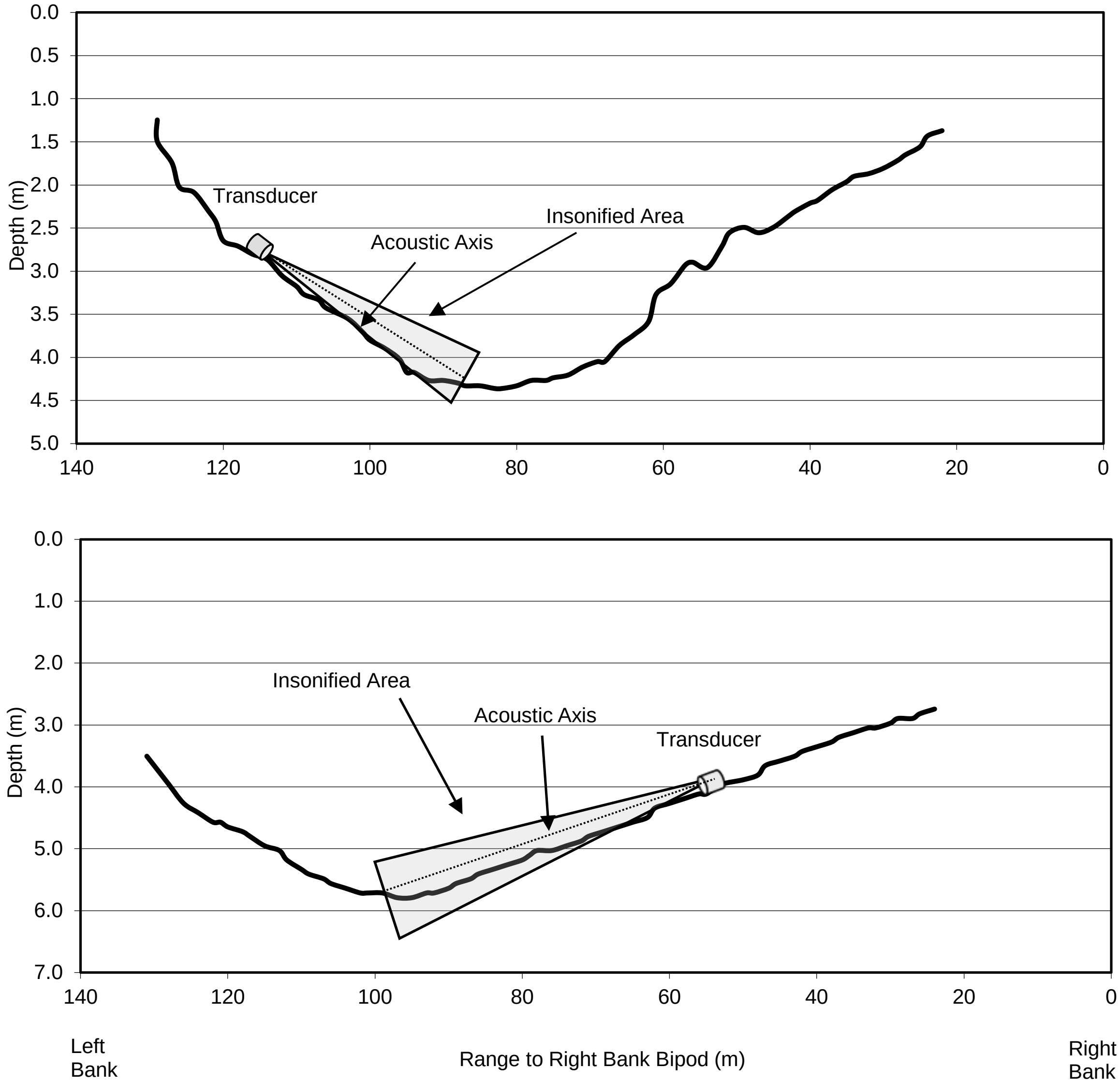


Figure 5.–Bottom profiles for the left-bank transducer (top) and right-bank transducer (bottom) at the Kenai River Chinook salmon sonar site with approximate transducer placement and sonar beam coverage for 16 May 2014.

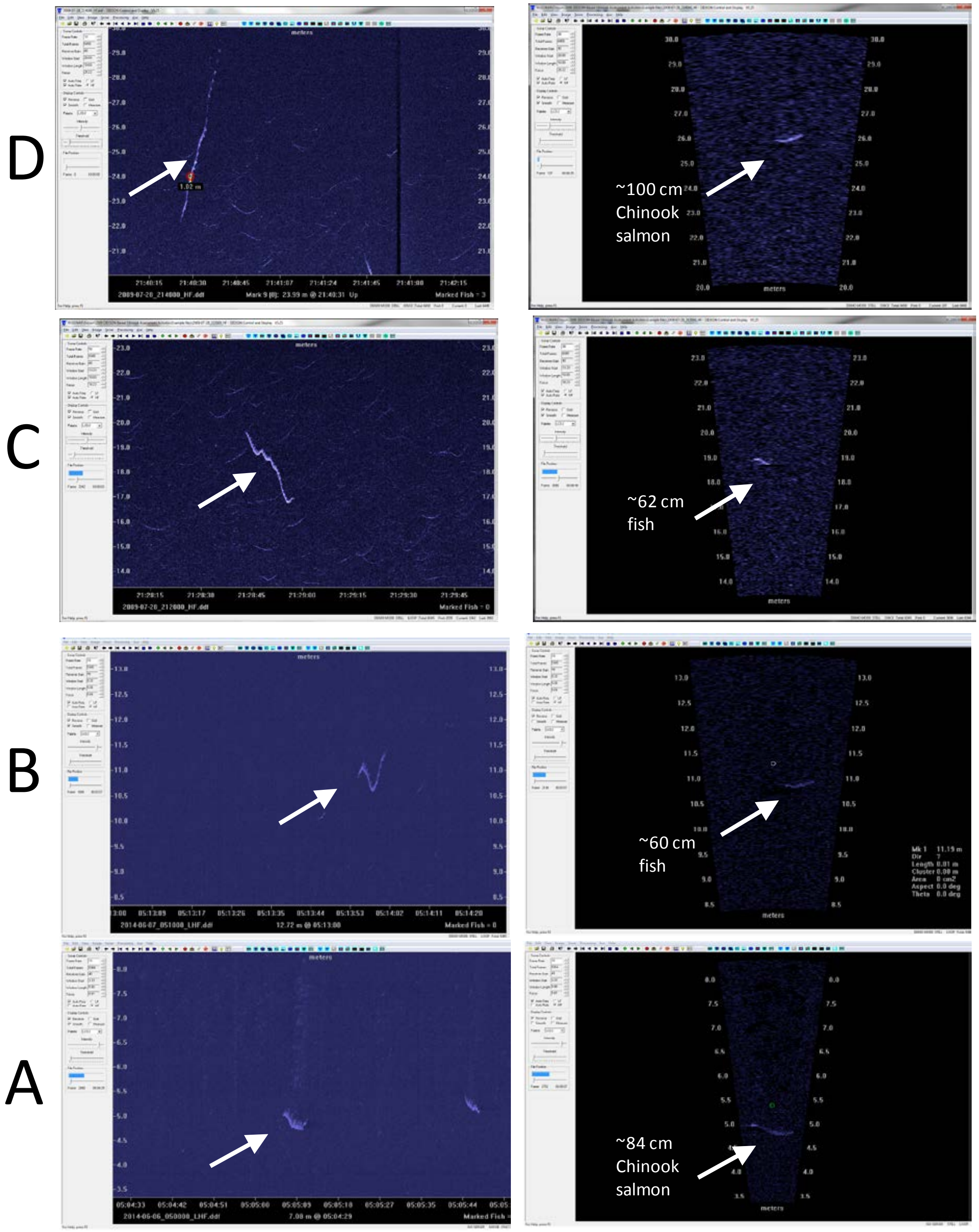


Figure 6.–Example fish traces with their measured sizes are shown on DIDSON echogram (at left) and video (at right) displays for each of the 4 range strata: 3.3–8.3 m (panel A), 8.3–13.3 m (panel B), 13.3–23.3 m (panel C), and 23.3–33.3 m (panel D).

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

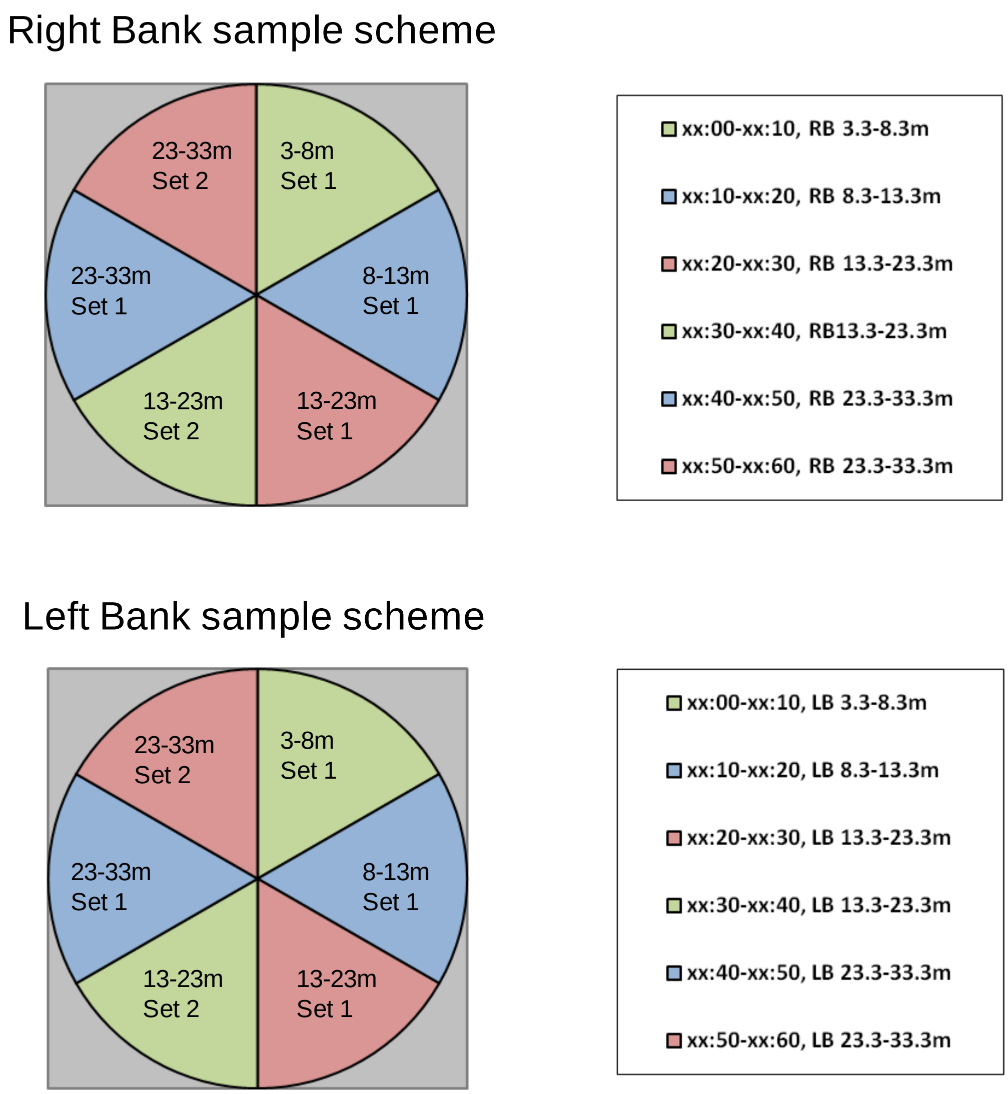


Figure 7.–Right-bank (top) and left-bank (bottom) range strata sampling schedules for 2014.

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

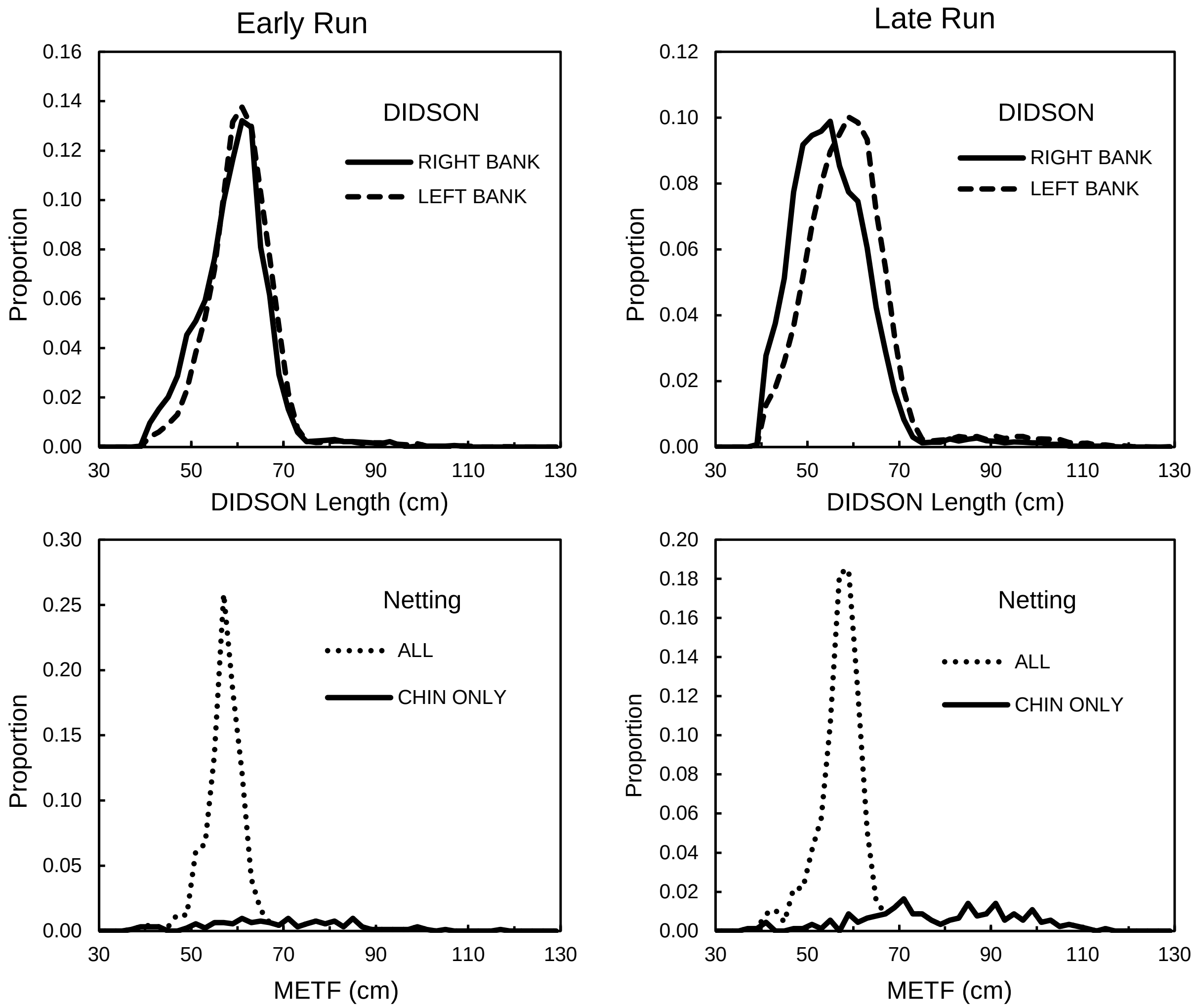


Figure 8.–Frequency distributions of fish length as measured by the DIDSON (top, by bank) and mid eye to tail fork (METF) measurements from an onsite netting project (bottom, all species vs. Chinook salmon only), Kenai River RM 8.6, early and late runs, 2014.

Note: Data were not filtered by direction of travel.

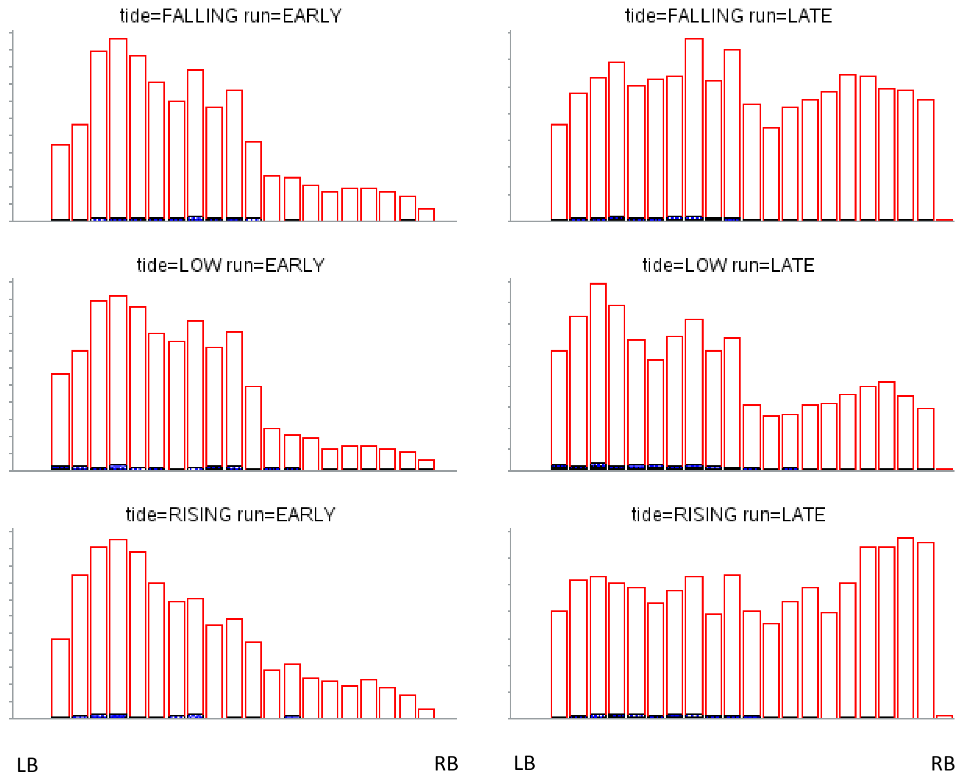


Figure 9.–Relative frequency distributions of horizontal (cross-river) position of upstream-bound fish by tide stage and DIDSON length class (black solid: ≥90 cm; blue hatched: 75–90 cm; red open: <75 cm), Kenai River RM 8.6, early and late runs, 2014.

Note: Vertical axis shows percent relative frequency (all columns sum to 1 for each graph) by run and tide stage. Approximately 60 meters separates the left-bank (LB) and right-bank (RB) transducers. For late run, only data from 1–27 July are plotted.

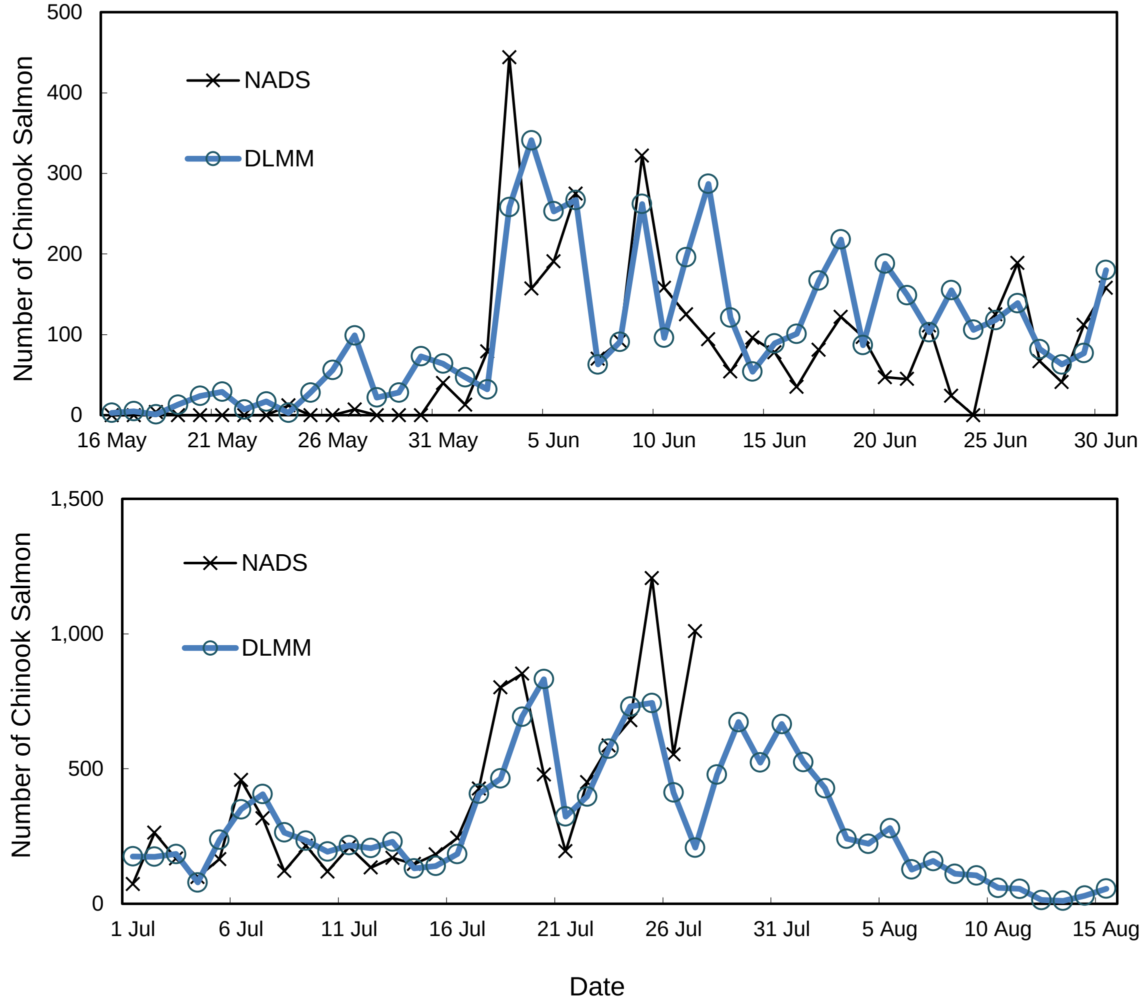


Figure 10.–Estimated upstream-bound fish passage based on net-apportioned DIDSON (NADS), and DIDSON-length mixture model (DLMM), for early- (top) and late-run (bottom) Kenai River Chinook salmon, 2014.

Note: Counts of targets less than 75 cm were not recorded starting 28 July.

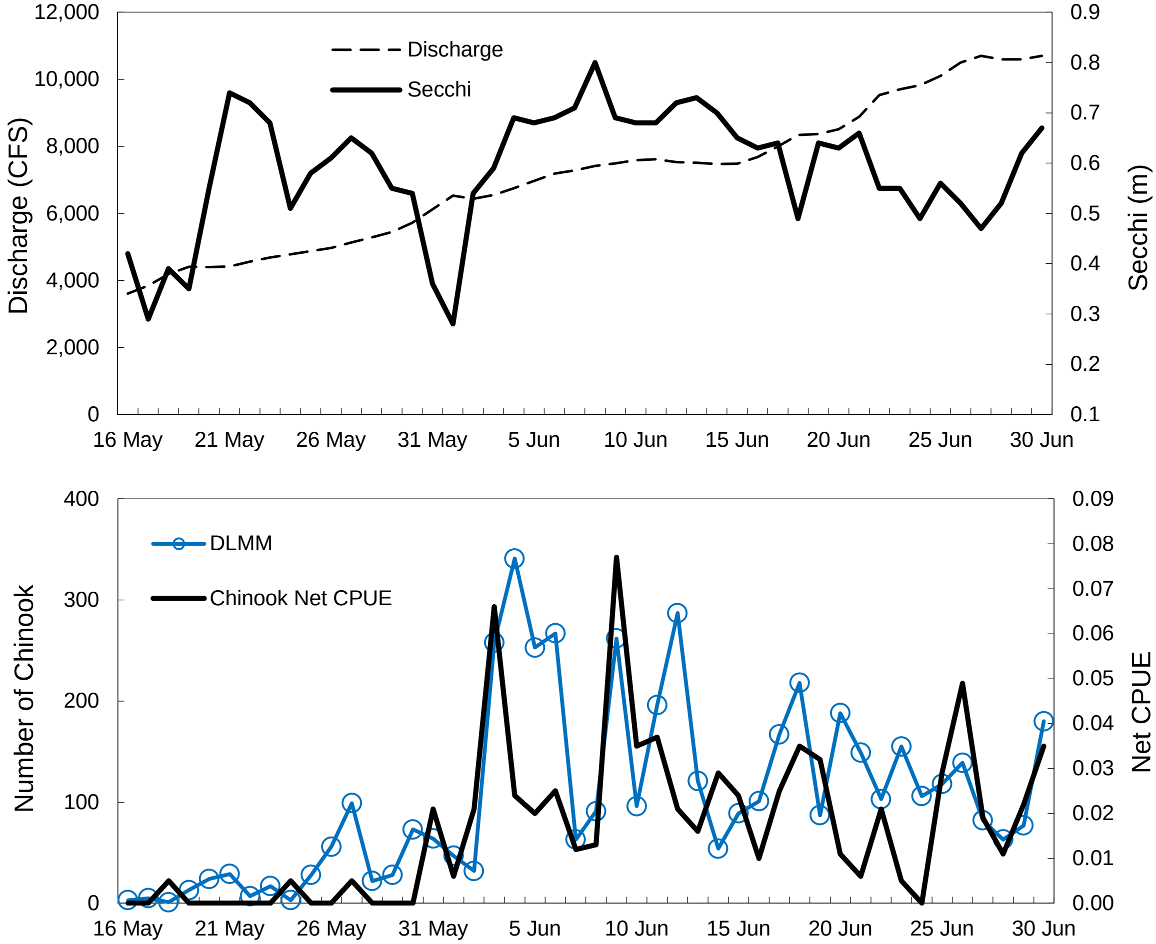


Figure 11.–Daily discharge rates collected at the Soldotna Bridge, Secchi disk readings taken at the RM 8.6 sonar site (top), and DIDSON-length mixture model (DLMM) estimates of Chinook salmon passage (bottom), early run Kenai River, 2014.

Source: River discharge from USGS[4]. Net CPUE from Perschbacher (*In prep*).
Note: The sport fishery closed for the early run.

[4] USGS Water resource data, Alaska, water year 2014. Website Daily Streamflow for Alaska, Soldotna gauging station, site #15266300, accessed June 25, 2015. http://water.usgs.gov/ak/nwis/discharge.

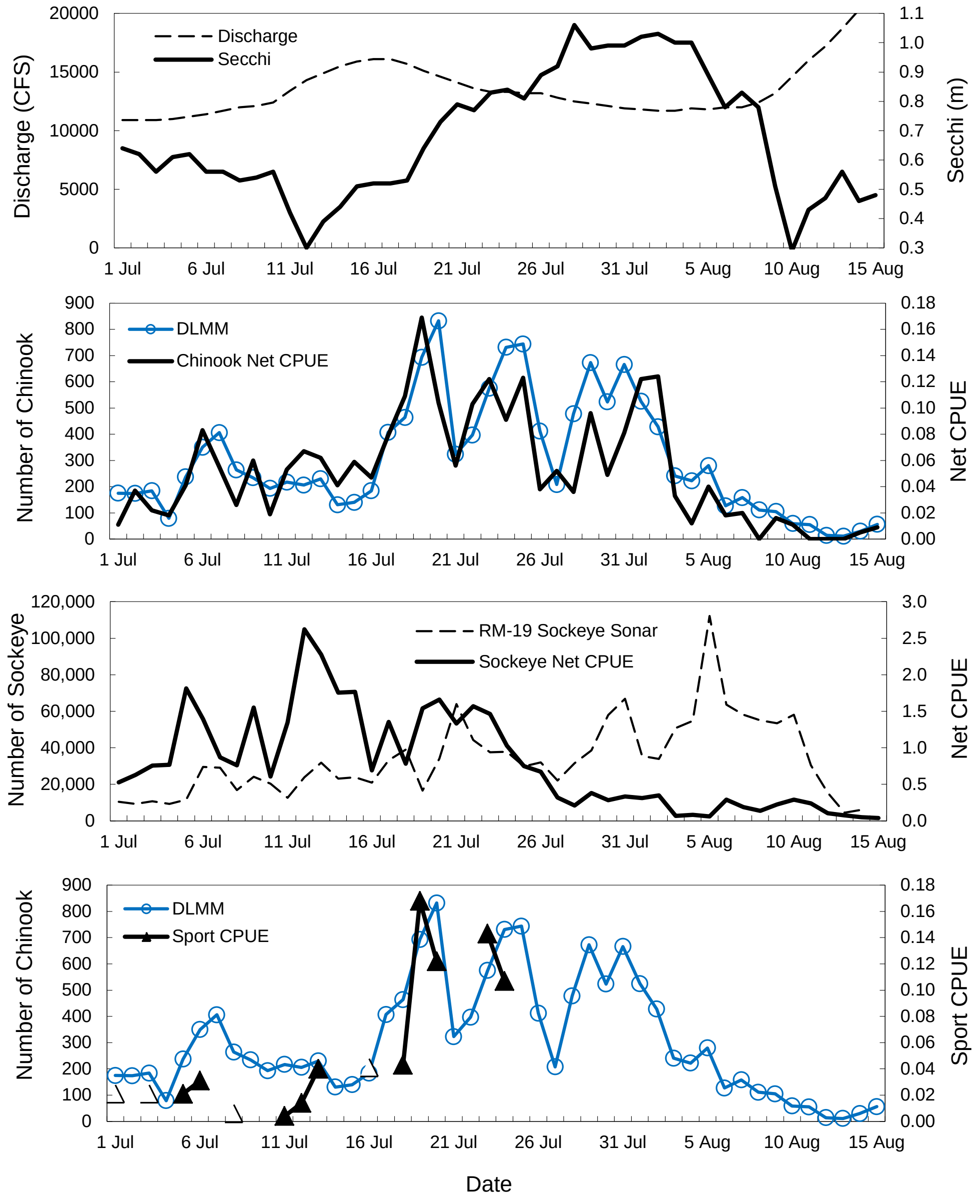


Figure 12.–Daily discharge rates collected at the Soldotna Bridge and Secchi disk readings taken at the RM 8.6 sonar site (top), DIDSON-length mixture model (DLMM) estimates of Chinook salmon passage and inriver gillnet Chinook salmon CPUE (top middle), RM 19 sockeye salmon sonar passage and inriver gillnet sockeye salmon CPUE (bottom middle), and DLMM estimates compared to Chinook salmon sport fishery CPUE (bottom), Kenai River, late run, 2014.

Note: River discharge taken from USGS[5]. Net CPUE and sport fish CPUE taken from Perschbacher (*In prep.*). RM 19 sonar estimates are preliminary (Bill Glick, Commercial Fish Biologist, ADF&G, Soldotna, personal communication). Open triangles represent days on which only unguided anglers were allowed to fish. RM 19 sonar from Glick and Willete (*In prep*). The sport fishery closed after 25 July.

[5] USGS Water resource data, Alaska, water year 2013. Website Daily Streamflow for Alaska, Soldotna gauging station, site #15266300, accessed June 23, 2015. http://water.usgs.gov/ak/nwis/discharge.

APPENDIX A: DIDSON CONFIGURATION FOR KENAI RIVER CHINOOK SONAR STUDY, 2014

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 A2 and A3). 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).

-continued-

Resolution

The resolution of a DIDSON image is defined in terms of downrange 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 downrange 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 downrange 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 2 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 2 subsequent range strata, a compromise that allowed a relatively high resolution while allowing a reasonable distance to be covered by each stratum. The downrange resolution (or pixel height) for a 5 m range window is 1 cm (500 cm/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:

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

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 10 m that started at 15 m, the focus range would be 15 m + [10 m/2] = 20 m).

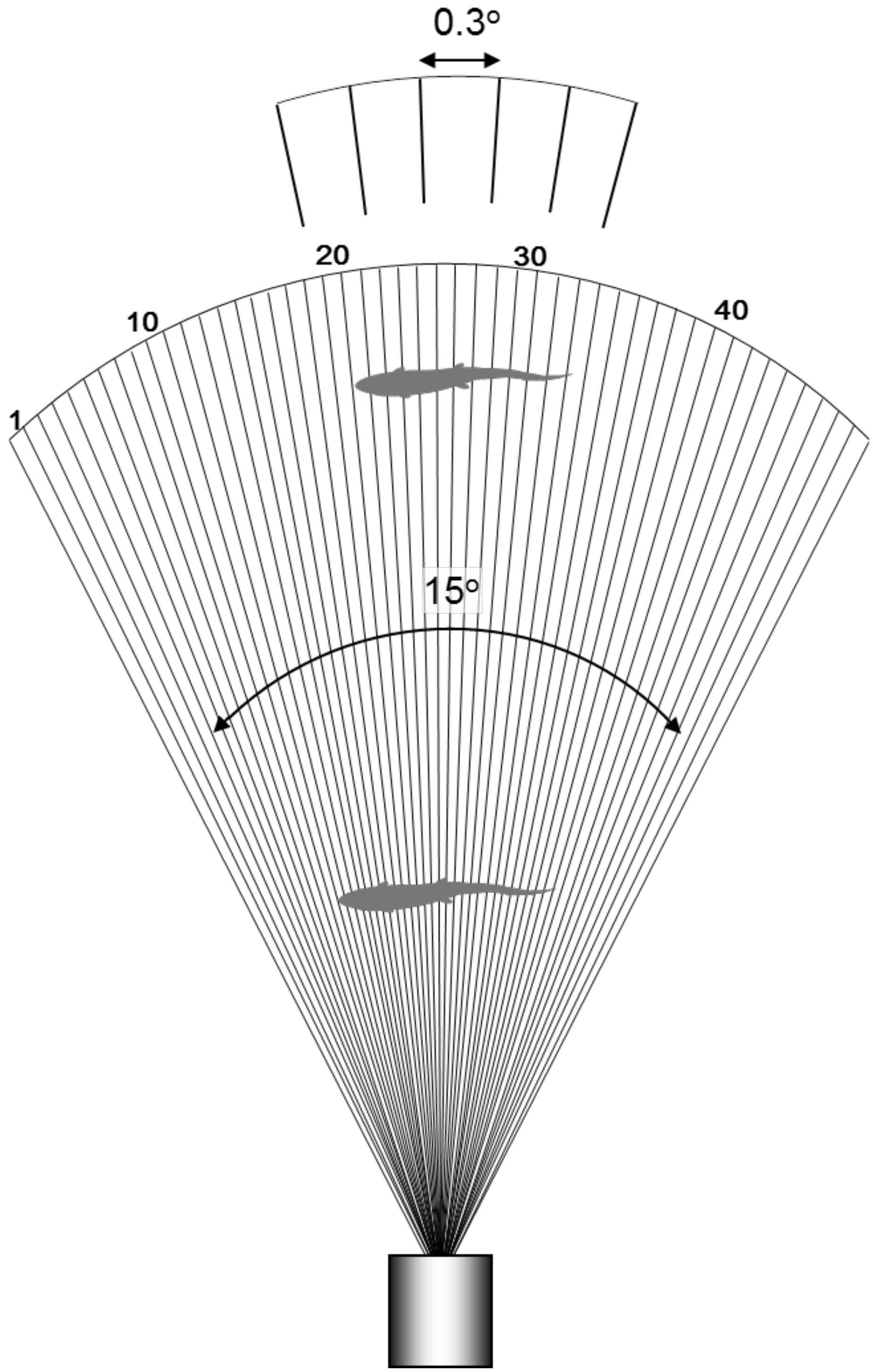
Appendix A2.–Summary of manufacturer specifications for maximum range, individual beam dimensions, and spacing for a DIDSON-S and a DIDSON-LR with (HRL) and without the addition of a high resolution lens (specifications from Sound Metrics Corporation).

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.

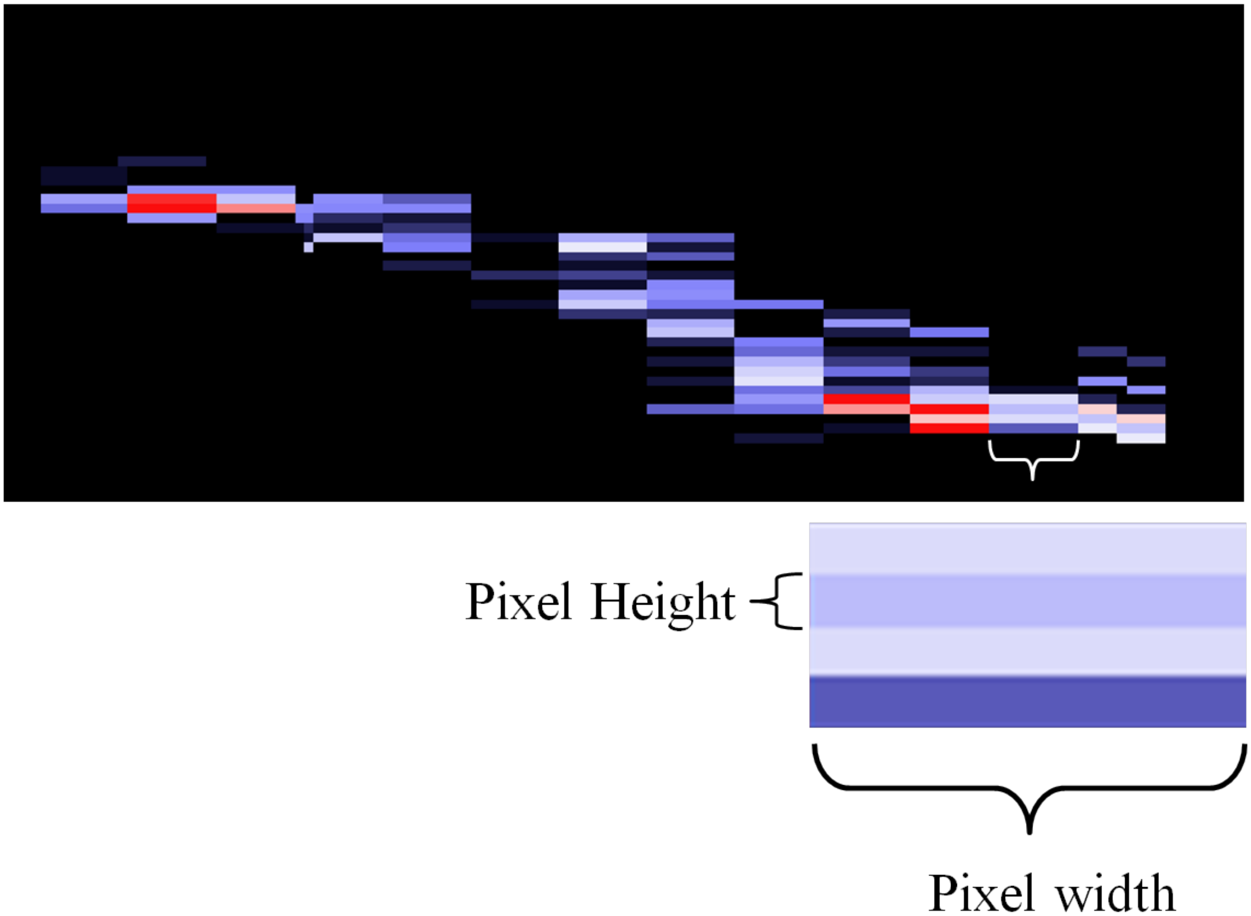
[c] Values for beam spacing and beam width are approximate. Beam widths are slightly wider near the edges of the beam and the beam spacing is slightly narrower. Conversely, beams are slightly narrower near the center of the beam, and the beam spacing is slightly wider (e.g., the center beam spacing is 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 the high resolution) lens.



Appendix A3.–Diagram showing the horizontal plane of a DIDSON-LR sonar with a high resolution lens (DIDSON-LR+HRL).

Source: Adapted from Burwen et al. 2007.

Note: The overall horizontal beam width of 15° is composed of 48 sub-beams with approximately 0.3° beam widths. Fish at close range are better resolved than fish at far range because the beam widths grow wider with range.



Appendix A4.–An enlargement of a tethered Chinook salmon showing the individual pixels that compose the image.

Source: Adapted from Burwen et al. 2010.

Note: 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.

Appendix A5.–Instructions and settings used for manual length measurements from DIDSON images in 2014 using Sound Metrics Software Version 5.25.47.

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 **File Creation** 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 the threshold and intensity settings for each range stratum as indicated in the table 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-

4) Select **<EG>** (for view echogram) from toolbar or under **<Processing><Echogram><View echogram**>.
5) **<left click>** on the echogram near or on the fish trace of interest to "mark it." A white circle should be visible.
6) **<right click>** INSIDE the white circle to switch to Movie mode (Movie mode will play the 16 frames encompassing this circle continuously).
7) Press **<space bar>** to pause the movie.
8) 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).
9) **<right mouse click drag>** will magnify the area in the rectangle.
10) **<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).
11) **<double left click>** or select **<f>** key to add measurement to file.
12) **<right click>** to unzoom.
13) **<right click>** to return to the echogram.

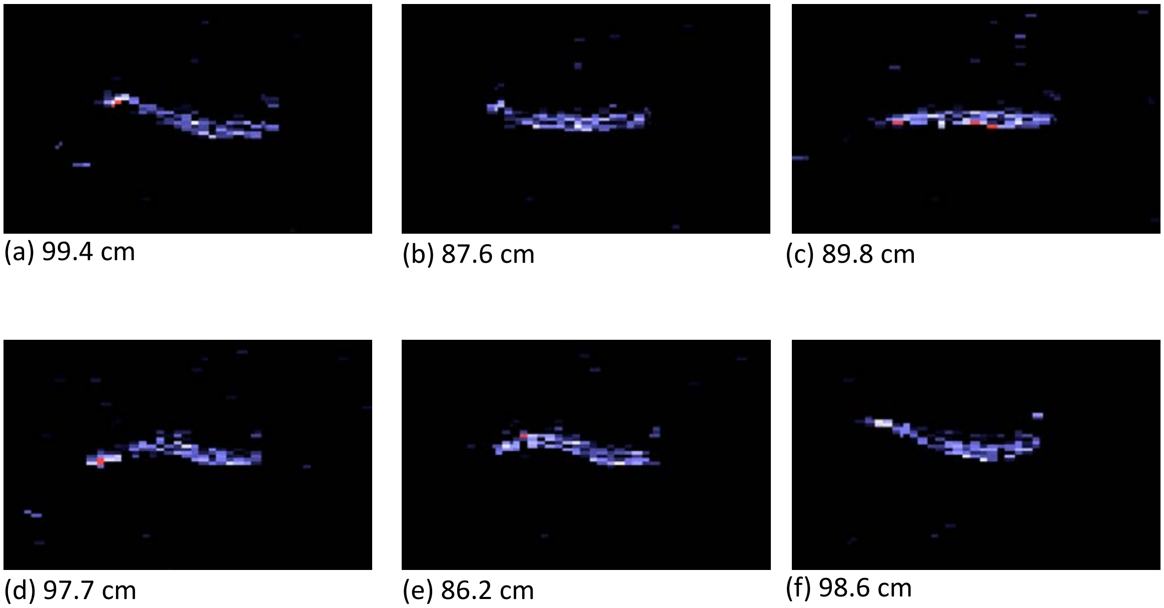
Hot keys

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" the 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

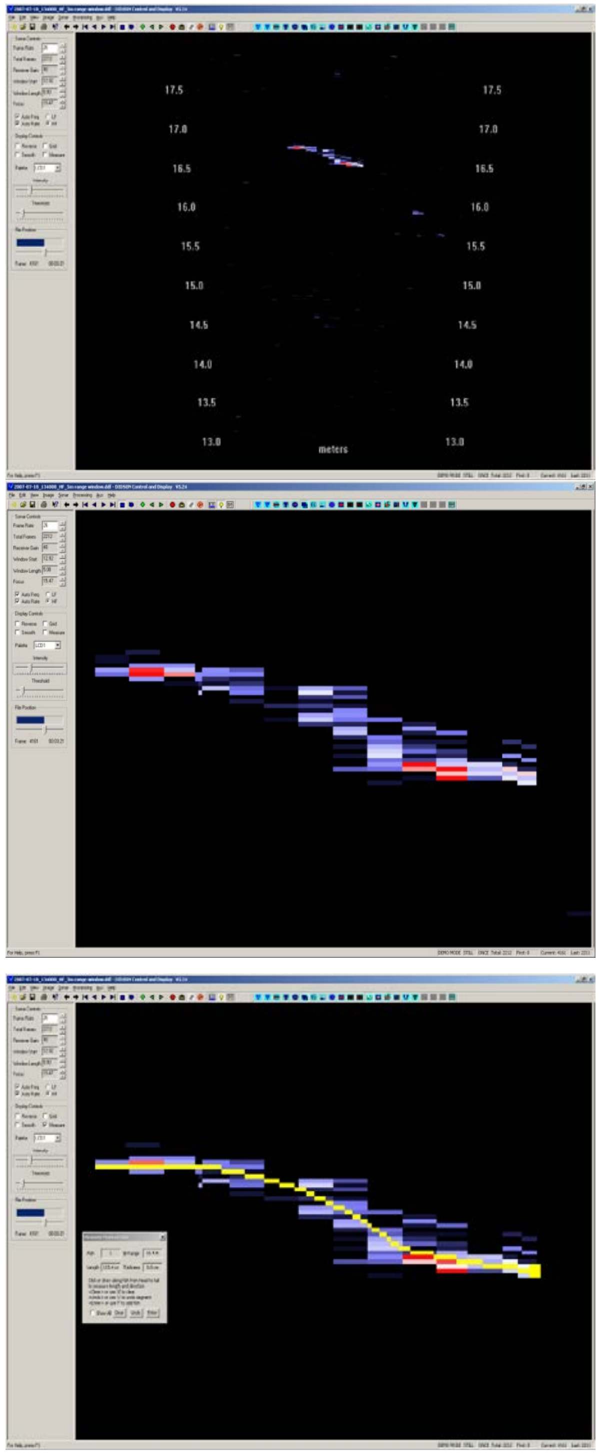
Measurements should be taken from frames where contrast between the fish image and background are high and where the fish displays its full length (e.g., panels a, d, and f in Appendix A6). In general, the best images are obtained when the fish is sinusoidal in shape, rather than linear (e.g., panel 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.



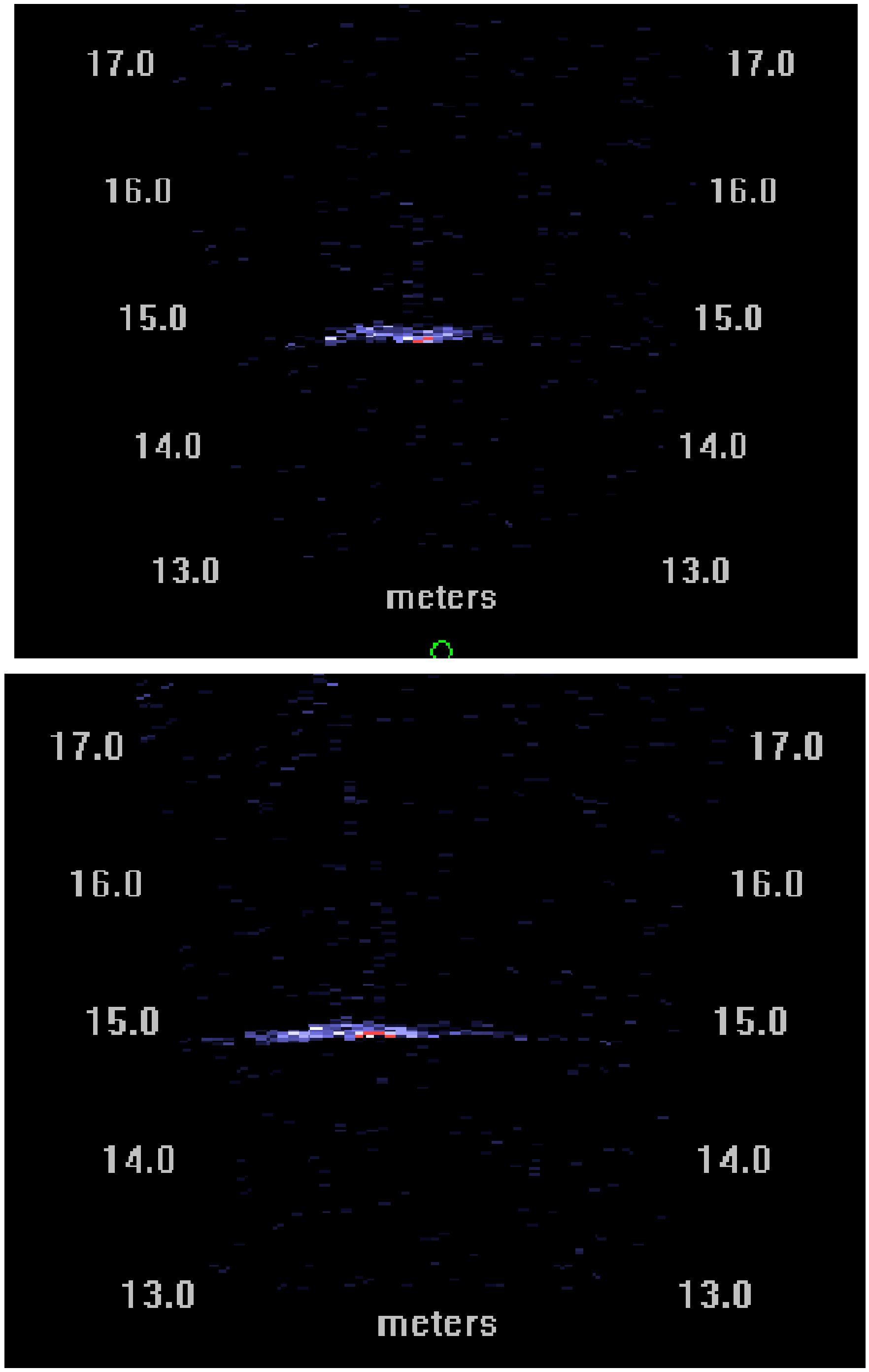
Appendix A6.–Panels a–f show the variability in length measurements from DIDSON images of a tethered Chinook salmon during 1 full tail-beat cycle.

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.

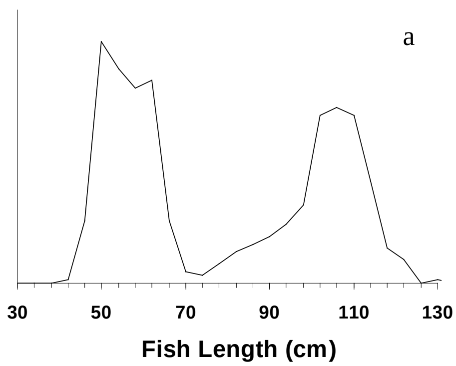


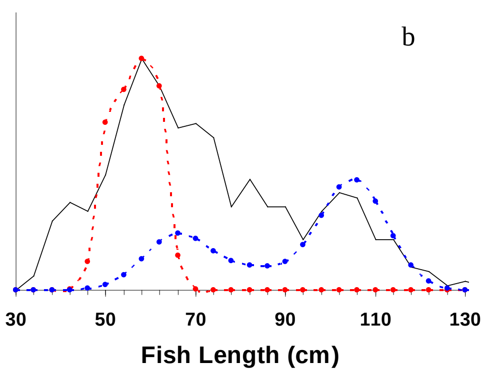
Appendix A8.–DIDSON images from a Chinook salmon showing a well-defined image of the fish swimming through the beam (top) and a “smeared” image of the same fish (bottom).

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:

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

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*:

$$w_i = \beta_0 + \beta_1 x_i + \varepsilon_i \quad \text{(B2)}$$

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:

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

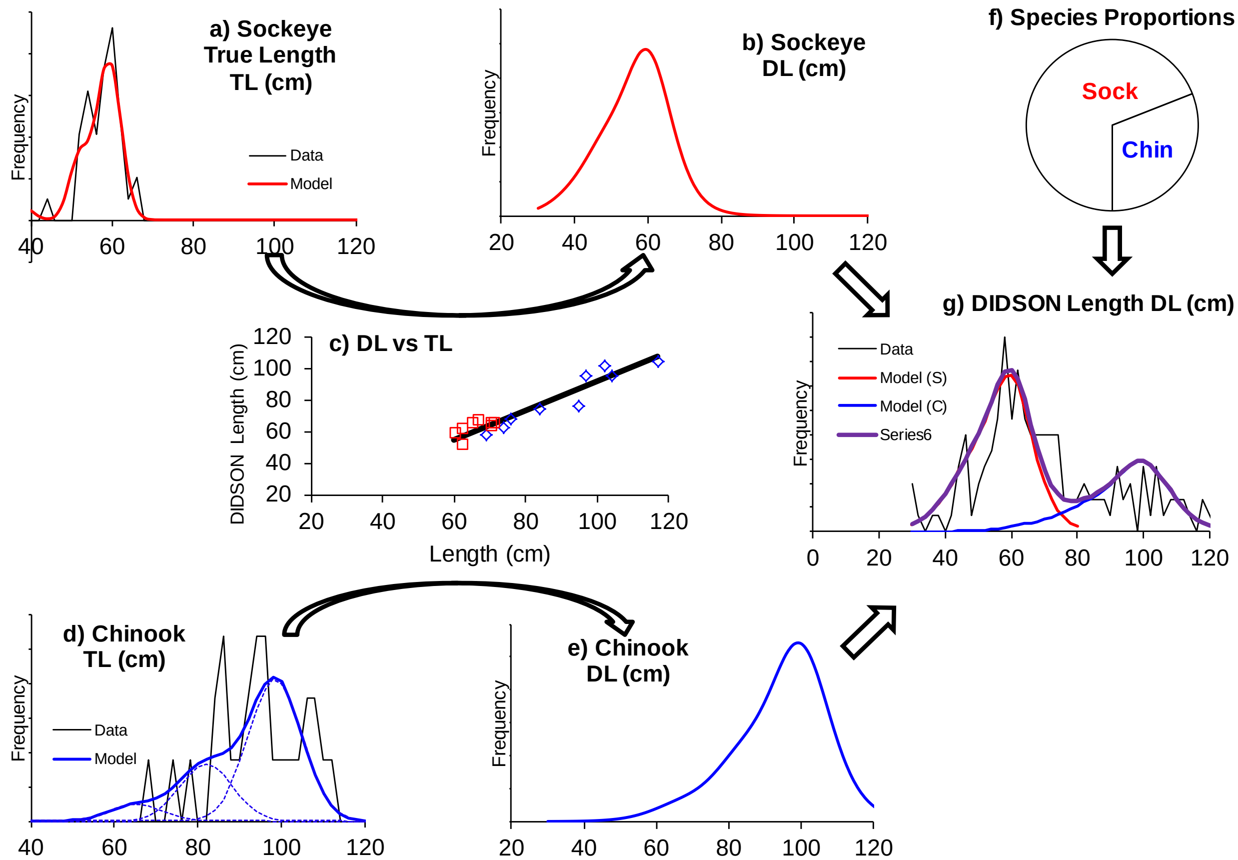
$$f_C(x) = \theta_{C1} f_{C1}(x) + \theta_{C2} f_{C2}(x) + \theta_{C3} f_{C3}(x) \quad \text{(B4)}$$

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

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

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

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 showing how 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 (AppendixB5). 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[6] 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 3 age classes. Netting length data (Perschbacher *In prep*) from days $d-3$ through $d+3$ were paired with DIDSON length data from day d.

After 14 July, "Fast-Track" (FT) 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 versus FT protocols. Between 4 July and 4 August 2010, 29 days with uncensored data were censored and reanalyzed with the FT protocol, yielding a 0.9994 to 1.0 relationship with a coefficient of determination of 0.998.

-continued-

6 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[7] 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 FT 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.

[7] 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]])
  }
}
```

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

Appendix B5.–WinBUGS code for the standard protocol DIDSON-length mixture model.

```
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)
   }
 }
```

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

Appendix B6.–Substitute WinBUGS code for the FT protocol DIDSON-length mixture model.

```
 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)
  }
 }
```

Note: Statements replace last paragraph of Appendix B5. Likelihoods are in blue. Data DL3 are unmeasured fish judged to be less than 75 cm.

The methods used to produce preliminary DLMM estimates of midriver Chinook salmon abundance used during the fishing season to inform inseason management differ in several respects from those used to produce the final estimates published in this and previous reports (Miller et al. 2013–2015).

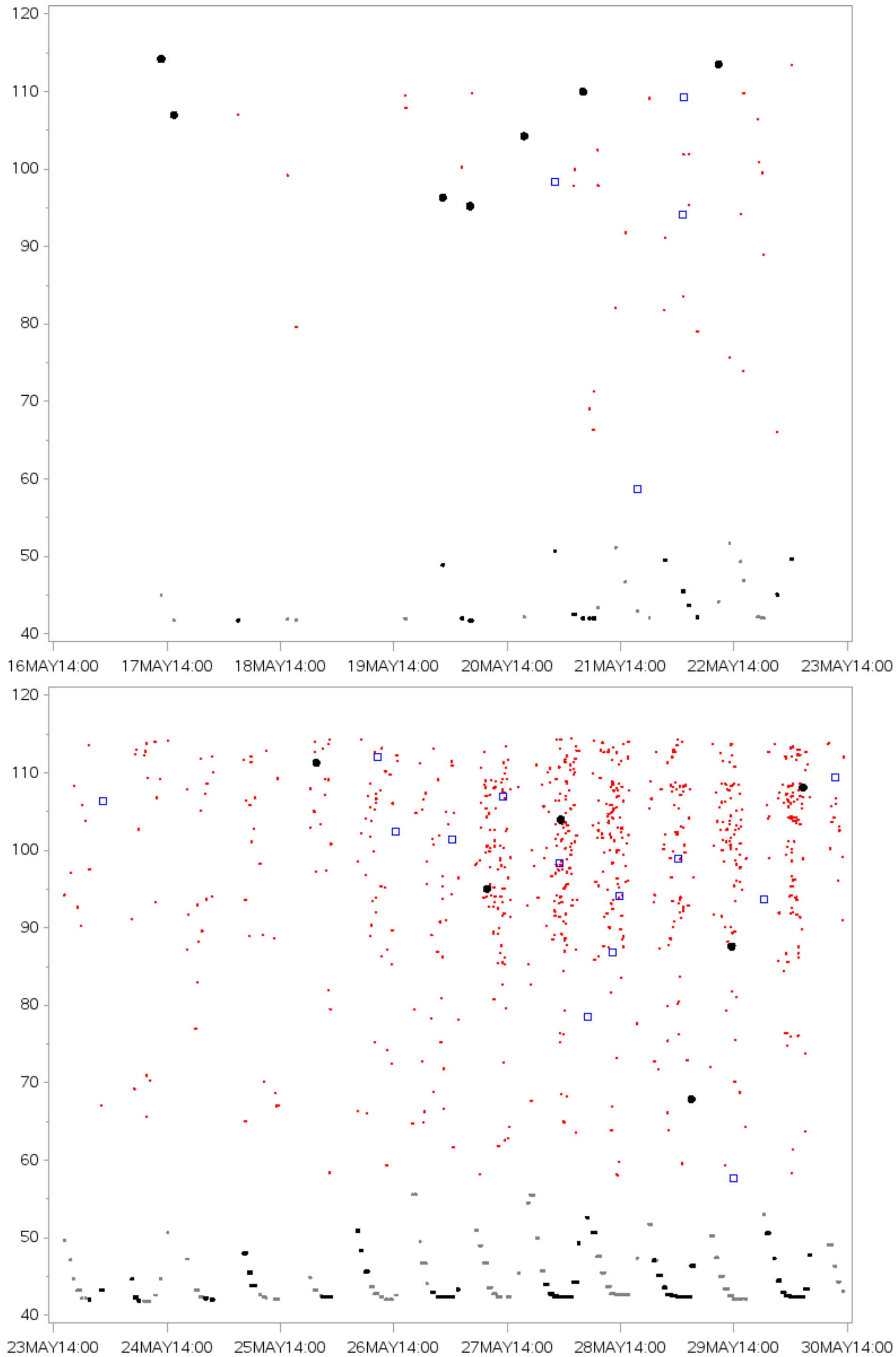
1) When abundance is low, it can be difficult to capture enough Chinook salmon in the inriver netting project to provide reliable information about Chinook salmon age proportions $\{\theta_{Ca}\}$ in "real time." Therefore, for preliminary estimates, $\{\theta_{Ca}\}$ were assigned informative Dirichlet priors based on a hierarchical analysis of historical data (Appendix B4). By using such "prior" distributions, which differ by week, the analysis considers prior information accumulated during previous seasons about approximate expected Chinook salmon age composition during a given day. Essentially, the resulting DLMM estimates incorporate a weighted average of the historical age proportions and information from the current year's data. When netting sample sizes are small early in the season, the prior (historical) information carries relatively more weight. As netting catches increase, the current data eventually overwhelm the prior information.
2) Because of management-related time constraints, preliminary estimates for day *d* cannot be postponed until netting data are observed on day *d+3*. Therefore, the preliminary DLMM estimate for day *d* was generated from paired sonar data from day *d* with netting data from days *d–6* to *d*.
3) Preliminary DLMM estimates also assume that probability of capture differs by age class, based on a previous analysis of net selectivity. Net selectivity is assumed to be equal across age classes for the estimates in this report.

The current escapement goals for Kenai River Chinook salmon are based on a comprehensive analysis of data that included preliminary DLMM estimates for 2010–2012 (Fleischman and McKinley 2013: Table 4; McKinley and Fleischman 2013: Table 5). Inseason management continues to be based on such preliminary estimates in order to preserve comparability to such goals.

Preliminary and final DLMM estimates for 2010–2014 early and late runs are tabulated below. With the exception of the 2014 early run, revisions to estimates have been between −3% to +14%.

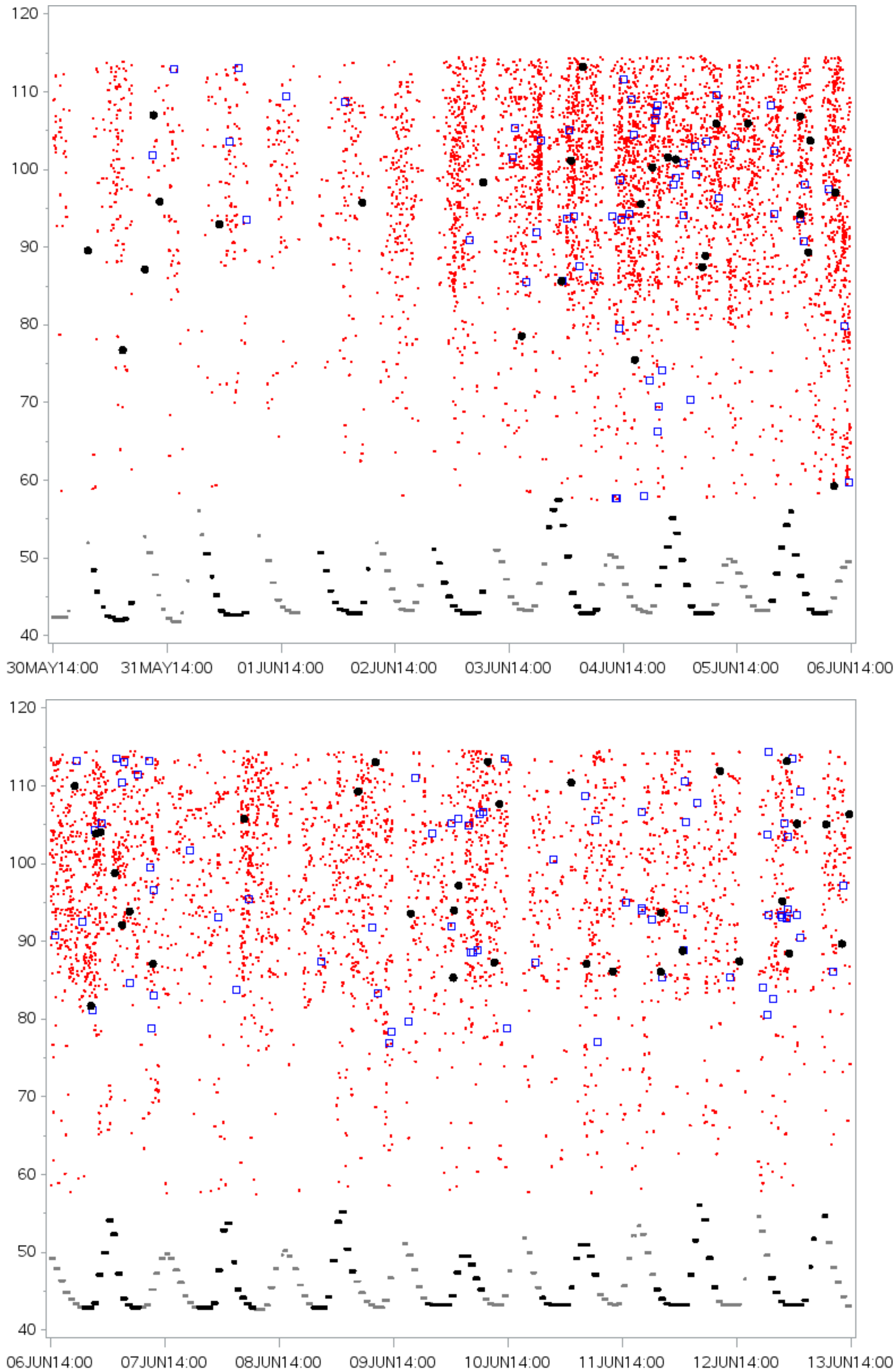
	Early Run			Late Run		
Year	Preliminary	Final	% revised	Preliminary	Final	% revised
2010	5,376	5,874	9%	19,000	18,401	-3%
2011	6,515	7,366	13%	21,036	23,713	13%
2012	3,339	3,228	-3%	21,914	21,613	-1%
2013	1,314	1,439	10%	13,290	15,185	14%
2014	3,426	4,862	42%	13,125	13,952	6%

APPENDIX C: SPATIAL AND TEMPORAL DISTRIBUTION OF FISH BY SIZE AS MEASURED BY DIDSON, RM 8.6 KENAI RIVER, 2014



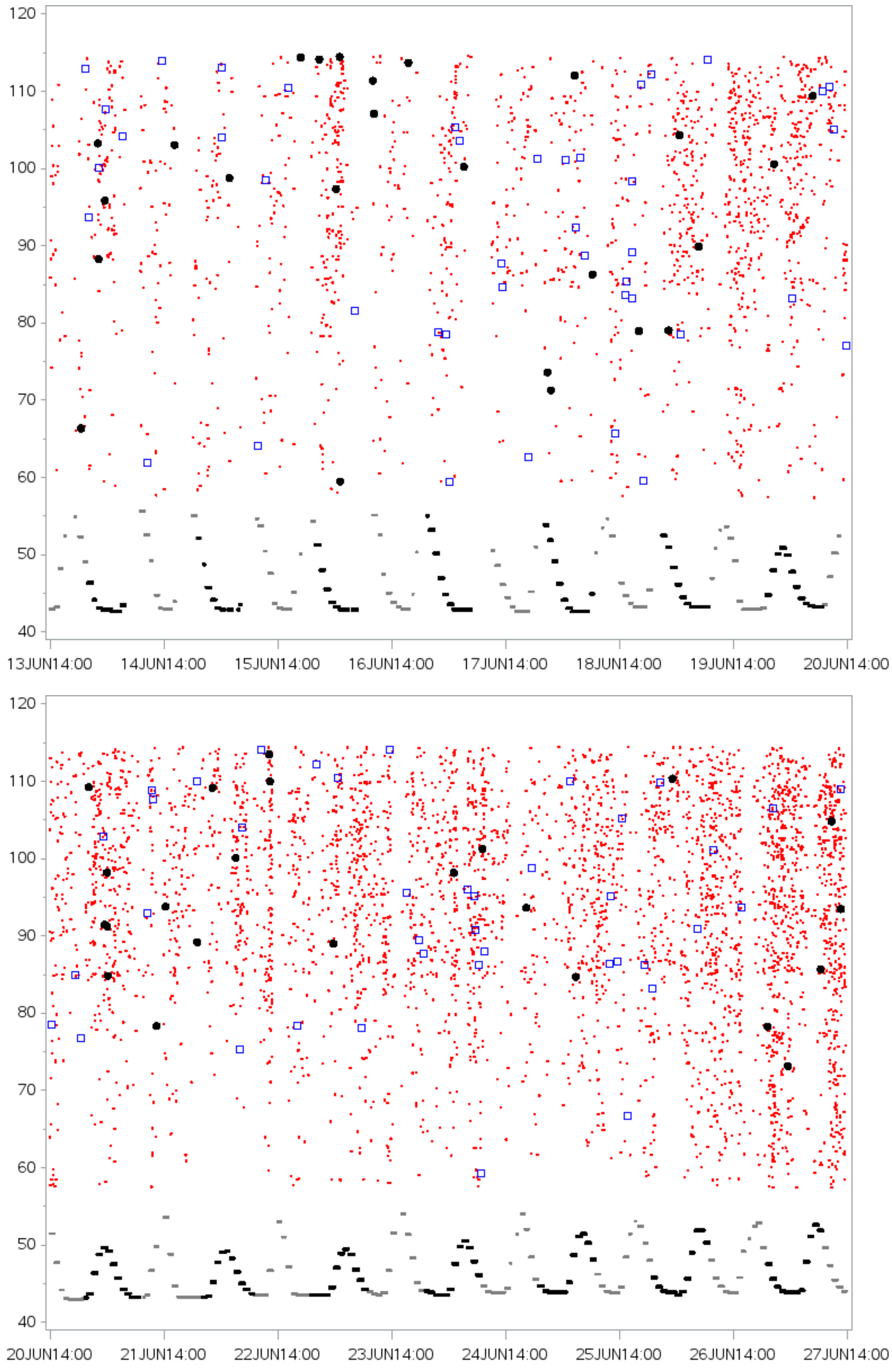
Appendix C1.–Spatial and temporal distribution of small (DIDSON length DL < 75 cm; small red symbols), medium (75 cm ≤ DL < 90 cm; larger blue squares), and large fish (DL ≥ 90 cm; large black symbols), RM 8.6 Kenai River, 16–22 May (top) and 23–29 May (bottom) 2014.

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.



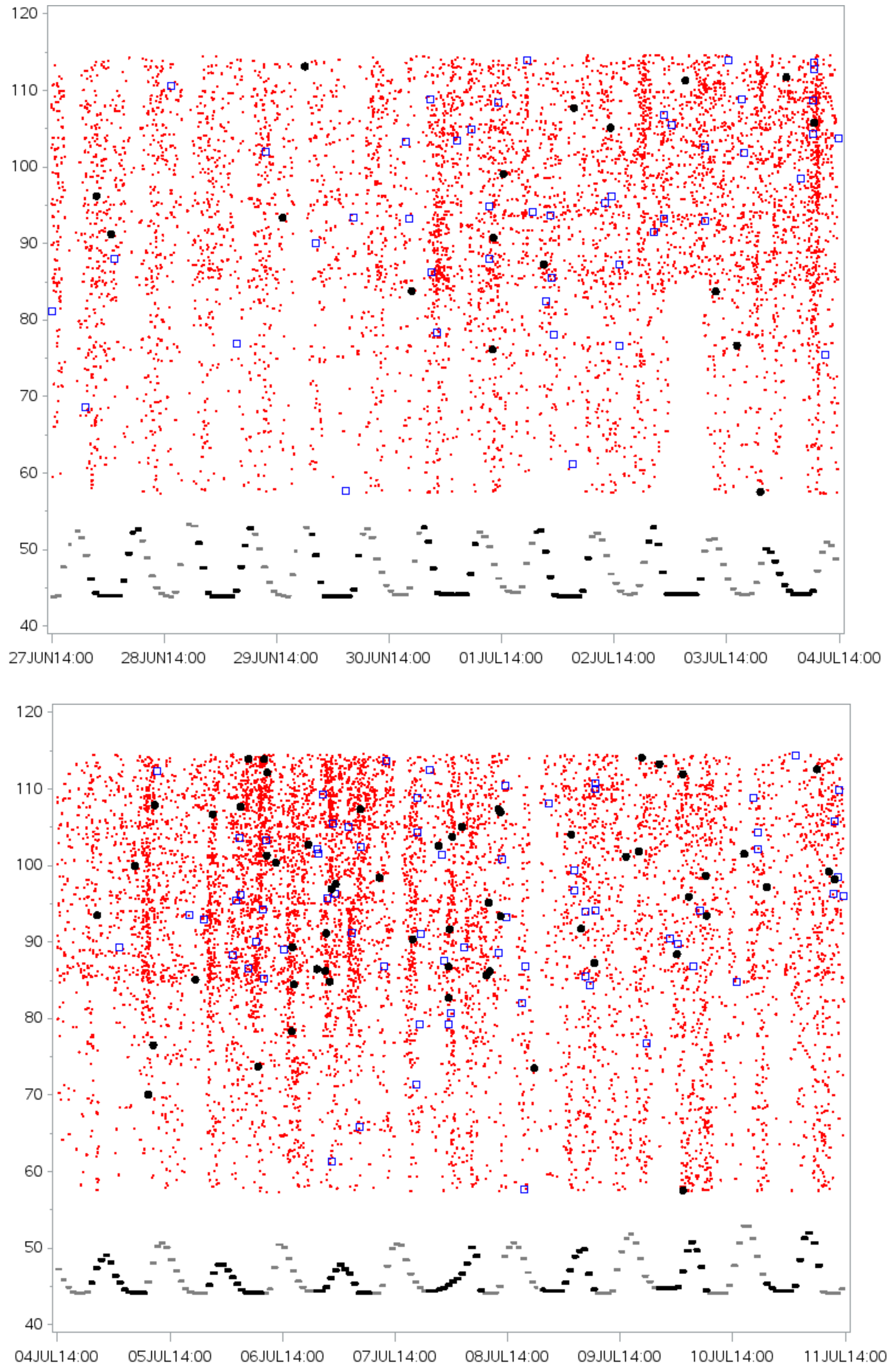
Appendix C2.–Spatial and temporal distribution of small (DIDSON length DL < 75 cm; small red symbols), medium (75 cm ≤ DL < 90 cm; larger blue squares), and large fish (DL ≥ 90 cm; large black symbols), RM 8.6 Kenai River, 30 May–5 June (top) and 6–12 June (bottom) 2014.

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.



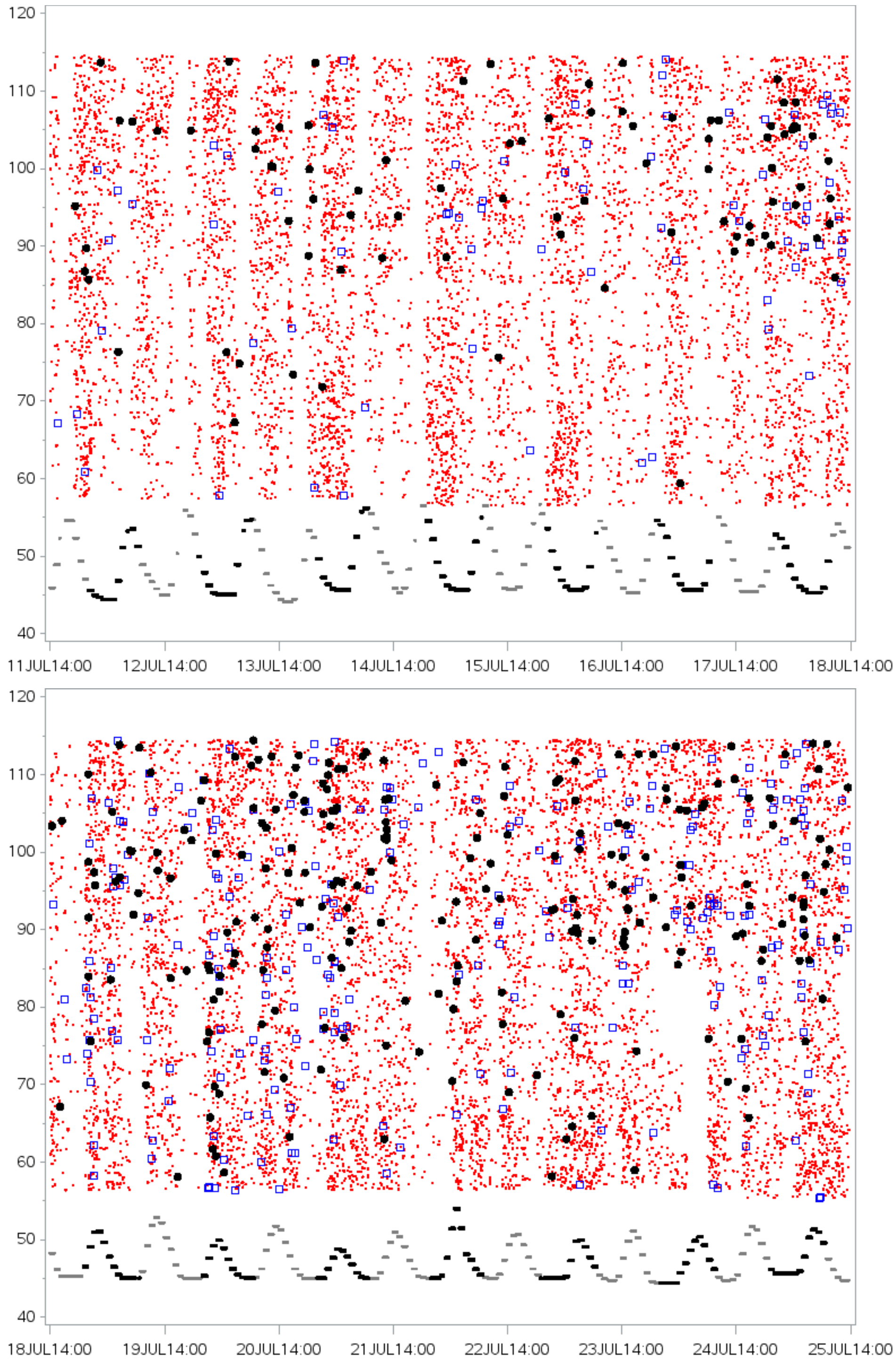
Appendix C3.–Spatial and temporal distribution of small (DIDSON length DL < 75 cm; small red symbols), medium (75 cm ≤ DL < 90 cm; larger blue squares), and large fish (DL ≥ 90 cm; large black symbols), RM 8.6 Kenai River, 13–19 June (top) and 20–26 June (bottom) 2014.

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.



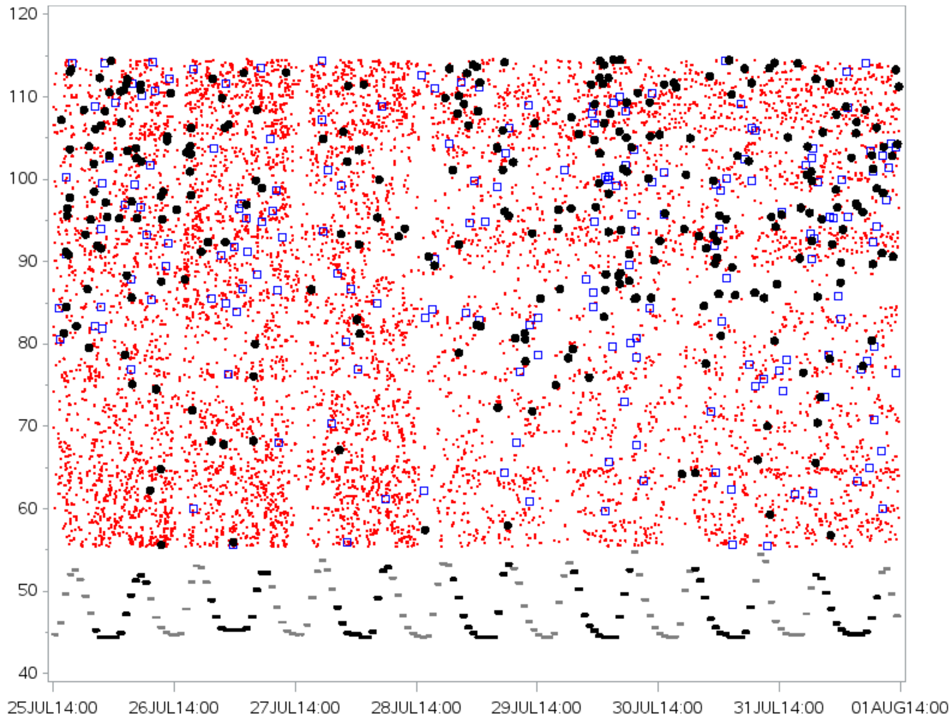
Appendix C4.–Spatial and temporal distribution of small (DIDSON length DL < 75 cm; small red symbols), medium (75 cm ≤ DL < 90 cm; larger blue squares), and large fish (DL ≥ 90 cm; large black symbols), RM 8.6 Kenai River, 27 June–3 July (top) and 4–10 July (bottom) 2014.

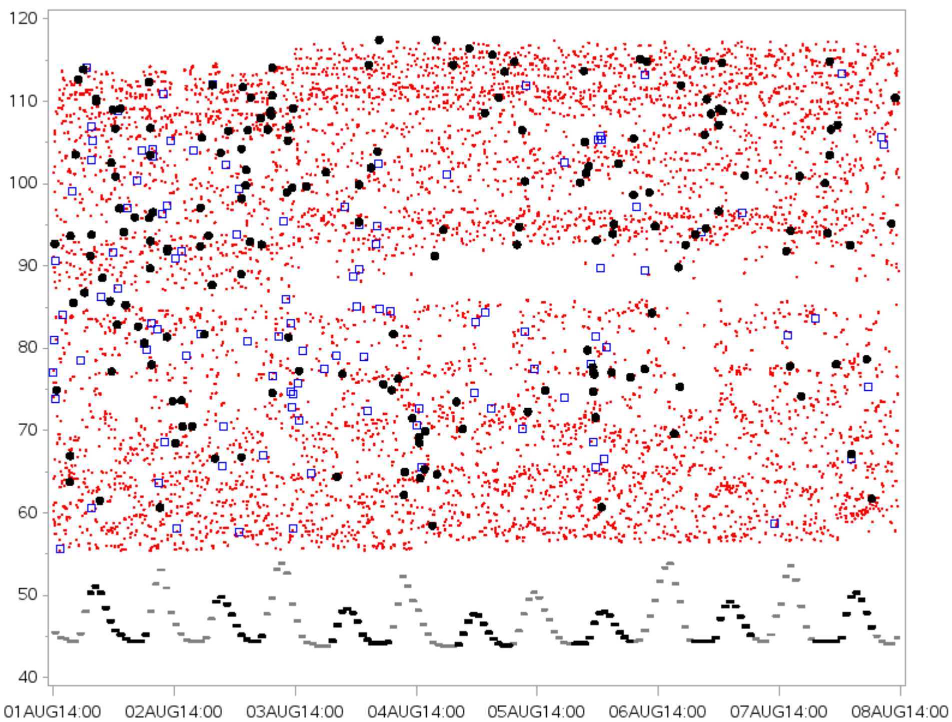
Note: Vertical axis is distance (m) from benchmark on right-bank shore, except that relative water level is plotted at bottom (small grey symbols) with netting periods in black.



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) 2014.

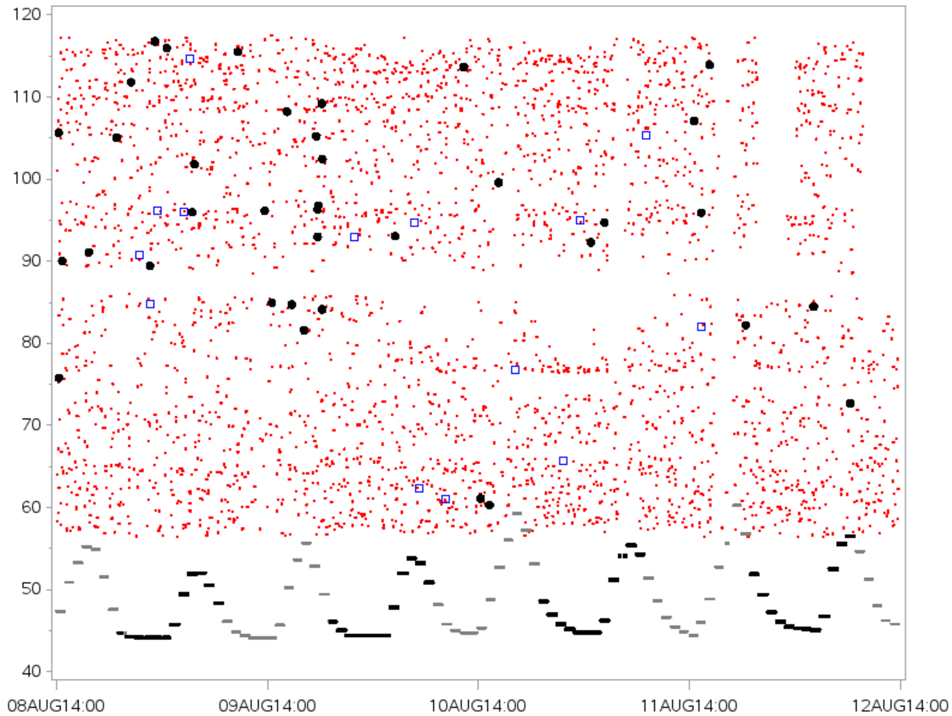
Note: Vertical axis is distance (m) from benchmark on right-bank shore, except that relative water level is plotted at bottom (small grey symbols) with netting periods in black.





Appendix 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) 2014.

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, 8–11 August 2014.

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 D: DIRECTION OF TRAVEL OF LARGE FISH DETECTED BY DIDSON, RM 8.6 KENAI RIVER, 2014

Appendix D1.–Daily numbers and percentages of upstream- and downstream-moving fish greater than or equal to 75 cm DIDSON length for the early run, RM 8.6 Kenai River, 2014.

Date	Number moving downstream	Number moving upstream	Total fish sampled	Percent moving downstream	Percent moving upstream
16 May	0	1	1		100%
17 May	0	1	1	0%	100%
18 May	0	0	0		
19 May	1	2	3	33%	67%
20 May	0	3	3	0%	100%
21 May	0	4	4	0%	100%
22 May	0	0	0		
23 May	1	1	2	50%	50%
24 May	0	0	0		
25 May	1	2	3	33%	67%
26 May	0	4	4	0%	100%
27 May	0	5	5	0%	100%
28 May	0	3	3	0%	100%
29 May	1	4	5	20%	80%
30 May	0	6	6	0%	100%
31 May	0	5	5	0%	100%
1 Jun	0	3	3	0%	100%
2 Jun	0	2	2	0%	100%
3 Jun	0	21	21	0%	100%
4 Jun	5	31	36	14%	86%
5 Jun	0	16	16	0%	100%
6 Jun	0	24	24	0%	100%
7 Jun	0	5	5	0%	100%
8 Jun	0	7	7	0%	100%
9 Jun	0	21	21	0%	100%
10 Jun	0	8	8	0%	100%
11 Jun	3	16	19	16%	84%
12 Jun	1	26	27	4%	96%
13 Jun	1	11	12	8%	92%
14 Jun	0	6	6	0%	100%
15 Jun	1	9	10	10%	90%
16 Jun	1	9	10	10%	90%
17 Jun	0	11	11	0%	100%
18 Jun	0	14	14	0%	100%
19 Jun	0	7	7	0%	100%
20 Jun	0	13	13	0%	100%

-continued-

Appendix D1.–Page 2 of 2.

Date	Number moving downstream	Number moving upstream	Total fish sampled	Percent moving downstream	Percent moving upstream
21 Jun	0	10	10	0%	100%
22 Jun	0	6	6	0%	100%
23 Jun	0	11	11	0%	100%
24 Jun	1	7	8	13%	88%
25 Jun	0	8	8	0%	100%
26 Jun	0	8	8	0%	100%
27 Jun	0	5	5	0%	100%
28 Jun	1	3	4	25%	75%
29 Jun	1	5	6	17%	83%
30 Jun	0	13	13	0%	100%
Total	19	377	396	4.8%	95.2%

Appendix D2.–Daily numbers and percentages of upstream and downstream moving fish greater than or equal to 75 cm DIDSON length for the late run, RM 8.6 Kenai River, 2014.

Date	Number moving downstream	Number moving upstream	Total fish sampled	Percent moving downstream	Percent moving upstream
1 Jul	0	13	13	0%	100%
2 Jul	1	10	11	9%	91%
3 Jul	0	14	14	0%	100%
4 Jul	0	7	7	0%	100%
5 Jul	0	20	20	0%	100%
6 Jul	1	26	27	4%	96%
7 Jul	0	28	28	0%	100%
8 Jul	0	16	16	0%	100%
9 Jul	0	15	15	0%	100%
10 Jul	0	15	15	0%	100%
11 Jul	0	17	17	0%	100%
12 Jul	1	15	16	6%	94%
13 Jul	0	22	22	0%	100%
14 Jul	0	16	16	0%	100%
15 Jul	0	16	16	0%	100%
16 Jul	0	23	23	0%	100%
17 Jul	0	49	49	0%	100%
18 Jul	3	57	60	5%	95%
19 Jul	1	86	87	1%	99%
20 Jul	2	99	101	2%	98%
21 Jul	0	37	37	0%	100%
22 Jul	0	46	46	0%	100%
23 Jul	3	69	72	4%	96%
24 Jul	4	81	85	5%	95%
25 Jul	5	89	94	5%	95%
26 Jul	4	53	57	7%	93%
27 Jul	2	30	32	6%	94%
28 Jul	6	59	65	9%	91%
29 Jul	4	85	89	4%	96%
30 Jul	4	67	71	6%	94%
31 Jul	9	94	103	9%	91%

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Appendix D2.–Page 2 of 2.

Date	Number moving downstream	Number moving upstream	Total fish sampled	Percent moving downstream	Percent moving upstream
1 Aug	4	75	79	5%	95%
2 Aug	1	63	64	2%	98%
3 Aug	0	36	36	0%	100%
4 Aug	0	36	36	0%	100%
5 Aug	4	42	46	9%	91%
6 Aug	0	20	20	0%	100%
7 Aug	2	25	27	7%	93%
8 Aug	2	18	20	10%	90%
9 Aug	2	17	19	11%	89%
10 Aug	2	9	11	18%	82%
11 Aug	0	7	7	0%	100%
Total	67	1622	1689	4.0%	96.0%

Note: Sonar operations ended on 11 August.

APPENDIX E: DIDSON LENGTH THRESHOLD ESTIMATES OF LARGE CHINOOK SALMON, RM 8.6 KENAI RIVER, 2014

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 2014.

	DL ≥ 75 cm		DL ≥ 80 cm		DL ≥ 90 cm	
Date	Passage	SE	Passage	SE	Passage	SE
16 May	6	5	6	5	6	5
17 May	6	5	6	5	6	5
18 May	0	0	0	0	0	0
19 May	12	7	12	7	12	7
20 May	18	9	18	9	12	7
21 May	24	12	12	7	6	5
22 May	0	0	0	0	0	0
23 May	6	5	6	5	0	0
24 May	0	0	0	0	0	0
25 May	12	7	6	5	6	5
26 May	24	9	24	9	6	5
27 May	30	12	12	10	6	5
28 May	18	8	12	6	12	6
29 May	24	9	12	7	6	5
30 May	36	9	36	9	30	10
31 May	30	10	18	9	6	5
1 Jun	18	9	12	7	6	5
2 Jun	12	7	12	7	6	5
3 Jun	127	13	78	15	24	10
4 Jun	181	22	145	18	48	12
5 Jun	116	25	72	21	42	18
6 Jun	145	28	115	24	48	11
7 Jun	30	9	18	7	6	5
8 Jun	42	13	42	13	12	7
9 Jun	127	22	96	19	42	12
10 Jun	48	17	48	17	18	9
11 Jun	96	27	84	24	24	12
12 Jun	157	27	103	16	48	9
13 Jun	66	16	54	15	24	10
14 Jun	36	12	24	9	12	7
15 Jun	54	17	54	17	42	15
16 Jun	54	11	36	12	12	7
17 Jun	66	15	60	14	24	9
18 Jun	84	21	60	15	24	10
19 Jun	42	12	30	11	12	7
20 Jun	78	17	72	17	36	15

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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	60	16	54	16	36	14
22 Jun	36	11	30	10	6	5
23 Jun	66	14	42	11	12	7
24 Jun	42	8	36	9	12	7
25 Jun	48	12	42	11	6	5
26 Jun	48	15	36	11	30	11
27 Jun	30	9	18	8	12	7
28 Jun	18	9	18	9	0	0
29 Jun	30	11	30	11	12	7
30 Jun	78	15	54	14	18	11
Total	2,281	95	1,755	83	768	57

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 2014.

	DL ≥ 75 cm		DL ≥ 80 cm		DL ≥ 90 cm	
Date	Passage	SE	Passage	SE	Passage	SE
1 Jul	78	16	36	15	24	9
2 Jul	75	26	46	16	12	7
3 Jul	84	29	60	19	24	10
4 Jul	46	13	41	13	42	18
5 Jul	121	28	115	28	54	19
6 Jul	157	31	127	27	72	20
7 Jul	169	33	133	27	78	24
8 Jul	108	29	75	22	33	15
9 Jul	90	17	90	17	60	17
10 Jul	90	17	66	16	30	10
11 Jul	102	27	96	25	54	17
12 Jul	90	20	78	19	54	17
13 Jul	151	36	98	24	73	19
14 Jul	96	23	72	17	42	11
15 Jul	96	16	90	14	54	14
16 Jul	139	22	115	24	78	22
17 Jul	295	48	265	46	145	28
18 Jul	360	53	303	51	150	29
19 Jul	519	62	464	62	271	33
20 Jul	597	65	549	59	308	43
21 Jul	223	38	199	36	133	19
22 Jul	277	38	229	34	169	28
23 Jul	465	54	420	49	227	34
24 Jul	488	67	398	48	205	38
25 Jul	537	46	482	45	362	41
26 Jul	320	48	289	47	169	32
27 Jul	181	33	133	26	96	24
28 Jul	356	48	332	50	217	37
29 Jul	513	52	476	47	308	37
30 Jul	392	43	368	40	259	29
31 Jul	567	52	513	45	314	33

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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	504	75	481	76	275	49
2 Aug	423	50	404	51	313	59
3 Aug	217	37	205	37	109	19
4 Aug	217	27	205	26	145	16
5 Aug	253	36	235	34	163	27
6 Aug	121	32	115	32	103	34
7 Aug	151	27	139	26	109	21
8 Aug	109	21	96	22	78	19
9 Aug	102	22	90	22	78	20
10 Aug	48	13	42	13	24	9
11 Aug	42	11	42	11	36	9
Total	9,969	251	8,812	232	5,550	174

Note: All estimates are of upstream-bound fish in midriver between and greater than 3 m from the transducers. Sonar operations ended on 11 August.

APPENDIX F: NET-APPORTIONED ESTIMATES, KENAI RIVER, 2014

Appendix F1.–DIDSON-based upstream fish passage (all species) at split-beam ranges (greater than 10 m from the left-bank transducer and greater than 15 m from the 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 2014.

	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	0	0	0.000	0.000	0	0	
17 May	12	7	zero fish caught				
18 May	12	7	0.330	0.278	4	4	0.89
19 May	24	10	0.000	0.000	0	0	
20 May	54	16	0.000	0.000	0	0	
21 May	60	18	0.000	0.000	0	0	
22 May	36	11	0.000	0.000	0	0	
23 May	90	14	0.000	0.000	0	0	
24 May	139	27	0.083	0.079	12	11	0.92
25 May	235	27	0.000	0.000	0	0	
26 May	579	44	0.000	0.000	0	0	
27 May	935	88	0.007	0.007	7	7	0.94
28 May	669	70	0.000	0.000	0	0	
29 May	718	101	0.000	0.000	0	0	
30 May	718	99	0.000	0.000	0	0	
31 May	953	99	0.042	0.019	40	18	0.46
1 Jun	959	76	0.014	0.014	13	13	1.03
2 Jun	2,720	232	0.029	0.015	79	41	0.52
3 Jun	5,548	645	0.080	0.026	444	152	3.23
4 Jun	6,034	348	0.026	0.013	157	79	4.99
5 Jun	6,353	529	0.030	0.016	191	103	5.30
6 Jun	3,932	248	0.070	0.039	275	154	0.56
7 Jun	2,400	207	0.029	0.019	70	46	0.65
8 Jun	2,545	187	0.036	0.022	92	56	0.61
9 Jun	2,557	226	0.126	0.036	322	96	0.30
10 Jun	1,562	143	0.101	0.032	158	52	0.33
11 Jun	1,833	196	0.068	0.019	125	37	0.30
12 Jun	1,737	172	0.054	0.025	94	44	0.47
13 Jun	802	104	0.067	0.033	54	27	0.50
14 Jun	537	74	0.179	0.105	96	57	0.60
15 Jun	971	129	0.080	0.059	78	58	0.74
16 Jun	772	87	0.045	0.030	35	23	0.67
17 Jun	892	94	0.091	0.039	81	36	0.44
18 Jun	1,387	120	0.088	0.037	122	52	0.43
19 Jun	2,159	144	0.045	0.019	97	41	0.43
20 Jun	2,026	182	0.023	0.017	47	35	0.74

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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	1,948	310	0.023	0.022	45	43	0.95
22 Jun	2,273	181	0.049	0.030	111	69	0.62
23 Jun	2,436	260	0.010	0.010	24	24	1.02
24 Jun	1,972	184	0.000	0.000	0	0	
25 Jun	2,786	194	0.045	0.018	125	51	0.41
26 Jun	4,390	344	0.043	0.012	189	55	0.29
27 Jun	3,033	224	0.022	0.012	67	37	0.55
28 Jun	2,581	182	0.016	0.011	41	28	0.69
29 Jun	2,105	161	0.053	0.025	112	53	0.47
30 Jun	4,377	344	0.036	0.014	158	62	0.39
Total	80,861	1,391			3,565	351	0.10

Note: All estimates are germane to upstream-bound fish in midriver (greater than 10 m from the left-bank transducer and greater than 15 m from the 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 (greater than 10 m from the left-bank transducer and greater than 15 m from the 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 2014.

	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	3,630	191	0.02	0.013	73	47	0.65
2 Jul	4,788	289	0.055	0.017	263	83	0.31
3 Jul	5,770	639	0.029	0.016	167	94	0.56
4 Jul	4,310	434	0.023	0.013	99	57	0.57
5 Jul	7,501	616	0.022	0.009	165	69	0.42
6 Jul	8,182	695	0.056	0.021	458	176	0.38
7 Jul	5,463	485	0.058	0.022	317	123	0.39
8 Jul	3,661	319	0.033	0.016	121	59	0.49
9 Jul	5,807	636	0.037	0.013	215	79	0.37
10 Jul	3,844	244	0.031	0.022	119	85	0.71
11 Jul	5,521	382	0.038	0.019	210	106	0.5
12 Jul	5,367	436	0.025	0.012	134	65	0.49
13 Jul	6,296	627	0.027	0.013	170	83	0.49
14 Jul	6,383	496	0.023	0.009	147	58	0.4
15 Jul	5,734	653	0.032	0.01	183	61	0.33
16 Jul	3,870	422	0.063	0.026	244	103	0.42
17 Jul	7,912	754	0.054	0.022	427	178	0.42
18 Jul	6,854	1,065	0.117	0.032	802	250	0.31
19 Jul	8,785	925	0.097	0.029	852	269	0.32
20 Jul	8,386	954	0.057	0.015	478	136	0.29
21 Jul	4,987	495	0.039	0.013	194	67	0.35
22 Jul	7,893	391	0.057	0.017	450	136	0.3
23 Jul	8,140	720	0.072	0.023	586	194	0.33
24 Jul	9,578	1,061	0.071	0.025	680	250	0.37
25 Jul	11,487	1,102	0.105	0.03	1,206	362	0.3
26 Jul	14,544	1,465	0.038	0.014	553	210	0.38
27 Jul	14,031	2,503	0.072	0.032	1,010	477	0.47
28 Jul			0.074	0.036			
29 Jul			0.094	0.034			
30 Jul			0.056	0.022			
31 Jul			0.058	0.017			

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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			0.058	0.021			
2 Aug			0.039	0.011			
3 Aug			0.008	0.004			
4 Aug			0.003	0.003			
5 Aug			0.006	0.004			
6 Aug			0.008	0.005			
7 Aug			0.015	0.007			
8 Aug			0	0			
9 Aug			0.01	0.007			
10 Aug			0.006	0.004			
11 Aug			0	0			
12 Aug			0	0			
13 Aug			0	0			
14 Aug			0.007	0.007			
15 Aug			0.022	0.016			
Total	188,724	4,370			10,323	916	0.089

Note: All estimates are germane to upstream-bound fish in midriver (greater than 10 m from the left-bank transducer and greater than 15 m from the 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. Sonar estimates of upstream all-species passage were not available after 27 July. Consequently, net-apportioned Chinook salmon passage estimates were also not available after 27 July.

APPENDIX G: DAILY ABUNDANCE MODEL FITTED TO KENAI RIVER CHINOOK SALMON DATA, 2014

Appendix G1.–OpenBUGS code for daily abundance model fit to 2014 Kenai River Chinook salmon sonar and gillnetting data.

```
model{
q ~ dnorm(0,1.0E-6)I(0,1)
tau ~ dgamma(0.001,0.001)
sigma <- 1/sqrt(tau)
N.LR <- sum(N[1:46])
N.imputed <- sum(N[43:46])
for (d in 1:46) {
 log.N[d] ~ dnorm(0,1.0E-12)I(0,)
 N[d] <- exp(log.N[d])
 tau.log.DID[d] <- 1 / log(cv.DID[d]*cv.DID[d] + 1)
 DID[d] ~ dlnorm(log.N[d],tau.log.DID[d])
 Expected.Catch[d] <- (1 - exp(-q*Effort[d])) * N[d]
 log.EC[d] <- log(Expected.Catch[d])
 lambda[d] ~ dlnorm(log.EC[d],tau)
 Catch[d] ~ dpois(lambda[d])
 }
}
```

Note: Prior distributions are in green font, likelihoods in blue. Block updaters were disabled prior to compiling. Posterior distribution for node "N" is the basis for DIDSON-equivalent estimates described in report text.