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Estimates of Chinook Salmon Passage in the Kenai River Using Split-Beam Sonar, 2008–2009

by

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

Symbols and Abbreviations

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Weights and measures (metric)

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

Weights and measures (English)

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

Time and temperature

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

Physics and chemistry

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

General

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

Mathematics, statistics

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

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ABSTRACT

Chinook salmon (*Oncorhynchus tshawytscha*) passage in the Kenai River in 2008 and 2009 was estimated using split-beam sonar technology. Early (16 May–30 June) and late (1 July–10 August) runs of Kenai River Chinook salmon have been monitored acoustically since 1987. A 200 kHz split-beam sonar system has been used since 1995 to estimate numbers of adult Chinook salmon migrating into the Kenai River. From 1987 to 1994, a 420 kHz dual-beam sonar was used to generate similar estimates. In 2008, the sonar project operated 16 May through 3 August. The standard estimate of total upstream passage of Chinook salmon in 2008, based on target strength and range thresholds, was 46,294 (SE 528) fish: 15,355 (SE 296) during the early run (16 May–30 June) and 30,939 (SE 438) during the late run (1 July–3 August 2008). Total (expanded for missing days) late-run passage estimated for 1 July through 10 August was 34,641 fish (SE 1,682). In 2009, the sonar project operated 16 May through 4 August. The standard estimate of total upstream passage of Chinook salmon in 2009, based on target strength and range thresholds, was 37,022 (SE 512) fish: 11,334 (SE 263) during the early run and 25,688 (SE 440) during the late run. The standard errors associated with these estimates reflect only sampling error and no other sources of uncertainty (such as target detection, species composition, direction of travel, and target tracking). Comparisons with alternative estimators of abundance suggest that the standard estimates for both years are too high. Tests of long-range Dual-frequency Identification Sonar (DIDSON) continued in the Kenai River in 2008 and 2009. DIDSON exhibited many advantages over split-beam sonar with respect to target detection, target tracking, and species classification, confirming its potential as a tool for inseason monitoring of Chinook salmon run strength.

Key words: split-beam sonar, DIDSON, Chinook salmon, *Oncorhynchus tshawytscha,* acoustic assessment, Kenai River, riverine sonar, early run, late run.

INTRODUCTION

Chinook salmon (*Oncorhynchus tshawytscha*) returning to the Kenai River (Figure 1) support one of the largest and most intensively managed recreational fisheries in Alaska (Gamblin et al. 2004). Kenai River Chinook salmon are among the largest in the world and have sustained in excess of 100,000 angler-days of fishing effort annually (Mills 1979-1980, 1981a-b, 1982-1994; Howe et al. 1995-1996, 2001a-d; Walker et al. 2003; Jennings et al. 2004, 2006a-b, 2007, 2009a-b, 2011). The Kenai River Chinook salmon fishery has been a source of contention because of competition for a fully allocated resource among sport, commercial, subsistence, and personal use fisheries.

Chinook salmon returning to the Kenai River are managed as two distinct runs (Burger et al. 1985): early (16 May–30 June) and late (1 July–10 August). Early-run Chinook salmon are harvested primarily by sport anglers, and late-run Chinook salmon are harvested by commercial, sport, subsistence, and personal use fisheries. These fisheries may be restricted if the projected run size falls below escapement goals adopted by the Alaska Board of Fisheries (BOF). From 1989 to 1998, these runs were managed for spawning escapement goals of 9,000 for early-run and 22,300 for late-run Chinook salmon (McBride et al. 1989). In February 1999, BOF adopted revised escapement goals based on Chinook salmon passage estimated by sonar and the understanding by the Alaska Department of Fish and Game (ADF&G) of biases associated with the sonar (Hammarstrom and Hasbrouck 1998, 1999; Bosch and Burwen 1999). The revised escapement goals defined a range of escapement levels: 7,200 to 14,400 fish for early-run Chinook salmon and 17,800 to 35,700 fish for late-run Chinook salmon. In January 2005, based on additional brood year information, BOF lowered the early-run escapement goal range to 5,000–9,000 Chinook salmon. Escapement goal ranges (as defined by the 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*]) are expected to provide a stable fishing season without compromising sustainability.

Sonar estimates of inriver Chinook salmon passage provide the basis for estimating spawning escapement and implementing management plans that regulate harvest in competing sport and commercial fisheries for this stock. Implementation of these management plans has been contentious and attracts public scrutiny. Restrictions were imposed on the sport fishery to meet escapement goals during the early run in 1990 through 1992, 1997, 1998, 2000, and 2002, and during the late run in 1990, 1992, and 1998.

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). From 1985 through 1990, the 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). These estimates had low precision and appeared to be positively biased, particularly during the late run (Bernard and Hansen 1992).

ADF&G initiated studies in 1984 to determine whether an acoustic assessment program could provide timely and accurate daily estimates of Chinook salmon passage in the Kenai River (Eggers et al. 1995). Acoustic assessment of Chinook salmon in the Kenai River is complicated by the presence of more abundant sockeye salmon (*O. nerka*), which migrate concurrently with Chinook salmon. From 1987 to 2009, sockeye salmon escapement estimates generated by the river mile-19 sockeye salmon sonar project ranged from 625,000 to 1,600,000 fish (Westerman and Willette 2011) while late-run Chinook salmon passage estimates generated by the Chinook salmon sonar project at river mile 8.5 ranged from 29,000 to 56,000 fish. Dual-beam sonar was initially chosen for the Chinook salmon sonar project because of its ability to estimate acoustic size (target strength), which was to serve as the discriminatory variable to systematically identify and count only Chinook salmon. Because of the considerable size difference between Chinook salmon and other fish species in the Kenai River, it was postulated that dual-beam sonar 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). Target strength (TS) is the proportion of the incident energy backscattered from a fish (a way of measuring "loudness" of the returning echo), corrected for position of the fish in the beam. Sockeye salmon are smaller, on average, than Chinook salmon, and were assumed to have smaller target strength. A target strength threshold was established to censor small fish. Sockeye salmon also were thought to migrate primarily near the bank, therefore a range or distance threshold was also imposed. Since 1987, "TS-based estimates" based on these two criteria have been the primary basis for monitoring the number of Chinook salmon returning to the Kenai River, for comparison with established escapement goals.

TS-based estimates generated from dual-beam sonar were consistently lower than the 1987–1990 mark–recapture estimates (Eggers et al. 1995). The inconsistencies between sonar and mark–recapture estimates were greatest during the late run, presumably due to the mark–recapture biases mentioned above.

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 three-dimensional position of an acoustic target in the sonar beam. Consequently, the direction of travel for each target and the three-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 2005b). It also interfaced with improved fish-tracking software, which reduced the interference from boat wake, and improved fish-tracking capabilities (Burwen and Bosch 1996). The split-beam system was deployed side-by-side with the dual-beam and was run concurrently for much of the 1994 season (Burwen et al. 1995). Both systems detected comparable numbers of fish. The split-beam data confirmed earlier studies (Eggers et al. 1995) showing that most fish targets were strongly oriented to the river bottom. However, experiments conducted with the split-beam system could not confirm that Chinook salmon could be discriminated from sockeye salmon based on target strength. Modeling exercises performed by Eggers (1994) also questioned the feasibility of discriminating between Chinook and sockeye salmon using target strength. It was hypothesized that discrimination between the two species was primarily accomplished using range thresholds on the acoustic data that exploited the known 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.

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 river mile-8.5 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 the concurrent sonar experiment using live fish tethered in front of the split-beam sonar, most sockeye salmon had mean target strengths exceeding the target strength threshold.

Radio telemetry projects were implemented in 1996 and 1997 to estimate the magnitude of bias introduced into the Chinook salmon passage estimates during periods of high sockeye salmon passage (Hammarstrom and Hasbrouck 1998, 1999). The radio telemetry 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 is greatest. Although the precision of both the radio telemetry estimates and the previous mark–recapture estimates was similar, the use of radio telemetry 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.

An investigation in 1999 (Burwen et al. 2000) attempted to identify alternative sites that were not only above tidal influence but also exhibited stronger bank orientation of sockeye salmon, where range thresholds would be more effective. The investigation concentrated on a site located at river mile 13.2 that was upstream of tidal influence, but downstream of major spawning areas. Gillnetting data indicated that there were fewer sockeye salmon in the offshore area at the alternative site than at the current site. However, there were still relatively large numbers of sockeye salmon present in the offshore area of the alternative site during peak migration periods as well as high numbers of Chinook salmon present in the nearshore area. The alternate sonar site also had several disadvantages over the current site including more boat traffic, less acoustically favorable bottom topography, and higher background noise, resulting in difficult fish tracking conditions.

The inriver drift gillnetting program, originally designed to collect age, sex, and length 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 effectively fished 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 used as a comparison 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, 2003-2005, 2007a-b, 2010).

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, we refined the species discrimination algorithm for TS-based estimates, censoring (removing from analysis) selected hourly samples based on fish behavior. During 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, uses 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), and have proven useful for tracking short term trends in Chinook salmon abundance.

The second alternative estimate is 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 is 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 is 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 2002–2006. Because echo length measurements can be corrupted when two 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 three-dimensional fish location, we began monitoring the distance between fish in the beam and censoring those within 1 meter of any other fish[1] before fitting the mixture model. ELSD-based estimates published in the 2007 report (Miller et al. 2011) supplant the previously published early run estimates.

ADF&G began testing dual-frequency identification sonar (DIDSON[2]) 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 2005b), with the advantage that images can be obtained in dark or turbid waters. Fish size was immediately evident from DIDSON footage[3] 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 with a standard DIDSON operating at 1.8 MHz using live tethered salmon showed that precise estimates of fish length could be obtained from DIDSON images at ranges up to 12 m (Burwen et al. 2007).

Ranges to 30 m are required to adequately insonify the Kenai River at the current sonar location (river mile 8.5), and subsequent advancements in DIDSON technology resulted in improved long-range image resolution. The development of a lower frequency DIDSON model (i.e., “long-range” DIDSON operating at 1.1 MHz) in 2004 extended the range of high-frequency operation to approximately 30 m, and a high resolution lens developed in 2007 improved the resolution by nearly a factor of two. Tethered-fish experiments conducted in 2007 with a long-range DIDSON model and high-resolution lens yielded promising results at ranges up to at least 22 m with the potential for further ranges after updating the sonar firmware (Burwen et al. 2010; Miller et al. 2011).

In this report, we present daily and seasonal TS-based, net-apportioned, and ELSD-based split-beam sonar estimates of Kenai River Chinook salmon inriver abundance for 2008 and 2009. We also summarize the results of continued testing and development of DIDSON technology in the Kenai River, including additional tethered fish experiments at ranges to 32 m, and development of methods to track, count, and estimate the size of fish using manual and automated methods.

OBJECTIVES

The stated primary objective of this project was to produce daily and seasonal target-strength-based (TS-based) estimates of the inriver runs of Chinook salmon to the Kenai River such that the upper and lower bounds of the 95% confidence interval were within 5% of the seasonal (early- and late-run) point estimate. This estimate was based on target strength and range thresholds, with hourly samples subject to censoring based on fish behavior. In keeping with previous practice, the

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1 Essentially, fish swimming close to other fish are assumed not to be Chinook salmon.

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

3 DIDSON imagery resembles video footage taken from above the river’s surface.

precision criterion addressed only the sampling error of the estimates, but not errors due to species classification, tracking, and detection.

The second objective was to produce weekly and seasonal ELSD-based estimates of inriver runs of Chinook salmon to the Kenai River such that the seasonal estimate was within 10% of the true value 95% of the time. This estimate was based on mixture modeling of ELSD measurements subject to censoring based on fish behavior. The precision criterion for ELSD-based estimates was intended to address sampling error and species classification, but not target tracking or detection.

In addition, daily ELSD-based estimates of Chinook salmon passage were produced based on a calibrated ELSD threshold. This estimate served as a proxy for the ELSD-based estimate mentioned above, which was produced only once per week.

Objectives related to DIDSON testing were as follows: 1) to estimate the error standard deviation associated with measuring, from DIDSON images, the length of Chinook salmon tethered at distances 15 to 30 m from the transducer; 2) to establish an inseason data-processing protocol that would enable ADF&G staff to generate inseason estimates of Chinook salmon passage in the Kenai River using SMC software to manually track and measure fish; and 3) to explore the potential for using Myriax[4] software to improve data-processing efficiency by implementing an automated process for tracking and sizing fish.

METHODS

STUDY AREA

The Kenai River drainage is approximately 2,150 square miles. It is glacially influenced, with discharge rates lowest during winter, increasing throughout the summer, and peaking in August (USDA 1992). The Kenai River has 10 major tributaries, many of which provide important spawning and rearing habitat for salmon. Tributaries include the Russian River, Skilak River, Killey River, Moose River, and Funny River.

The Kenai River drainage is located in a transitional zone between a maritime climate and a continental climate (USDA 1992). The geographic position and local topography influence both rainfall and temperature throughout the drainage. Average annual (1971–2006) precipitation for the City of Kenai, located at the mouth of the Kenai River, is 48 cm (WRCC 2008). Average summer (June, July, and August) temperature for the City of Kenai is 12°C (WRCC 2008).

SITE DESCRIPTION

The Chinook salmon sonar site was located 14 km (8.5 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 24 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

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

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.[5]

SPLIT-BEAM SONAR DATA COLLECTION AND PROCESSING

Acoustic Sampling

A Hydroacoustic Technology Inc. (HTI) split-beam sonar system was operated from 16 May to 3 August in 2008[6] and from 16 May to 4 August in 2009.[7] Components of the system are listed in Table 1 and are further described in HTI manuals (HTI 1996, 1997). A brief explanation of the theory of split-beam sonar and its use in estimating target strength can be found in Appendix A1. A more detailed explanation can be found in Ehrenberg (1983).

Sonar System Configuration

Sonar sampling on both banks was controlled by electronics housed in a tent located on the right (north) bank of the river. Communication cables were connected to the sonar equipment on both banks. Cables leading to the left-bank equipment were suspended above the river at a height that would not impede boat traffic (Figure 3). Steel tripods were used to deploy the transducers offshore. One elliptical, split-beam transducer was mounted horizontally (side-looking) on each tripod. At the start of the season, the transducer tripods were placed on each bank in a position close to shore but still submerged at low tide. Throughout the season, water levels at low tide increased approximately 1.2 m in 2008 and 1.7 m in 2009. Rising water level and heavy debris accumulation resulted in occasional relocation of transducer tripods. Total range insonified during the 2008 season by both (right and left bank) sonar beams ranged from approximately 60.1 to 65.8 m (Figure 4). Total range insonified during the 2009 season ranged from approximately 59.8 to 79.0 m (Figure 5).

Vertical and horizontal aiming of each transducer was remotely controlled by a dual-axis electronic pan-and-tilt system. A digital readout from an angular measurement device (attitude sensor) attached to the transducer indicated the aiming angle in the vertical and horizontal planes. In the vertical plane, the transducer was aimed using an oscilloscope and chart recorder to verify that the sonar beam was aligned along the river bottom. In the horizontal plane, the transducer was aimed perpendicular to the river flow to maximize probability of insonifying fish from a lateral aspect. The range encompassed by each transducer was determined by the river bottom contour and the transducer placement. Transducers were placed to maximize the counting range and to fully insonify the cross section of the river between the right- and left-bank transducers.

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[5] In 2005, approximately 98% of the early-run Chinook salmon sport fishing effort and 86% of the late-run effort occurred upstream of the Chinook salmon sonar site (Eskelin 2007).

[6] Sampling was terminated prior to 10 August due to numerous fish holding in the sonar beam, making it difficult to accurately track fish targets. Chinook passage was estimated through 3 August.

[7] Sampling was terminated prior to 10 August due to low Chinook salmon passage (three consecutive days of passage less than 1% of the total to date).

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 information from the attitude sensor, a detailed visualization of how the water column above the bottom substrate is insonified by the acoustic beam can be generated (Figures 6 and 7). 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 new 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 to the thalweg (Miller et al. 2004).

Sonar System Calibration

Prior to sonar sampling, HTI performed reciprocity calibrations with a naval standard transducer to ensure consistent target strength parameters for among-year sonar comparisons. Calibrations were verified at the calibration facility with a 38.1-mm tungsten carbide sphere (Foote and MacLennan 1984) and verified at the sonar site using the same sphere at the beginning of each season. For each standard sphere measurement, we recorded the maximum background noise level and voltage threshold in addition to the data collected automatically by the onboard signal-processing software.

Sampling Procedure

A systematic sampling design (Cochran 1977) was used to estimate fish passage from each bank for 20 minutes each hour. Although the sonar system is capable of sampling both banks continuously, data collection was restricted to 20-min samples per hour to limit the data processing time and personnel required to estimate daily fish passage. The equipment was automated to sample the right bank for 20 min starting at the top of each hour followed by a 20-min left-bank sample. The system was inactive for the third 20-min period unless ancillary sonar studies were being conducted. This routine was followed 24 hours per day and seven days per week unless a transducer on one or both banks was inoperable. A test of this sampling design in 1999 found no significant difference between estimates of Chinook salmon passage obtained using 1-hour counts and estimates obtained by extrapolating 20-min counts to one hour (Miller et al. 2002).

Because fish passage rates are related to tides (Eggers et al. 1995), tide stage was recorded at the top of each hour and at 20 min past each hour to coincide with the start of each 20-min sample. Tide stage was determined using water level measurements taken from depth sensors attached to the sonar transducers.

Data Collection Parameters

An HTI Model 244 digital echo sounder (DES) was used for data collection. Key data collection parameters (echo sounder settings) are listed in Table 2 with complete summaries by bank in Appendices B1 and B2. Most echo sounder settings were identical for each bank and remained consistent throughout the sampling period. High power and low gain settings were used to maximize SNR. The transmitted pulse width was set relatively low to maximize resolution of individual fish and SNR.

Data Acquisition

The DES performed the initial filtering of returned echoes based on user-selected criteria (Table 3; Appendices B1 and B2) that are input via software stored on an external data processing computer (Table 1, Figure 8). The DES recorded the start time, date, and number of pings (acoustic pulses) processed for each sample.

Echoes that originated in the transducer near field (≤2.0 m) were excluded because fluctuating sound intensity near the face of the transducer results in unreliable data (Simmonds and MacLennan 2005a). Echoes that exceeded maximum vertical and horizontal angles off-axis were also excluded to prevent consideration of unreliable data near the edge of the sonar beam.

Voltage thresholds were used to exclude most background noise from spurious sources such as boat wake, the river bottom, and the water surface. Collection of data from unwanted noise causes data management problems and makes it difficult to distinguish echoes originating from valid fish targets. The level of background noise is determined largely by the dimensions of the sonar beam in relation to the depth of the river. Because the water level at the sonar site is strongly influenced by tidal stage (vertical fluctuations of more than 4 m), the background noise fluctuates periodically, with the lowest noise levels during high tide and the highest levels during falling and low tides. Voltage thresholds corresponding to a −35 dB target on-axis were selected for each bank as the lowest threshold that would exclude background noise at low tide when noise was at a maximum.

For each echo passing initial filtering criteria, the DES wrote information in ASCII file format (*.RAW files). This file provided a record of all raw echo data, which could then be used by other post-processing software. A uniquely-named file was produced for each sample hour. The file stored the following statistics for each tracked echo: 1) distance from the transducer, 2) sum channel voltage produced by the echo, 3) pulse widths measured at −6 dB, −12 dB, and −18 dB down from the peak voltage, 4) up-down (vertical) angle, left-right (horizontal) angle, and 5) multiplexer port.

The sum channel voltage from the DES was also output to a printer, to a Nicolet 310 digital storage oscilloscope, and to a Harp HC2 color chart monitor. Output to the printer was filtered only by a voltage threshold, which was set equal to the DES threshold. Real-time echograms were produced for each sample. The echograms were used for data backup and transducer aiming, and to aid in manual target tracking. Voltage output to the oscilloscope and color monitor was not filtered. Monitoring the unfiltered color echogram ensured that sub-threshold targets were not being unintentionally filtered. Advanced features on the digital oscilloscope aided in performing field calibrations with a standard target and in monitoring the background noise level relative to the voltage threshold level.

Fish Tracking and Echo Counting

Using HTI proprietary software called TRAKMAN 1400 (version 1.31), echoes (from the *.RAW files) were manually grouped (tracked) into fish traces. TRAKMAN produces an electronic chart recording for all valid echoes collected during a 20-min sample. Selected segments of the chart can be enlarged and echoes viewed on a Cartesian grid. Echoes that displayed a sequential progression through the beam were selected by the user and classified into fish traces (targets). TRAKMAN then produced two output files. The first file contained each echo that was tracked from a valid target (*.MEC file) and included the following data for each echo: track (fish) number; ping number; estimated *X* (left-right), *Y* (up-down), and *Z* (distance from the transducer) coordinates in meters, where the transducer face is the origin of the coordinate system; pulse widths measured at −6 dB, −12 dB, and −18 dB amplitude levels; combined beam pattern factor in dB; and target strength in dB. The second fixed-record ASCII file (*.MFS file) summarized data from all echoes associated with an individual tracked target and output the following fields by target: track (fish) number; starting and ending ping numbers; total number of echoes tracked; starting *X*, *Y*, and *Z* coordinates; distance traveled (m) in the *X*, *Y*, and *Z* directions; mean velocity (m/sec); and mean target strength (dB). Direction of travel was estimated by calculating the simple linear regression of *X*-axis position (distance up- or downriver from the beam axis) on ping number, for echoes with absolute *X*-axis angle less than 5 degrees. On the right bank, a target was classified as upstream-bound if the slope of the regression was negative or downstream-bound if the slope was positive. On the left bank the criteria were reversed. Only upstream targets contributed to estimates of Chinook salmon passage. A diagram illustrating data flow can be found in Appendix C1.

Downstream-moving targets (and occasionally upstream-moving targets during a strong flood tide) were further classified as fish or debris primarily by looking at the angle of passage and degree of movement in the *Z*-axis (distance from transducer) as the target moved through the acoustic beam. For debris, the angle of passage through the beam is constant with little change in the range as it passes through the beam. Consequently, debris resembles a line drawn on the echogram with a straightedge. A fish typically leaves a meandering trace that reflects some level of active movement as it passes through the acoustic beam. Separate summary files were generated for tracked targets classified as debris (i.e., *.DEC and *.DFS files). Except for debris, only targets comprising echoes displaying fish-like behavior were tracked. Echoes from structures, boat wakes, and sport-fishing tackle were ignored.

Data Analysis

Tidal and Temporal Distribution

Falling tide was defined as the period of decreasing river depth readings, low tide as the period of low static readings, and rising tide as the period of both increasing readings and high static readings (i.e., high slack tide). The rising and high slack tides were combined into one category because of the very short duration of high slack tide at the sonar site. Data from both banks were combined to summarize fish passage by tide stage (falling, low, and rising) for both upstream- and downstream-traveling fish. Data were first filtered using target strength and range criteria.

Spatial Distribution

Knowledge of the spatial distribution of fish is desirable for developing strategies for insonifying a specific area, for determining appropriate transducer beam dimensions, and for evaluating the probability of detecting fish near the edge of the acoustic beam (Mulligan and Kieser 1996).

Fish range (*Z*-axis) distributions (distance from shore) for each bank were plotted separately for upstream- and downstream-moving targets. Fish range distributions were calculated using the mean distance from transducer for each target. Before 2000, range distribution comparisons were made using z_m, the distance from the face of the transducer to the target location (Miller et al. 2002). These comparisons provided information on distribution of fish targets from the face of the transducer. However, the comparisons were poor descriptors of actual fish range distributions across the river because tripod–transducer locations changed throughout the season. Beginning in 2000, estimates of distance from bank were standardized to the nearest shore transducer deployment for that bank based on distances to a fixed point (cable bipod) on the right bank (Figures 3–5):

$$z_a = z_m + \left| z_t - z_n \right|, \tag{1}$$

where

z_a = adjusted range (in meters),

z_t = distance (in meters) from right bank bipod to transducer, and

z_n = distance (in meters) from right bank bipod to nearest shore (right bank or left bank) deployment location.

Range distribution plots were produced with the adjusted (standardized) range estimates allowing for comparisons of actual fish target locations across the river. The end range in these distribution graphs was the maximum distance covered (generally to the thalweg) by the sonar beam on that particular bank.

Vertical distributions were plotted by direction of travel (upstream and downstream) and tide stage. Vertical distributions were calculated from the midpoint angle off-axis[8] in the vertical plane as follows:

$$\theta_v = \arcsin \frac{v_s + \left(\frac{d_v}{2} \right)}{z_m}, \tag{2}$$

where

θ_v = vertical angle-off-axis midpoint (degrees),
v_s = starting vertical coordinate (in meters), and
d_v = distance traveled in vertical direction (in meters).

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8 Axis or acoustic axis refers to the center of the beam in either the vertical or horizontal plane.

Upstream Midriver Fish Passage Estimates

The following procedures were used to estimate the number of salmon of all species that migrated upstream past the sonar site in midriver, where midriver is defined as at least 15 m from the right-bank transducer and at least 10 m from the left-bank transducer. This "unfiltered"[9] estimate was used as the basis for all other estimates described herein. The remaining estimates pertain only to Chinook salmon, and differ in the manner in which species classification was carried out.

As mentioned above, the sonar operated 20 minutes per hour from each bank of the river, 24 hours per day. The number of salmon-sized fish (hydroacoustic variable *y*) passing midriver and upstream through the sonar beams during day *i* was estimated as follows:

$$\hat{y}_i = 24\hat{\bar{y}}_i \tag{3}$$

where

$$\hat{\bar{y}}_i = \frac{1}{n_i}\sum_{j=1}^{n_i}\hat{y}_{ij} , \tag{4}$$

where n_i is the total number of hours (j) during which fish passage was estimated[10] for day *i*, and

$$\hat{y}_{ij} = \sum_{k=1}^{2}\hat{y}_{ijk} , \tag{5}$$

where $\hat{y}_{ijk}$ is the estimate of upstream midriver fish passage on bank *k* during hour *j* of day *i*.

When the sonar was functional on bank *k* during hour *j* of day *i*, then hourly upstream midriver fish passage was estimated as follows:

$$\hat{y}_{ijk} = \frac{60}{m_{ijk}}c_{ijk} \tag{6}$$

where

m_{ijk} = number of minutes (usually 20) sampled from bank *k* during hour *j* of day *i*, and

c_{ijk} = number of upstream-bound fish greater than 15 m from the right-bank transducer and greater than 10 m from the left-bank transducer, for bank *k*, hour *j*, and day *i*.

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9 These are known in-house as "unfiltered" estimates in the sense that TS and time-varying range thresholds have not been applied. Technically, these counts are still filtered by time-invariant minimum range criteria to exclude fish very close to the transducer. These fish are subject to imperfect detection due to the narrowness of the sonar beams at close range, and have been assumed to be composed almost entirely of sockeye salmon.

10 Hours for which passage is not estimated include hours when equipment on both banks were not functional (<1% of time).

When the sonar system was functional on one bank but not the other, the passage on the non-functional bank k' was estimated from passage on the functional bank k as follows:

$$\hat{y}_{ijk'} = \hat{R}_{ikt}\hat{y}_{ijk}\,, \tag{7}$$

where the estimated bank-to-bank ratio R_{ikt} for day i and tide stage t is calculated by pooling counts from all hours at tide stage t (set J_t) during the previous two days (to ensure adequate sample size):

$$\hat{R}_{ikt} = \frac{\sum_{j\in J_t}\hat{y}_{(i-2)jk'} + \sum_{j\in J_t}\hat{y}_{(i-1)jk'}}{\sum_{j\in J_t}\hat{y}_{(i-2)jk} + \sum_{j\in J_t}\hat{y}_{(i-1)jk}}. \tag{8}$$

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

$$\hat{V}\left[\hat{y}_i\right] \cong 24^2(1-f)\frac{\sum_{j=2}^{24}\phi_{ij}\phi_{i(j-1)}\left(\hat{y}_{ij}-\hat{y}_{i(j-1)}\right)^2}{2\sum_{j=1}^{24}\phi_{ij}\sum_{j=2}^{24}\phi_{ij}\phi_{i(j-1)}}, \tag{9}$$

where f is the sampling fraction (proportion of time sampled daily, usually 0.33), and ϕ_{ij} is 1 if $\hat{y}_{ij}$ exists for hour j of day i, or 0 if not.

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

$$\hat{Y} = \sum_i \hat{y}_i \text{ and} \tag{10}$$

$$\hat{V}\left[\hat{Y}\right] = \sum_i \hat{V}\left[\hat{y}_i\right]. \tag{11}$$

Target Strength (TS)-based Chinook Salmon Passage Estimates

To produce TS-based estimates, upstream fish counts (c_{ijk}) were filtered using two criteria: target strength (greater than −28 dB) and distance from the transducer (greater than customized range thresholds, see below). TS-based estimates were the standard metric for comparison with escapement goals. Although target strength and range thresholds do not exclude all sockeye salmon (see Introduction, also Eggers 1994 and Burwen et al. 1995), we continued their use for historical comparability, while we developed other means of discriminating between fish species.

Range thresholds differed by bank and over time. Range thresholds were changed when transducer tripods were moved or when fish distribution and behavior indicated that species discrimination could be improved. In 2008, the left-bank range threshold remained the same (10 m) throughout the season (16 May to 3 August). The right-bank range threshold was 15 m from 16 May to 15 July and increased to 20 m from 16 July to 3 August (Figure 4). In 2009, the left-bank range threshold remained the same (10 m) throughout the season (16 May to 4 August). The right-bank range threshold in 2009 was 15 m from 16 May to 25 July, 20 m for 26 July, and 25 m from 27 July to 4 August (Figure 5).

Target strength was calculated for individual echoes and averaged for each fish trace (Appendix A1). TS-based daily passage estimates for day *i*, $\hat{y}_{TSi}$, were calculated using equations 3–10 after substituting c'_{ijk} for c_{ijk}, where

c'_{ijk} = number of upstream-bound fish on bank *k* meeting range and target-strength criteria during t_{ijk}.

where t_{ijk} is the tide stage on bank *k* for hour *j* of day *i*.

Additionally, for TS-based estimates, some sample hours were excluded when there was evidence (greater than 50% of targets in closely-spaced groups) of increased sockeye salmon abundance. Under these conditions, and at the discretion of the project leader, the entire hourly sample was dropped and the daily estimate was based on the remaining samples. Censored hourly samples for both years are listed in Appendices D1–D2.

Variance estimates consider only sampling error due to temporal expansion, not error due to imperfect detection or tracking of fish, nor error due to imperfect species classification. Therefore, equation 11 represents only a minimal estimate of variance.

Downstream TS-based Chinook salmon passage[11] for day *i* was estimated as follows:

$$\hat{x}_{TSi} = \hat{y}_{TSi} \frac{\sum_j \sum_k d_{ijk}}{\sum_j \sum_k c'_{ijk}}, \qquad (12)$$

where d_{ijk} is the number of downstream-bound fish on bank *k* meeting range and target-strength criteria during t_{ijk}.

Net-Apportioned Chinook Salmon Passage Estimates

The "net-apportioned" daily estimate of Chinook salmon passage was calculated by multiplying the upstream midriver fish passage estimate by the estimated proportion of Chinook salmon ($\hat{\pi}_{NETi}$) in 5-inch and 7.5-inch drift net catches near the sonar site (Eskelin 2010).

$$\hat{y}_{NETi} = \hat{y}_i \hat{\pi}_{NETi} \qquad (13)$$

The variance estimate followed Goodman (1960):

$$\hat{\mathrm{var}}(\hat{y}_{NETi}) = \hat{y}_i^2 \, \hat{\mathrm{var}}(\hat{\pi}_{NETi}) + \hat{\pi}_{NETi}^2 \, \hat{\mathrm{var}}(\hat{y}_i) - \hat{\mathrm{var}}(\hat{\pi}_{NETi}) \hat{\mathrm{var}}(\hat{y}_i) \qquad (14)$$

Echo Length Standard Deviation (ELSD)-based Chinook Salmon Passage Estimates

Alternative estimates based on echo length standard deviation were first produced in 2002, based on work initiated in the mid-1990s that showed ELSD to be a better predictor of fish size than target strength (Burwen et al. 2003). ELSD-based estimates are generated by fitting a statistical species or age mixture model to sonar and netting data. Mixture model methodology is described below.

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[11] These quantities are reported for historical comparability only.

Mixture Models and Thresholds

Mixture models are useful for extracting information from the observed frequency distribution of a carefully-selected measurement. Imagine being able to observe the exact length, but not the species, of every fish passing the sonar. The distribution of such measurements might look something like Figure 9A. If we have knowledge of the sockeye and Chinook salmon length distributions, the shape of the overall distribution can tell us quite a lot about the relative abundance of sockeye and Chinook salmon. For instance, if we know that sockeye salmon do not exceed 70 cm in length, and that small Chinook salmon are very rare, then we can conclude that the left hand mode of the distribution is almost all sockeye salmon and that the species composition is perhaps 50:50 sockeye to Chinook salmon. Mixture model analysis is merely 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.

As another example, imagine that there are substantial numbers of small Chinook salmon, and that there is error in the length measurements. The effect of the measurement error is to cause the modes to begin to overlap, reducing the ability to detect detail in the length distribution and reducing the precision of the estimates (e.g., Figure 9B). Here, the human brain could still hazard a guess about the true species composition, but to quantify the uncertainty is more difficult, and is best accomplished by fitting a mixture model.

Mixture models can also be conducted on measurements of other quantities, like ELSD, that are related to length. Given quantitative knowledge of the relationship between length and ELSD (gleaned from tethered fish experiments; Burwen et al. 2003), it is straightforward to convert from length units to ELSD units by including the slope, intercept, and mean squared error of the relationship in the mixture model (Equation 17 below). The more closely related the surrogate measurement is to the one of interest, the more the 2 distributions will resemble each other and the better the resulting estimate will be. Because ELSD is a reasonably good predictor of fish length (Figure 10)[12], the observed frequency distribution of ELSD supplies valuable information about species composition, even though there is some overlap of ELSD measurements between species. An ELSD distribution with greater mass on the left hand side indicates an abundance of sockeye salmon, whereas more mass on the right hand side indicates more Chinook salmon (Figure 11). The relationship between target strength and fish length is less precise than between ELSD and fish length (Burwen et al. 2003) and it is also less predictable (the relationship changes over time). Furthermore, TS-based species discrimination is implemented in the form of a threshold (TS less than −28dB are sockeye salmon; TS greater than −28dB are Chinook salmon), and the threshold approach has several important drawbacks. When distributions overlap between species, thresholds are unbiased only when compensating errors are equal (e.g., when the number of sockeye salmon exceeding the threshold is equal to the number of Chinook salmon beneath the threshold). But the size of the respective errors depends on the species composition itself (Figure 11): when sockeye salmon are dominant there are more misclassified sockeye salmon than misclassified Chinook salmon (and the resulting estimate of Chinook

[12] ELSD is a good predictor of length, though not as precise as the DIDSON length estimates. DIDSON-measured length will be an excellent candidate for mixture model analysis in the future.

salmon proportion is too high), and when Chinook salmon are dominant there are more misclassified Chinook salmon than misclassified sockeye salmon (and the resulting estimate of Chinook salmon proportion is too low). Thus, threshold-based discrimination is subject to bias that worsens for species proportions near zero and one. Furthermore, threshold-based estimates are sensitive to fish size distributions. For instance, in the example illustrated in Figure 11, the number of Chinook salmon misclassified as sockeye salmon (number with ELSD < 2.7) depends largely on the relative abundance of small Chinook salmon, which changes over time.[13]

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). As a result, it is not subject to the same pitfalls as thresholds. There is less bias against extreme proportions, and the estimates are germane to the entire population of Chinook salmon, not just those Chinook salmon larger than sockeye salmon. Finally, as long as length and hydroacoustic measurements are paired in time, mixture model estimates of species proportions are insensitive to temporal changes in fish size distribution.

Mixture Model Details[14]

Echo length standard deviation (ELSD) was calculated as

$$ELSD = \sqrt{\sum_{j=1}^{n_E} \left(EL_j - \overline{EL}\right)^2 \Big/ \left(n_E - 1\right)}, \tag{15}$$

where n_E is the number of echoes and EL_j is the length of the j^{th} echo measured in 48 kHz sample units at −12 dB or higher, depending on peak echo amplitude. If peak amplitude was greater than 12 dB above the voltage threshold, then echo length was measured at 12 dB below peak amplitude. If peak amplitude was 6–12 db above the threshold, echo length was measured at the threshold. If peak amplitude was less than 6 dB above threshold, EL_j was not defined.

Fish traces with fewer than eight defined measurements of −12 dB pulse width ($n_E < 8$) were excluded from the mixture model; they were assumed to be sockeye salmon because they generally occurred at close ranges, where the beam is very narrow. These fish generally comprised only 1–3% of all fish in the dataset.

The probability density function (PDF) of ELSD (denoted here as y, for convenience) was modeled as a weighted mixture of two component distributions arising from sockeye and Chinook salmon (Figure 12):

$$f(y) = \pi_S f_S(y) + \pi_C f_C(y), \tag{16}$$

where $f_S(y)$ and $f_C(y)$ are the PDFs of the sockeye and Chinook salmon component distributions, and the weights π_S and π_C are the proportions of sockeye and Chinook salmon in the population.

[13] In fact, use of such a threshold by itself does not discriminate Chinook salmon from sockeye salmon, but rather, distinguishes large Chinook salmon from sockeye salmon and small Chinook salmon.

[14] Statistical notation in this section may overlap with the notation used in the remainder of the report. Specifically, the meaning of variables *x*, *y*, and *z* are unique to this section.

Individual observations of y for fish I were modeled as normal random variables whose mean was a linear function of fish length x:

$$y_i = \beta_0 + \beta_1 x_i + \gamma z_i + \varepsilon_i \, , \tag{17}$$

where β_0 is the intercept; β_1 the slope; γ is the mean difference in y between sockeye and Chinook salmon after controlling for length; z_i equals 1 if fish i was a sockeye salmon, or 0 if Chinook salmon; and the error ε_i is normally distributed with mean 0 and variance σ^2.

Thus, the component distributions $f_S(y)$ and $f_C(y)$ were functions of the length distributions $f_S(x)$ and $f_C(x)$ and the linear model parameters β_0, β_1, γ, and σ^2 (Figure 12). The species proportions π_S and π_C were the parameters of interest.

Length measurements were obtained from fish captured by gillnets (e.g., Eskelin 2010) immediately downstream of the sonar site. Length data 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 as 3-component normal age mixtures:

$$f_S(x) = \theta_{S1}\, f_{S1}(x) + \theta_{S2}\, f_{S2}(x) + \theta_{S3}\, f_{S3}(x) \text{ and} \tag{18}$$

$$f_C(x) = \theta_{C1}\, f_{C1}(x) + \theta_{C2}\, f_{C2}(x) + \theta_{C3}\, f_{C3}(x), \tag{19}$$

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

$$f_{Sa}(x) \sim N(\mu_{Sa},, \tau^2{}_{Sa}) \text{ and} \tag{20}$$

$$f_{Ca}(x) \sim N(\mu_{Ca},, \tau^2{}_{Ca}), \tag{21}$$

where μ is mean length-at-age and τ is the standard deviation. The overall design was therefore a mixture of (transformed) mixtures. That is, the observed hydroacoustic data were modeled as a two-component mixture (sockeye and Chinook salmon) of echo length standard deviation (y), each component of which was transformed from a 3-component normal age mixture of fish length (x).

Bayesian statistical methods were employed because they provided realistic estimates of uncertainty and the ability to incorporate 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 (1,1) prior. Age proportions $\{\theta_{Sa}\}$ and $\{\theta_{Ca}\}$ were assigned informative Dirichlet priors based on a hierarchical analysis of historical data (Appendix E1). Likewise, informative normal priors based on historical data were used for the length-at-age means μ and standard deviations τ (Appendix E1). Informative priors were used for regression parameters β_0, β_1, γ, and σ^2 based on linear statistical models of tethered fish data reported by Burwen et al. (2003).

WinBUGS uses Markov chain Monte Carlo methods to sample from the joint posterior distribution of all unknown quantities in the model. We started three Markov chains for each run and monitored Gelman-Rubin statistics to assess convergence (Gelman et al. 2004). Burn-in periods of 10,000 or more samples were used. Samples were thinned 10 to 1, and at least 10,000 samples per chain were retained.

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.

Sample size limitations occasionally necessitated pooling the data over more than one day. WinBUGS code for the ELSD mixture model is in Appendix E2. Figure 12 is a flow chart with major components of the ELSD mixture model. See also Fleischman and Burwen (2003).

Behavior-Censored ELSD Mixture Model Chinook Salmon Passage Estimates

Behavior-censored ELSD mixture model estimates of daily Chinook salmon passage were obtained as follows. First, the proportion p_{Mi} of sonar-sampled fish that satisfied the sample size criterion ($n_E \geq 8$) and the proportion p_{Bi} that satisfied the behavior criterion (fish could not be less than 1 m of range from another fish) for day *i* were calculated. Then the ELSD frequency distribution from fish meeting both criteria was analyzed with the mixture model methods described above, yielding $\hat{\pi}_{Ci}$, the posterior mean of the Chinook salmon fraction in the reduced data set for day *i*.

The estimated number of Chinook salmon passing during day *i* was then calculated as follows:

$$\hat{y}_{ELi} = \hat{y}_i \hat{\pi}_{Ci} p_{Mi} p_{Bi} , \tag{22}$$

with estimated variance

$$\hat{\text{var}}(\hat{y}_{ELi}) = \left[\hat{y}_i^2 \, \hat{\text{var}}(\hat{\pi}_{Ci}) + \hat{\pi}_{Ci}^2 \, \hat{\text{var}}(\hat{y}_i) - \hat{\text{var}}(\hat{\pi}_{Ci}) \hat{\text{var}}(\hat{y}_i)\right] \hat{p}_{Mi}^2 \hat{p}_{Bi}^2 , \tag{23}$$

where $\hat{\text{var}}(\hat{\pi}_{Ci})$ is the squared posterior standard deviation from the mixture model. Uncertainty about p_{Mi} and p_{Bi} was ignored because it was negligible compared to $\hat{\text{var}}(\hat{\pi}_{Ci})$.

Adaptive ELSD Threshold Passage Estimate

The ELSD threshold estimate of daily Chinook salmon passage was calculated by following Equations 1–9 after substituting c''_{ijk} for c_{ijk}, where

c''_{ijk} = number of upstream-bound fish greater than 15 m from the right-bank transducer and greater than 10 m from the left-bank transducer meeting sample size, fish behavior, and echo-length criteria during t_{ijk}.

To meet the ELSD threshold criteria, fish needed 8 or more echoes with valid measurements of −12 dB pulse width, could never be within 1 m of another fish, and the standard deviation of −12 dB pulse width needed to exceed the daily ELSD threshold. The value of the ELSD threshold was updated weekly by applying the mixture model methods described above to recent ELSD data and determining the threshold that resulted in daily passage estimates that closely approximated the mixture model estimates.

Expansion for Missing Days

In 2008, the sonar was terminated early on 3 August because numerous fish were holding in the sonar beam, making it difficult to accurately track fish targets. Passage estimates were expanded for the missing days as follows. Late-run passage through 10 August ($\hat{Y}_e$) was estimated by dividing the estimated upstream midriver passage for the 2008 sonar period (through 3 August) by the mean proportion of passage ($\overline{p}$) through 3 August for the 10 years (1987–1988, 1990, 1992–1993, 1995, and 1998–2001) when the sonar project operated through at least 9 August:

$$\hat{Y}_e = \frac{\hat{Y}}{\overline{p}} \tag{24}$$

where

$$\overline{p} = \frac{\sum_g p_g}{10}, \tag{25}$$

$$p_g = \frac{\sum_{i=1July}^{3Aug} \hat{y}_i}{\sum_{i=1July}^{10Aug} \hat{y}_i}, \tag{26}$$

and g was the year. The variance of $\hat{Y}_e$ was calculated as follows:

$$\hat{V}\left[\hat{Y}_e\right] = \hat{V}\left[\hat{Y}\right]\overline{p}^{-2} + \hat{V}\left[\overline{p}^{-1}\right]\hat{Y}^2 - \hat{V}\left[\hat{Y}\right]\hat{V}\left[\overline{p}^{-1}\right] \tag{27}$$

where

$$\hat{V}\left[\overline{p}^{-1}\right] = \frac{\sum_{g=1}^{10}\left(p^{-1}{}_g - \overline{p}^{-1}\right)^2}{10(10-1)}. \tag{28}$$

DUAL-FREQUENCY IDENTIFICATION SONAR (DIDSON) TRIALS

Based on the results of limited tests in 2007 with a leased DIDSON (Burwen et al. 2010, Miller et al. 2011), a long-range DIDSON coupled with a high-resolution lens was purchased in June 2008 for more extensive testing. The DIDSON was deployed on the left bank of the river, mounted in a side-by-side configuration with the split-beam transducer on the same pan-and-tilt aiming device (Figure 13). The DIDSON was subject to the same deployment configuration and aiming protocol described above for the split-beam transducer with one exception: DIDSON was aimed at a vertical angle approximately 1 degree lower than the split-beam sonar (approximately −4.5 degrees versus approximately −3.5 degrees) to achieve better image quality.

Tethered Fish

Results from tethered fish experiments in 2007 indicated that relatively accurate measurements of fish length from DIDSON images were possible at ranges up to 22 m and potentially further with modification of the sonar firmware by the manufacturer (Burwen et al. 2010). During 2009, after resolving the firmware limitation, additional experiments focused on fish tethered at ranges 15–33 m from the transducer to determine whether accurate measures of fish length were possible over the full range required for complete coverage of the river at this site (i.e., at least 30 m).

Tethered fish experiments were conducted in June and July 2009 following methods similar to those used in 2007, except that tethered fish data were collected on the left bank to minimize disruption to ongoing data collection on free-swimming fish (i.e., DIDSON was already deployed to continuously sample free-swimming fish on the left bank, see below). Live Chinook and sockeye salmon were captured with gillnets and held in live pens or totes until they could be deployed. The fish were tethered to an upstream anchor using a length of 100-lb test Dacron line that positioned the fish in front of the sonar beam once it drifted downstream to the end of the line. The upstream anchor was positioned 15–30 m offshore from the DIDSON. The sonar was deployed in the same configuration used for counting free-swimming fish, i.e., near the bank with the beam directed across the river perpendicular to the current so that a tethered fish presented a nearly side-aspect orientation. The beam was aimed down at a vertical angle of approximately -5.0° to insonify the near-bottom area where the tethered fish were anticipated to settle. After a tethered fish was deployed, minor adjustments to the aim were made to center the fish in the beam. More detail on fish-tethering procedures at this site can be found in Burwen and Fleischman (1998) and Burwen et al. (2007, 2010).

Free-swimming Fish

“Window length” (i.e., the range interval sampled by the sonar) controls the down-range resolution of the DIDSON image. Because the DIDSON image is composed of 512 samples in range, images with shorter window lengths are better resolved (i.e., down-range resolution = window length/512). Window length can be set to discrete values of 2.5, 5.0, 10.0, or 20.0 m. For this study, the window length was set at 10 m, a compromise that allowed coverage of a reasonable distance while still operating in high-frequency mode for optimal resolution. The down-range resolution (or pixel height) for a 10-m window length is 2 cm (1,000 cm/512). A 10 m “window length” was used to sample the range stratum from 15–25 m in 2008 providing overlapping coverage with approximately the last 10 m of range insonified by the split-beam system. This bank and range stratum was selected for continued testing with DIDSON because it is the stratum with the highest passage rates recorded by the split-beam sonar in recent years. These data provided the opportunity to evaluate the ability of the DIDSON to detect fish at various distances from the transducer, determine direction of travel for fish and debris, and distinguish among individual fish at high passage rates. In 2009, this range stratum was modified slightly to 13.3–23.3 m to accommodate a long-term strategy to insonify a total of 30 m from each bank in 3 consecutive 10 m range strata as follows: 3.3–13.3 m, 13.3–23.3 m, and 23.3–33.3 m. These 3 range strata should allow sampling to start and end at optimal distances from the transducer; i.e., to start at the minimum range where the beam width is sufficiently wide to view near-range fish and extending to the maximum limit of the high frequency sampling range, which is approximately 30 m.

DIDSON footage was recorded 60 minutes per hour in 20-minute increments from 14 June to 9 August in 2008 and from 16 May to 3 August 2009, except when interrupted by equipment malfunctions, tethered fish data collection, or other temporary experimental trials with other equipment settings.

The transmit power of the DIDSON sonar is fixed, and 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 [25 m + 15 m]/2). The frame rate was fixed at seven frames per second.

Manual DIDSON Fish Length Measurements

During 2008 and 2009, a software engineer from Sound Metrics Corporation (SMC) worked with ADF&G personnel to further develop and streamline the process of counting and measuring fish from DIDSON images using their proprietary Control and Display software (Version 5.19 in 2008 and Version 5.23 in 2009). Electronic echograms similar to those generated from split-beam data provided a system to manually count, track, and size individual fish (Figure 14). Noise from stationary structures was removed from the images using SMC's algorithm for dynamic background removal. Fish traces displayed on the echogram could also be displayed in video mode through a toggle function (Figure 15). In video mode, technicians used the manual measuring tools to estimate the DIDSON-based length (DL) for each fish. Additional detail on procedures and software settings used to obtain manual fish length measurements can be found in Burwen et al. (2010) and in Appendix F1.

Manual fish measurements were made independently by two observers on all tethered fish. Measurements of free-swimming fish depended on image quality and budget considerations. In 2008, DIDSON data were subsampled systematically, generally with 4–6 hourly samples measured daily. By 2009, fish measurement procedures had been streamlined, making it possible to measure fish from all 60 minutes of data for each of 24 hours per day. Date, time, frame number, range, and direction of travel were also recorded for each free-swimming fish.

DIDSON Fish Length Measurement Automation Trials

During 2008 and 2009, a consultant from Aquacoustics, Inc. worked with ADF&G staff and software developers at Myriax Software to develop a semi-automated data-processing approach to count, measure, and track Chinook salmon using Myriax's commercial software product Echoview. Prior to input to Echoview, DIDSON data were first processed by SMC Control and Display software to remove bottom structure from the files and to remove blank space using SMC's Convolved Samples over Threshold algorithm. Echoview then developed cluster overlays from which the fish length was measured (Figure 16). Additional detail on procedures and settings used to generate automated length measurements can be found in Burwen (*Forthcoming*).[15]

Automated measurements of tethered fish could not be made because tethered fish often display only limited movement and are subject to being "subtracted" by the background removal algorithm.

[15] Burwen, D.L. *Forthcoming*. Semi-automated DIDSON data analysis for the assessment of Kenai Chinook salmon – field manual. Alaska Department of Fish and Game. Special Publication.

Data Analysis

Linear statistical models (Neter et al. 1985) were fitted to assess the relationship between DIDSON length and measured fork length, and to test for the effect of range (distance from the transducer) on the measurements. DIDSON length was the dependent variable.

DIDSON-based estimates of the proportion of passing fish that were Chinook salmon were obtained by fitting a mixture model (page 15) to DIDSON length data. The mixture model was identical to the ELSD mixture model (page 16) except that Dlength was substituted for ELSD and there was no γ parameter in the model, and thus the following was substituted for Equation 17:

$$y_i = \beta_0 + \beta_1 x_i + \varepsilon_i. \tag{29}$$

Also, there was no need for censoring fish based on behavior or number of echoes, so the following was substituted for Equation 22:

$$\hat{y}_{DLi} = \hat{y}_i \hat{\pi}_{Ci}, \tag{30}$$

where $\hat{y}_{DLi}$ is the estimated number of Chinook salmon passing during day *i* as obtained from the DIDSON length mixture model.

The results of 2007 DIDSON tethered fish experiments (Burwen et al. 2010) were used to inform the β_0 and β_1 parameters. WinBUGS code for the DIDSON length mixture model is in Appendix E3.

RESULTS

SPLIT-BEAM SONAR

System Calibration

During system calibration at the Hydroacoustic Technology Inc. (HTI) calibration facility prior to the 2008 season, the target strength of a 38.1-mm tungsten carbide standard sphere was measured at −39.5 dB for the right-bank transducer and −39.4 dB for the left-bank transducer (HTI 2008; Table 4). The theoretical value for the sphere is −39.5 dB (MacLennan and Simmonds 1992). During a subsequent *in situ* calibration check using the same sphere, mean target strength measured –38.6 dB on the right bank and –38.8 dB on the left bank (Table 4).

During the 2009 preseason system calibration, the standard sphere was measured at −40.0 dB for the right-bank transducer and −39.5 dB for the left-bank transducer (HTI 2009; Table 4). Mean target strength values measured during subsequent in situ calibration checks in 2009 varied from −38.7 dB to −39.1 dB on the right bank and −39.9 dB to −40.5 dB on the left bank (Table 4). Small fluctuations in mean target strength are expected during *in situ* calibration checks because target strength can vary with signal to noise ratio (SNR), water temperature, depth, conductivity, and other factors.

Target Tracking

In 2008, 65,815 targets were manually tracked: 12,146 during the early run and 53,669 during the late run. In 2009, 45,158 targets were manually tracked: 7,679 during the early run and

37,479 during the late run. For the purpose of this report, filtered targets refer to those targets that meet range and target strength (TS) criteria.

The percentage of filtered targets that exhibited upstream movement in 2008 was 98% for the early run and 94% for the late run (Appendices G1 and G2). Daily upstream percentages varied from 61% to 100% during the early run and from 70% to 100% during the late run. The percentage of filtered targets that exhibited upstream movement in 2009 was 97% for the early run and 98% for the late run (Appendices G3 and G4). Daily upstream percentages varied from 21% to 100% during the early run and from 91% to 100% during the late run.

Tidal Distribution

In 2008, upstream-moving filtered targets were observed mostly during the falling tide for both the early (58.5%) and late (59.0%) run (Table 5, Figure 17). Downstream-moving targets were observed more during the falling tide for the early run (57.9%) and during the rising (45.4%) and falling (36.9%) tides for the late run.

In 2009, upstream-moving filtered targets were observed mostly during the falling tide for both the early (59.8%) and late (55.5%) runs (Table 6, Figure 18). Likewise, downstream passage occurred primarily during the falling tide for both the early (61.1%) and late (60.3%) run.

Spatial Distribution

Distribution by Bank

During both runs in 2008, more upstream-moving filtered targets were observed on the left bank than on the right bank (Table 7). In 2009, more upstream moving targets were observed on the left bank during the early run and on the right bank during the late run (Table 8).

Distribution by Range[16]

During the 2008 early run, upstream- and downstream-moving filtered targets on the left bank were distributed throughout the insonified range (Figure 19). Upstream- and downstream-moving filtered targets on the right bank were also distributed throughout the range, with peak passage occurring near the end of the insonified range (Figure 19).

During the 2008 late run, upstream-moving filtered targets on the left bank were relatively evenly distributed throughout the insonified range (Figure 20). Downstream-moving filtered targets on both banks and upstream-moving targets on the right bank exhibited bimodal distributions with peaks nearshore and offshore (Figure 20).

The effect of tide stage on the range distribution (distance from shore) of filtered targets in 2008 was more pronounced on the right bank than on the left bank during both runs (Figures 21 and 22). Upstream-moving targets on the left bank were relatively evenly distributed during all three tide stages. Upstream-moving targets on the right bank exhibited a higher offshore distribution during the falling and low tides, and a more uniform distribution during the rising tide (Figures 21 and 22).

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[16] Because transducers were moved throughout the season in response to changing water levels (Figure 4), range measurements were standardized (Figures 12–15) to reflect distance from a fixed geographic reference point (see Methods). Hence, the left side of the distributions (in Figures 12–15) reflects the combined effects of range thresholds and the geographic standardization.

During the 2009 early run, upstream- and downstream-moving filtered targets on the left bank were distributed throughout the insonified range (Figure 23). Upstream- and downstream-moving targets on the right bank were also distributed throughout the range, with peak passage occurring towards the end of the range (Figure 23).

During the 2009 late run, upstream-moving filtered targets on the left bank were relatively evenly distributed throughout the insonified range while upstream-moving targets on the right bank exhibited a bimodal distribution with nearshore and offshore peaks (Figure 24). The reduced passage on the left bank at 25–30 m was an artifact of relocating the tripod midseason and does not represent an actual drop in passage at these ranges.

The effect of tide stage on range distribution (distance from shore) of filtered targets in 2009 was evident during both runs (Figures 25 and 26). Upstream-moving targets on both banks during the early run and on the right bank during the late run exhibited a lower offshore distribution during the rising tide (Figures 25 and 26). In contrast, upstream-moving targets on the left bank during the late run were relatively evenly distributed during all three tide stages.

Distribution by Vertical Position

Although filtered targets were generally bottom oriented during the 2008 early and late runs, vertical distribution did vary by direction of travel, tide stage, and run (Appendices H1 and H2). During the 2008 early run, 65% of the upstream-moving filtered targets on the left bank and 66% on the right bank were on or below the acoustic axis (Figure 27). Forty-one percent of downstream-moving filtered targets on the left bank and 48% on the right bank were on or below the acoustic axis (Figure 27). Vertical position of downstream-moving targets during the early run (mean = 0.15°, SD = 0.50, *N* = 27) on the left bank was significantly higher (*t* = 1.99, *P* = 0.03) than that of upstream-moving targets (mean = –0.04°, SD = 0.40, *N* = 3,725). Similarly, on the right bank, vertical position of downstream-moving targets (mean = 0.07°, SD = 0.42, *N* = 98) was significantly higher (*t* = 2.59, *P* = 0.01) than that of upstream-moving targets (mean = –0.04°, SD = 0.34, *N* = 2,169). Upstream-moving targets were distributed higher in the water column during rising tides, particularly on the left bank (Figure 28).

During the 2008 late run, 63% of upstream-moving filtered targets on the left bank and 47% on the right bank were on or below the acoustic axis (Figure 29). Similarly, 64% of downstream-moving filtered targets on the left bank and 52% on the right bank were on or below the acoustic axis (Figure 29). There was no significant difference (*t* = 0.27, *P* = 0.39) between the vertical position of late-run upstream-moving targets (mean = –0.09°, SD = 0.38, *N* = 6,876) and downstream-moving targets (mean = –0.09°, SD = 0.41, *N* = 505) on the left bank. On the right bank, the vertical position of downstream-moving targets (mean = 0.11°, SD = 0.25, *N* = 408) was significantly higher (*t* = 6.15, *P* < 0.01) than the vertical position of upstream-moving targets (mean = 0.03°, SD = 0.20, *N* = 6,107). Vertical distribution of upstream-moving targets was higher during the rising tide on both banks (Figure 30).

In 2009, the vertical position of upstream-moving targets also varied by tide stage, direction of travel, and run (Appendices H3 and H4), but most targets during the 2009 early and late runs were bottom oriented. During the early run, 63% of the upstream-moving targets on the left bank and 86% on the right bank were on or below the acoustic axis (Figure 31). Forty-four percent of downstream-moving targets on the left bank and 87% on the right bank were on or below the acoustic axis (Figure 31). There was no significant difference (*t* = –0.37, *P* = 0.36) between the vertical position of upstream-moving targets (mean = –0.07°, SD = 0.41, *N* = 2,510) and downstream-moving targets (mean = -0.13°, SD = 0.75, N = 18) on the left bank. Vertical position of downstream-moving targets (mean = -0.38°, SD = 0.45, N = 93) on the right bank was significantly lower ($t = -2.87$, $P < 0.01$) than that of upstream-moving targets (mean = -0.24°, SD = 0.35, N = 1,556). Upstream-moving targets were distributed higher in the water column during rising tides (Figure 32), particularly on the left bank.

During the 2009 late run (Figure 33), 75% of upstream-moving targets on the left bank and 47% of upstream-moving targets on the right bank were on or below the acoustic axis. Fifty-five percent of downstream-moving targets on the left bank and 42% on the right bank were on or below the acoustic axis. Downstream-moving targets (mean = -0.09°, SD = 0.54, N = 83) on the left bank were significantly higher in the water column ($t = 1.71$, $P = 0.05$) than upstream-moving targets (mean = -0.19°, SD = 0.39, N = 5,932). Likewise, the vertical position of downstream-moving targets (mean = 0.12°, SD = 0.40, N = 222) on the right bank was significantly higher ($t = 2.74$, $P < 0.01$) than the vertical position of upstream-moving targets (mean = 0.05°, SD = 0.32, N = 8,332). Vertical distribution of upstream-moving targets was slightly higher during the rising tide on both banks (Figure 34).

TS-based Estimates of Chinook Salmon Passage

In 2008, daily TS-based estimates of Chinook salmon passage were generated for 16 May through 3 August. A total of 597 hours of acoustic data were processed from the right bank and 618 hours from the left bank during the 80-day season. This represented 31% of the total available sample time (on average in a 24-hour period) for the right bank and 32% for the left bank.

Estimated upstream[17] TS-based Chinook salmon passage from 16 May to 3 August 2008 was 46,294 (SE 528) fish, composed of 15,355 (SE 296) early-run fish and 30,939 (SE 438) late-run fish (Tables 9 and 10). Estimated late-run passage through the end of the run on 10 August was 34,641 (SE 1,682) fish (Appendix I2). Peak daily passage during the early run occurred on 12 June; 50% of the run passed by 11 June (Figure 35). Early run escapement timing was early compared to historic mean escapement timing (Figure 35 and Appendix I1). Peak daily passage during the late run occurred on 15 July; 50% of the late run passed by 22 July (Figure 36). Timing of the late run was late compared to historic mean escapement timing (Figure 36 and Appendix I2).

In 2009, daily TS-based estimates of Chinook salmon passage were generated for 16 May through 4 August. A total of 586 hours of acoustic data were processed from the right bank and 624 hours from the left bank during the 81-day season. This represented 30% of the total available sample time (on average in a 24-hour period) for the right bank and 32% for the left bank.

Estimated upstream[17] TS-based Chinook salmon passage from 16 May to 4 August, 2009 was 37,022 (SE 512) fish, composed of 11,334 (SE 263) early-run fish and 25,688 (SE 440) late-run fish (Tables 11 and 12). Peak daily passage during the early run occurred on 11 June; 50% of the run passed by 12 June (Figure 37). The 2009 early run was average compared with historic mean

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[17] Due to our inability to accurately differentiate between debris and downstream moving fish, only upstream-moving targets were used to produce the upstream passage estimate (i.e. no adjustments were made for downstream passage).

escapement timing (Figure 37 and Appendix I1). Peak daily passage during the late run occurred on 14 July; 50% of the late run passed by 16 July (Figure 38). Timing of the late run was early compared to historic mean escapement timing (Figure 38 and Appendix I2).

Alternative Estimates of Chinook Salmon Passage

Net-apportioned estimates of upstream Chinook salmon passage in 2008 were 4,822 (SE 350) fish for the early run and 36,012 (SE 1,770) fish for the late run (Appendices J1–J2). Peak daily passage based on net-apportioned estimates occurred on 24 June for the early run and 31 July for the late run.

Behavior-censored ELSD-based estimates of upstream Chinook salmon passage in 2008 were 6,560 (SE 252) fish for the early run and 24,557 (SE 933) fish for the late run (Appendices J1–J2). Peak daily passage, based on behavior-censored ELSD-based estimates, occurred on 11 June for the early run and 31 July for the late run.

Daily early- and late-run passage estimates produced inseason in 2008, based on a calibrated ELSD threshold (also referred to as an adaptive ELSD threshold), are presented in Figure 39 and Appendices K1–K2.

Net-apportioned estimates of upstream Chinook salmon passage in 2009 were 2,834 (SE 73) fish for the early run and 17,725 (SE 297) fish for the late run (Appendices J3–J4). Peak daily passage, based on net-apportioned estimates, occurred on 29 June for the early run and 14 July for the late run.

Behavior-censored ELSD-based estimates of upstream Chinook salmon passage in 2009 were 4,428 (SE 201) fish for the early run and 15,656 (SE 893) fish for the late run (Appendices J3–J4). Peak daily passage based on behavior-censored ELSD-based estimates occurred on 11 June for the early run and 17 July for the late run.

Daily early- and late-run passage estimates produced inseason in 2009 based on a calibrated ELSD threshold are presented in Figure 40 and Appendices K3–K4.

DIDSON TRIALS

A long-range DIDSON coupled with a high-resolution lens was deployed on the left bank of the Kenai River from 14 June to 9 August in 2008 and from 16 May to 3 August in 2009.

Tethered Fish

On 15–17 June and 20 July 2009, 37 sockeye and Chinook salmon, varying in fork length from 57 to 115 cm, were tethered at ranges 22–32 m from the transducer and were measured by two observers using DIDSON software. Measurements differed by observer to varying degrees (mean difference 1.7 cm, SD 5.7, range 0 to 15), but on average they were highly correlated (Figure 41; R^2 = 0.89). As a result, the estimated relationships of DIDSON-measured length DL to fork length FL were almost identical for observers 1 and 2: slope = 0.836 versus 0.847; intercept = 9.9 versus 7.4; R^2 = 0.93 versus 0.92; RMSE = 4.4 versus 4.8 cm; respectively (Figure 42). Using average measurements, the slope was 0.842, the intercept was 8.6, R^2 = 0.95, and RMSE = 3.7 cm (Figure 43). These results did not differ significantly ($P > 0.05$) from those of a 2007 experiment (Burwen et al. 2010).

Because the intercept between DL and FL was positive, and the slope was slightly less than one, there was a slight negative bias in the DIDSON length estimates for salmon-sized fish

(Figure 43). There was no apparent effect of range on DIDSON estimates of fish length, given true length (multiple regression of average DL on FL and range; $t = -0.5$, df = 35, $P = 0.64$).

Free-swimming fish

During 2008 tests, sediment accumulated rapidly inside the DIDSON lens, causing adverse effects on DIDSON image quality. As a result, images of sufficiently high resolution for length measurements were available for only 8 of 57 days (14 and 15 June; 15, 17, 19, 22, 23, and 26 July) in 2008. In 2009, the lens was protected with a silt-proof enclosure, resulting in much improved resolution. Measurements were made on all but 4 of 57 days between 31 May and 26 July 2009. Daily estimates of upstream fish passage in 2009 for the insonified zone (13–23 m from left-bank transducer) are plotted with split-beam versions of the same quantities in Figure 44. The split beam detected approximately 78% as many total upstream fish as did the DIDSON (Figure 45). DIDSON-based estimates of Chinook salmon passage were closely related to ELSD-based estimates of Chinook salmon passage (Figure 46). Estimates of Chinook salmon passage (in the insonified zone) for all 53 sampled days in 2009 were almost identical (DIDSON = 1,625, SE = 54; ELSD = 1,659, SE = 71). Daily DIDSON- and ELSD-based estimates of Chinook salmon proportion in 2007–2009 had a positive, possibly non-linear, relationship (Figure 47).

DIDSON Fish Length Measurement Automation Trials

During the years 2008–2009, ADF&G worked with Aquacoustics and Myriax, LTD, to implement the commercial software package Echoview with the necessary features for automatically sizing fish from DIDSON images. The Echoview software was highly successful in automatically tracking individual fish (Figure 48), even at high densities.

Figure 16 demonstrates the Echoview auto-measurement feature. The vertical line on the echogram (left) determines the frame displayed in movie mode at right. Echoview software produces a cluster overlay (middle) of the fish image (right) from which a fish length measurement can be automatically calculated by fitting a line through the image from the snout to the tail. Although highly correlated with manually-measured lengths, the Echoview-generated lengths were generally smaller because they involved averaging the lengths of cluster overlays which typically underestimate rather than overestimate the DIDSON-based length (and consequently the fork length).

Multiple algorithms were tested to generate potential surrogates for fish size, several of which showed promise. Mean automated fish length, when analyzed in a mixture model, yielded estimates of fish passage almost identical to those generated from manual measurements (Figure 49).

A detailed manual for using Echoview software was produced by Aquacoustics, Inc. and can be found in Burwen (see Burwen *Forthcoming*).

DISCUSSION

ACCURACY OF SPLIT-BEAM PASSAGE ESTIMATES

Sonar estimates of Chinook passage are subject to potential biases from several sources, including 1) imperfect target detection (fish swimming above, below, or behind the effective beam, or not meeting the voltage threshold); 2) errors in target tracking (including direction of travel); and 3) inaccurate species discrimination. Biases from imperfect target detection and tracking are generally small, consistent, or negative (resulting in conservative estimates). For more details about target detection see Miller et al. (2007a). At present, we are more concerned about species discrimination errors, which could hypothetically occur in either direction, and which have the potential to be large in magnitude.

Through a series of research projects in the mid- and late-1990s, we learned that our current species discrimination algorithm, based on target strength and range thresholds, is less than satisfactory. Target strength is an imprecise predictor of fish size and species; many sockeye salmon exceed the –28 dB target strength threshold and many Chinook salmon do not (Burwen and Fleischman 1998). Although only a small fraction of sockeye salmon swim beyond our range thresholds, they can comprise more than 50% of midchannel fish (Burwen et al. 1998). Under these circumstances, range thresholds are ineffective and Chinook salmon passage can be overestimated.

Beginning in 2002, in response to these shortcomings, we began censoring hourly samples of TS-based estimates of Chinook salmon passage, and developed alternative net-apportioned (see page 14) and ELSD-based estimates (see page 14) of Chinook salmon passage.

Historically, we have also compared sonar estimates of Chinook salmon passage with several other indices of Chinook and sockeye salmon abundance to aid in evaluating accuracy of the sonar estimates. These indices include Chinook CPUE from the inriver netting program (see Introduction), Chinook salmon CPUE estimated by an onsite creel survey of the lower river sport fishery (Eskelin 2010), and daily estimates of sockeye salmon at the river mile-19 sonar site.

The river mile-19 sockeye salmon sonar site, located upriver of the Chinook salmon sonar site, provides an index of inriver sockeye salmon abundance. This sonar project is conducted from 1 July to mid-August by the ADF&G Division of Commercial Fisheries and targets sockeye salmon near shore (Westerman and Willette 2011). Although travel time between the river mile-8.5 Chinook salmon sonar site and the river mile–19 sockeye salmon sonar site varies, we believe it averages one to two days. This project identifies periods when sockeye salmon are abundant and when the potential for misclassifying sockeye salmon as Chinook salmon may be high.

2008 Early Run

The 2008 early-run TS-based sonar passage estimate of 15,355[18] Chinook salmon was slightly less than average compared to past 20 years (Appendix I1).

The daily ELSD mixture model estimates and net-apportioned estimates of Chinook salmon passage were substantially lower than the TS-based estimates throughout most of the early run (Appendix J1, Figure 50). The early-run total ELSD mixture model estimate (6,560 fish) is 57% less than the TS-based estimate, and the early-run net-apportioned estimate (4,822 fish) is 69% less than the TS-based estimate. In general, daily ELSD mixture model estimates and net-apportioned estimates tracked each other well throughout the early run.

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[18] Forty-nine of 2,008 hourly samples were censored to produce this estimate (Appendix D1). Inclusion of all available hourly samples, regardless of the presence of grouping behavior, would have generated an early-run estimate (16 May–30 June) of 17,544 (SE 400) fish.

The TS-based estimate and Chinook salmon gillnet CPUE tracked each other well through early June, but differed substantially beginning in mid-June (Figure 51). Pronounced peaks in gillnet CPUE observed the third week in June were not evident in the daily TS-based passage estimates from the same time period.

Although Chinook salmon gillnet CPUE indicates the TS-based estimate may have been low the third week in June, the ELSD mixture model estimate and the net-apportioned estimate suggest the official TS-based estimate of total early-run Chinook salmon passage may be high.

2008 Late Run

The 2008 late-run TS-based sonar passage estimate of 30,939[19] Chinook salmon through 3 August was below average (Appendix I2).

The daily ELSD mixture model estimates and net-apportioned estimates of Chinook salmon passage tracked the official TS-based estimates closely throughout the late run, but the net-apportioned estimate diverged substantially from the other two estimates beginning in late July (Appendix J2, Figure 50). The late-run total TS-based estimate fell between the behavior-censored ELSD mixture model estimate (24,557 fish) and the net-apportioned estimate (36,012 fish). The ELSD mixture model estimate is 21% less than the TS-based estimate, and the late-run net-apportioned estimate is 16% greater than the TS-based estimate.

Sockeye salmon gillnet CPUE and river mile-19 sockeye salmon sonar estimates (Figure 52) both indicate the majority of sockeye salmon were present at the Chinook salmon sonar site during mid-July. Thus misclassification of sockeye salmon as Chinook salmon was more likely to occur in mid-July and less likely in late July. However, the presence of pink salmon in late July and early August may have influenced the TS-based Chinook salmon passage estimates during this time period because the target strength threshold may have misclassified some pink salmon as Chinook salmon.

Interestingly, the Chinook salmon gillnet CPUE estimates at the Chinook salmon sonar site exhibited an increasing trend in late July and early August (Figure 52). The highest gillnet CPUE estimates of the season were observed on 1 August and 3 August. This would imply that the TS-based passage estimate and the ELSD mixture model passage estimate were low. Another explanation might be that Chinook salmon catchability increased during this time for some unexplained reason.

2009 Early Run

The 2009 early-run TS-based sonar passage estimate of 11,334[20] Chinook salmon was below average (Appendix I1).

The daily ELSD mixture model estimates and net-apportioned estimates of Chinook salmon passage were substantially lower than the official TS-based estimates throughout most of the early run (Appendix J3, Figure 53). The early-run total ELSD mixture model estimate (4,428 fish) is 61% less than the TS-based estimate, and the early-run net-apportioned estimate

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[19] Of 1,632 samples, 122 were censored to produce this estimate (Appendix D1). Inclusion of all available hourly samples, regardless of the presence of grouping behavior, would have generated a late-run estimate through 3 August of 39,284 (SE 1,012) fish.

[20] Thirty-five of 2,008 hourly samples were censored to produce this estimate (Appendix D1). Inclusion of all available hourly samples, regardless of the presence of grouping behavior, would have generated an early-run estimate (16 May–30 June) of 12,232 (SE 297) fish.

(2,834 fish) is 75% less than the TS-based estimate. In general, daily ELSD mixture model estimates tracked the TS-based estimates more closely than the net-apportioned estimates.

The relationship between the TS-based estimate and Chinook salmon gillnet CPUE changed over time (Figure 54). The TS-based estimate and gillnet CPUE tracked each other fairly well in May, but the relationship was more variable in June with the TS-based estimate exhibiting proportionally larger peaks in passage in mid-June and gillnet CPUE exhibiting proportionally larger peaks the last few days in June.

Daily DIDSON estimates of fish passing 13–23 m from the left bank transducer agreed well with comparable range-censored ELSD mixture model estimates during the 2009 early run, except for 6 June and 10–13 June, when the ELSD estimates were higher (Figure 44).

Taken together, the above considerations indicate that the TS-based Chinook salmon passage estimate for the 2009 early run is probably too high.

2009 Late Run

The 2009 late-run TS-based sonar passage estimate of 25,688[21] Chinook salmon through 4 August was below average (Appendix I2).

The daily ELSD mixture model estimates and net-apportioned estimates of Chinook salmon passage tracked each other fairly well throughout much of the late run (Appendix J4, Figure 53). The TS-based estimate tracked the other two estimates short term, but diverged substantially from the other estimates during the third week in July. The late-run total TS-based estimate was higher than the behavior-censored ELSD mixture model estimate (15,656 fish) and the net-apportioned estimate (17,725 fish). The ELSD mixture model estimate is 39% less than the TS-based estimate, and the net-apportioned estimate is 31% less than the TS-based estimate.

Sockeye salmon gillnet CPUE indicates that sockeye salmon were present at the Chinook salmon sonar site throughout July, with peak sockeye salmon CPUE occurring on 11 July (Figure 55). Peak Chinook salmon CPUE occurred on 9 and 14 July, with the 14 July peak corresponding to peak daily Chinook salmon passage based on sonar (TS-based). Chinook salmon gillnet CPUE decreased the third week of July, but daily Chinook salmon TS-based estimates remained elevated. In contrast, Chinook salmon gillnet CPUE increased the last week of July while daily Chinook salmon TS-based passage decreased (Figure 55). This discrepancy may be explained in part by record high discharge rates experienced the second half of July (Figure 55) resulting in relocation of the right bank transducer tripod closer to the river bank on 26 July (Figure 4). Relocation of the tripod and the quality of the resulting aim may have affected fish detectability on the right bank and may have resulted in conservative daily passage estimates on the right bank during the last week of project operation (Figure 38).

Daily DIDSON estimates of fish passing 13–23 m from the left bank transducer agreed well with comparable range-censored ELSD mixture model estimates during the 2009 late run, except for 11 July, when the ELSD estimate was higher (Figure 44).

[21] Of 1,680 samples, 233 were censored to produce this estimate (Appendix D1). Inclusion of all available hourly samples, regardless of the presence of grouping behavior, would have generated a late-run estimate through 4 August of 42,912 (SE = 980).

Taken together, the above considerations indicate that the TS-based Chinook salmon passage estimate for the 2009 late run is probably too high.

Adaptive ELSD Threshold Passage Estimates

A comparison of the calibrated ELSD threshold daily passage estimates with the behavior-censored ELSD mixture model daily passage estimates indicates that the calibrated threshold estimates adequately approximated the mixture model estimates for daily inseason use in both 2008 and 2009 (Figures 39 and 40; Appendix K). During both the early and late run, the calibrated threshold estimate tracked the mixture model estimate very closely with only a few exceptions. Overall the calibrated ELSD estimate performed adequately in allowing for near real-time approximated ELSD mixture model estimates (Figures 39 and 40; Appendix K).

DIDSON TRIALS

In 2008, DIDSON data quality was impacted by silt accumulation in the lens, causing poor image resolution and severely restricting the number of days that DIDSON-based fish length measurements could be produced. Although this issue has been documented at other Alaskan DIDSON installations, the problem of lens siltation is particularly severe at this site, possibly because reduced or reversed current speed during rising and slack tides allows silt to accumulate in the lens. Because the sonar transducers are deployed offshore and are not easily accessed or retrieved, cleaning the lens on a daily basis was not possible. During the 2009 season, the DIDSON lens was encased in a silt-proof enclosure (Figure 14), and image quality was consistently good throughout most of the season.

Tethered fish data collected in 2009 confirmed earlier studies that showed that DIDSON provides more accurate measurements of fish size than is possible with split beam sonar (Burwen et al. 2010, Miller et al. 2010). The 2009 DIDSON trials also demonstrated (1) that DIDSON possessed advantages over split-beam sonar with respect to target detection, tracking, and identification; and (2) automation of the fish measuring process is potentially advantageous and feasible.

Target Detection, Tracking, and Identification

DIDSON generates an echogram similar to split-beam sonar. The DIDSON echogram utilizes data from 16 of 45 beams in the center of the array and often has better-defined fish traces than the split-beam sonar. DIDSON has the added advantage of being able to display video-like movies of fish swimming behavior. Figure 56 contrasts a split-beam echogram (top) with a DIDSON echogram (bottom) for approximately 1.5 minutes of paired data. Numbered arrows connect fish (or groups of fish) in the corresponding echograms. Table 13 describes how each of the numbered examples was interpreted differently by the two sonar types.

The advantage of viewing acoustic data in both echogram and video formats is evident in Figures 57, 58, and 59, which show video still frames for examples 1, 7, and 4, respectively, in Figure 56. Figure 57 reveals there are approximately 15 smaller fish in the group of targets shown on the echograms in Figure 56, example 1. Although the fish traces are more clearly displayed on the DIDSON echogram than on the split-beam echogram, it is not possible to accurately count the number of fish with either one. Both echograms have a “broken up” appearance due to the fact that heavy passage near the face of the transducer caused acoustic shadowing effects when the transducer was completely blocked by the body of a fish. However, when the DIDSON video footage is played, each of the individual fish can be identified and measured as they swim through the beam array.

DIDSON also has better detection capabilities for downstream-traveling fish. Downstream fish may travel faster with the benefit of the current and can be harder to detect than upstream fish because they are detected in fewer echoes per frames. The DIDSON frame in Figure 58 shows that a downstream-traveling Chinook salmon drifts through at such a steep aspect angle that very little surface area is presented to the sonar. On the split-beam echogram (Figure 56, example 7) only a few echoes are registered and the fish is essentially undetected because it does not meet minimum tracking criteria (i.e., too few pings that are separated in time) contrasted with the DIDSON echogram where a noticeable trace is produced. DIDSON video footage reveals that the fish is a 99-cm Chinook salmon (Figure 58).

Fish behavior can be difficult to interpret using split-beam echograms, and this can potentially influence the accuracy of abundance estimates in several ways. First, difficulties arise when fish are not sufficiently separated in space and time. The split-beam sonar cannot distinguish targets closer than 14.6 cm in range. Figure 59 shows two large traces in the split-beam echogram that are actually two pairs of smaller salmon swimming in a head-to-tail formation when viewed on a DIDSON video. Two salmon in this configuration can be difficult to distinguished using split-beam sonar, and can appear as one large fish. Besides undercounting the true number of fish, this also causes issues with the ELSD-based estimate of Chinook salmon abundance. When the two traces from the smaller fish are combined into one, they often have greater values of ELSD similar to those of a Chinook salmon.

Other behaviors such as milling and holding can influence the accuracy of split-beam estimates. Figure 60 shows a 108-cm Chinook salmon swimming past numerous pink salmon that are holding in a near-stationary position in the beam. During late summer of even-numbered years when pink salmon are abundant, fish may hold in the beam for hours before eventually resuming upstream migration. The split-beam sonar cannot easily distinguish migrating fish from stationary (holding) fish. The traces of holding fish appear like bottom structure in the electronic echograms, with no apparent direction of travel. Counting these fish is difficult because they may enter or leave the beam when the sonar is not sampling that particular stratum. When too many fish hold in the beam, the echogram can become so cluttered that it becomes useless for enumerating actively migrating fish. This holding behavior, combined with extreme levels of milling (e.g., Figure 61), has occasionally caused sonar operations to be terminated prior to the normal 10 August shut-down date because passage estimates become unreliable. DIDSON could conceivably generate estimates under these circumstances by counting only larger Chinook salmon (e.g. > 80 cm) that were clearly migrating up- or downstream, and ignoring the holding fish.

DIDSON also provided additional advantages over split-beam sonar with its ability to correctly distinguish non-salmonid targets such as flounder and seals from valid salmon targets. Individual frames from DIDSON videos can show detail on the morphology of the target. For example, the triangular shape and swimming motion of flounders make them easily distinguishable from salmon on DIDSON images (Figure 62), but are accepted as valid targets in split-beam data. Seals can also be difficult to distinguish from large Chinook salmon in split-beam data but are easily identified in DIDSON images (Figure 63). These non-salmonid targets typically return split-beam echoes that meet the criteria for a valid target and seals, in particular, often return echoes similar to larger Chinook salmon.

Although eulachon are only present in high numbers during late May and early June, and generally impact only a few samples throughout the day (large schools can mask other targets), an added benefit of DIDSON was its ability to detect salmon potentially masked by eulachon schools (Figure 64).

DIDSON Fish Length Measurement Automation Trials

Manual measurements of fish length from DIDSON images can be subjective, in the sense that somewhat arbitrary standards must be adopted to guide the choice of frame to measure and, once selected, the selection of pixels for inclusion in the fish image. Figure 65 shows how different measurements (94.3 cm versus 105.4 cm) can be obtained from the same fish on the same frame depending on the choice of pixels to include in the measurement and Figure 66 shows how measurements of the same fish can vary depending on the choice of frames. Figure 66 displays measurements taken on three different frames as the fish swims though the beam array. Each frame would be considered a good choice in that each shows little ambiguity in which pixels to include in the measurement and because the fish appears to be displaying its entire length based on the well-defined appearance of the snout, body, and tail.

Fish length measurements can also be influenced by the threshold and intensity settings used to display the images from which measurements are taken. Threshold and intensity settings used when processing DIDSON data affect the displayed image only and are used to increase or improve contrast between the fish image and the background noise. Similar to split-beam data processing, a threshold is used to censor extraneous background noise and minimize the chance of including background noise or structure in the fish measurement. When thresholds are used to classify large Chinook salmon versus other (small) salmon, such subjectivity can be an important source of uncertainty. Some DIDSON images are relatively robust to varying threshold levels whereas others are very sensitive to slight changes. Figure 67 shows the effect of changing the threshold on a frame where length measurements are unaffected by changes in threshold (top row) and a frame where changes in threshold result in large changes in measured length (bottom row).

Fortunately, mixture model analysis of length data is robust to changes in measurement standards because it uses the relative size of fish (the frequency distribution of length measurements) to make inferences about species composition, rather than relying on a fixed threshold to classify individual animals.

Efforts to automate the tracking and sizing of fish from DIDSON images using Echoview were successful because estimates of Chinook salmon abundance were repeatable with auto-generated length measurements from initial trials (Figure 49).

Despite this success, it is important to note that this technology is still in the early stages of development. Sensitivity of the results to auto-measurement configuration parameters, noise environment, and fish behavior would need to be explored. Significant time savings have not yet been demonstrated for the Kenai project. Evaluation of this methodology will continue as Echoview continues to develop its suite of DIDSON data-processing tools and as funds become available for continued feasibility studies.

SUMMARY AND OUTLOOK

Species discrimination continues to be the weak link in our ability to accurately estimate Chinook salmon passage in the Kenai River with sonar. Alternative split-beam sonar estimates, based on netting and echo length data, differed from TS-based split-beam sonar estimates during 2008 and 2009. Consequently, there continues to be considerable uncertainty surrounding Chinook salmon passage estimates based on split-beam sonar.

Ongoing studies with DIDSON technology continue to yield promising results. Tethered fish studies showed that the DIDSON can measure fish length with sufficient accuracy at ranges up to 30 m. DIDSON has advantages over split-beam sonar with respect to target detection, target tracking, distinguishing non-salmonid from valid salmonid targets, and interpreting complex fish behavior. In addition, DIDSON is able to detect fish closer to the transducer and track fish more accurately than split-beam sonar. The ability of DIDSON video footage to display and sort out complex fish behavior (e.g., milling and holding behaviors) may also allow the use of DIDSON during times when the split-beam sonar cannot be operated. Estimates of Chinook salmon passage derived from DIDSON length data matched up well with ELSD-based estimates in 2009.

These results further confirm the potential of DIDSON technology as a tool for inseason monitoring of Chinook salmon run strength in the Kenai River. Acquisition of a second DIDSON system and continued testing are planned for 2010. The addition of a second DIDSON system will provide coverage of the entire range now covered by the split-beam system, which will allow for a more complete comparison in the performance of the two systems.

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TABLES

Table 1.–Main components of the split-beam sonar system used during the 2008–2009 season.

System component	Description
Sounder	Hydroacoustics Technology Inc. (HTI) Model 244 Split-Beam Echo sounder operating at 200 kHz
Data processing computer	Dell Dimension 2350 personal computer
Transducers	(2) HTI Split-Beam transducers: Left Bank: nominal beam widths: 2.9^ox10.2^o Right Bank: nominal beam widths: 2.8^ox10.0^o
Chart recorder	HTI model 403 digital dual-channel chart recorder
Oscilloscope	Nicolet model 310 digital storage oscilloscope
Video display	Hydroacoustic Assessments HARP-HC
Remote pan and tilt aiming controller	Remote Ocean Systems Model PTC-1 Pan and Tilt Controller
Remote pan and tilt aiming unit	Remote Ocean Systems Model PT-25 Remote Pan and Tilt Unit
Heading and angular measurement device	JASCO Research Ltd. AIM-2000 Underwater Measurement Device.

Table 2.–Hydroacoustics Technology Inc. model 244 digital echo sounder settings used in 2008–2009.

Echo sounder parameters	Value
Transmit power	25 dB
System gain (G_r)	−18 dB
TVG	$40\log_{10}R$
Transmitted pulse width	0.20 msec
Ping rate right bank	11 pings/sec
Ping rate left bank	16 pings/sec

Table 3.–Echo acceptance criteria for digital echo processing, 2008–2009.

Bank	Pulse width[a] (ms) at −6 dB	Vertical angle off-axis (°)	Horizontal angle off-axis (°)	Threshold mV (dB)	Minimum range (m)
Right					
16 May–3 Aug, 2008	0.04 to 10.0	−2.5 to 2.0	−5.0 to 5.0	777 (−35 dB)	2.0
16 May–4 Aug, 2009	0.04 to 10.0	−2.5 to 2.0	−5.0 to 5.0	756 (−35 dB)	2.0
Left					
16 May–3 Aug, 2008	0.04 to 10.0	−2.5 to 2.0	−5.0 to 5.0	475 (−35 dB)	2.0
16 May–4 Aug, 2009	0.04 to 10.0	−2.5 to 2.0	−5.0 to 5.0	483 (−35 dB)	2.0

[a] Pulse width filters have not been used since 1996 (Burwen and Bosch 1998) in order to retain information potentially useful for species classification (Burwen et al. 2003; Fleischman and Burwen 2003).

Table 4.–Results of 2008 and 2009 *in situ* calibration varifications using a 38.1-mm tungstem carbide standard sphere.

Year/Bank	Date	Mean target strength (dB)	SD	*N*	Range (m)	Noise (mV)	Threshold (mV)
2008							
Right Bank							
HTI[a]	11 Apr 08	−39.5	0.43	532	6.1	N/A[b]	N/A[b]
Kenai River	15 May 08	−38.6	2.00	1,724	16.0	160	175
Left Bank							
HTI[a]	11 Apr 08	−39.4	0.40	516	6.2	N/A[b]	N/A[b]
Kenai River	15 May 08	−38.8	1.20	2,317	12.7	60	75
2009							
Right Bank							
HTI[a]	30 Mar 09	−40.0	0.57	553	6.2	N/A[b]	N/A[b]
Kenai River	13 May 09	−39.1	1.90	1,432	11.4	120	175
Kenai River	4 Aug 09	−38.7	2.20	408	12.0	150	175
Left Bank							
HTI[a]	30 Mar 09	−39.5	0.32	537	6.2	N/A[b]	N/A[b]
Kenai River	13 May 09	−40.5	1.45	2,226	13.4	75	75
Kenai River	4 Aug 09	−39.9	1.65	408	15.8	85	100

[a] Measurements taken at Hydroacoustic Technology Inc. facility during system calibration.

[b] Not available or not applicable.

Table 5.–Percentage of filtered targets by tide stage and direction of travel for the 2008 early (16 May–30 June) and late run (1 July–3 August).

Run	Direction	Total	Rising	Falling	Low
Early					
	Upstream				
	Row %	100.0%	21.4%	58.5%	20.1%
	Column %	97.8%	96.8%	97.8%	98.7%
	Downstream				
	Row %	100.0%	30.6%	57.9%	11.6%
	Column %	2.2%	3.2%	2.2%	1.3%
Late					
	Upstream				
	Row %	100.0%	28.4%	59.0%	12.6%
	Column %	94.3%	91.3%	96.1%	93.3%
	Downstream				
	Row %	100.0%	45.4%	39.6%	15.0%
	Column %	5.7%	8.7%	3.9%	6.7%

Note: Test for independence for early run: chi-square = 25.94, df = 2, $P < 0.0001$. Test for independence for late run: chi-square = 293.06, df = 2, $P < 0.0001$.

Table 6.–Percentage of filtered targets by tide stage and direction of travel for the 2009 early (16 May–30 June) and late run (1 July–4 August).

Run	Direction	Total	Rising	Falling	Low
Early					
	Upstream				
	Row %	100.0%	17.2%	59.8%	23.0%
	Column %	97.3%	97.2%	97.2%	97.5%
	Downstream				
	Row %	100.0%	17.6%	61.1%	21.3%
	Column %	2.7%	2.8%	2.8%	2.5%
Late					
	Upstream				
	Row %	100.0%	24.2%	55.5%	20.3%
	Column %	97.6%	97.9%	97.4%	97.8%
	Downstream				
	Row %	100.0%	21.0%	60.3%	18.7%
	Column %	2.4%	2.1%	2.6%	2.2%

Note: Test for independence for early run: chi-square = 0.49, df = 2, $P = 0.78$. Test for independence for late run: chi-square = 5.84, df = 2, $P = 0.05$.

Table 7.–Percentages of filtered targets by riverbank and direction of travel for the 2008 early (16 May–30 June) and late run (1 July–3 August).

Run Bank	Upstream	Downstream	Upstream and downstream[a]
Early			
Right bank	38%	79%	39%
Left bank	62%	21%	61%
Total	100%	100%	100%
Late			
Right bank	43%	43%	43%
Left bank	57%	57%	57%
Total	100%	100%	100%

Table 8.–Percentages of filtered targets by riverbank and direction of travel for the 2009 early (16 May–30 June) and late run (1 July–4 August).

Run Bank	Upstream	Downstream	Upstream and downstream[a]
Early			
Right bank	37%	84%	38%
Left bank	63%	16%	62%
Total	100%	100%	100%
Late			
Right bank	52%	69%	52%
Left bank	48%	31%	48%
Total	100%	100%	100%

Table 9.–Daily upstream TS-based Chinook salmon passage estimates, Kenai River sonar, early run, 2008.

Date	Left bank	Right bank	Daily total	Cumulative total
16 May	9	24	33	33
17 May	9	43	52	85
18 May	24	36	60	145
19 May	9	33	42	187
20 May	15	24	39	226
21 May	33	36	69	295
22 May	51	63	114	409
23 May	78	69	147	556
24 May	51	103	154	710
25 May	69	66	135	845
26 May	46	161	207	1,052
27 May	132	138	270	1,322
28 May	188	165	353	1,675
29 May	176	111	287	1,962
30 May	173	94	267	2,229
31 May	164	197	361	2,590
1 Jun	90	123	213	2,803
2 Jun	102	108	210	3,013
3 Jun	141	147	288	3,301
4 Jun	174	169	343	3,644
5 Jun	197	226	423	4,067
6 Jun	278	285	563	4,630
7 Jun	260	113	373	5,003
8 Jun	242	121	363	5,366
9 Jun	281	93	374	5,740
10 Jun	433	168	601	6,341
11 Jun	766	209	975	7,316
12 Jun	796	251	1,047	8,363
13 Jun	622	202	824	9,187
14 Jun	642	314	956	10,143
15 Jun	430	180	610	10,753
16 Jun	188	114	302	11,055
17 Jun	180	108	288	11,343
18 Jun	143	69	212	11,555
19 Jun	206	78	284	11,839
20 Jun	214	53	267	12,106
21 Jun	119	77	196	12,302
22 Jun	185	88	273	12,575
23 Jun	102	42	144	12,719
24 Jun	137	108	245	12,964
25 Jun	165	123	288	13,252
26 Jun	183	120	303	13,555
27 Jun	191	137	328	13,883
28 Jun	190	153	343	14,226
29 Jun	362	270	632	14,858
30 Jun	340	157	497	15,355
Total	9,586	5,769	15,355	

Table 10.–Daily upstream TS-based Chinook salmon passage estimates, Kenai River sonar, late run, 2008.

Date	Left bank	Right bank	Daily total	Cumulative total
1 Jul	299	228	527	527
2 Jul	284	236	520	1,047
3 Jul	270	191	461	1,508
4 Jul	125	132	257	1,765
5 Jul	105	116	221	1,986
6 Jul	104	84	188	2,174
7 Jul	77	165	242	2,416
8 Jul	103	157	260	2,676
9 Jul	241	477	718	3,394
10 Jul	290	609	899	4,293
11 Jul	224	258	482	4,775
12 Jul	442	450	892	5,667
13 Jul	298	334	632	6,299
14 Jul	195	219	414	6,713
15 Jul	835	801	1,636	8,349
16 Jul	593	704	1,297	9,646
17 Jul	732	617	1,349	10,995
18 Jul	451	378	829	11,824
19 Jul	515	276	791	12,615
20 Jul	471	338	809	13,424
21 Jul	784	473	1,257	14,681
22 Jul	725	567	1,292	15,973
23 Jul	651	509	1,160	17,133
24 Jul	650	431	1,081	18,214
25 Jul	452	424	876	19,090
26 Jul	688	347	1,035	20,125
27 Jul	991	586	1,577	21,702
28 Jul	912	483	1,395	23,097
29 Jul	831	446	1,277	24,374
30 Jul	925	483	1,408	25,782
31 Jul	1,049	537	1,586	27,368
1 Aug	962	423	1,385	28,753
2 Aug	804	373	1,177	29,930
3 Aug	643	366	1,009	30,939
4 Aug	-	-	682[a]	31,621
5 Aug	-	-	643[a]	32,264
6 Aug	-	-	622[a]	32,886
7 Aug	-	-	554[a]	33,440
8 Aug	-	-	537[a]	33,977
9 Aug	-	-	382[a]	34,359
10 Aug	-	-	282[a]	34,641
Total	-	-	34,641	

[a] Counting operations were terminated on 3 August due to numerous fish holding and milling in the beam and hampering our ability to accurately track targets. Daily passage for 4–10 August was estimated using total passage through 3 August and the mean proportion of passage from 4–10 August for years 1987, 1988, 1990, 1992, 1993, 1995, and 1998–2001.

Table 11.–Daily upstream TS-based Chinook salmon passage estimates, Kenai River sonar, early run, 2009.

Date	Left bank	Right bank	Daily total	Cumulative total
16 May	18	51	69	69
17 May	6	9	15	84
18 May	12	27	39	123
19 May	27	12	39	162
20 May	51	21	72	234
21 May	24	33	57	291
22 May	12	9	21	312
23 May	21	24	45	357
24 May	12	24	36	393
25 May	27	18	45	438
26 May	42	30	72	510
27 May	71	69	140	650
28 May	209	63	272	922
29 May	290	63	353	1,275
30 May	212	33	245	1,520
31 May	188	51	239	1,759
1 Jun	126	27	153	1,912
2 Jun	172	33	205	2,117
3 Jun	126	33	159	2,276
4 Jun	227	39	266	2,542
5 Jun	305	39	344	2,886
6 Jun	379	87	466	3,352
7 Jun	251	120	371	3,723
8 Jun	185	120	305	4,028
9 Jun	290	243	533	4,561
10 Jun	248	197	445	5,006
11 Jun	338	265	603	5,609
12 Jun	303	149	452	6,061
13 Jun	348	166	514	6,575
14 Jun	251	106	357	6,932
15 Jun	75	41	116	7,048
16 Jun	203	87	290	7,338
17 Jun	239	59	298	7,636
18 Jun	54	82	136	7,772
19 Jun	81	75	156	7,928
20 Jun	112	81	193	8,121
21 Jun	154	84	238	8,359
22 Jun	202	153	355	8,714
23 Jun	166	119	285	8,999
24 Jun	237	216	453	9,452
25 Jun	235	208	443	9,895
26 Jun	221	267	488	10,383
27 Jun	143	133	276	10,659
28 Jun	69	208	277	10,936
29 Jun	75	126	201	11,137
30 Jun	84	113	197	11,334
Total	7,121	4,213	11,334	

Table 12.–Daily upstream TS-based Chinook salmon passage estimates, Kenai River sonar, late run, 2009.

Date	Left Bank	Right Bank	Daily Total	Cumulative
1 Jul	252	379	631	631
2 Jul	315	440	755	1,386
3 Jul	409	547	956	2,342
4 Jul	341	410	751	3,093
5 Jul	328	328	656	3,749
6 Jul	276	143	419	4,168
7 Jul	371	380	751	4,919
8 Jul	341	325	666	5,585
9 Jul	326	284	610	6,195
10 Jul	373	301	674	6,869
11 Jul	598	493	1,091	7,960
12 Jul	678	436	1,114	9,074
13 Jul	487	335	822	9,896
14 Jul	696	704	1,400	11,296
15 Jul	487	612	1,099	12,395
16 Jul	477	659	1,136	13,531
17 Jul	579	670	1,249	14,780
18 Jul	398	526	924	15,704
19 Jul	403	746	1,149	16,853
20 Jul	344	665	1,009	17,862
21 Jul	373	541	914	18,776
22 Jul	414	638	1,052	19,828
23 Jul	292	534	826	20,654
24 Jul	175	352	527	21,181
25 Jul	242	337	579	21,760
26 Jul	289	670	959	22,719
27 Jul	276	114	390	23,109
28 Jul	286	155	441	23,550
29 Jul	332	120	452	24,002
30 Jul	285	147	432	24,434
31 Jul	234	110	344	24,778
1 Aug	183	33	216	24,994
2 Aug	155	39	194	25,188
3 Aug	111	45	156	25,344
4 Aug	208	136	344	25,688
Total	12,334	13,354	25,688	

Table 13.–Comparison of how fish were counted on corresponding split-beam and DIDSON echograms (see corresponding Figure 56).

Example #	Split-beam sonar count	DIDSON count	Difference (DIDSON − split)	Explanation
1	~5	15	~10	Identified as 15 smaller fish (~30–40cm) by DIDSON but only about 5 by the split-beam sonar. Groups of small fish often appear as a jumbled group of incoherent echoes in split-beam data (see Figure 57).
2	3	3	0	Identified as 3 medium-sized fish (~50–60 cm) by DIDSON and could be tracked as 2 or 3 fish from split-beam sonar depending on the skill of the technician.
3	3	3	0	Identified as 3 small fish (~30–40cm) by DIDSON and could be tracked as 2 or 3 fish from split-beam sonar depending on the skill of the technician.
4	2	4	2	Identified as 4 medium-sized fish (~60–70 cm) by DIDSON and tracked as 2 fish from split-beam sonar (see Figure 59).
5	1	1	0	1 medium-sized fish (~67cm) correctly identified by both sonars.
6	1	1	0	1 Chinook salmon (~103 cm) correctly identified by both sonars.
7	0	1	1	1 downstream-traveling Chinook salmon (~95cm) identified by DIDSON but missed by split-beam sonar because of its steep aspect angle while drifting downstream through beam (see Figure 58).
8	0	1	1	Identified as 1 medium-sized fish (~58cm) by DIDSON and detected by split-beam sonar but did not have enough pings to qualify as a valid split-beam target (i.e., track contained less than 10 echoes).
9	1	1	0	1 medium-sized fish (~65 cm) correctly identified by both sonars.
10	0	1	1	Identified as 1 small fish (~50cm) by DIDSON and detected by split-beam sonar but did not have enough pings to qualify as a valid split-beam target (i.e., track contained less than 10 echoes).
11	1	1	0	1 medium-sized fish (~60cm) correctly identified by both sonars.
Total fish	~17	32	~15	If you ignore the first example, difference is ~5 (12 vs. 17 fish)

FIGURES

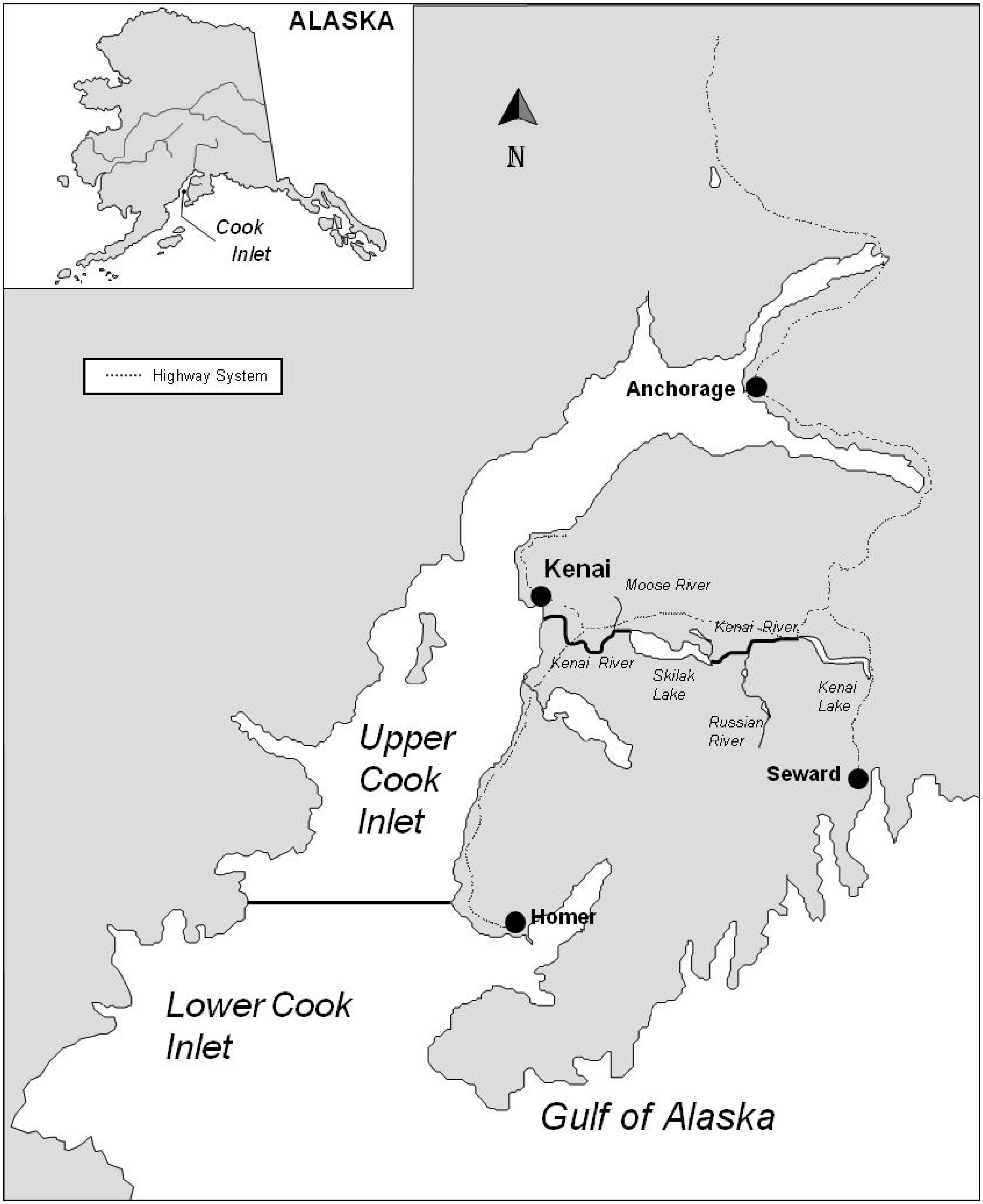


Figure 1.–Cook Inlet showing location of Kenai River.

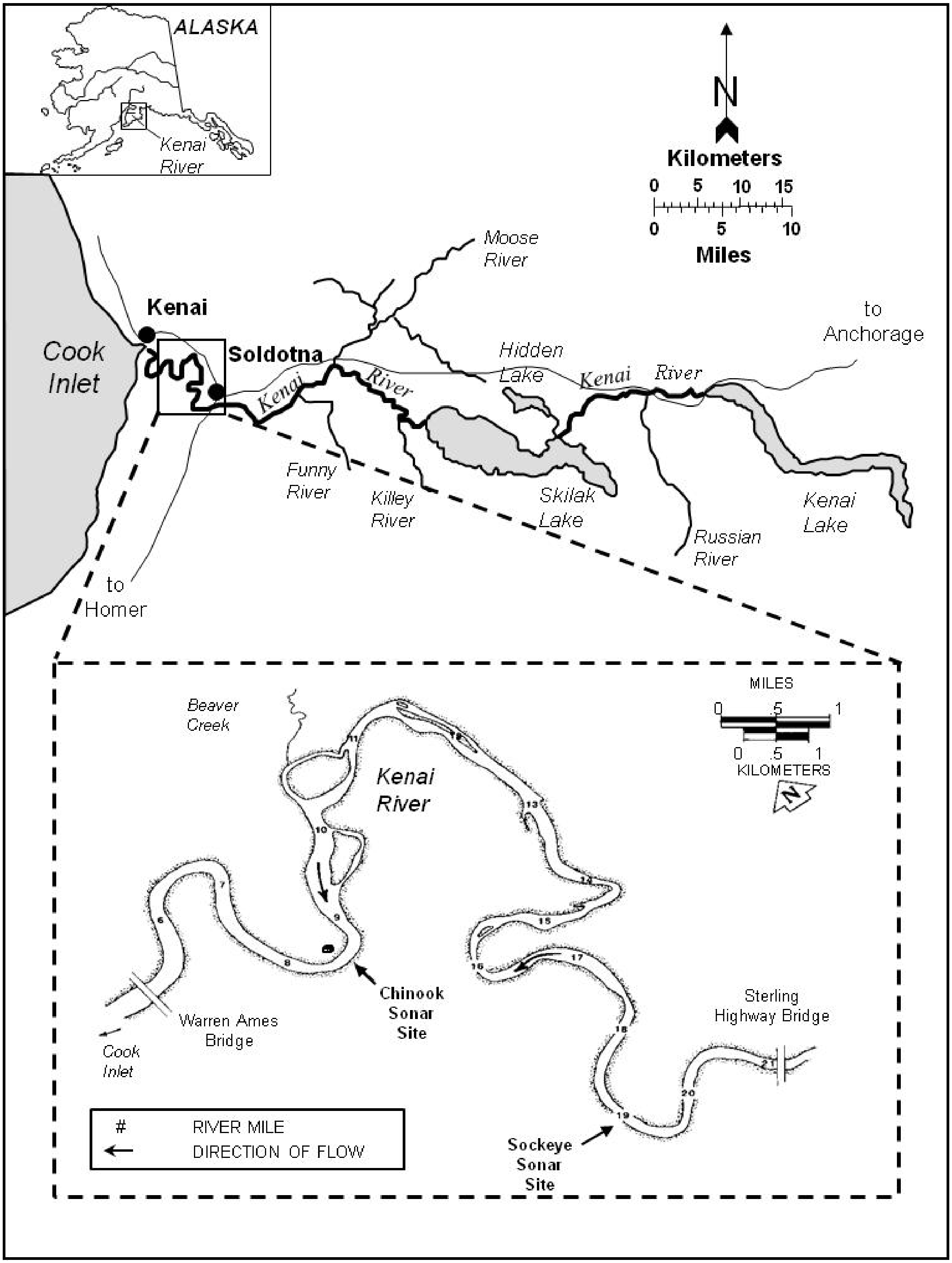


Figure 2.–Kenai River sonar site locations, 2008–2009.

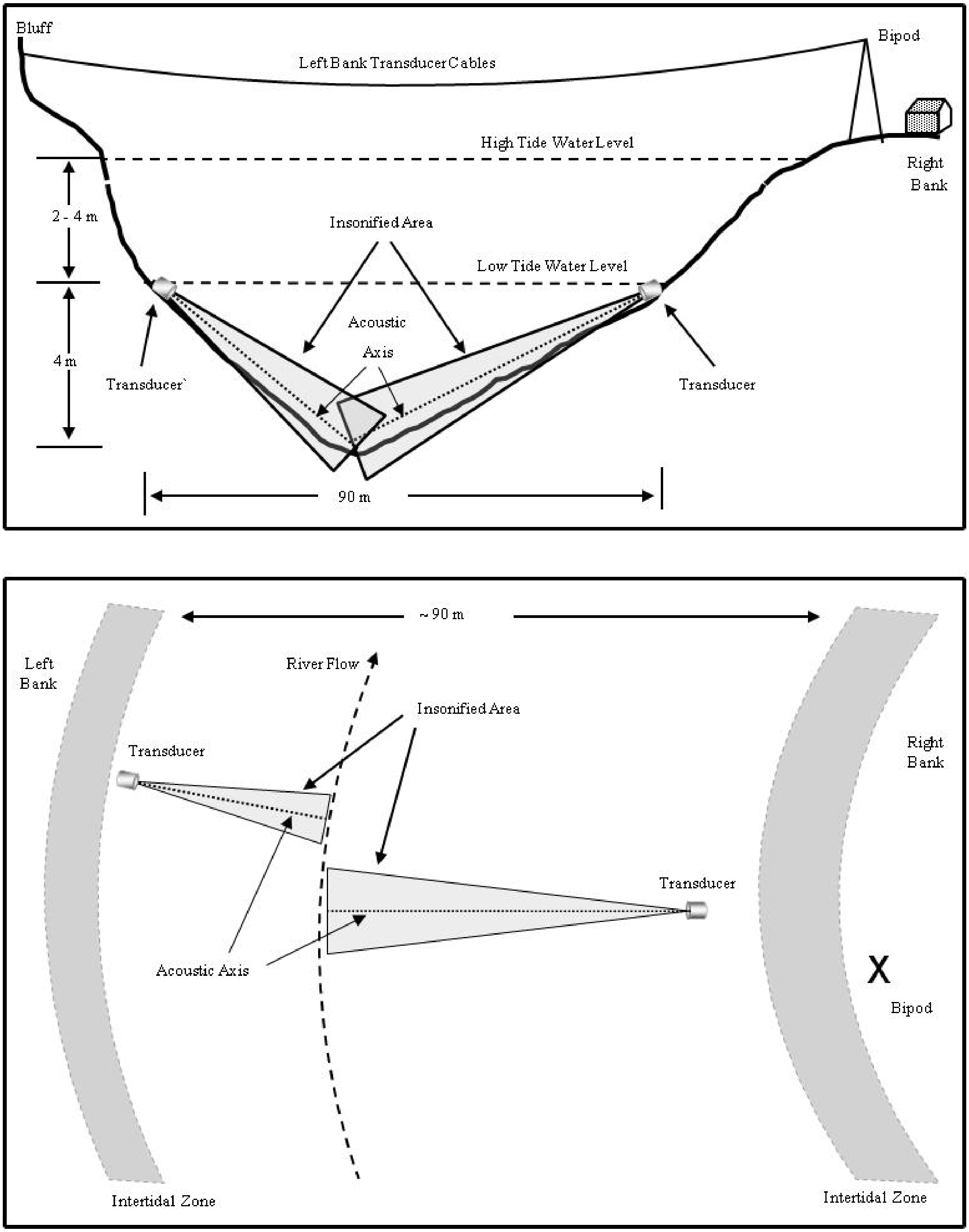


Figure 3.–Cross-sectional (top) and aerial (bottom) diagrams of sonar site illustrating insonified portions of the Kenai River, 2008–2009.

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

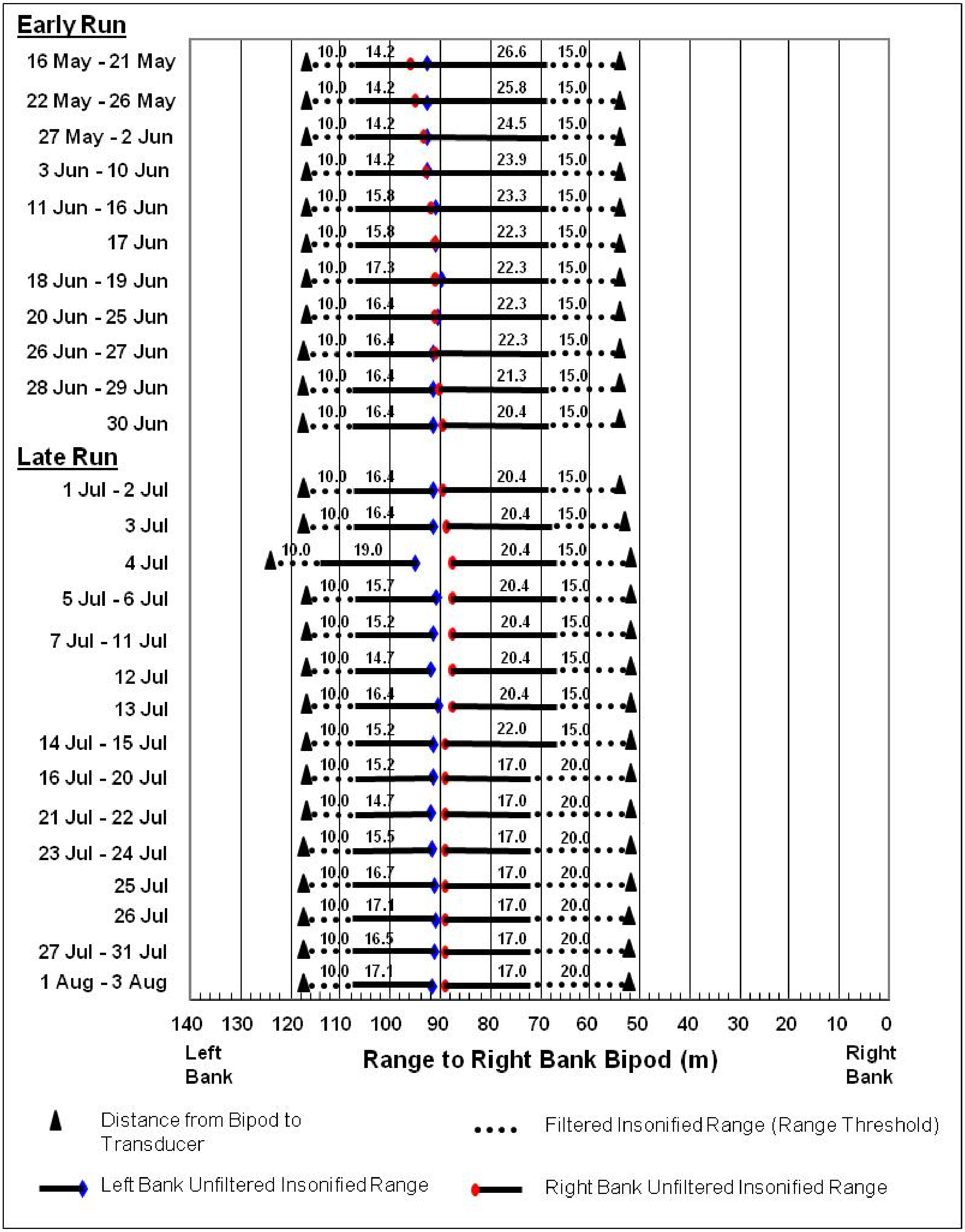


Figure 4.–Daily right- and left-bank transducer placement and insonified ranges relative to bipod tower located on the right bank, Kenai River, 2008.

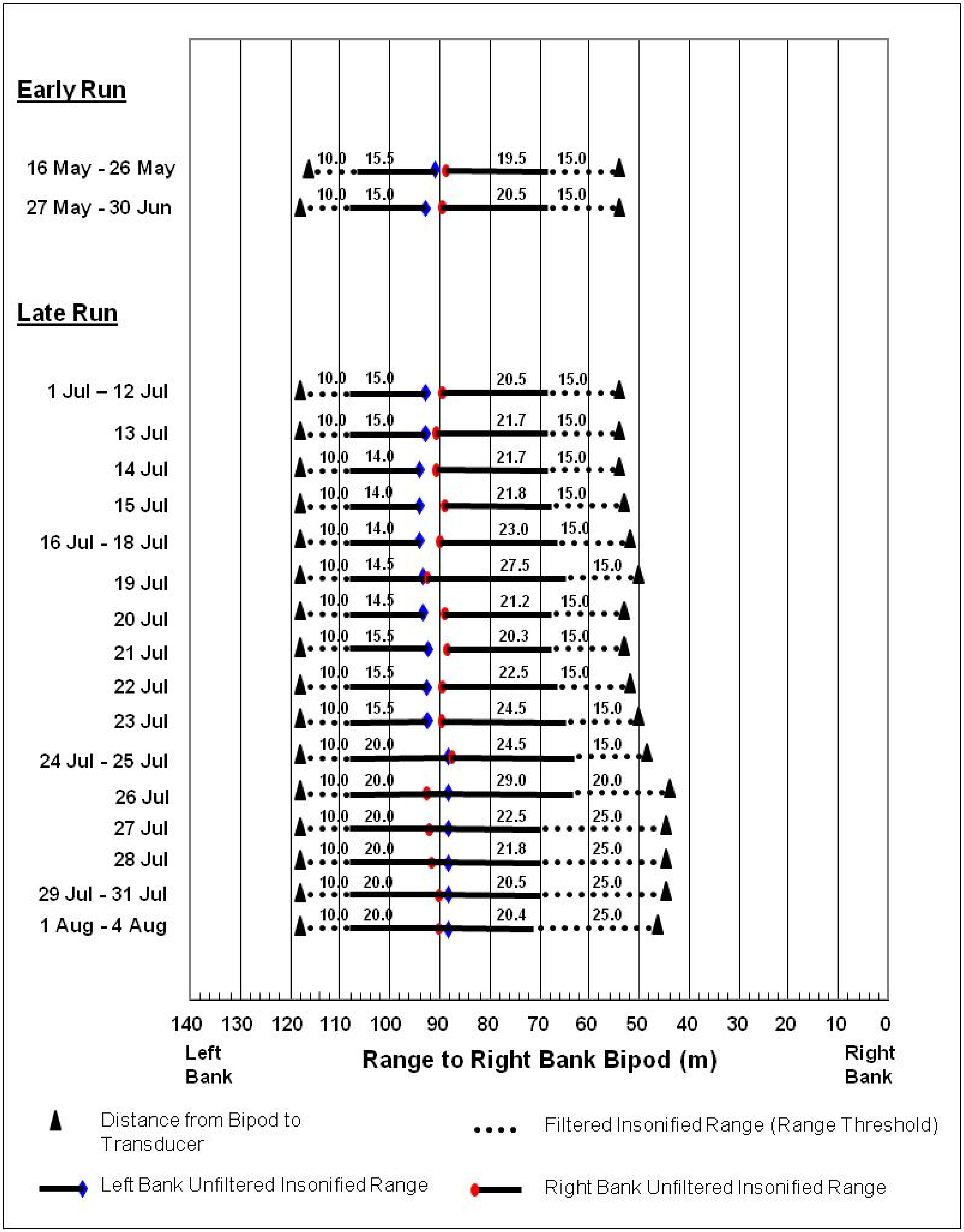


Figure 5.–Daily right- and left-bank transducer placement and insonified ranges relative to bipod tower located on the right bank, Kenai River, 2009.

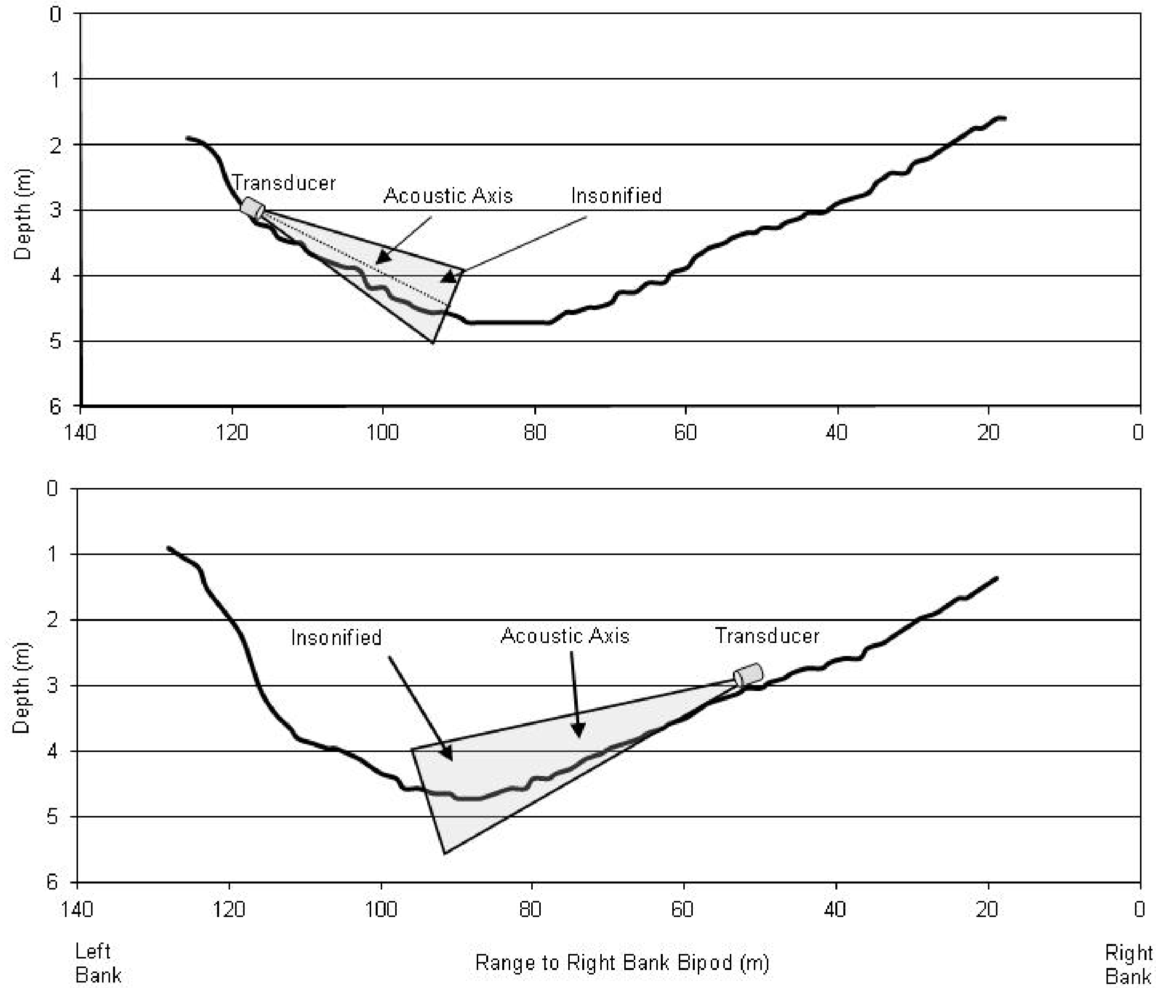


Figure 6.–Bottom profiles by bank for the Kenai River Chinook sonar site with approximate transducer placement and sonar beam coverage for 16 May 2008.

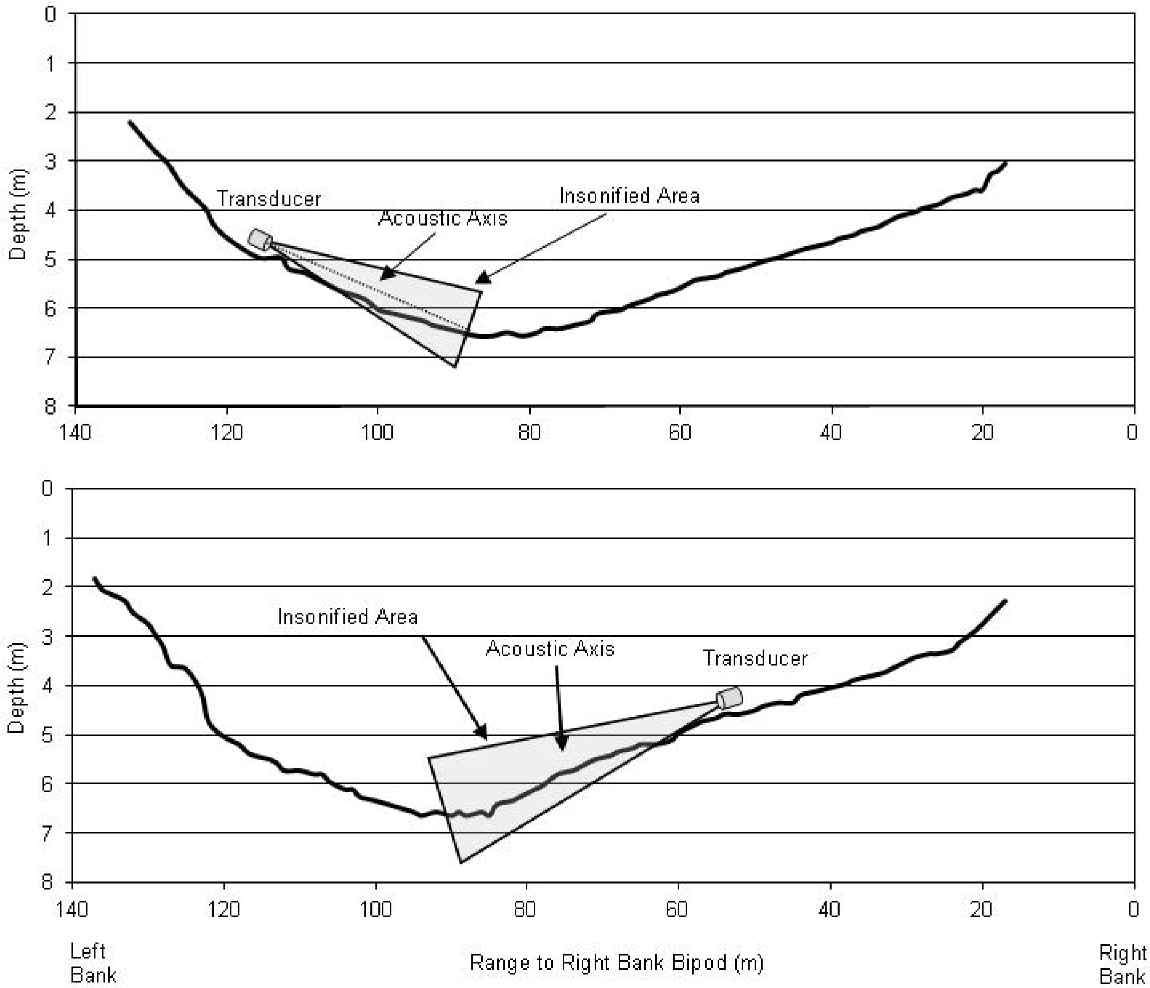


Figure 7.–Bottom profiles by bank for the Kenai River Chinook sonar site with approximate transducer placement and sonar beam coverage for 16 May 2009.

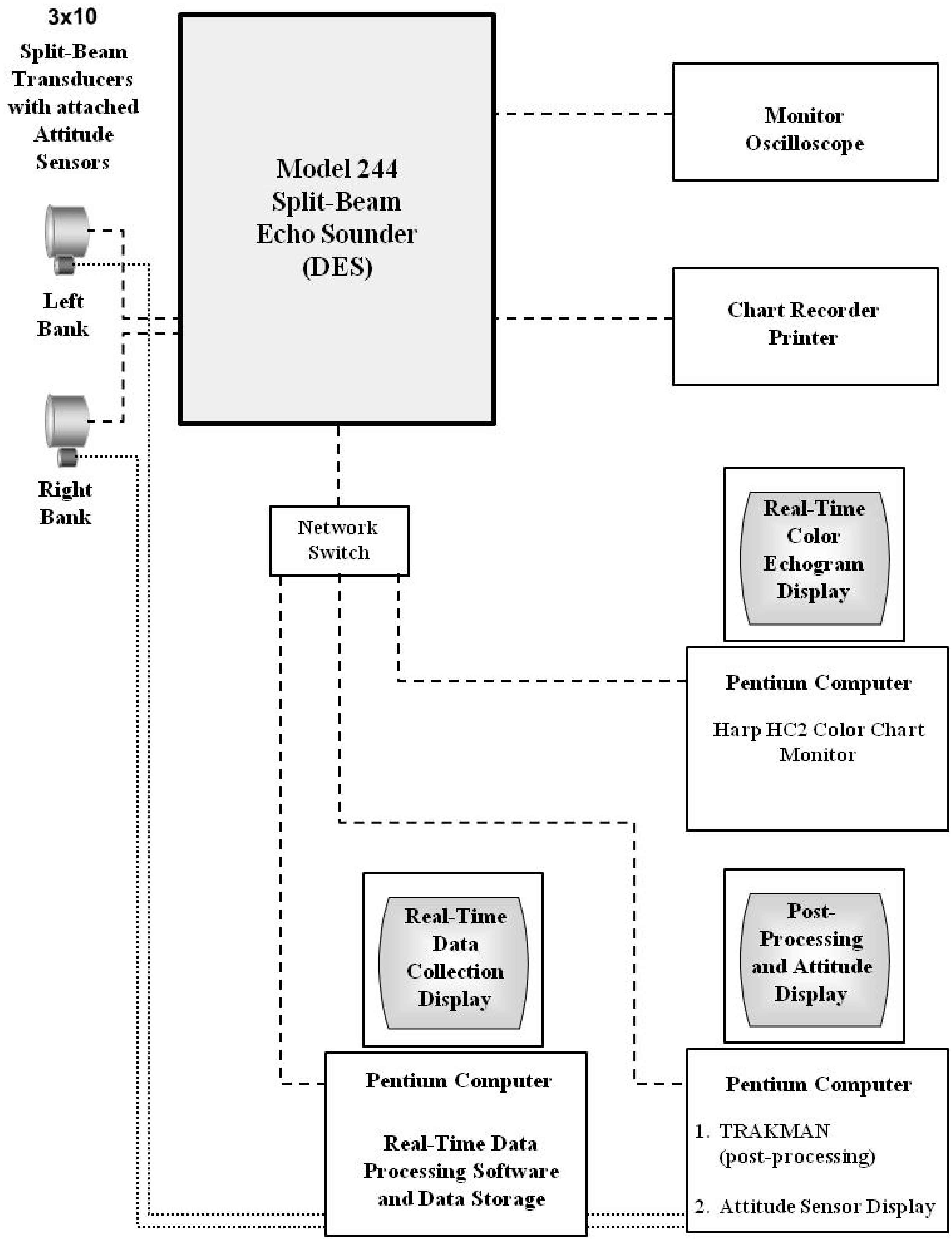
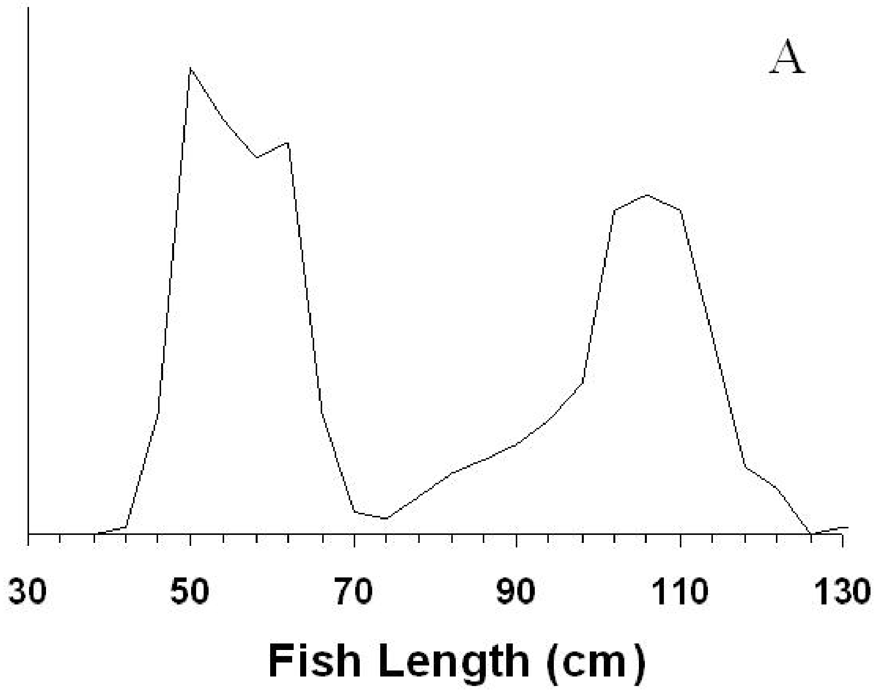


Figure 8.–Diagram of 2008–2009 split-beam sonar system configuration and data flow.



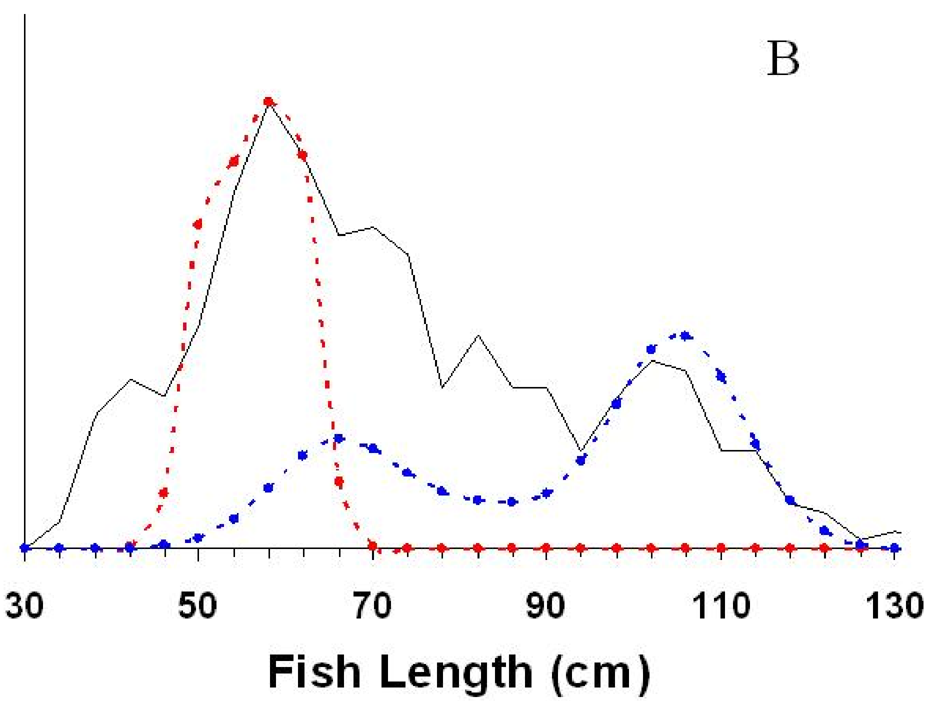


Figure 9.–Hypothetical distributions of fish length measurements (black solid lines) at the Kenai River sonar site. A, Few small Chinook salmon, no measurement error. The true species composition is 50% sockeye salmon, 50% Chinook salmon. B, 40% of Chinook salmon are small; measurement error standard deviation = 10 cm. Distributions of sockeye (red dashed line) and Chinook (blue dashed line) salmon true length are shown. The true species composition is 50% sockeye salmon, 50% Chinook salmon.

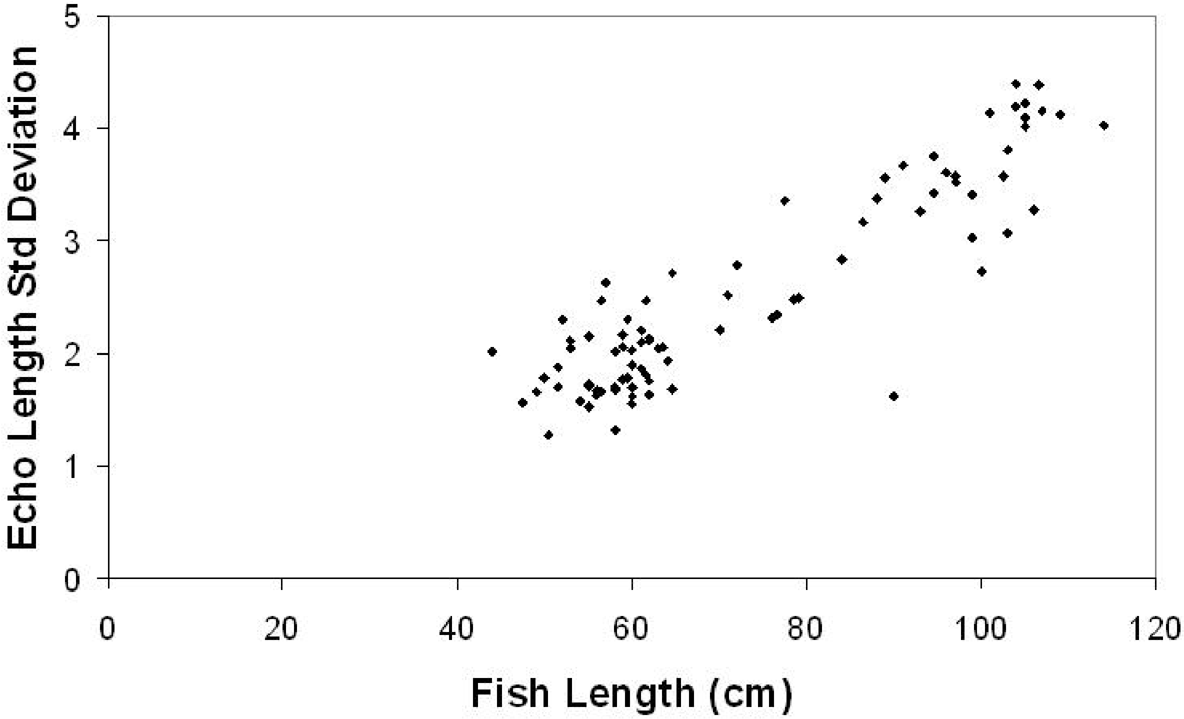


Figure 10.–Echo length standard deviation versus fish length for tethered Pacific salmon in the Kenai River, 1995. Data from Burwen and Fleischman (1998).

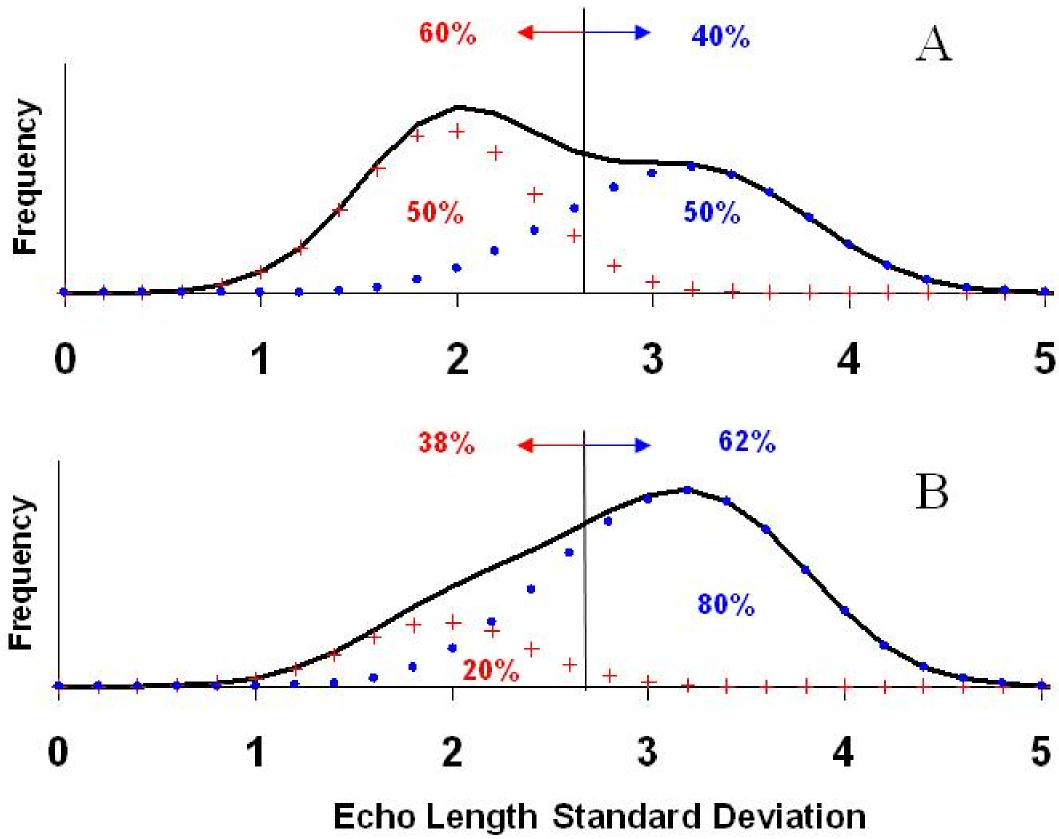


Figure 11.–An example of threshold-based discrimination of Chinook and sockeye salmon. Threshold-based discrimination is subject to bias when discriminating variables are imprecise. Solid lines are simulated frequency distributions of echo length standard deviation arising from component distributions due to sockeye salmon (plus symbols) and Chinook salmon (solid symbols). A, If the true species composition is 50% sockeye to 50% Chinook salmon, and a threshold criterion of 2.7 is used, estimated species composition will be 60:40. B, Using the threshold criterion above, if the true species composition is 20:80, estimated species composition will be 38:62.

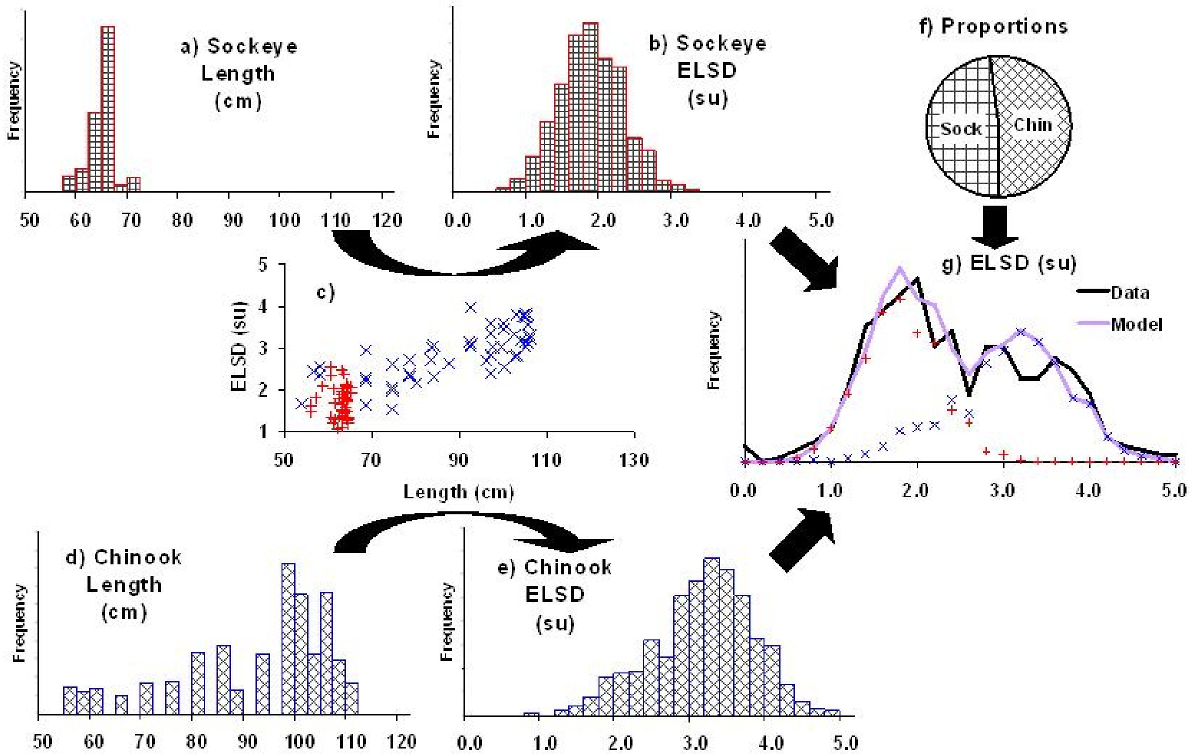


Figure 12.–Flow chart of a mixture model. The frequency distribution of echo length standard deviation (ELSD, panel g) is modeled as a weighted mixture of species-specific ELSD distributions (panels b and e), which in turn are the products of species-specific size distributions (panels a and d) and the relationship between ELSD and fish length (panel c). The weights (species proportions, panel f) are the parameters of interest. Plus symbol = sockeye salmon, x = Chinook salmon. Checkered pattern = sockeye salmon, cross-hatched = Chinook salmon. Units for ELSD are 48 kHz digital sampling units.

Figure 13.–A long-range DIDSON with a high-resolution large lens (left) is mounted side-by-side with a split-beam transducer (right). The DIDSON is sealed in a silt-proof enclosure.

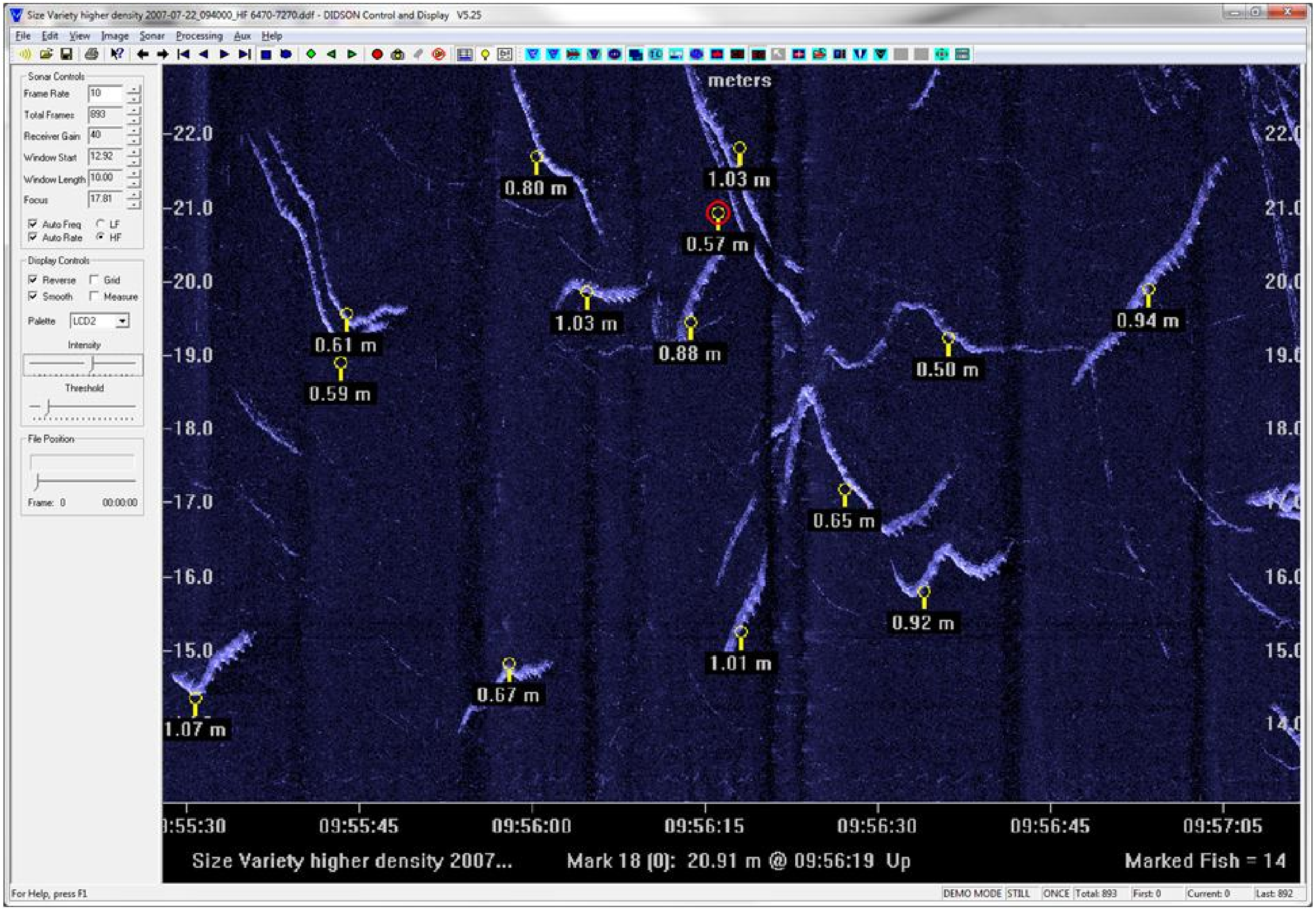


Figure 14.–DIDSON echogram displaying fish traces and manual length measurements.

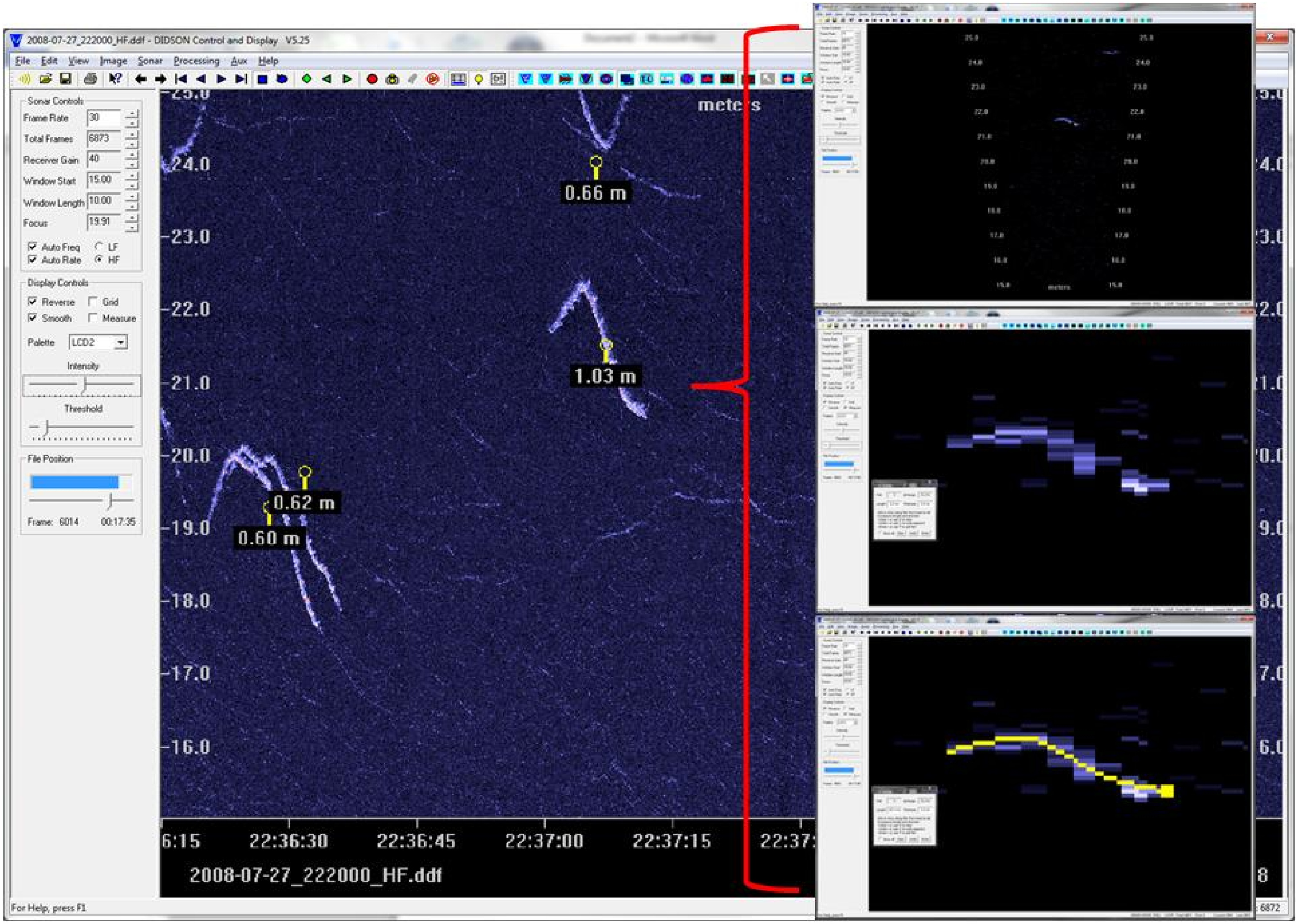


Figure 15.–Demonstration of the SMC manual-measuring tool. The user toggles from the chart mode to the movie mode by right-clicking on the fish trace, pauses the DIDSON movie on a frame displaying the full length of the fish (top), zooms in (middle), and measures the fish length with a segmented line (bottom) created by mouse clicks along the center axis of the fish.

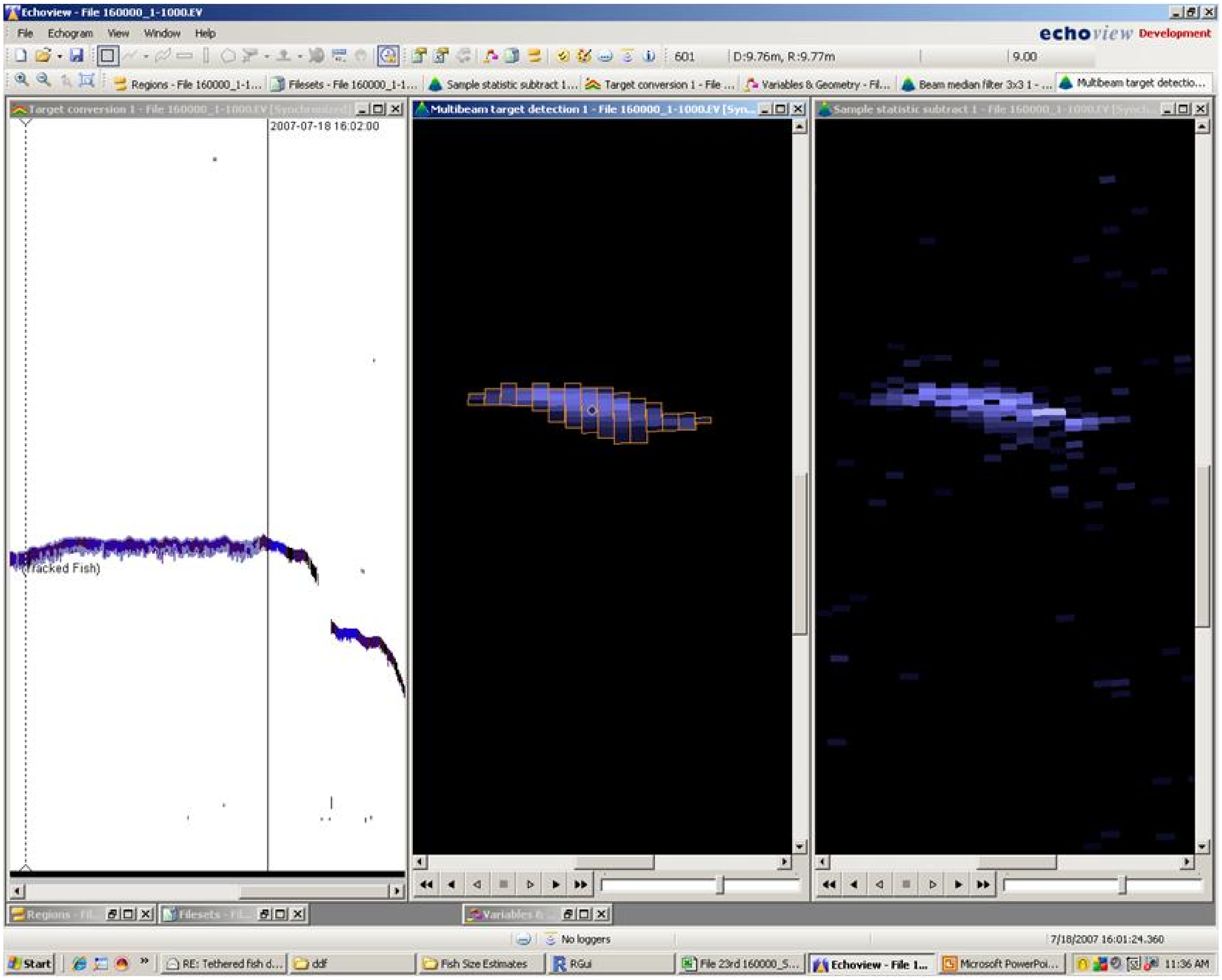


Figure 16.–Demonstration of the Echoview auto-measurement feature. Echoview can simultaneously display an Echogram (left) and movie modes (middle and right). Echoview produces a cluster overlay (middle) of the fish image (right) from which a fish length measurement can be automatically calculated. The vertical line on the echogram determines the frame displayed in movie mode at right.

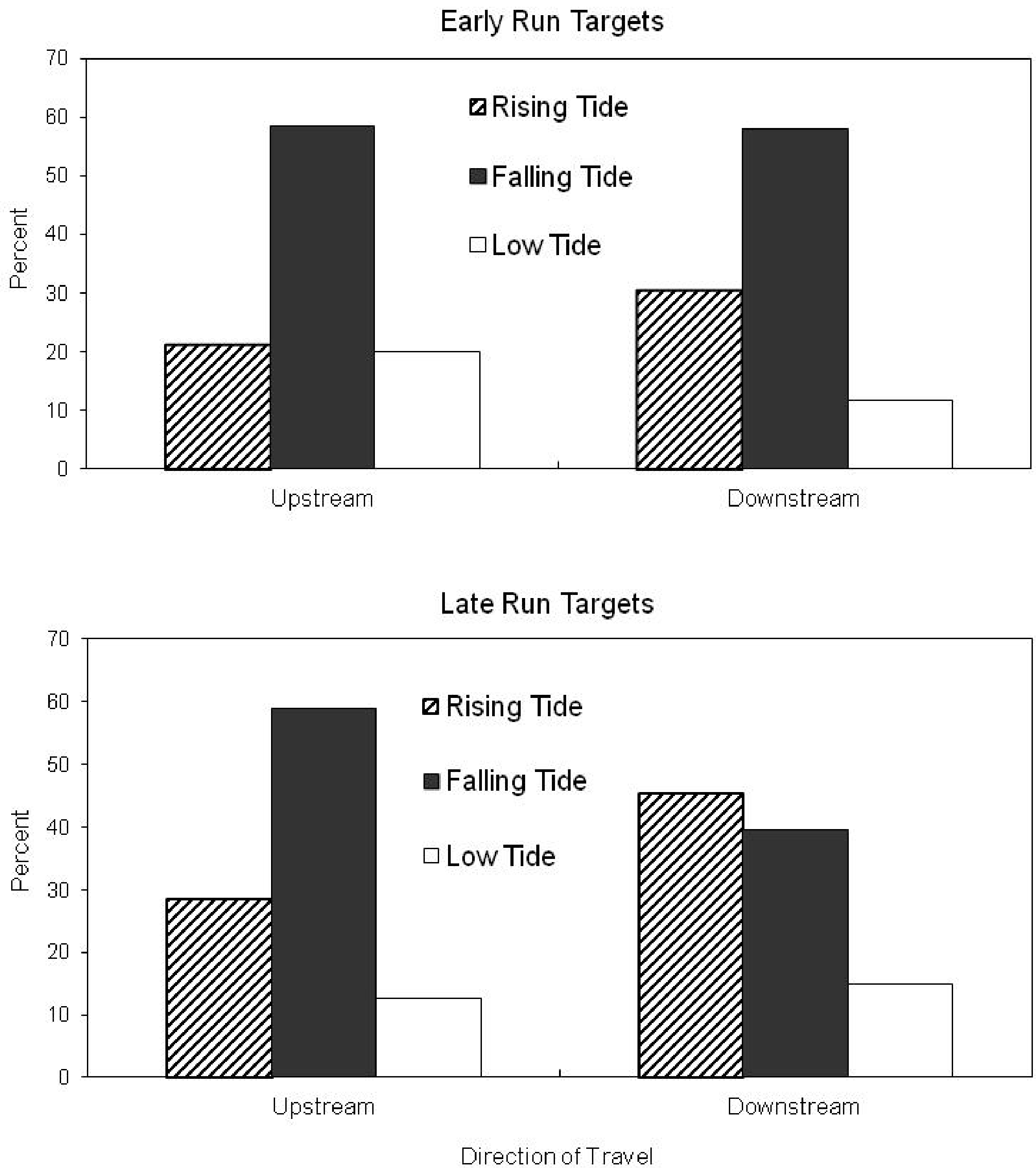


Figure 17.–Percentage of upstream- and downstream-moving filtered targets by tide stage for the early (top) and late (bottom) runs, Kenai River, 2008.

Note: Data have been filtered by range (distance from transducer) and target strength criteria.

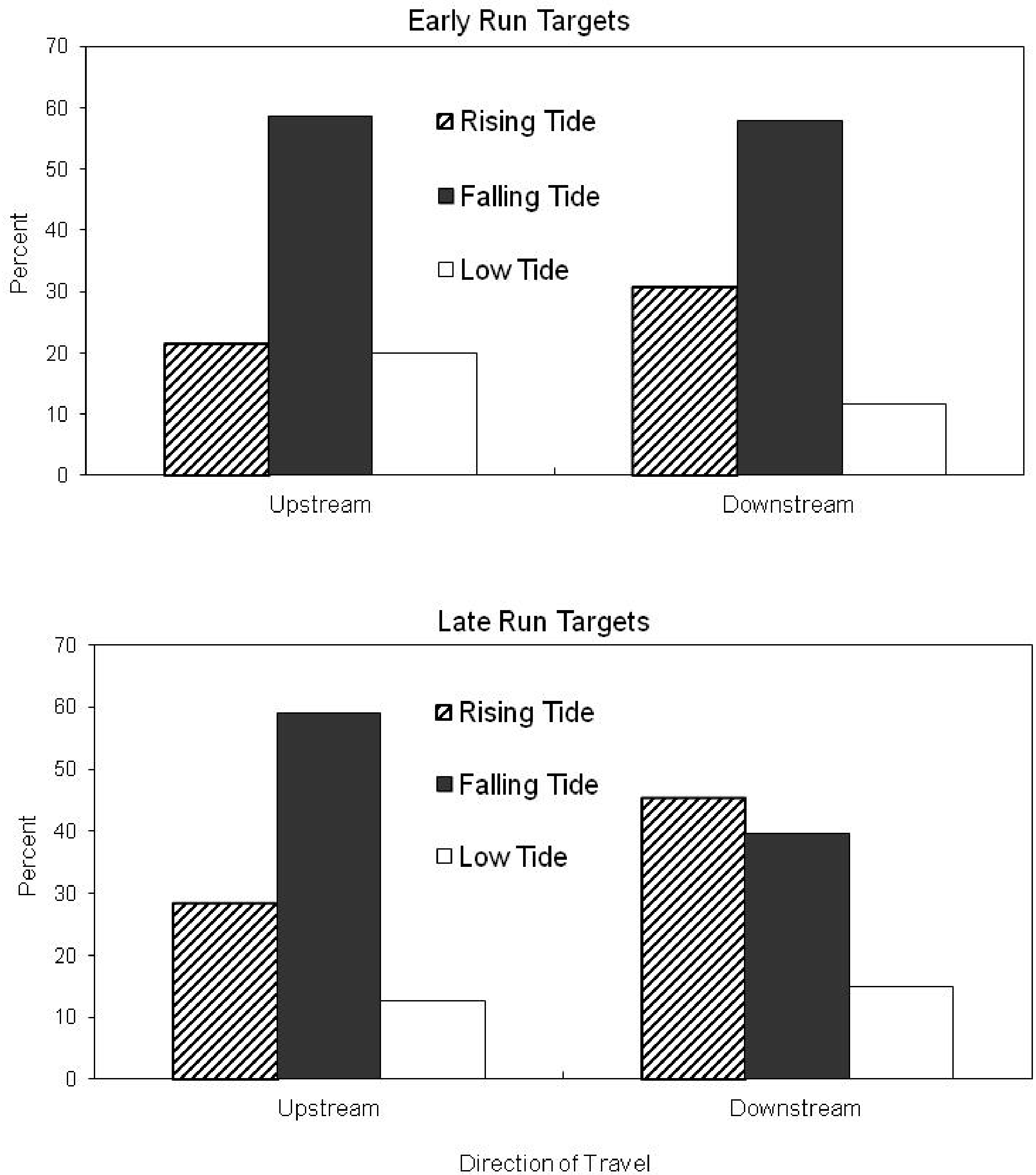


Figure 18.–Percentage of upstream- and downstream-moving filtered targets by tide stage for the early (top) and late (bottom) runs, Kenai River, 2009.

Note: Data have been filtered by range (distance from transducer) and target strength criteria.

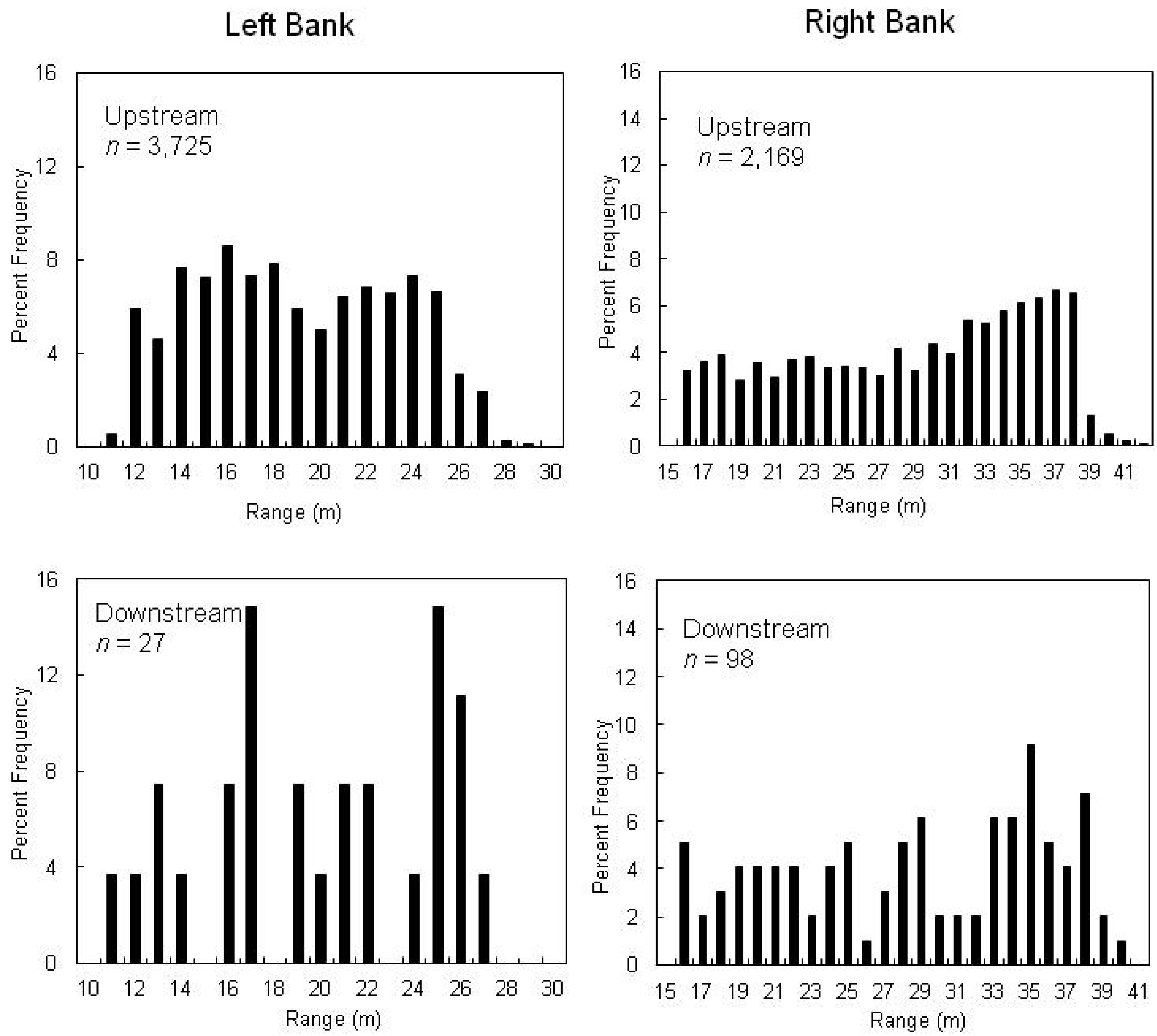


Figure 19.–Standardized distance from transducer (range) of early-run upstream- and downstream-moving filtered targets by bank, Kenai River, 2008.

Note: Data have been filtered by range (distance from transducer) and target strength criteria.

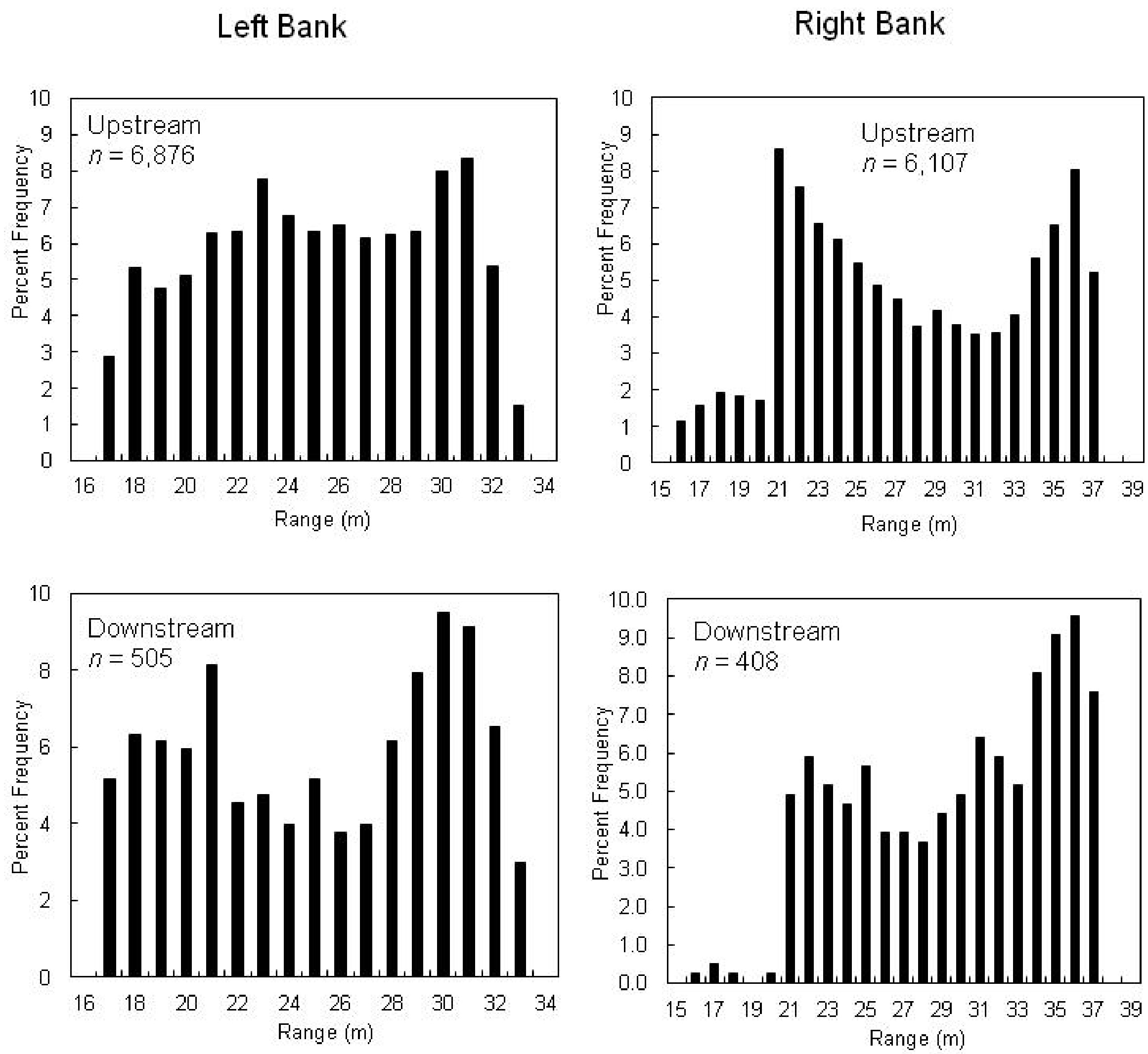


Figure 20.–Standardized distance from tranducer (range) of late-run upstream- and downstream-moving filtered targets by bank, Kenai River, 2008.

Note: Data have been filtered by range (distance from transducer) and target strength criteria.

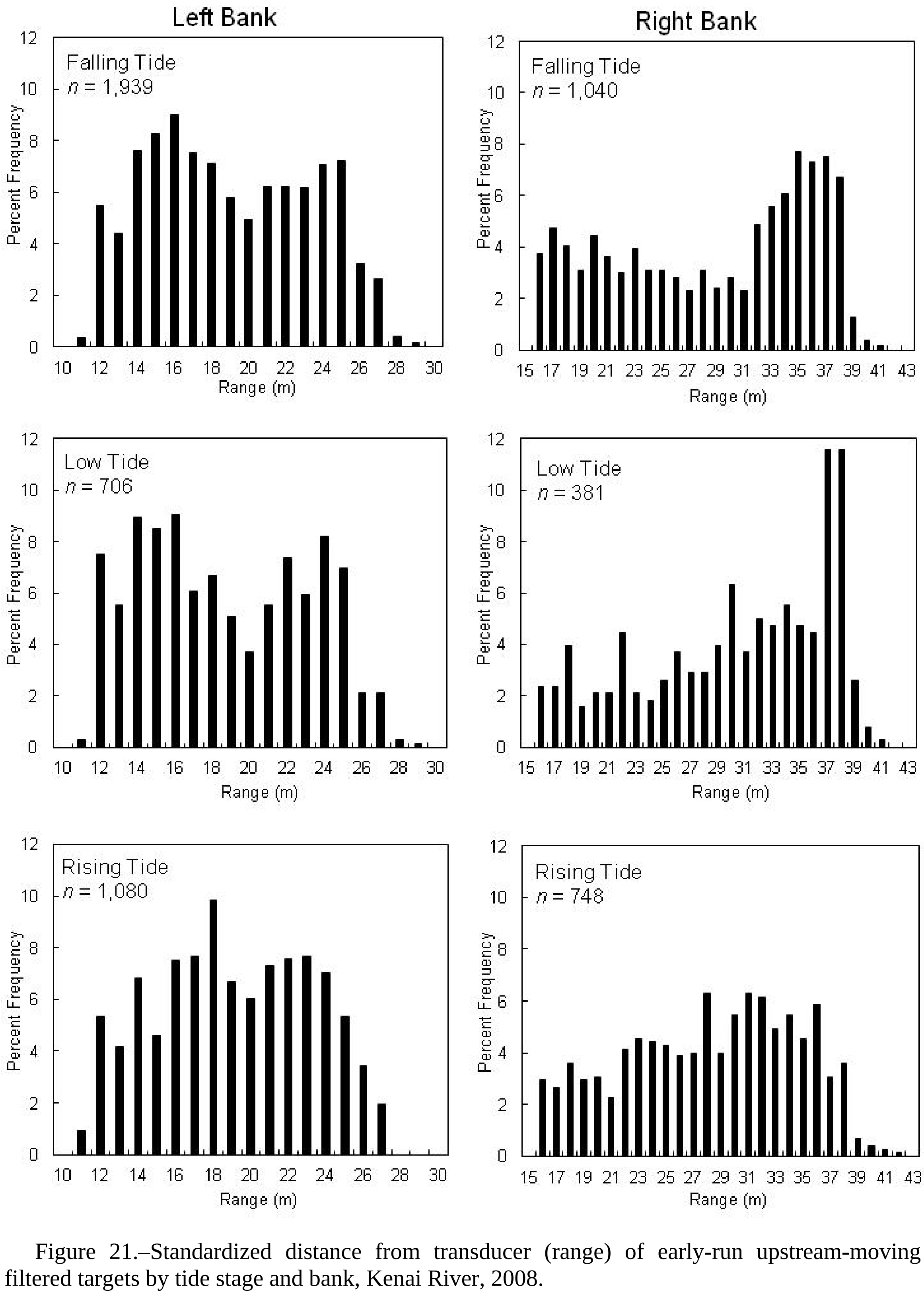


Figure 21.–Standardized distance from transducer (range) of early-run upstream-moving filtered targets by tide stage and bank, Kenai River, 2008.

Note: Data have been filtered by range (distance from transducer) and target strength criteria.

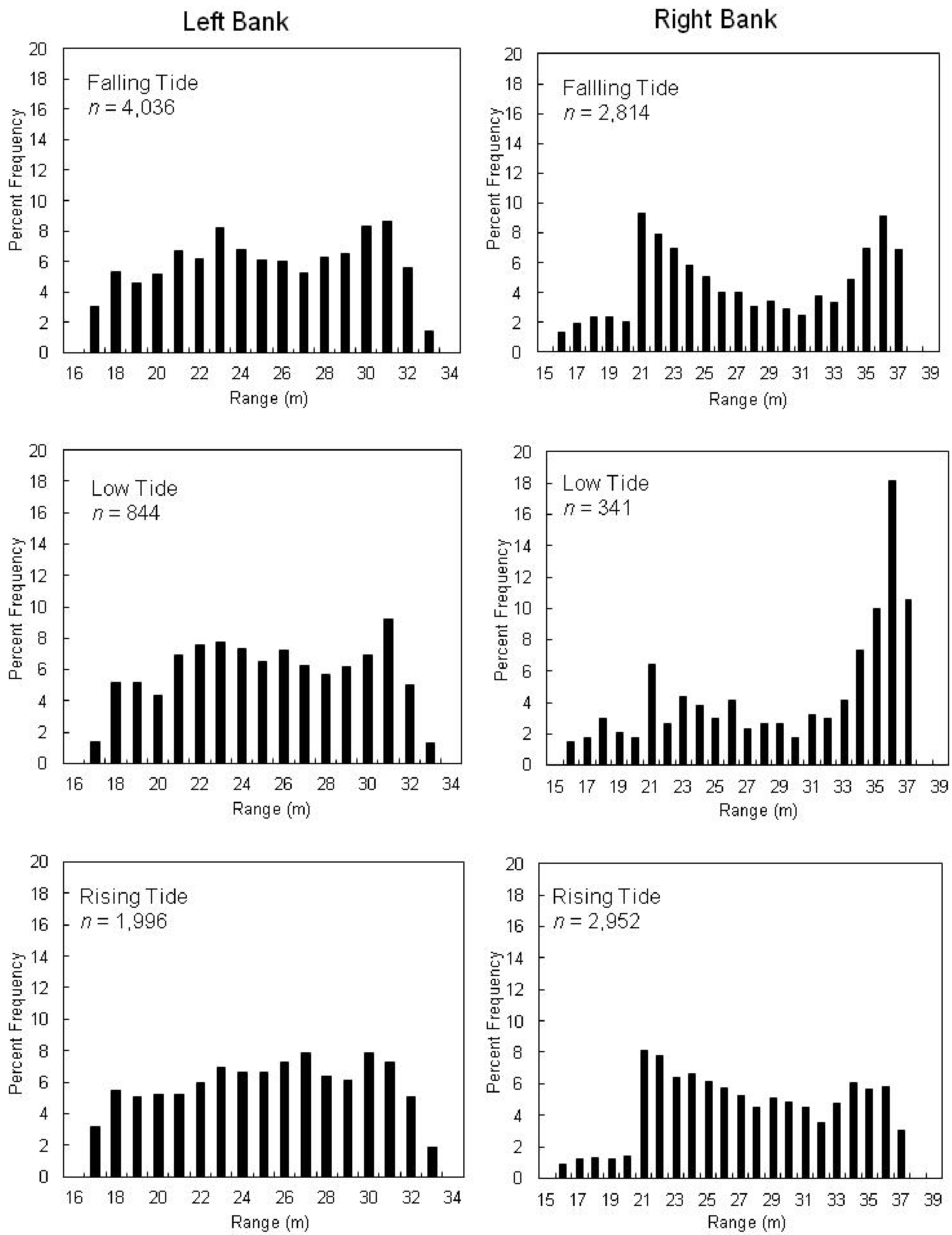


Figure 22.–Standardized distance from transducer (range) of late-run upstream-moving filtered targets by tide stage and bank, Kenai River, 2008.

Note: Data have been filtered by range (distance from transducer) and target strength criteria.

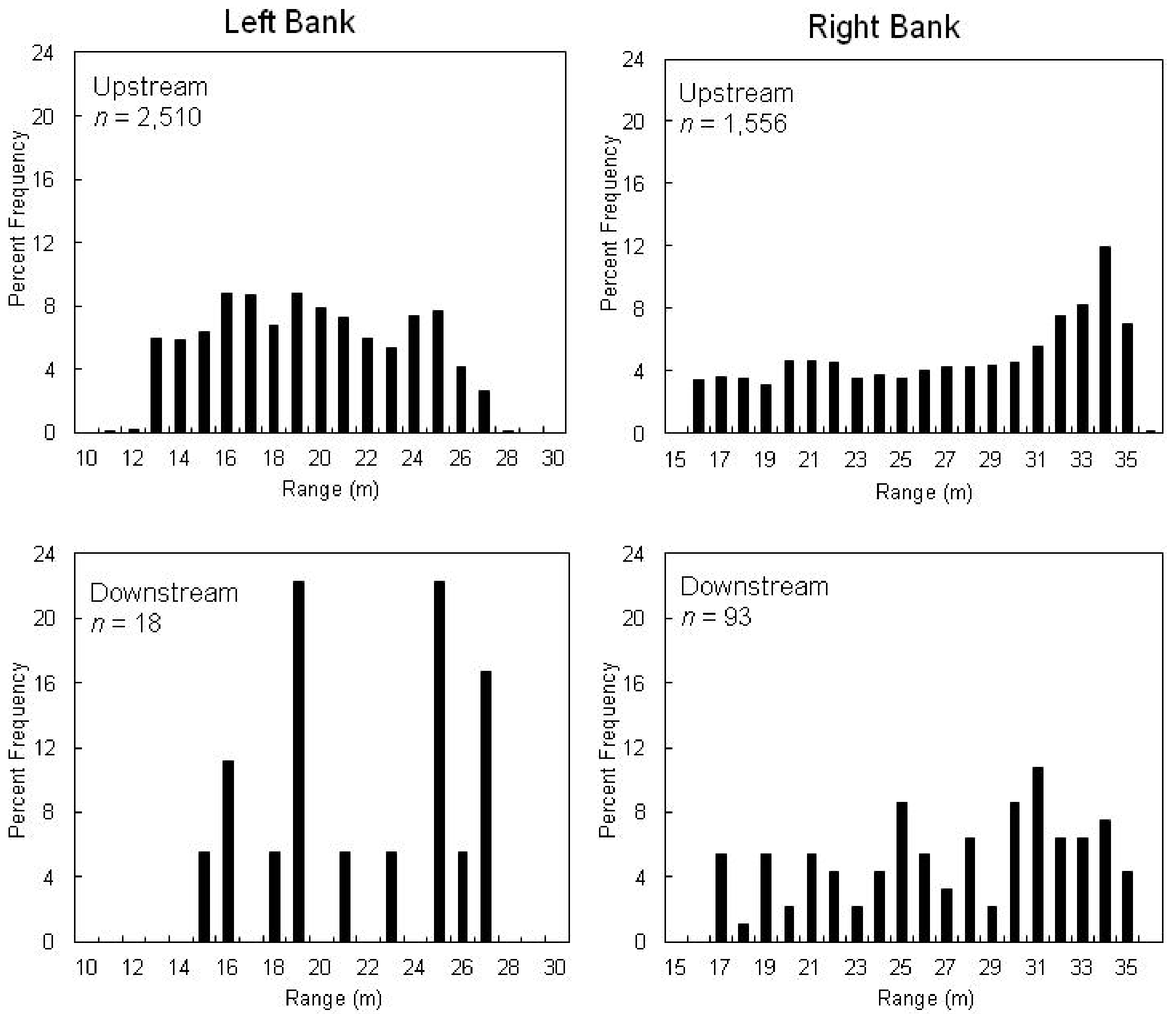


Figure 23.–Standardized distance from transducer (range) of early-run upstream and downstream-moving filtered targets by bank, Kenai River, 2009.

Note: Data have been filtered by range (distance from transducer) and target strength criteria.

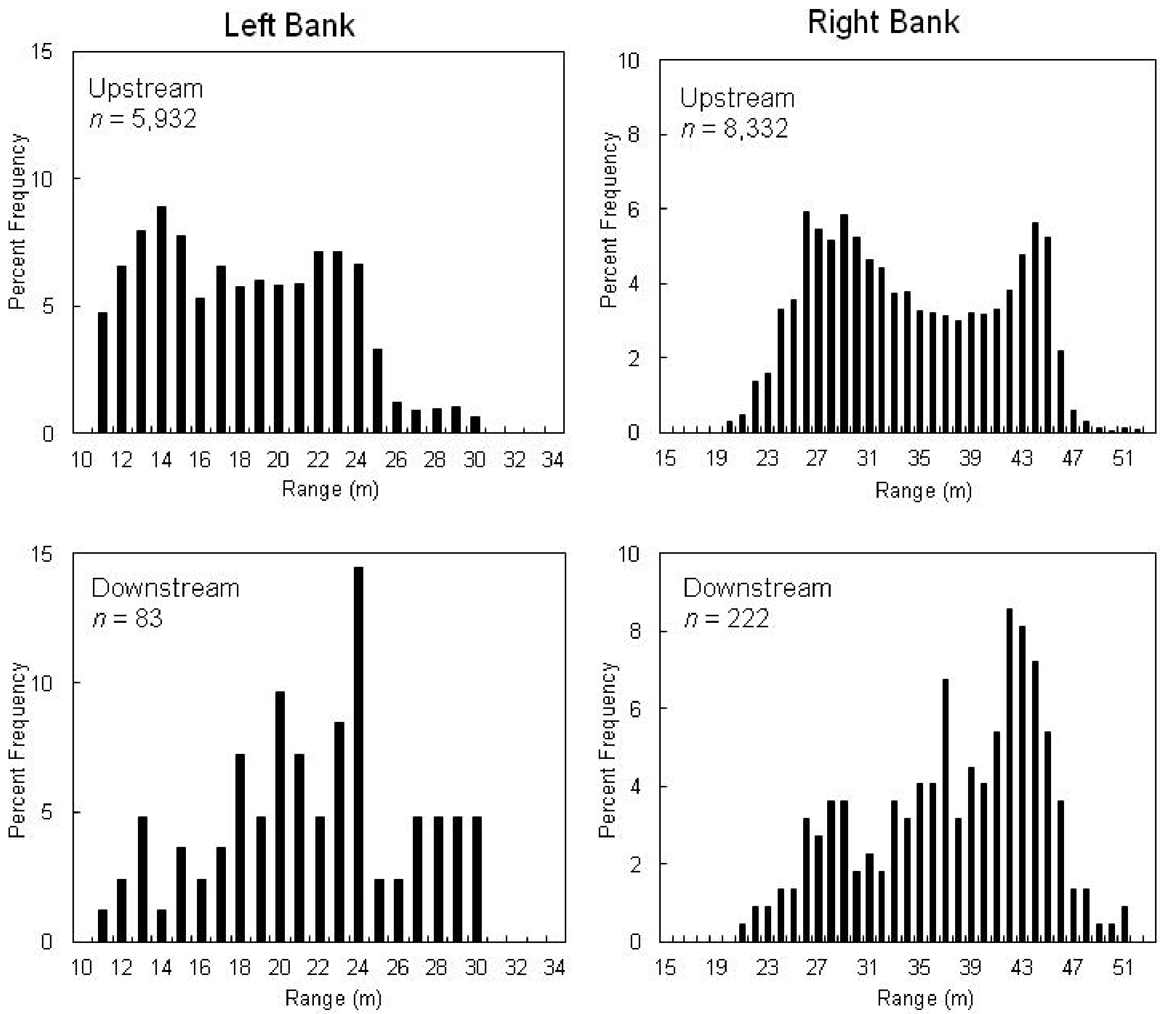


Figure 24.–Standardized distance from transducer (range) of late-run upstream- and downstream-moving filtered targets by bank, Kenai River, 2009.

Note: Data have been filtered by range (distance from transducer) and target strength criteria.

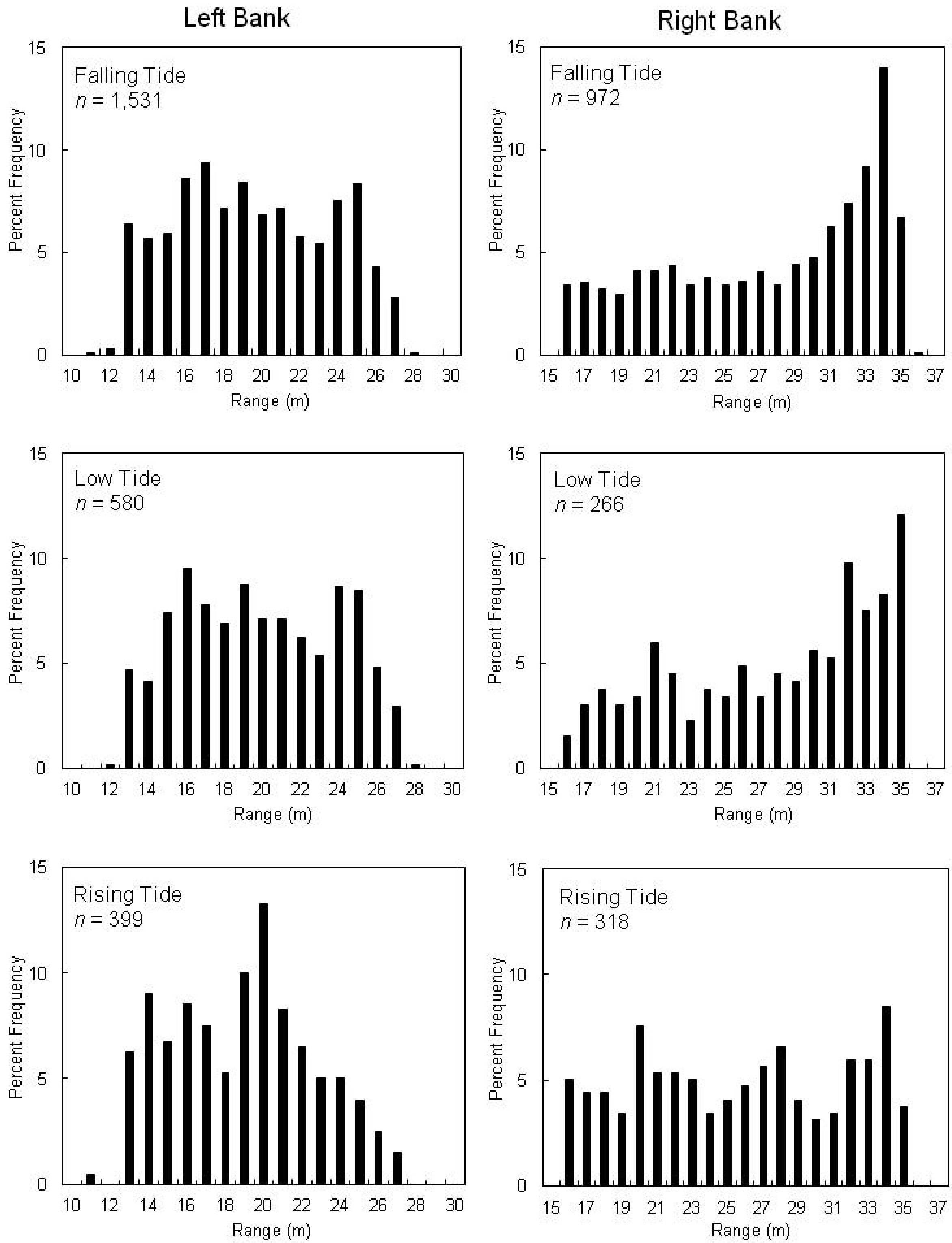


Figure 25.–Standardized distance from transducer (range) of early-run upstream-moving filtered targets by tide stage and bank, Kenai River, 2009.

Note: Data have been filtered by range (distance from transducer) and target strength criteria.

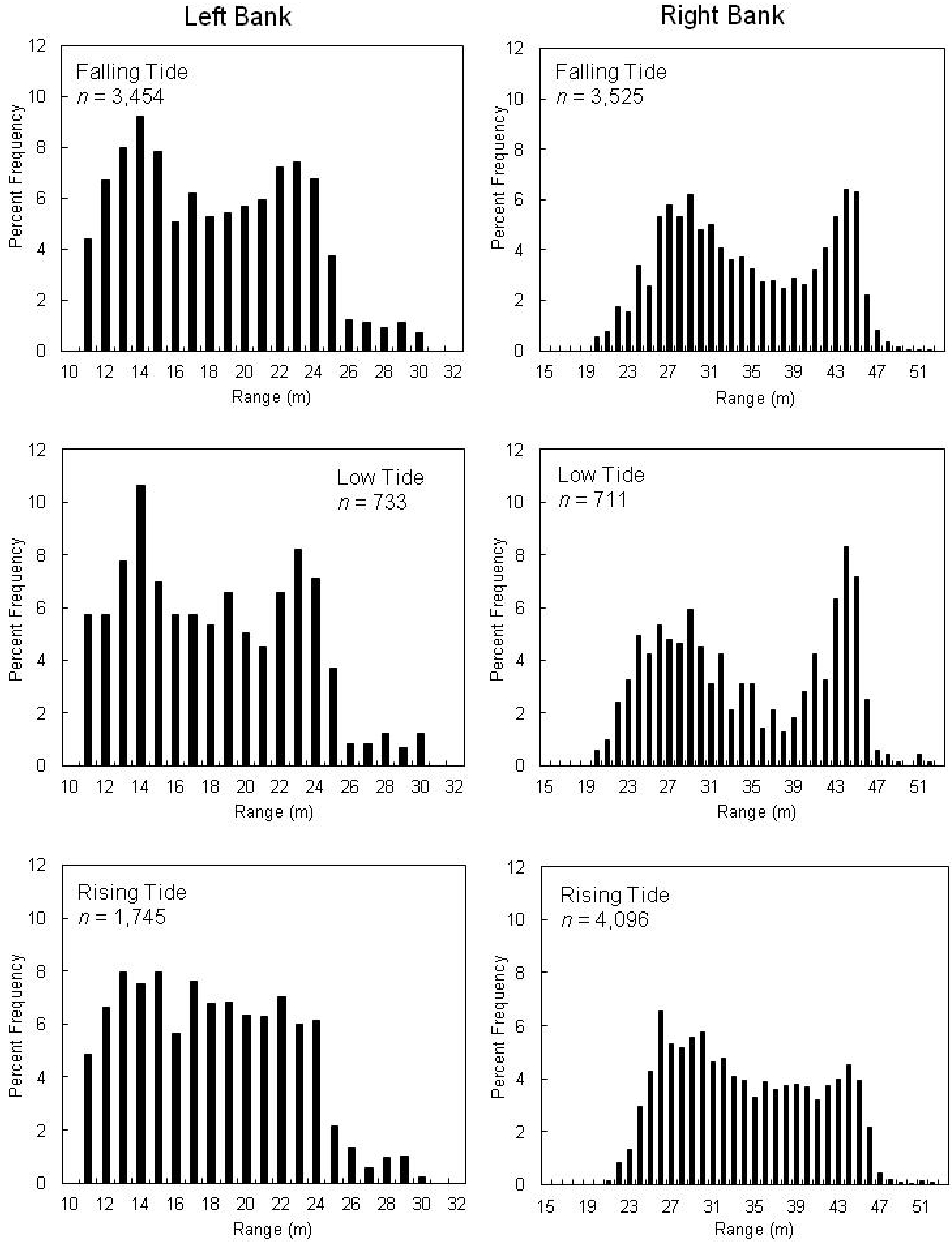


Figure 26.–Standardized distance from transducer (range) of late-run upstream-moving filtered targets by tide stage and bank, Kenai River, 2009.

Note: Data have been filtered by range (distance from transducer) and target strength criteria.

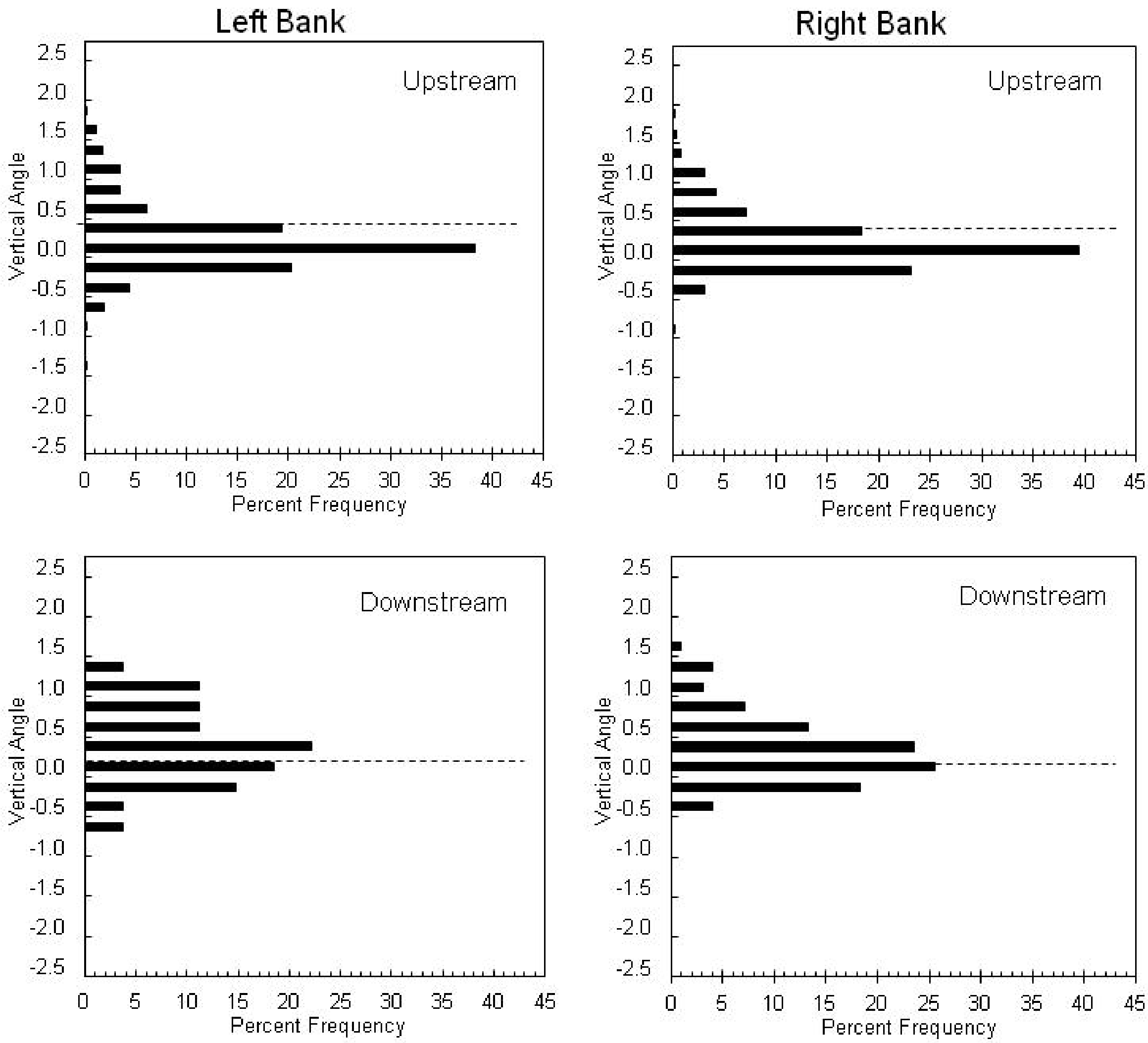


Figure 27.–Vertical distributions above and below the acoustic axis of early-run upstream- and downstream-moving filtered targets by bank, Kenai River, 2008.

Note: Data have been filtered by range (distance from transducer) and target strength criteria. Acoustic axis = 0.0.

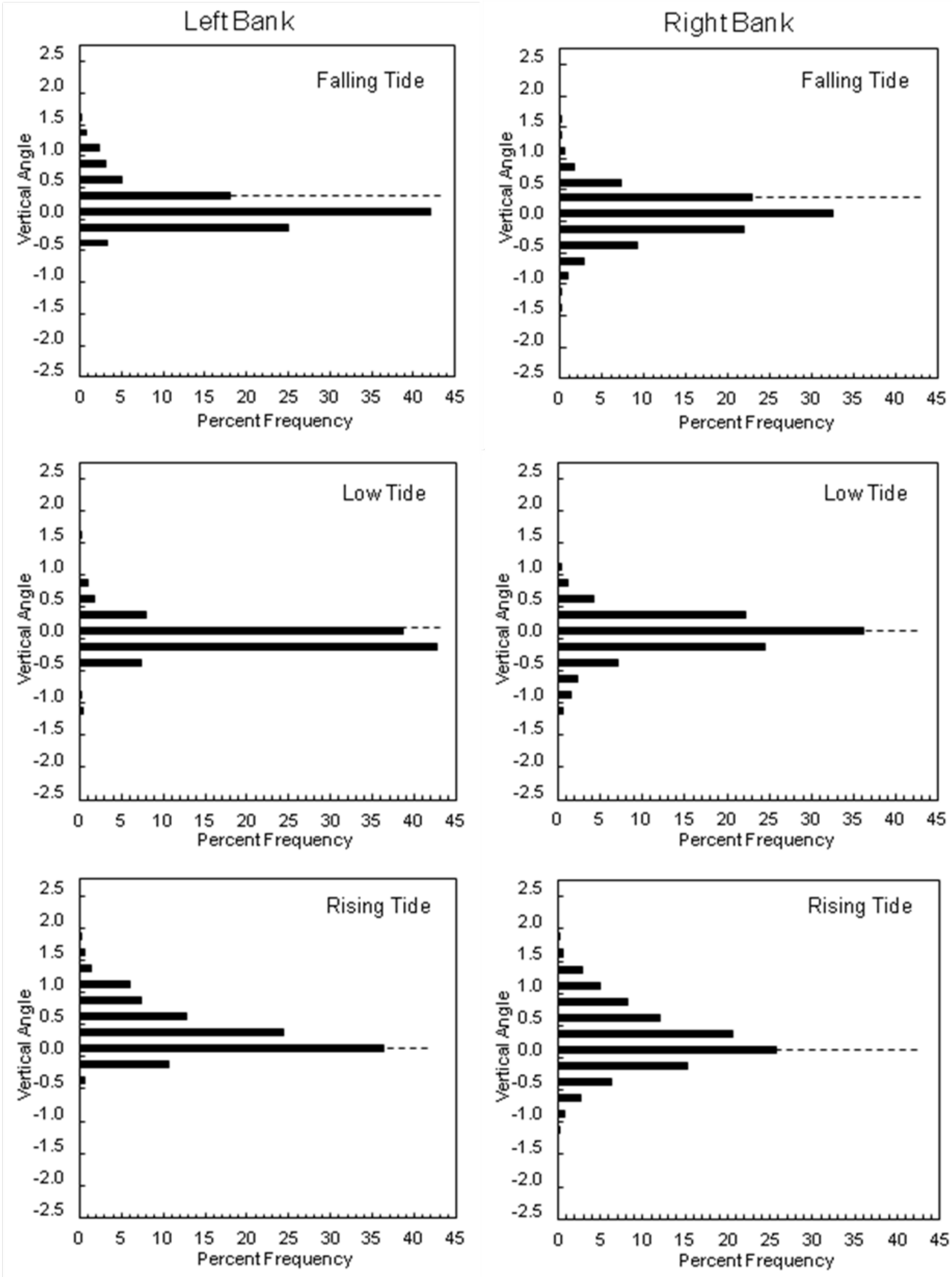


Figure 28.–Vertical distributions above and below the acoustic axis of early-run upstream moving filtered targets by tide stage and bank, Kenai River, 2008.

Note: Data have been filtered by range (distance from transducer) and target strength criteria. Acoustic axis = 0.0.

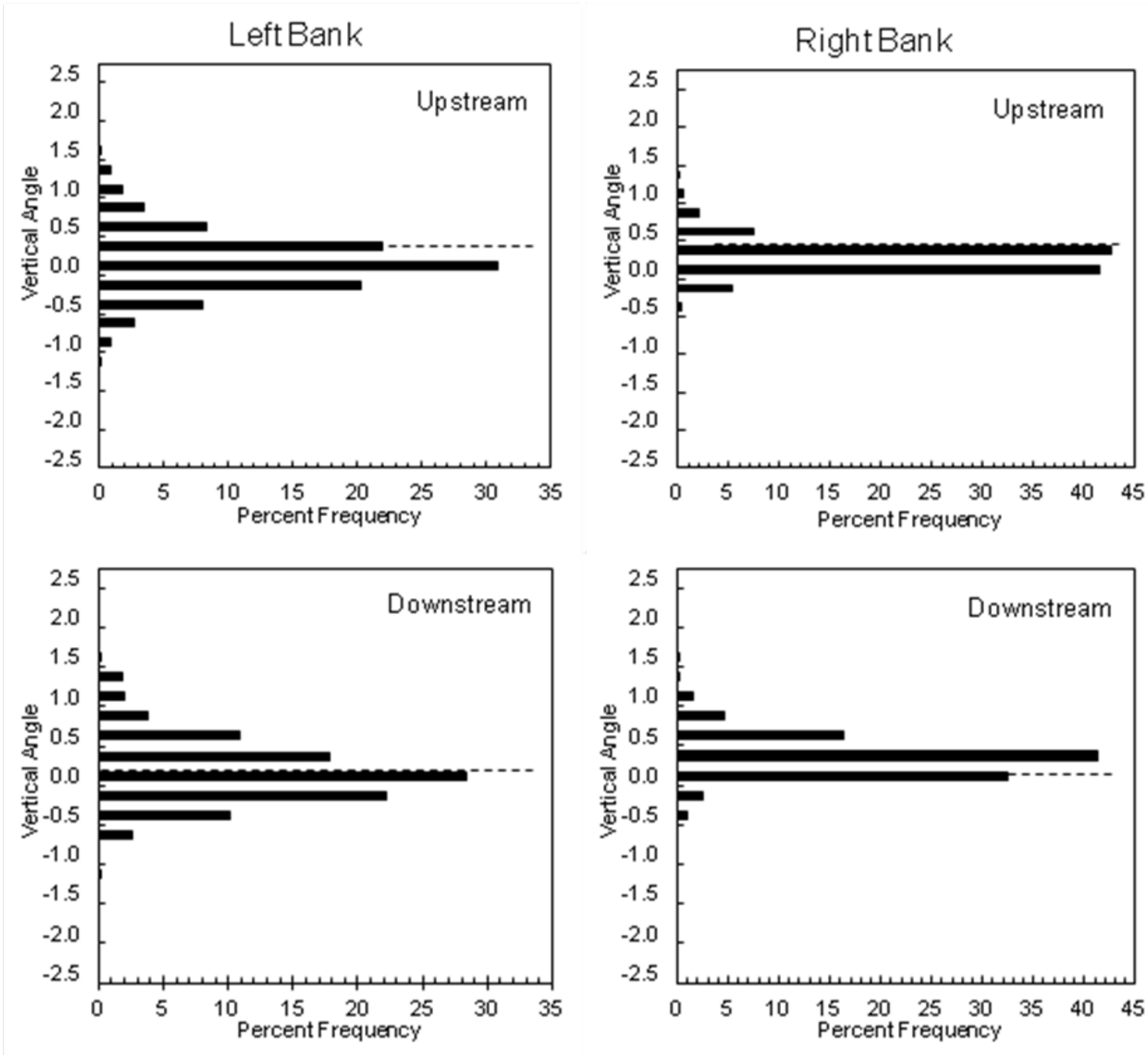


Figure 29.–Vertical distributions above and below the acoustic axis of late-run upstream- and downstream-moving filtered targets by bank, Kenai River, 2008.

Note: Data have been filtered by range (distance from transducer) and target strength criteria. Acoustic axis = 0.0.

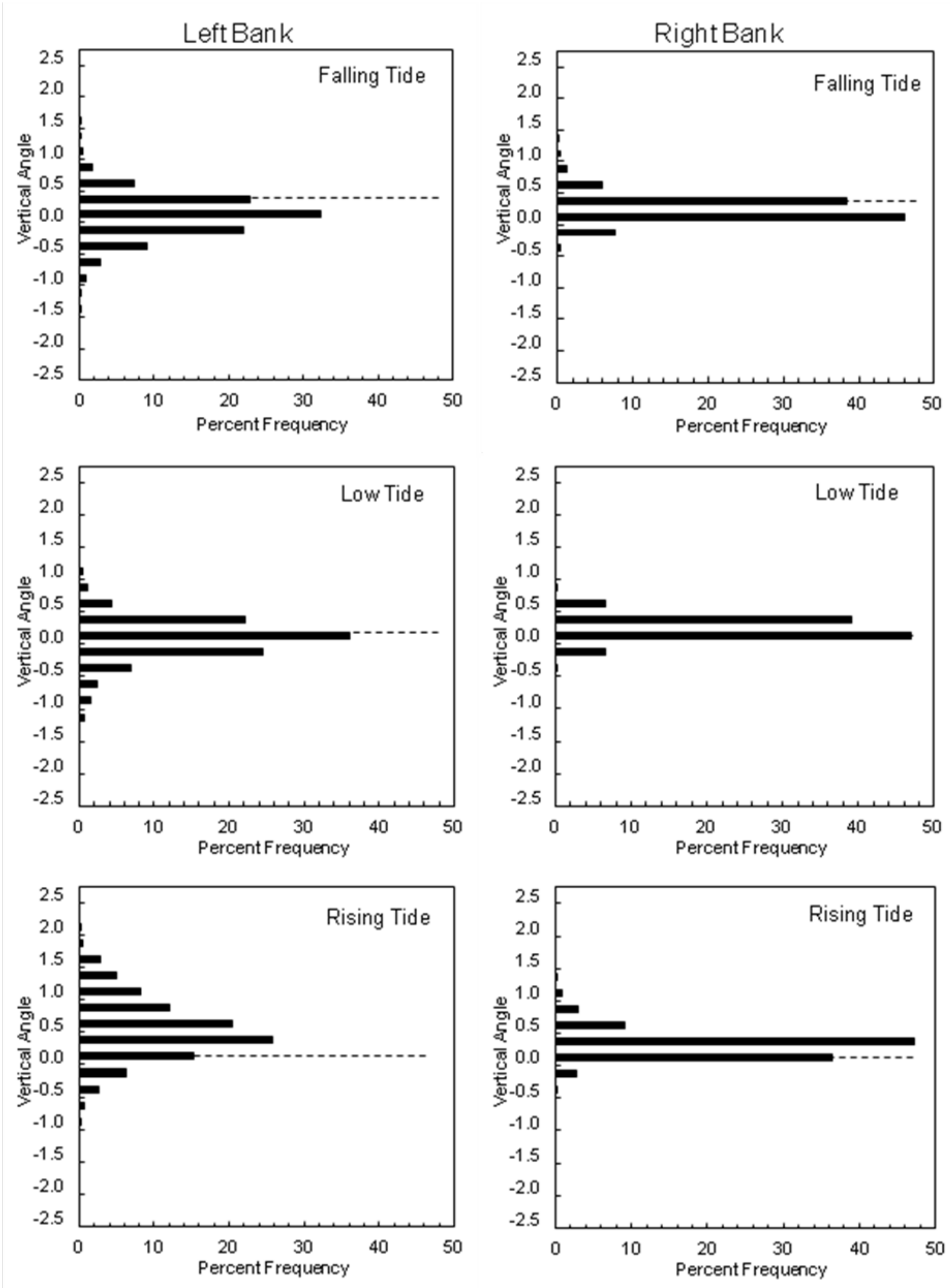


Figure 30.–Vertical distributions above and below the acoustic axis of late-run upstream-moving filtered targets by tide stage and bank, Kenai River, 2008.

Note: Data have been filtered by range (distance from transducer) and target strength criteria. Acoustic axis = 0.0.

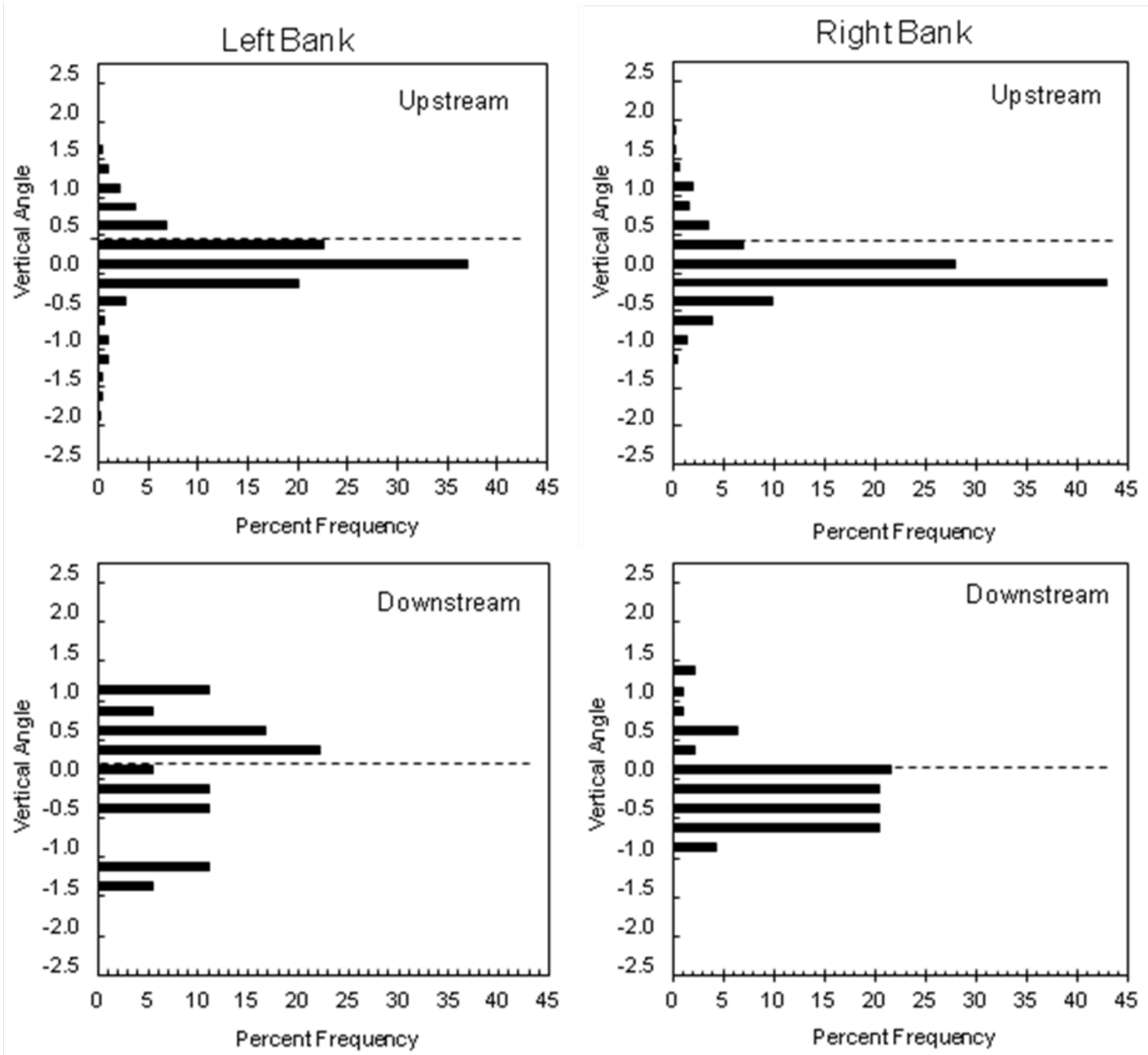


Figure 31.–Vertical distributions above and below the acoustic axis of early-run upstream- and downstream-moving filtered targets by bank, Kenai River, 2009.

Note: Data have been filtered by range (distance from transducer) and target strength criteria. Acoustic axis = 0.0.

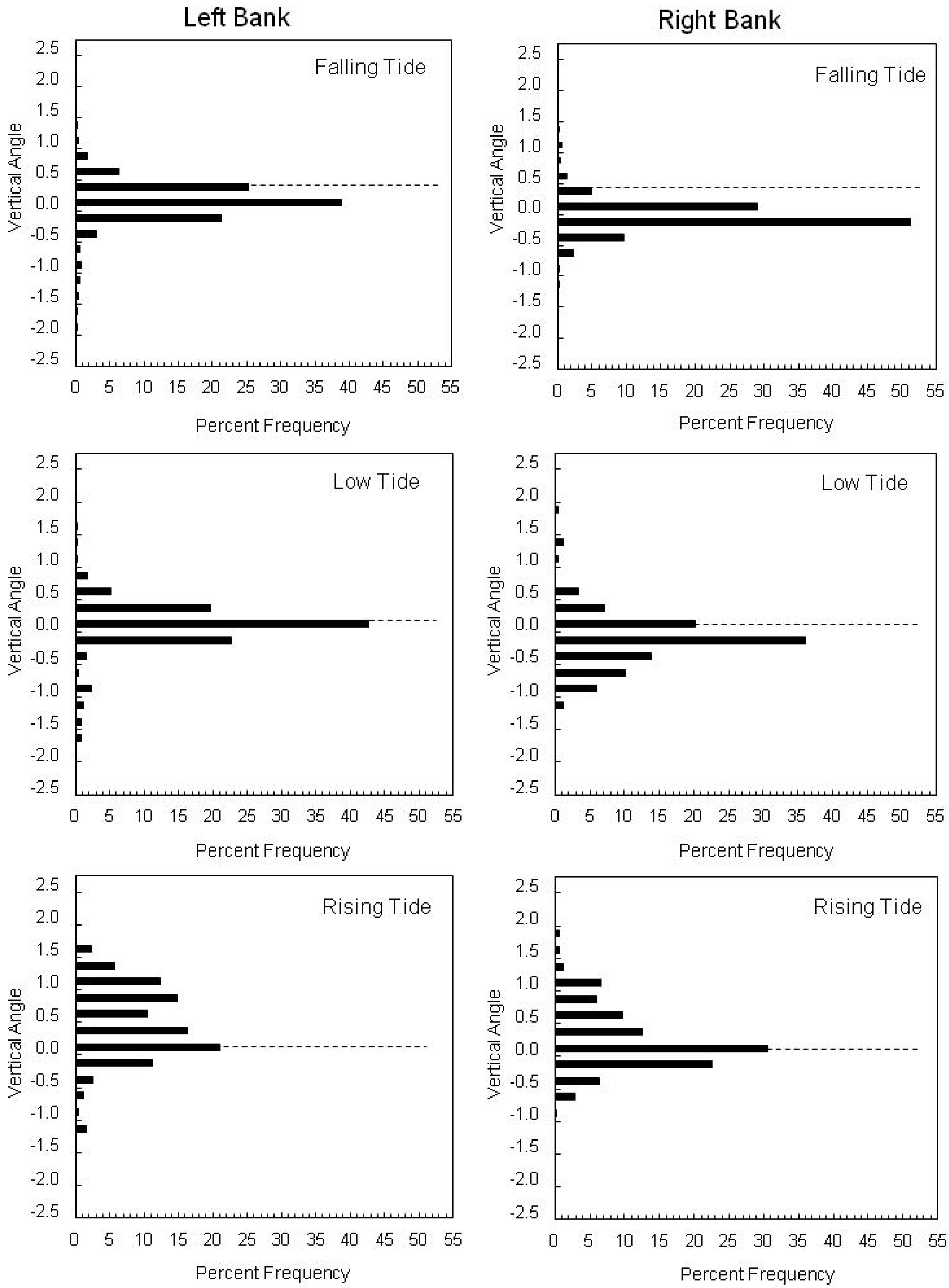


Figure 32.–Vertical distributions above and below the acoustic axis of early-run upstream moving filtered targets by tide stage and bank, Kenai River, 2009.

Note: Data have been filtered by range (distance from transducer) and target strength criteria. Acoustic axis = 0.0.

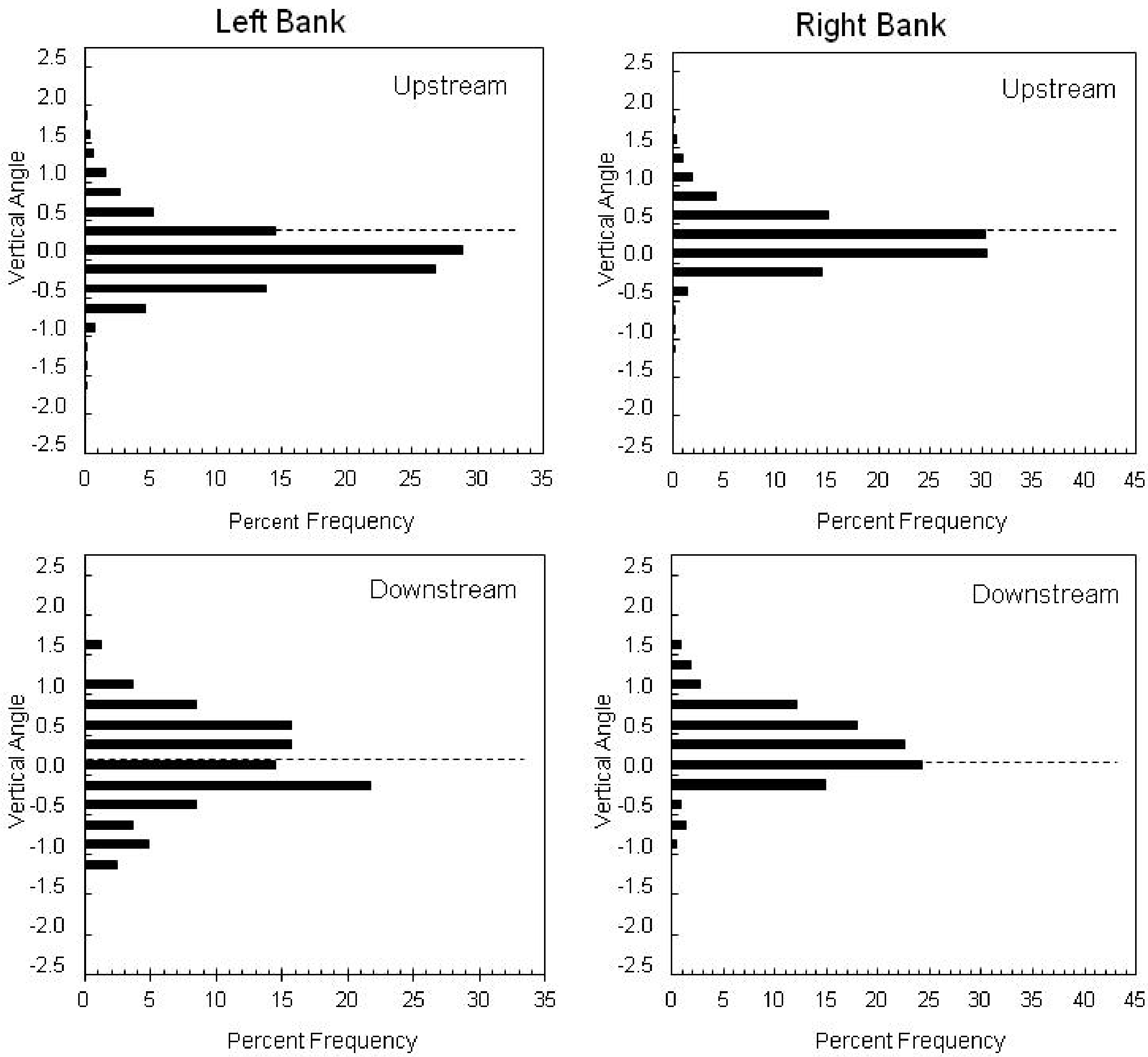


Figure 33.–Vertical distributions above and below the acoustic axis of late-run upstream- and downstream-moving filtered targets by bank, Kenai River, 2009.

Note: Data have been filtered by range (distance from transducer) and target strength criteria. Acoustic axis = 0.0

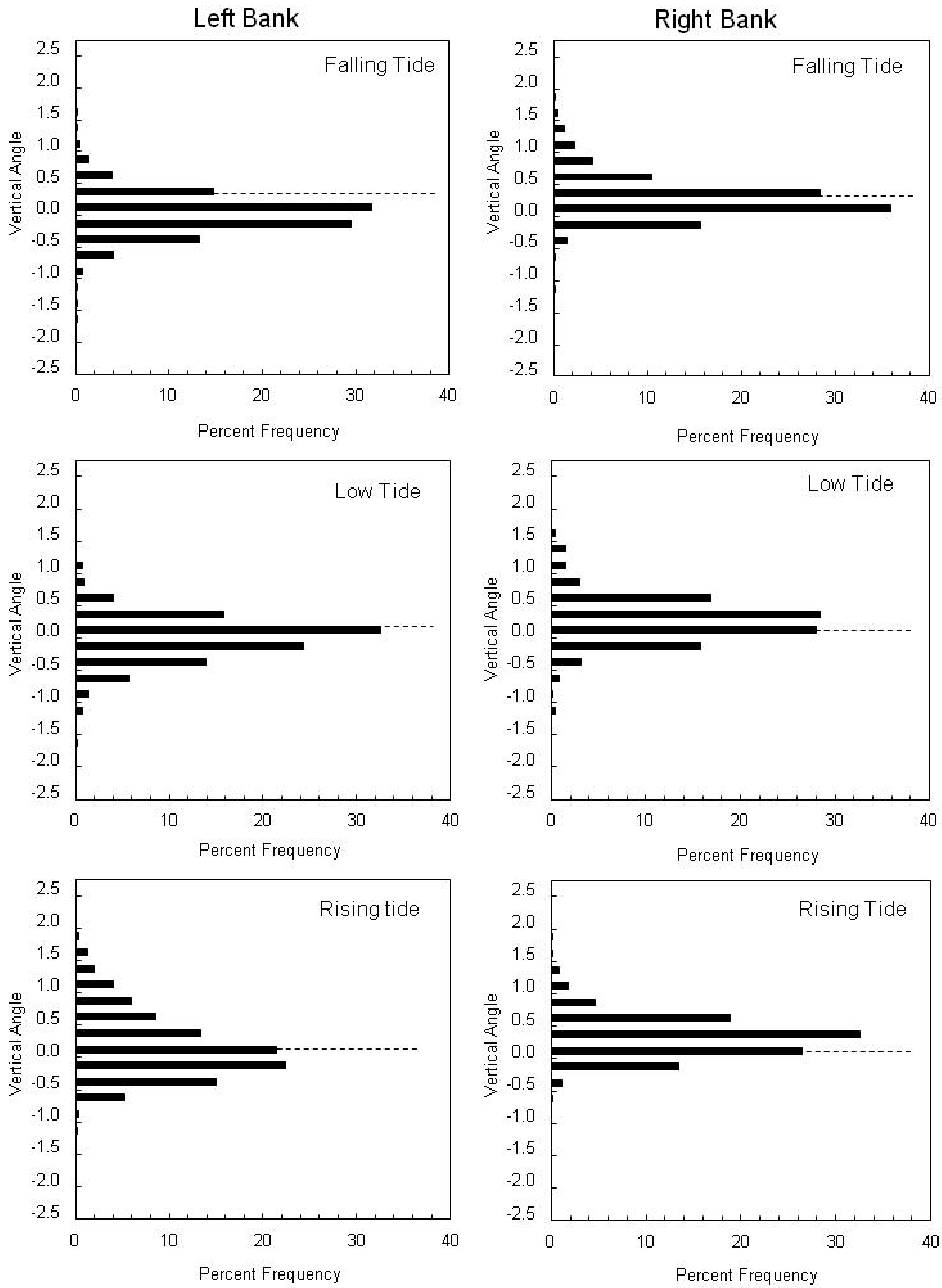


Figure 34.–Vertical distributions above and below the acoustic axis of late-run upstream-moving filtered targets by tide stage and bank, Kenai River, 2009.

Note: Data have been filtered by range (distance from transducer) and target strength criteria. Acoustic axis = 0.0

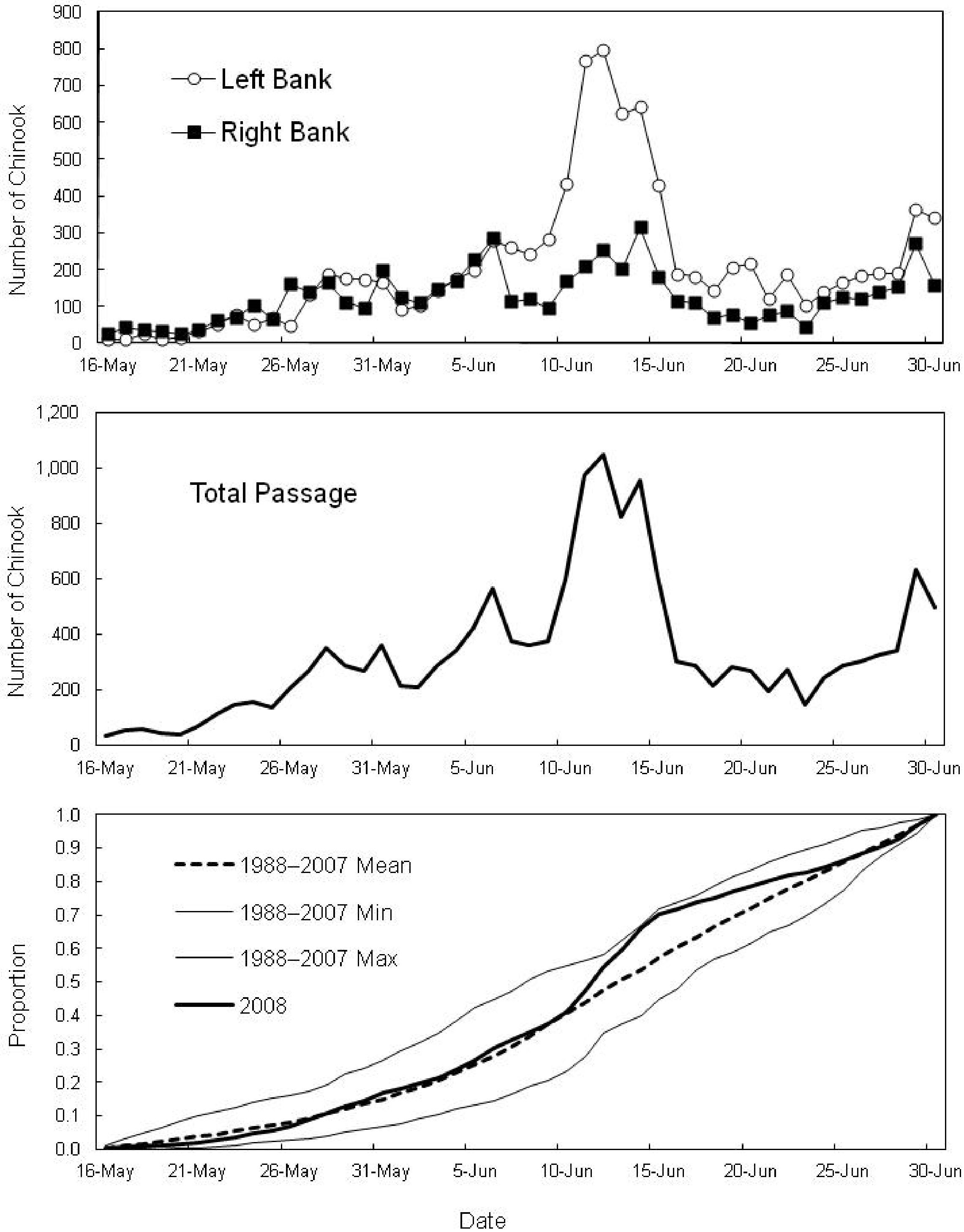


Figure 35.–TS-based daily sonar passage estimates by bank (top), total passage (center), and historical cumulative proportions (bottom) for the Chinook salmon early run returning to the Kenai River, 2008.

Note: Mean in bottom panel is based on passage through 4 August and on estimates of combined upstream and downstream passage for 1987–1997 and upstream only passage for 1998–2007.

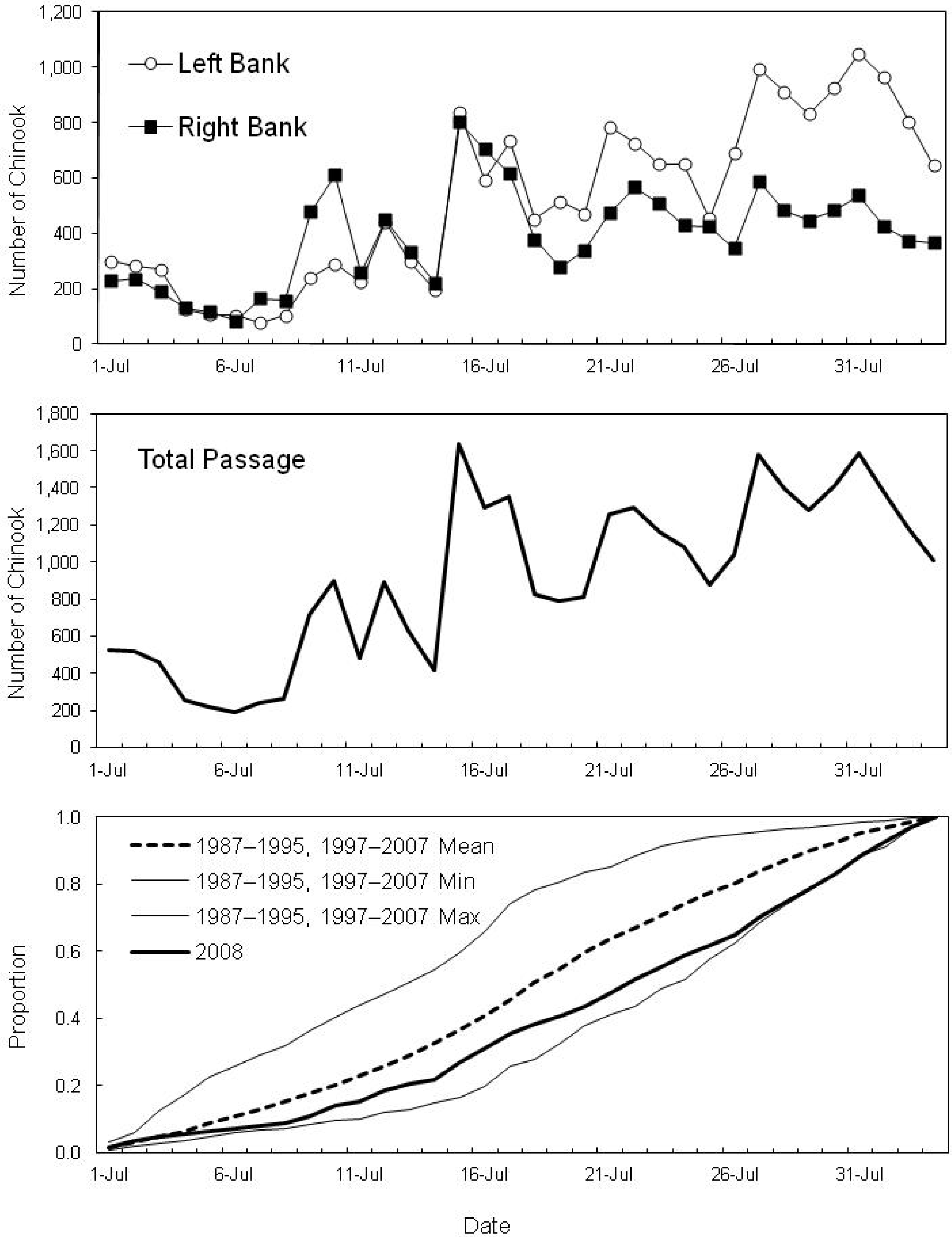


Figure 36.–TS-based daily sonar passage estimates by bank (top), total passage (center), and historical cumulative proportions (bottom) for the Chinook salmon late run returning to the Kenai River, 2008.

Note: Mean in bottom panel is based on passage through 4 August and on estimates of combined upstream and downstream passage for 1987–1997 and upstream only passage for 1998–2007. Passage from 1996 was excluded due to early termination of the project that year.

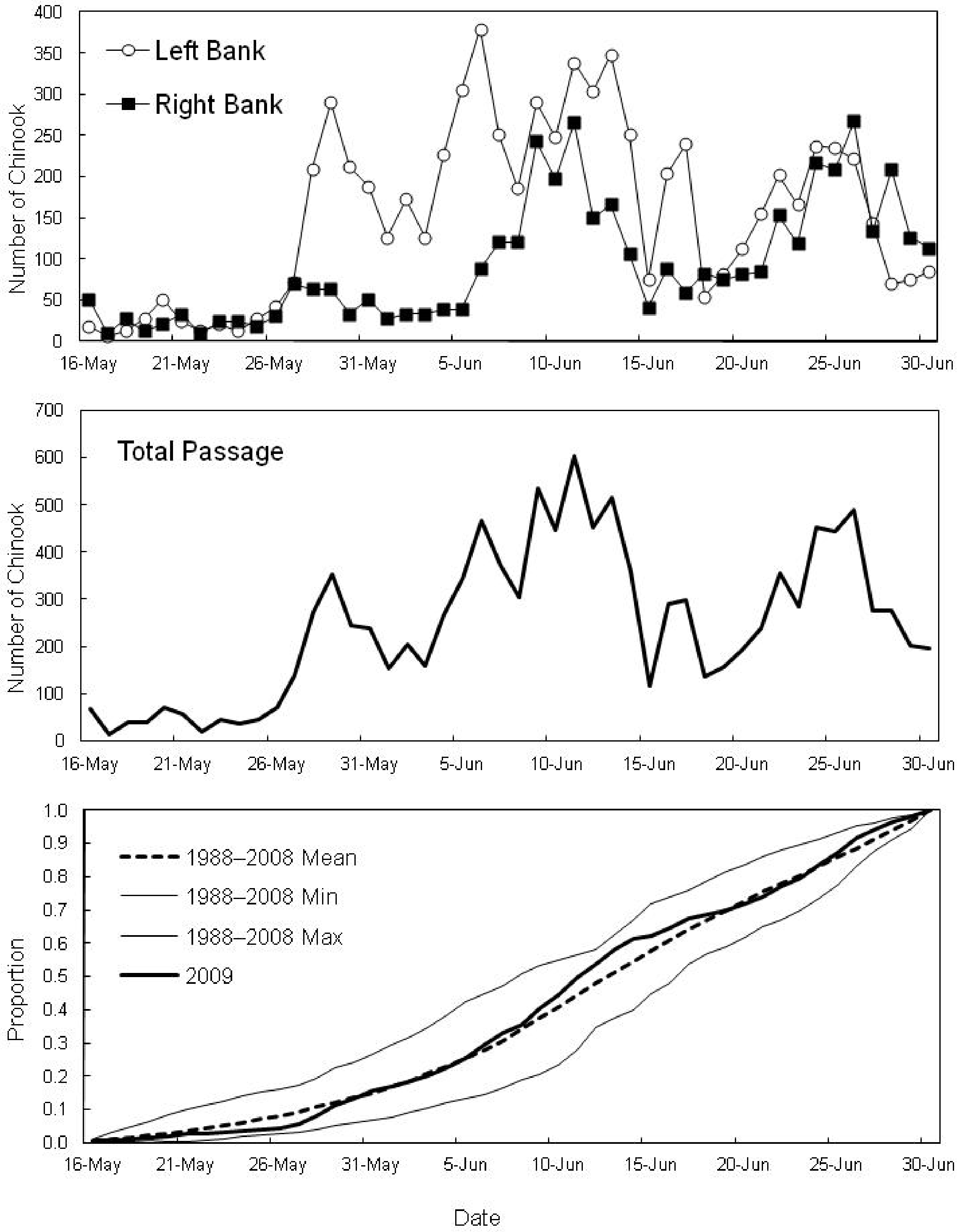


Figure 37.–TS-based daily sonar passage estimates by bank (top), total passage (center), and historical cumulative proportions (bottom) for the Chinook salmon early run returning to the Kenai River, 2009.

Note: Mean in bottom panel is based on estimates of combined upstream and downstream passage for 1988–1997 and upstream only passage for 1998–2008.

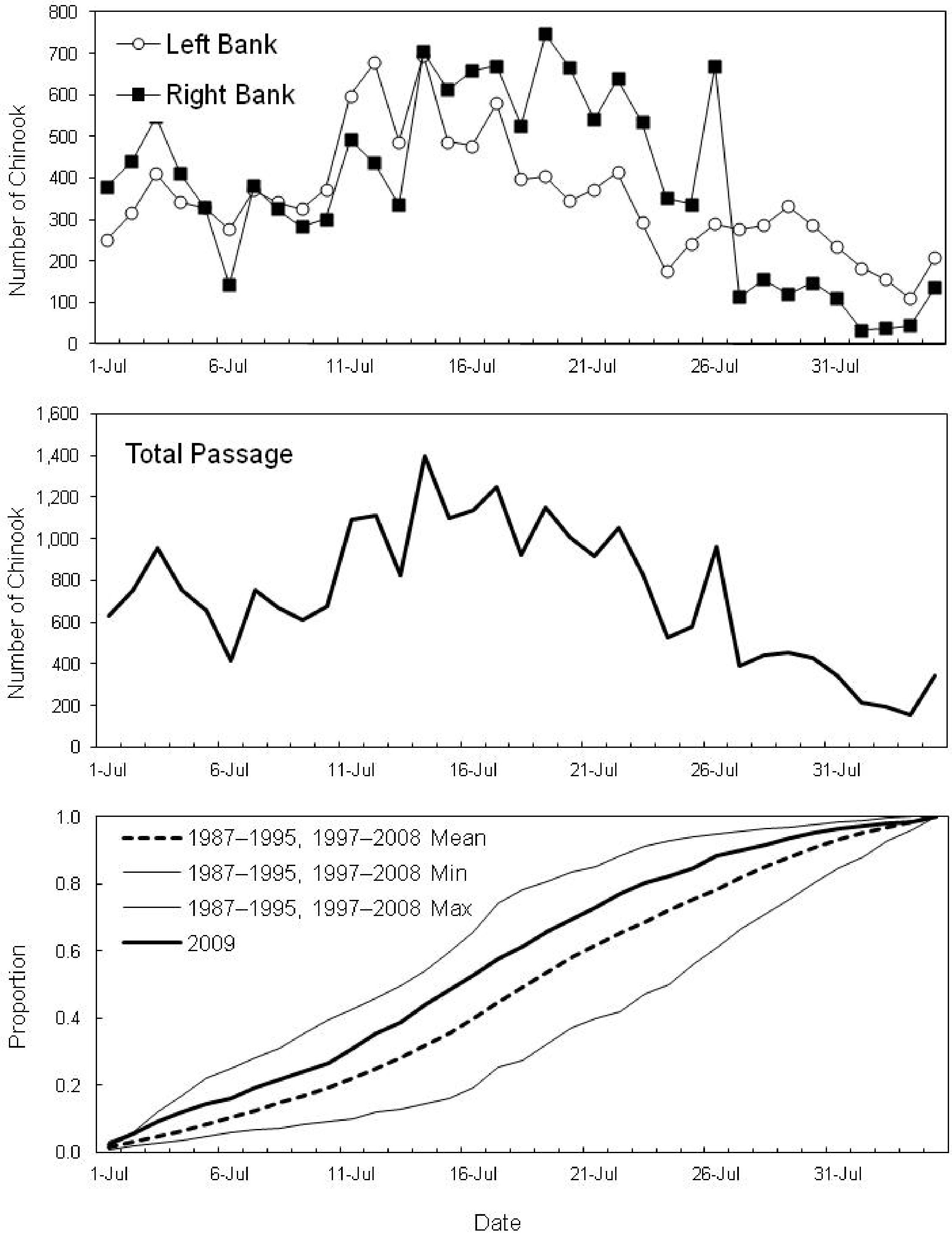


Figure 38.–TS-based daily sonar passage estimates by bank (top), total passage (center), and historical cumulative proportions (bottom) for the Chinook salmon late run returning to the Kenai River, 2009.

Note: Mean in bottom panel is based on passage through 4 August and on estimates of combined upstream and downstream passage for 1987–1997 and upstream only passage for 1998–2008. Passage from 1996 was excluded due to early termination of the project that year.

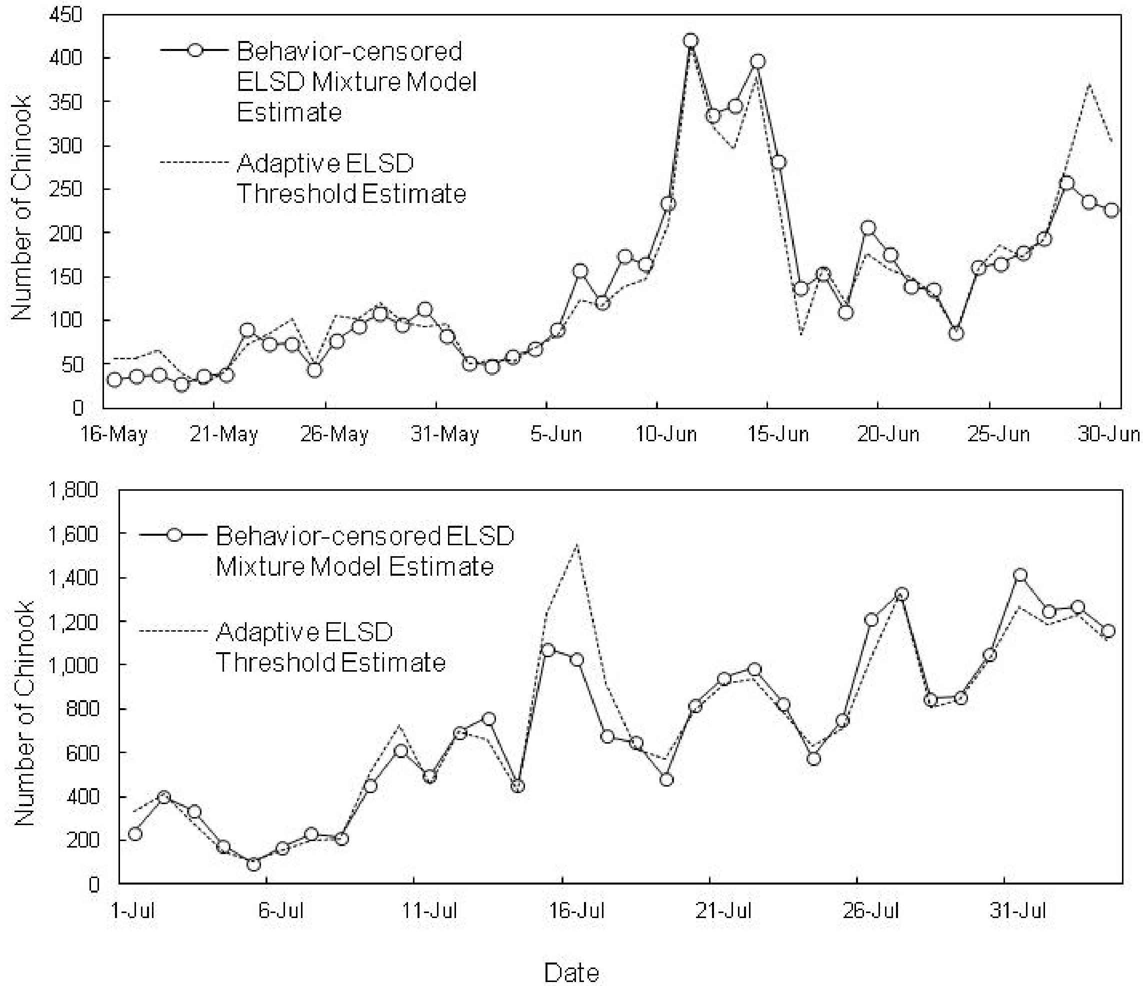


Figure 39.–Estimated early- (16 May–30 June; top) and late-run (1 July–3 August; bottom) Chinook salmon passage by day based on post-season behavior-censored ELSD estimation technique and inseason adaptive ELSD threshold estimation technique, Kenai River, 2008.

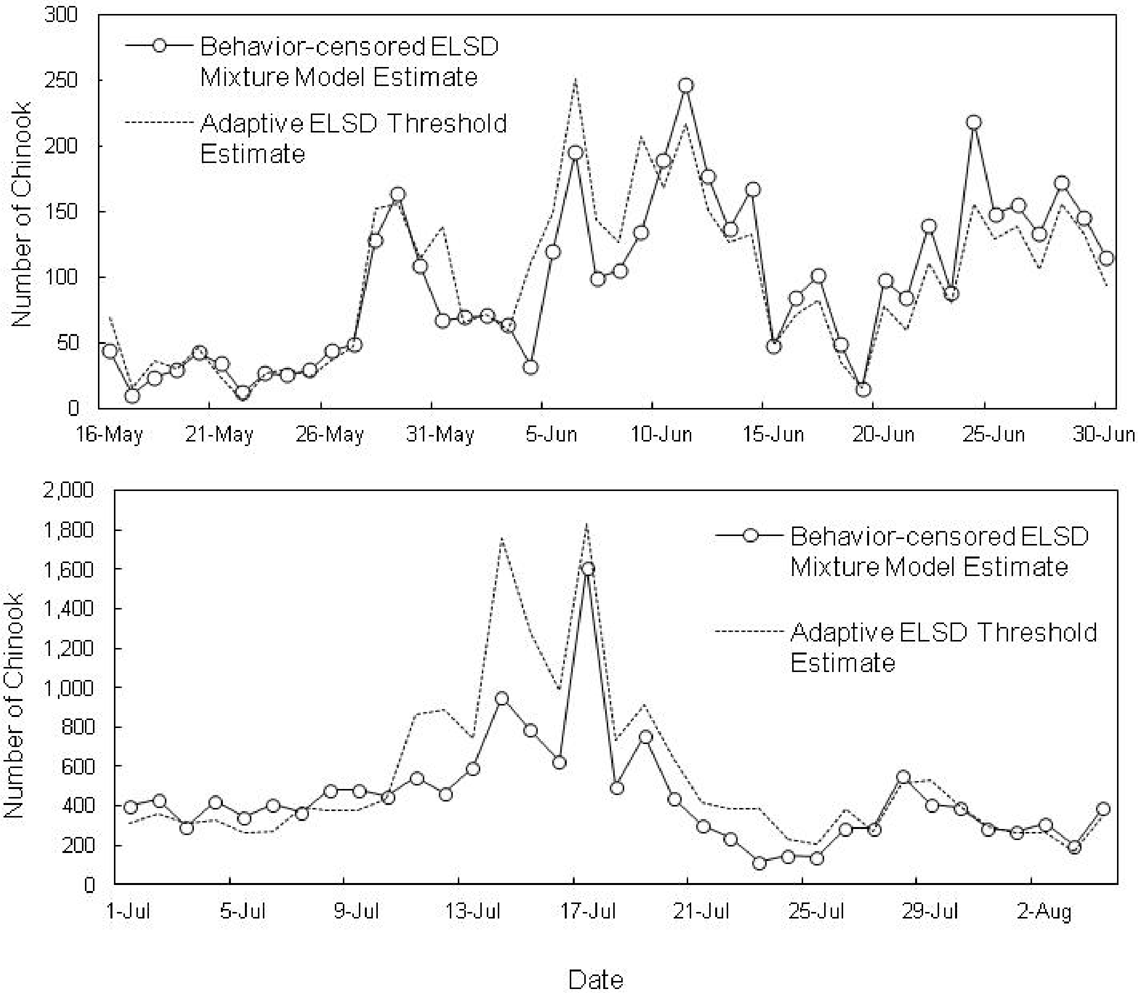


Figure 40.–Estimated early- (16 May–30 June; top) and late-run (1 July–4 August; bottom) Chinook salmon passage by day based on post-season behavior-censored ELSD estimation technique and inseason adaptive ELSD threshold estimation technique, Kenai River, 2009.

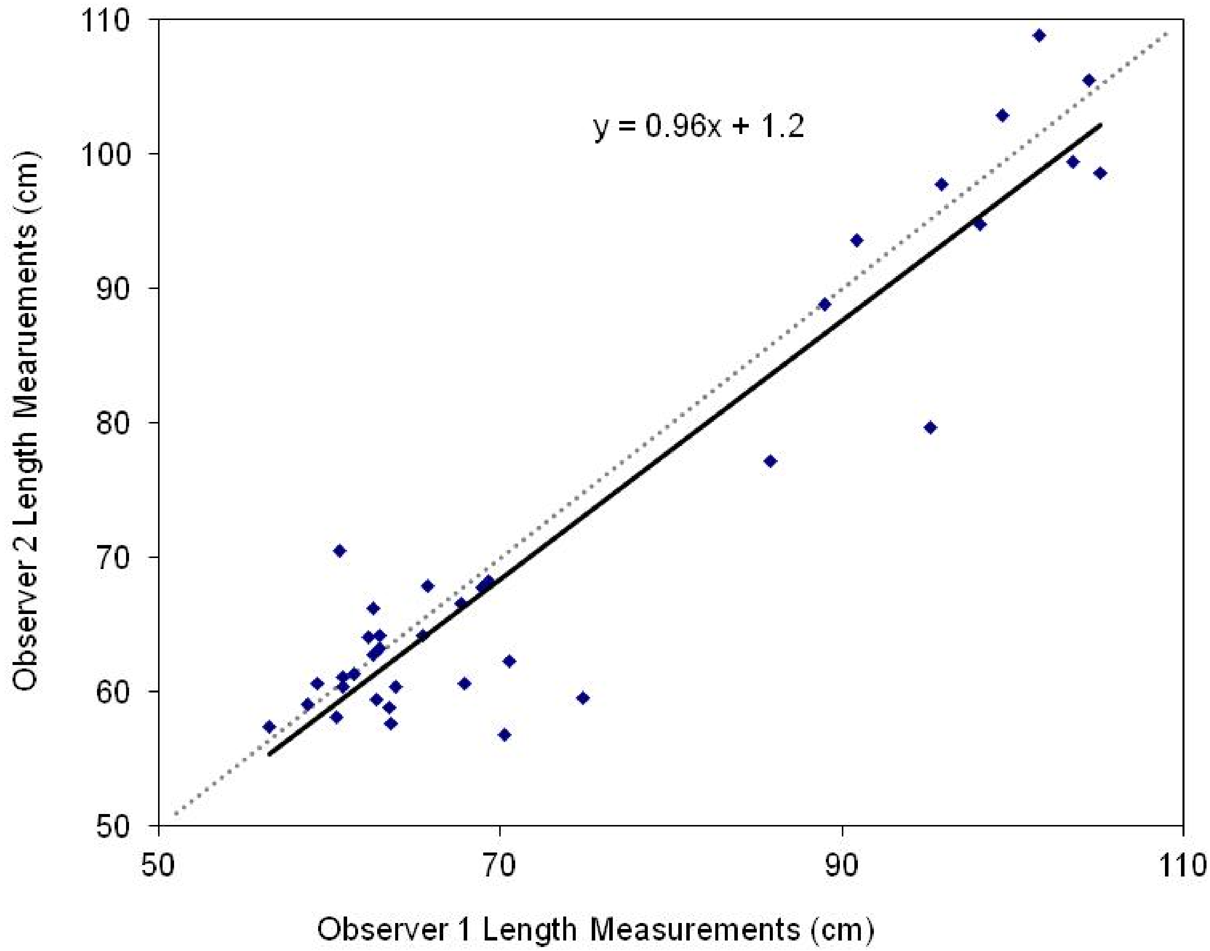


Figure 41.–Fish length measured from DIDSON images by two observers for 37 tethered sockeye and Chinook salmon, Kenai River, 2009. Dotted line is 1:1.

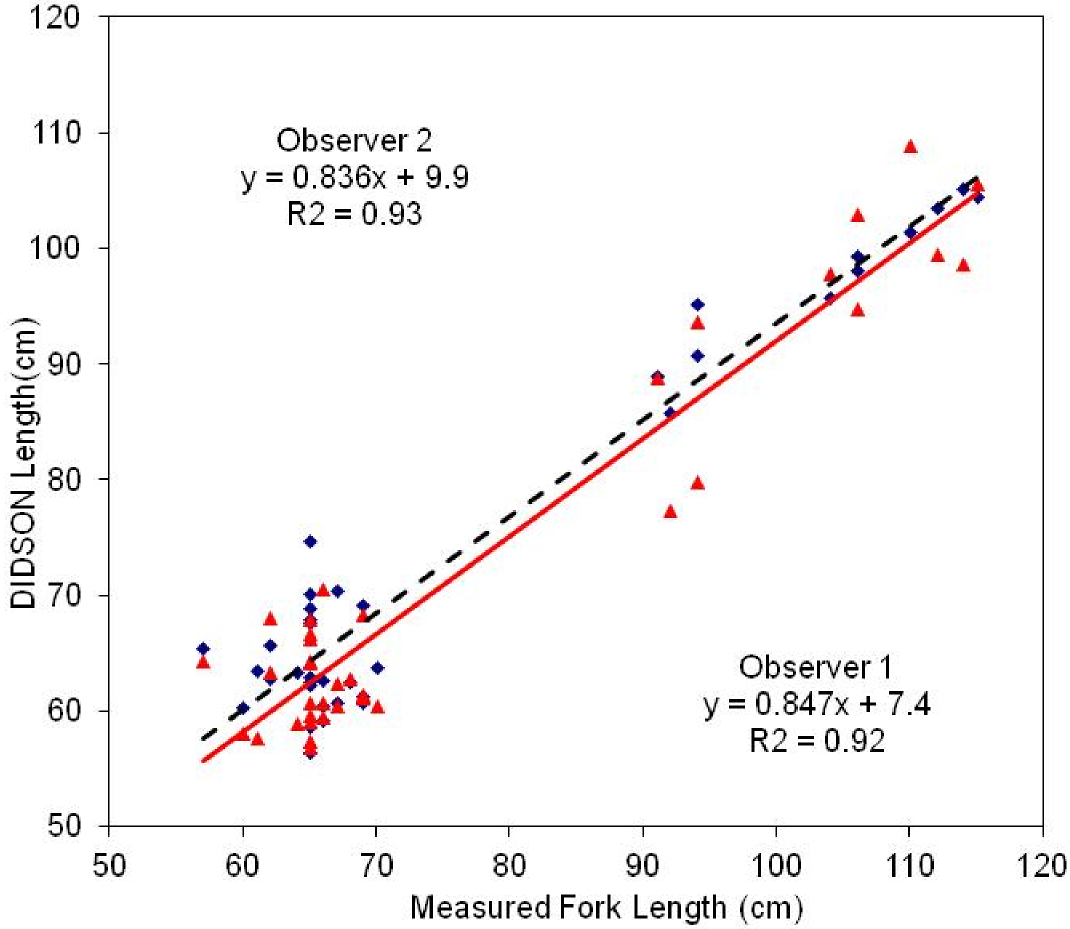


Figure 42.–Fish length measured from DIDSON images by two observers for 37 tethered sockeye and Chinook salmon, Kenai River, 2009. Solid line and triangles are observer 1; dashed line and diamonds are observer 2.

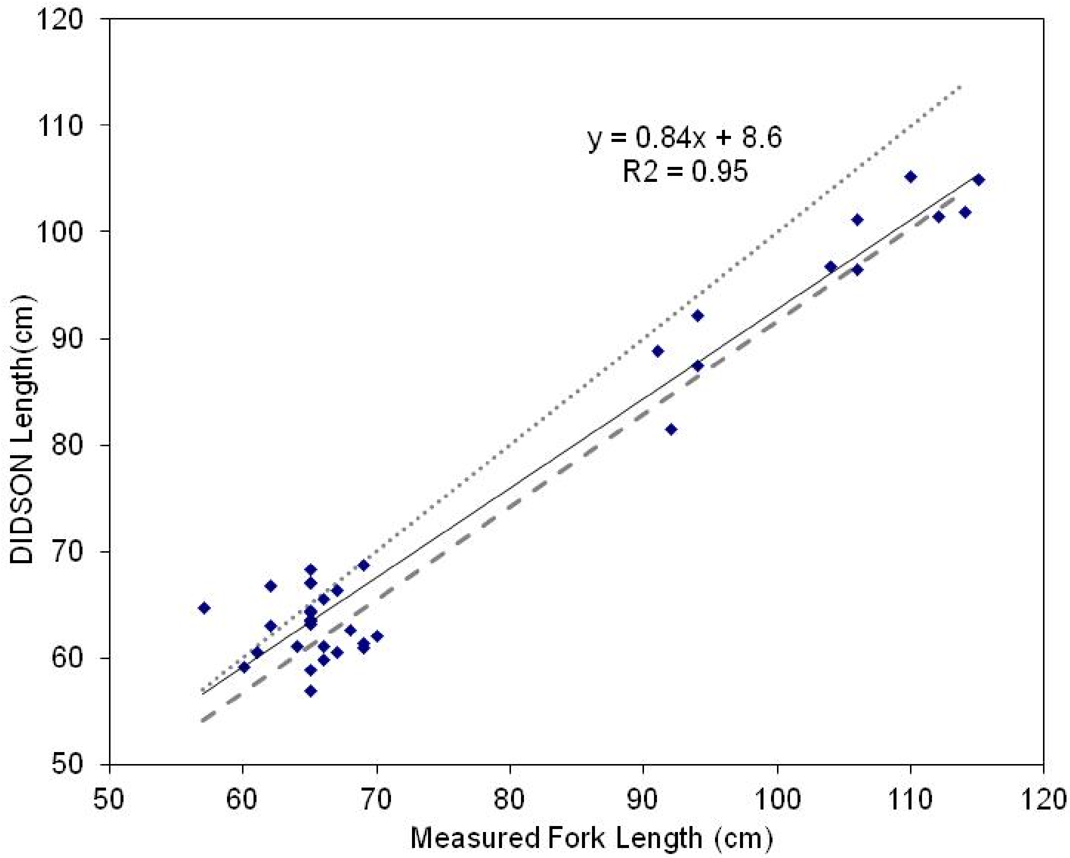


Figure 43.–Fish length measured from DIDSON images, averaged across two observers, for 37 tethered sockeye and Chinook salmon, Kenai River 2009. Solid line and symbols represent 2009 results. Dashed line shows 2007 results for comparison. Dotted line is 1:1.

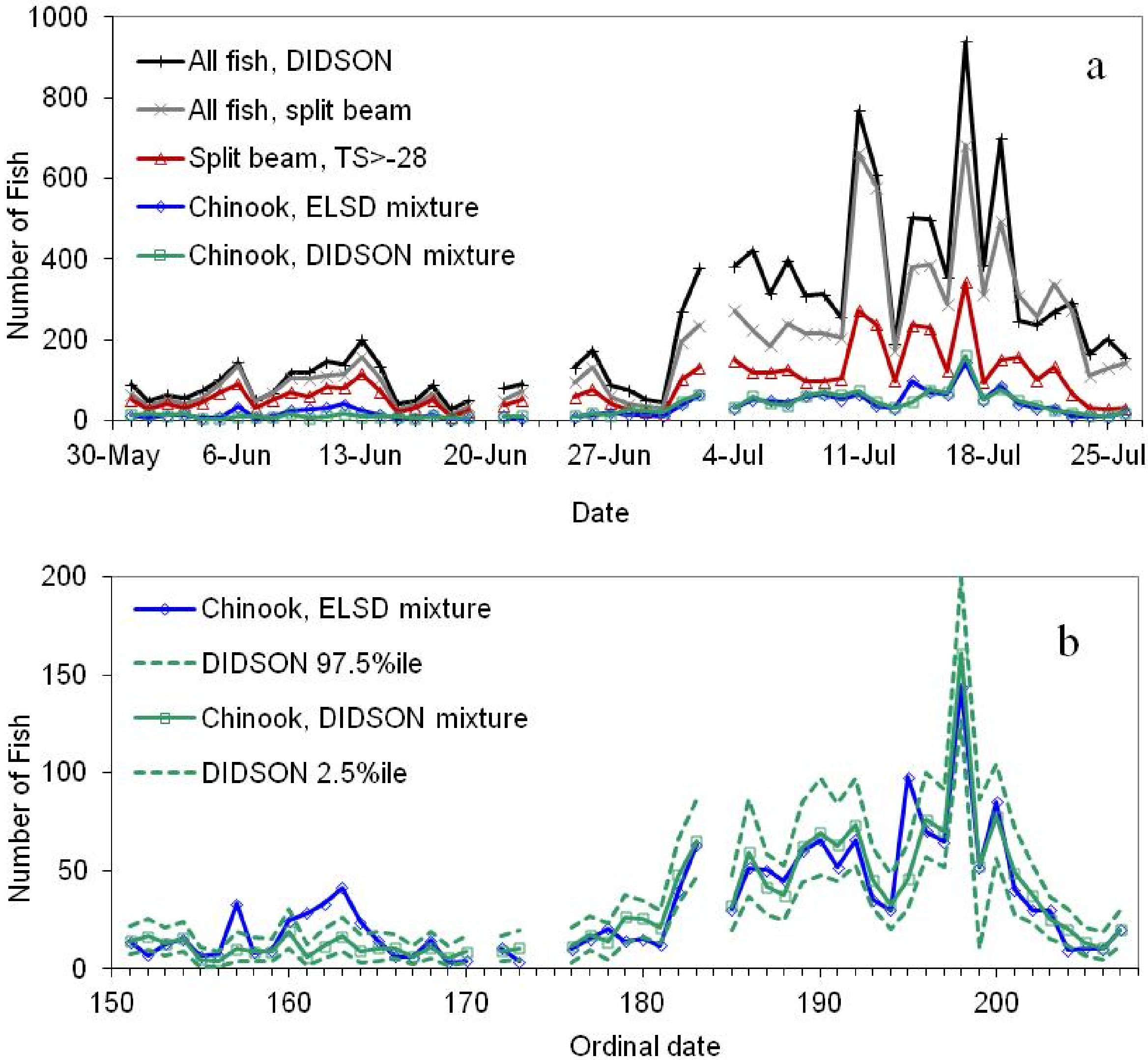


Figure 44.–Estimated number of fish passing upstream in 13–23 m range from left bank Kenai River transducer 31 May–26 July 2009 (ordinal dates 151–207), as estimated by DIDSON and split-beam sonar. All fish = total fish regardless of size or species; TS > −28 = split-beam fish greater than −28 dB target strength; ELSD mixture = echo length standard deviation mixture model; DIDSON mixture = DIDSON length mixture model. Bottom plot (b) is zoomed version (reduced vertical scale) of the top plot (a), with ordinal date labels on the x-axis. Dashed lines show 95% credibility intervals of DIDSON mixture estimates.

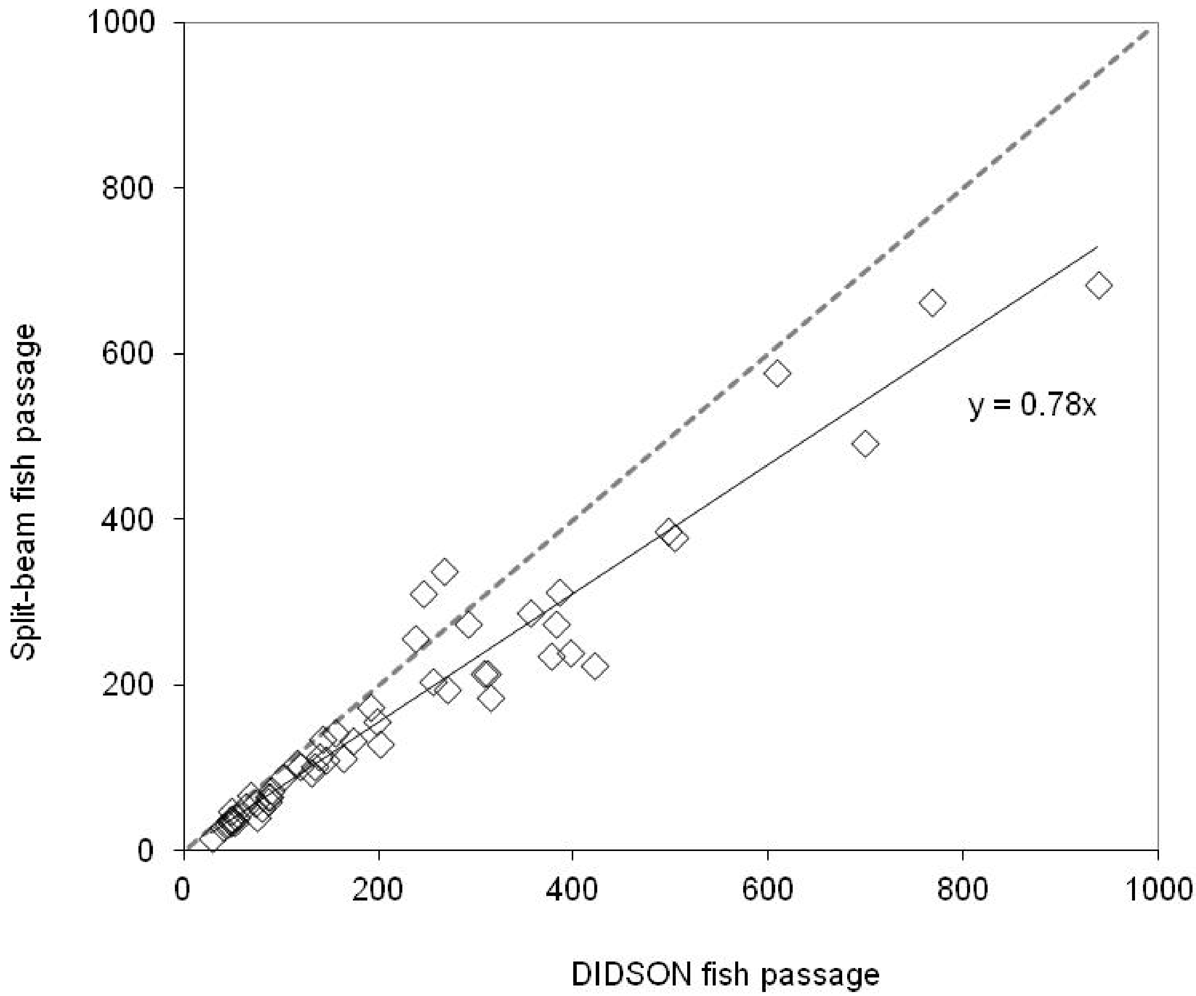


Figure 45.–Estimated number of all fish (total fish regardless of size or species) passing upstream 13–23 m from the left bank Kenai River transducer during 31 May–26 July 2009, as estimated by split-beam sonar versus DIDSON.

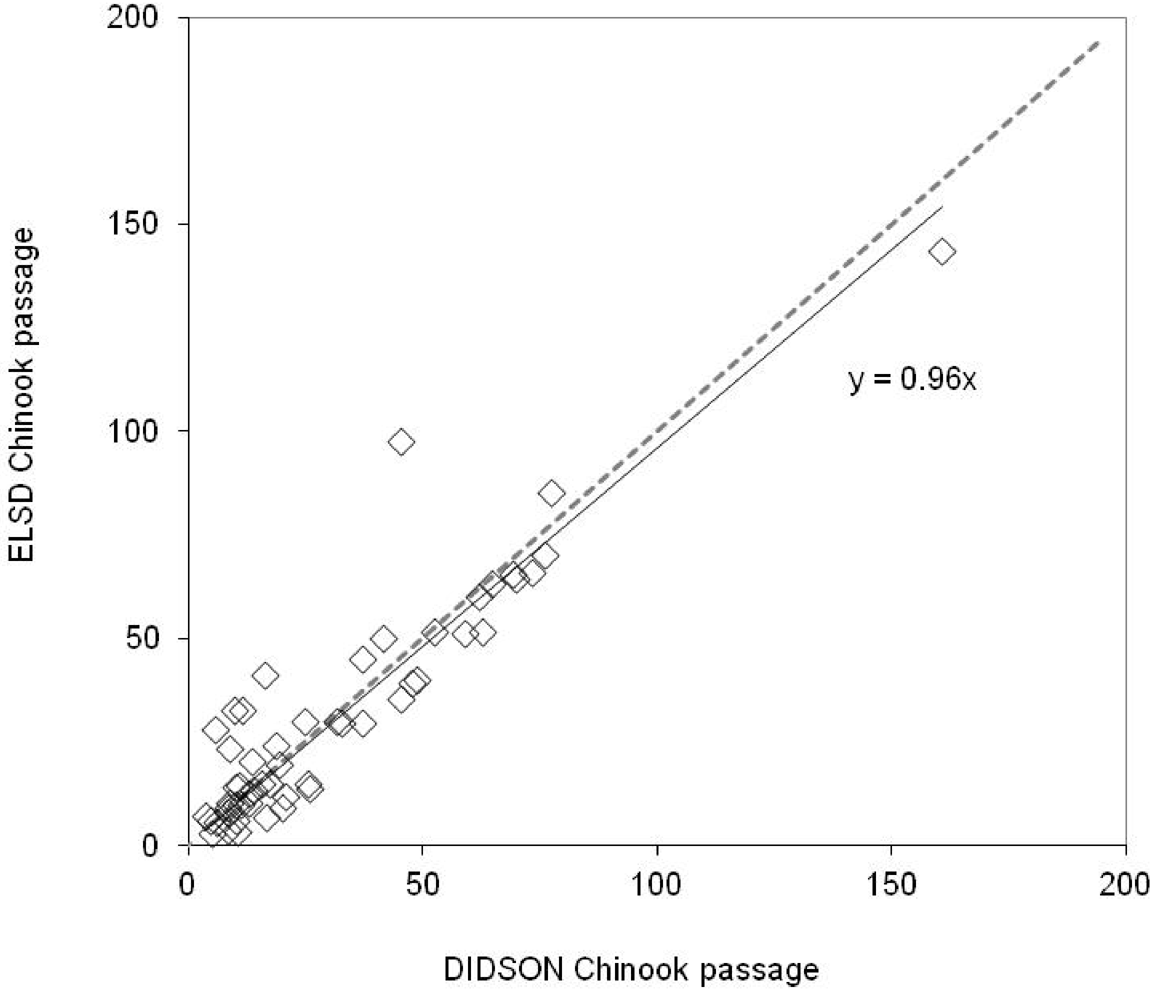


Figure 46.–Estimated number of Chinook salmon passing upstream 13–23 m from the left bank Kenai River transducer during 31 May–26 July 2009, as estimated by split-beam sonar (ELSD) versus DIDSON.

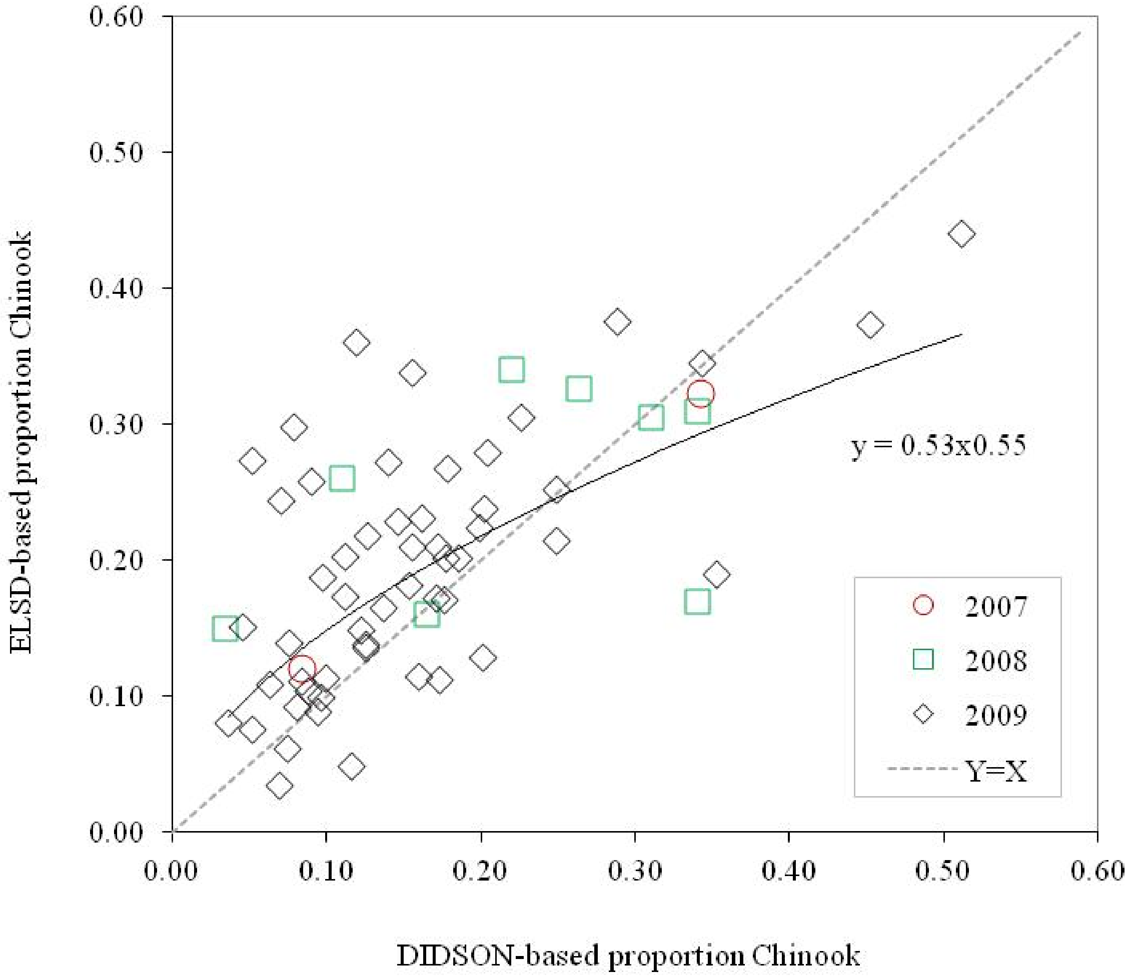


Figure 47.–Estimated proportion of fish that were Chinook salmon passing upstream 13–23 m from the left bank Kenai River transducer during 31 May–26 July, as estimated by split-beam sonar (ELSD) versus DIDSON.

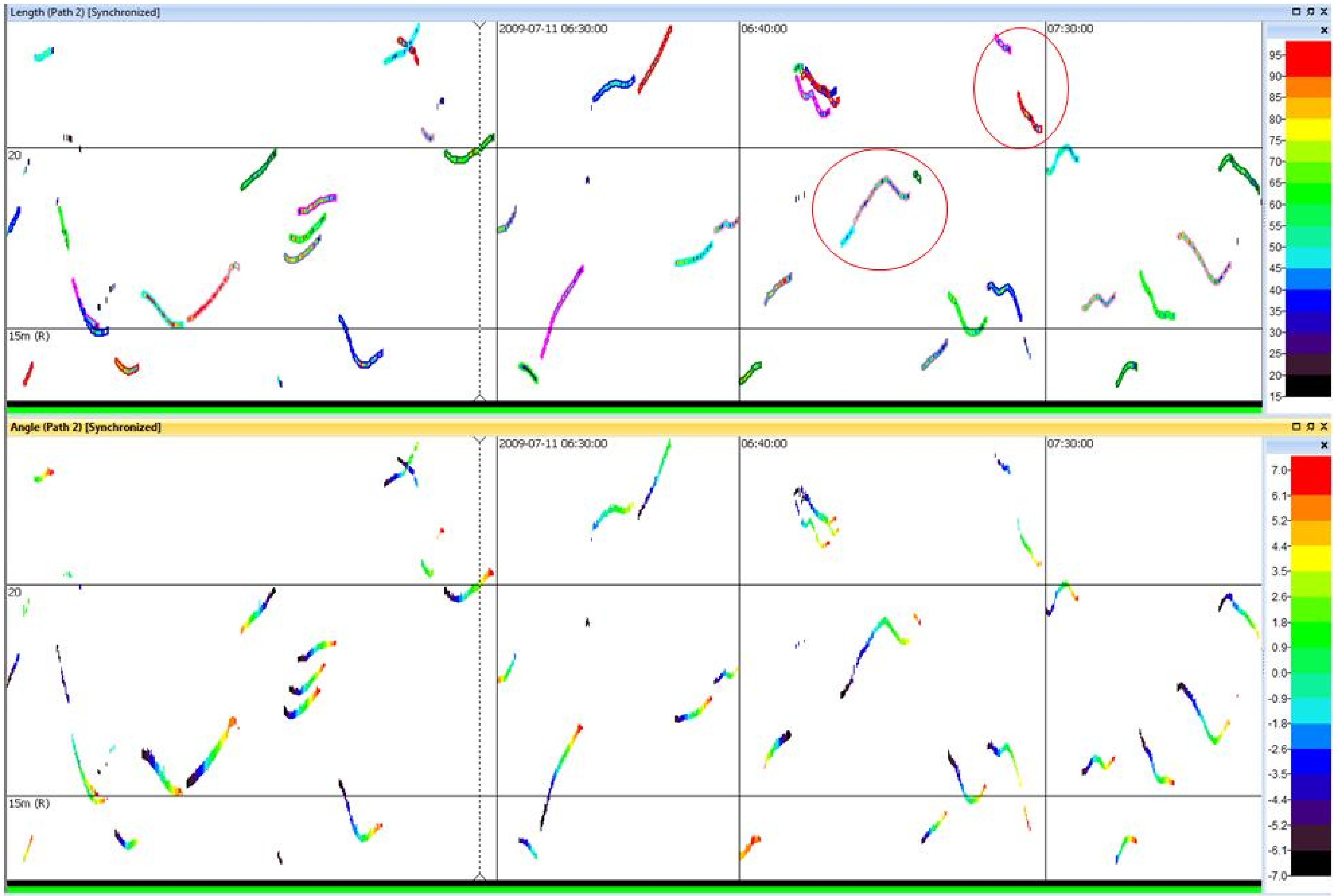


Figure 48.–Example of fish traces tracked by the Echoview auto-tracking algorithm. The display shows a length echogram (top pane) and angle echogram (bottom pane) of the same sample file. For each echogram, the X-axis represents time (increasing left to right) and the Y-axis represents range (increasing bottom to top). Echo (or frame) color represents either target length in centimeters (top pane) or the horizontal angle of the target in degrees (bottom pane). The target outline color in the length echogram identifies individual fish. Note that only two fish from a total of 41 were tracked incorrectly (circled in red), requiring minor editing by the user. For these two fish, the trace was broken into multiple traces by the automatic tracker, even though the angle echogram shows they were single traces moving completely through the beam from left to right.

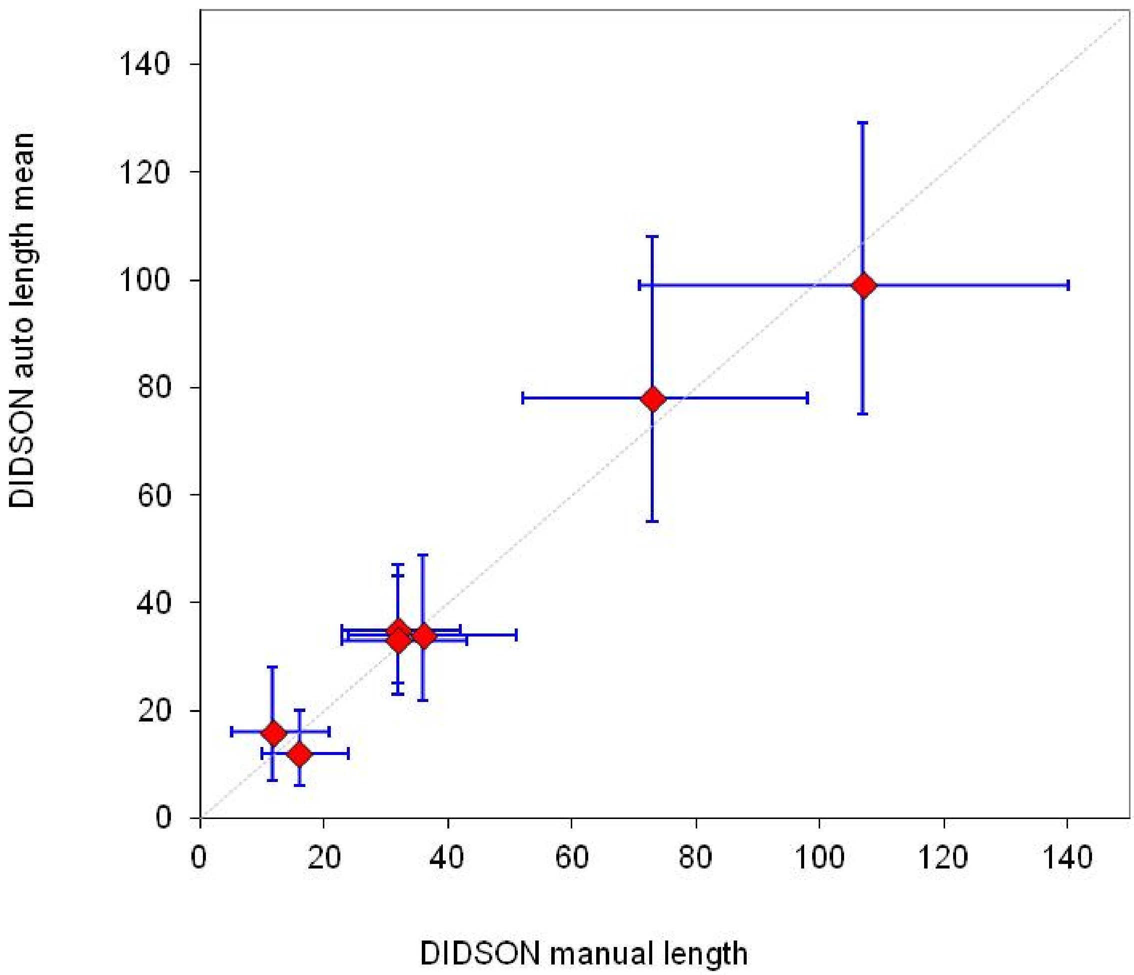
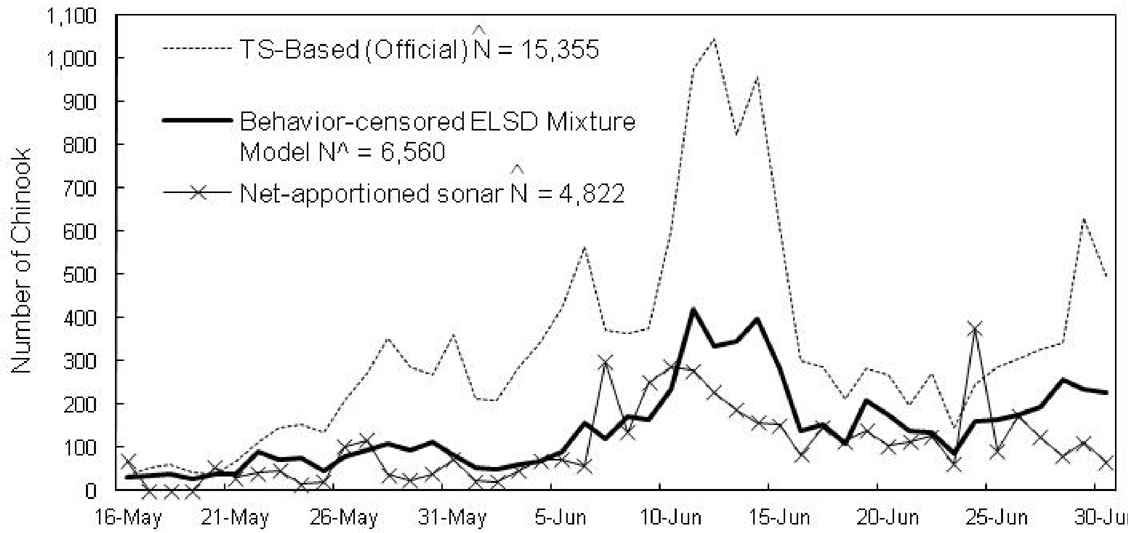


Figure 49.–Daily numbers of Chinook salmon passing upstream 13–23 m from the left bank Kenai River transducer for selected days in 2009, as estimated by mixture model analysis of automated versus manual length measurements.



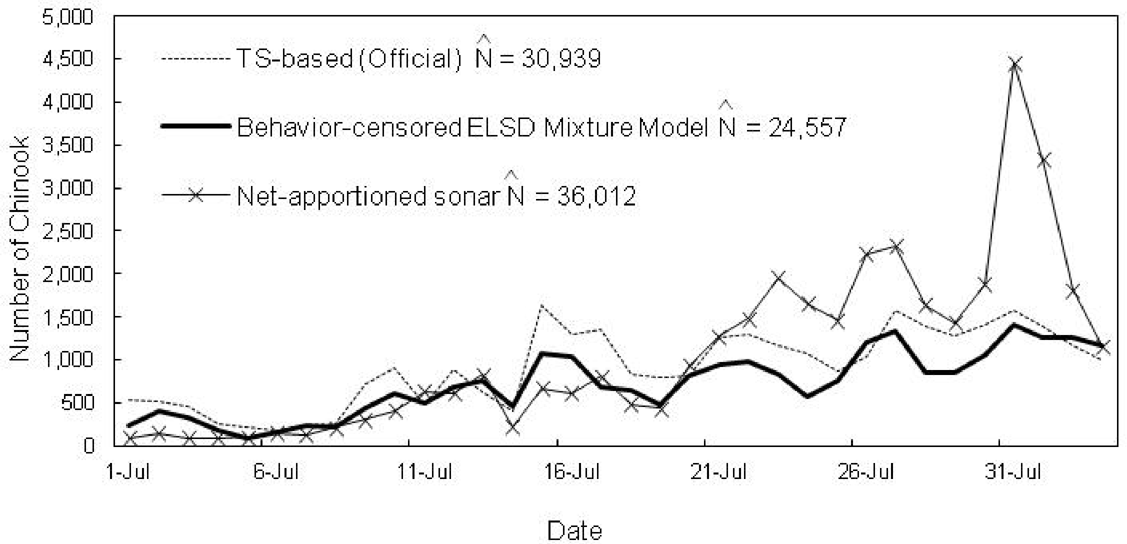


Figure 50.–Estimated upstream fish passage in midriver (all species), TS-based (Chinook salmon only), net-apportioned (alternative estimate Chinook salmon only), and behavior-censored ELSD-based sonar (alternative estimate, Chinook salmon only) for early (16 May–30 June; top) and late run (1 July–4 August; bottom), Kenai River, 2008.

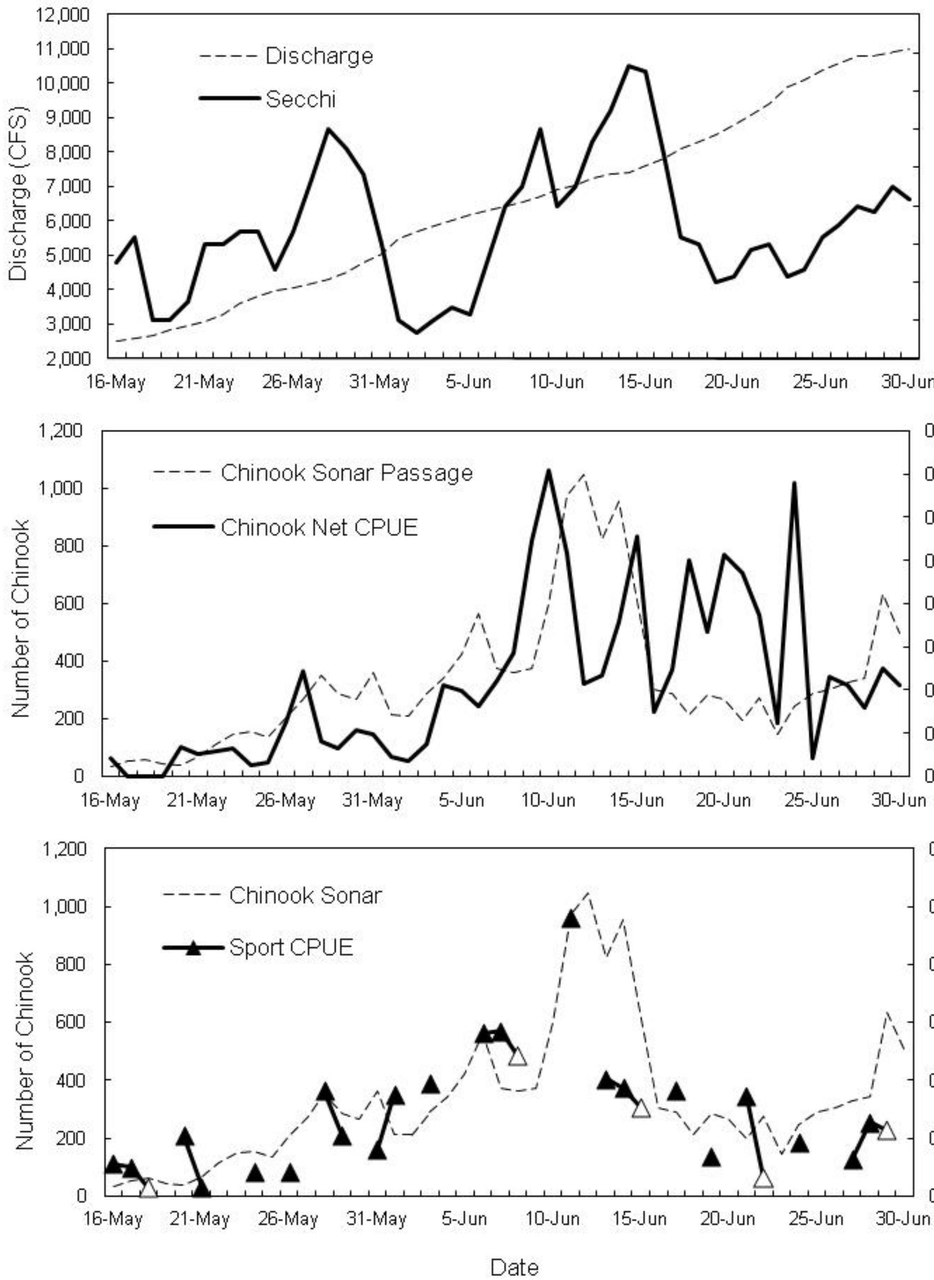


Figure 51.–Daily discharge rates collected at the Soldotna Bridge (top), Secchi disk readings taken at the sonar site (top), Chinook salmon TS-based sonar passage estimates (middle, bottom), inriver gillnet CPUE (middle), and Chinook salmon sport fish CPUE (bottom), early run (16 May–30 June), Kenai River, 2008.

Note: River discharge taken from USGS (2008). Net CPUE and sport fish CPUE taken from Eskelin (*In prep*).[22] Open triangles represent days on which only unguided anglers were allowed to fish.

[22] Eskelin, A. *In prep.* Chinook salmon creel survey and inriver gillnetting study lower Kenai River, Alaska, 2009. Alaska Department of Fish and Game, Fishery Data Series.

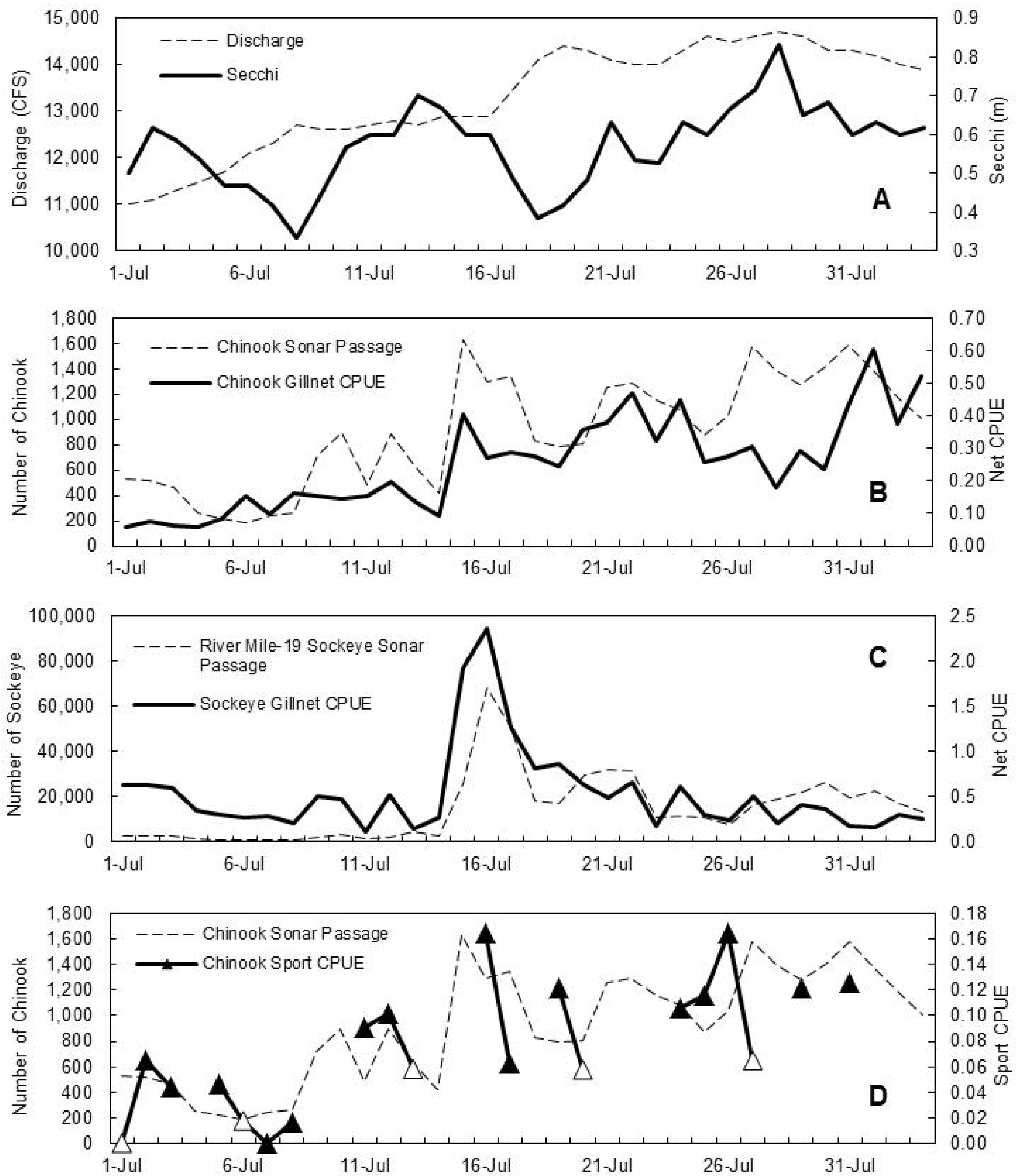


Figure 52.–Daily discharge rates collected at the Soldotna Bridge (A), Secchi disk readings taken at the sonar site (A), Chinook salmon TS-based sonar passage estimates (B, D), Chinook salmon inriver gillnet CPUE (B), river mile–19 sockeye salmon sonar passage estimates (C), sockeye salmon gillnet CPUE (C) and Chinook salmon sport fish CPUE (D), late run (1 July–3 August), Kenai River, 2008.

Note: River discharge taken from USGS (2008). River mile–19 sockeye sonar estimates taken from Westerman and Willette (2010). Net CPUE and sport fish CPUE taken from Eskelin (*In prep*). The Chinook salmon sport fishery closed by regulation on 31 July, so sport fish CPUE data were not available after this date. Open triangles represent days when only unguided anglers were allowed to fish.

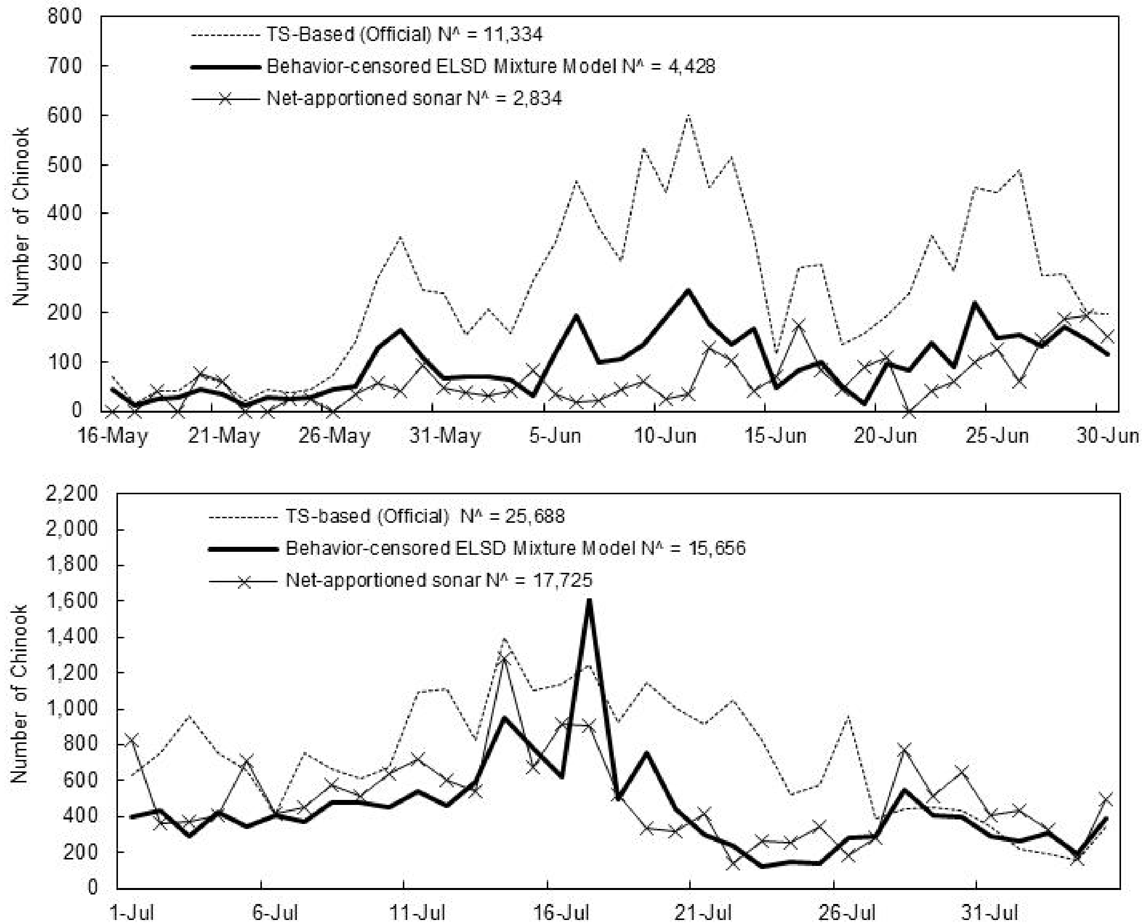


Figure 53.–Estimated upstream fish passage in midriver (all species), TS-based (Chinook salmon only), net-apportioned (alternative estimate Chinook salmon only) and behavior-censored ELSD-based sonar (alternative estimate, Chinook salmon only), early- (16 May–30 June; top) and late-run (1 July–4 August; bottom), Kenai River, 2009.

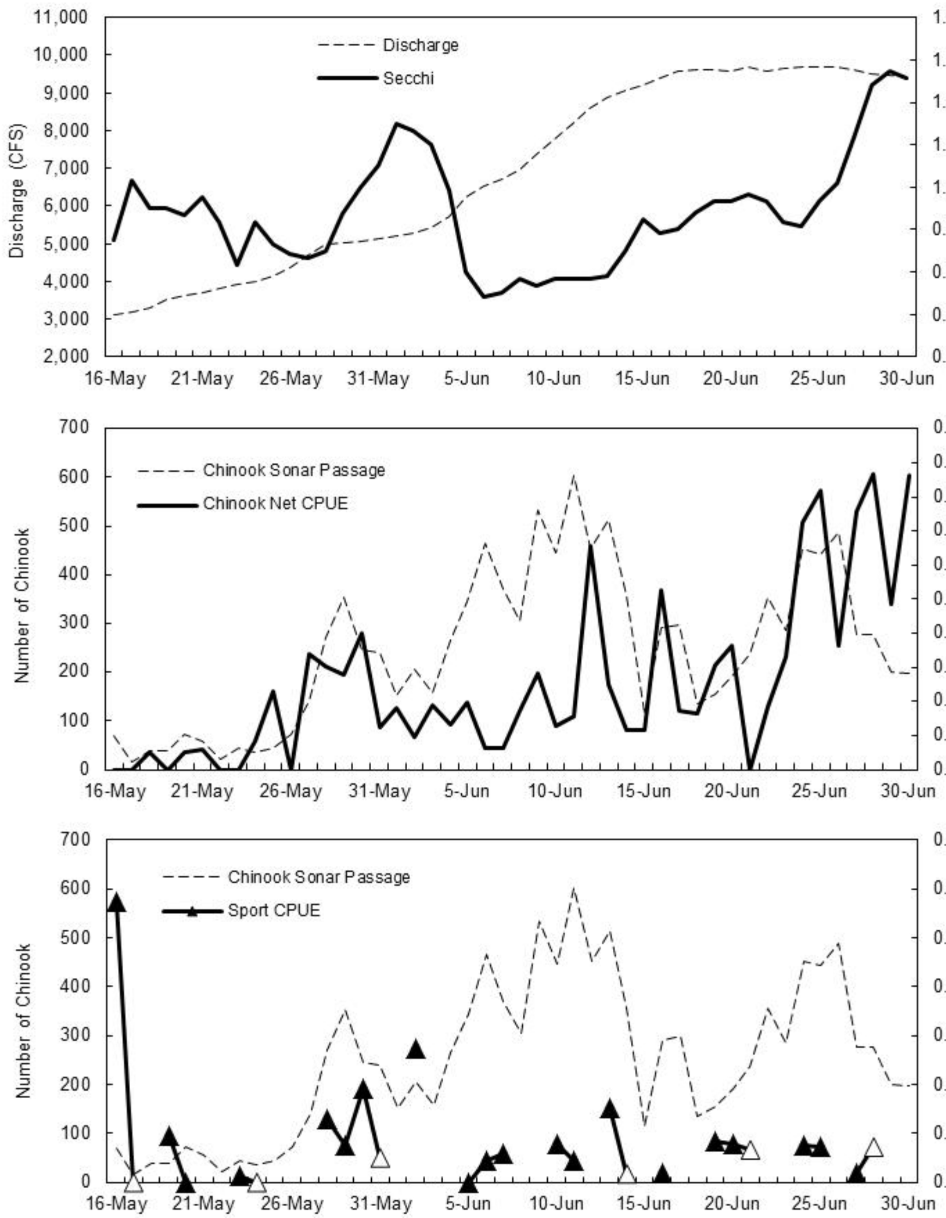


Figure 54.–Daily discharge rates collected at the Soldotna Bridge (top), Secchi disk readings taken at the sonar site (top), Chinook salmon TS-based sonar passage estimates (middle, bottom), inriver gillnet CPUE (middle), and Chinook salmon sport fish CPUE (bottom), for the early run (16 May–30 June), Kenai River, 2009.

Note: River discharge taken from USGS (2009). Net CPUE and sport fish CPUE taken from Perschbacher (2012). Open triangles represent days on which only unguided anglers were allowed to fish.

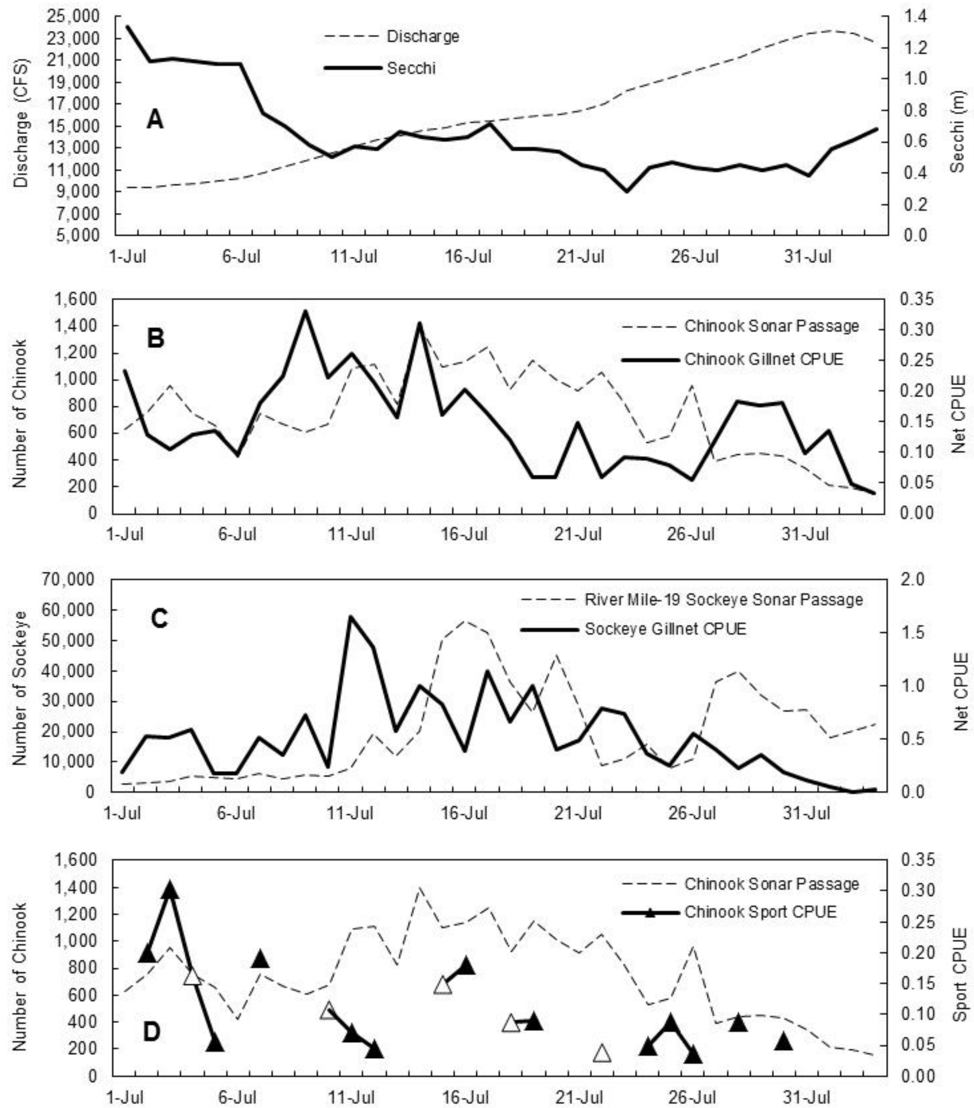


Figure 55.–Daily discharge rates collected at the Soldotna Bridge (A), Secchi disk readings taken at the sonar site (A), Chinook salmon TS-based sonar passage estimates (B, D), Chinook salmon inriver gillnet CPUE (B), river mile–19 sockeye salmon sonar passage estimates (C), sockeye salmon gillnet CPUE (C), and Chinook salmon sport fish CPUE (D), for the late run (1 July–4 August), Kenai River, 2009.

Note: River discharge taken from USGS (2009). River mile-19 sockeye sonar estimates taken from Westerman and Willette (2011). Net CPUE and sport fish CPUE taken from Perschbacher (2012). The Chinook salmon sport fishery closed by regulation on 31 July, so sport fish CPUE data were not available after this date. Open triangles represent days when only unguided anglers were allowed to fish.

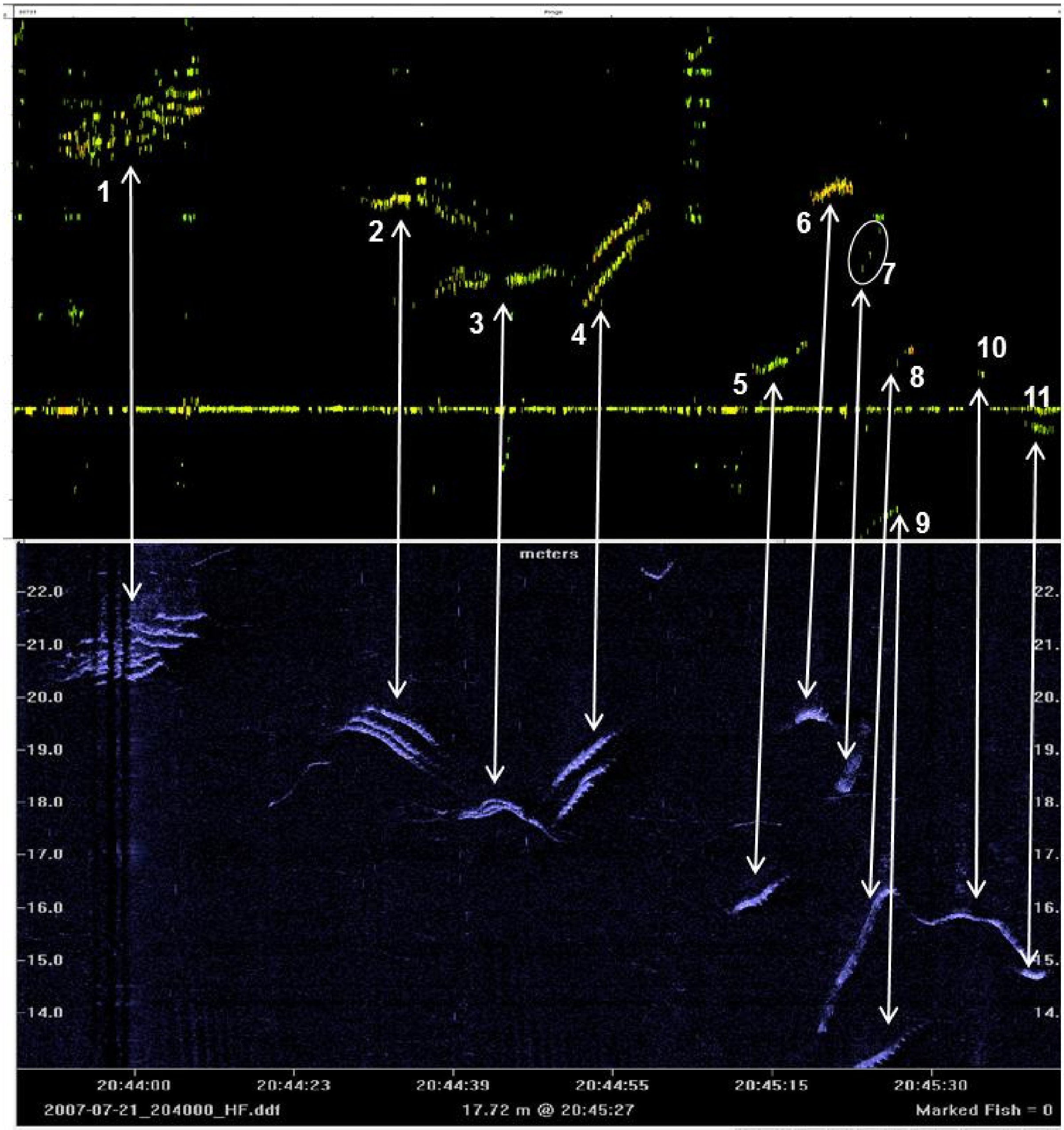


Figure 56.–Corresponding split-beam (top) and DIDSON (bottom) echograms. The DIDSON echogram was created using 16 beams. Numbered arrows indicate matching individual and groups of fish.

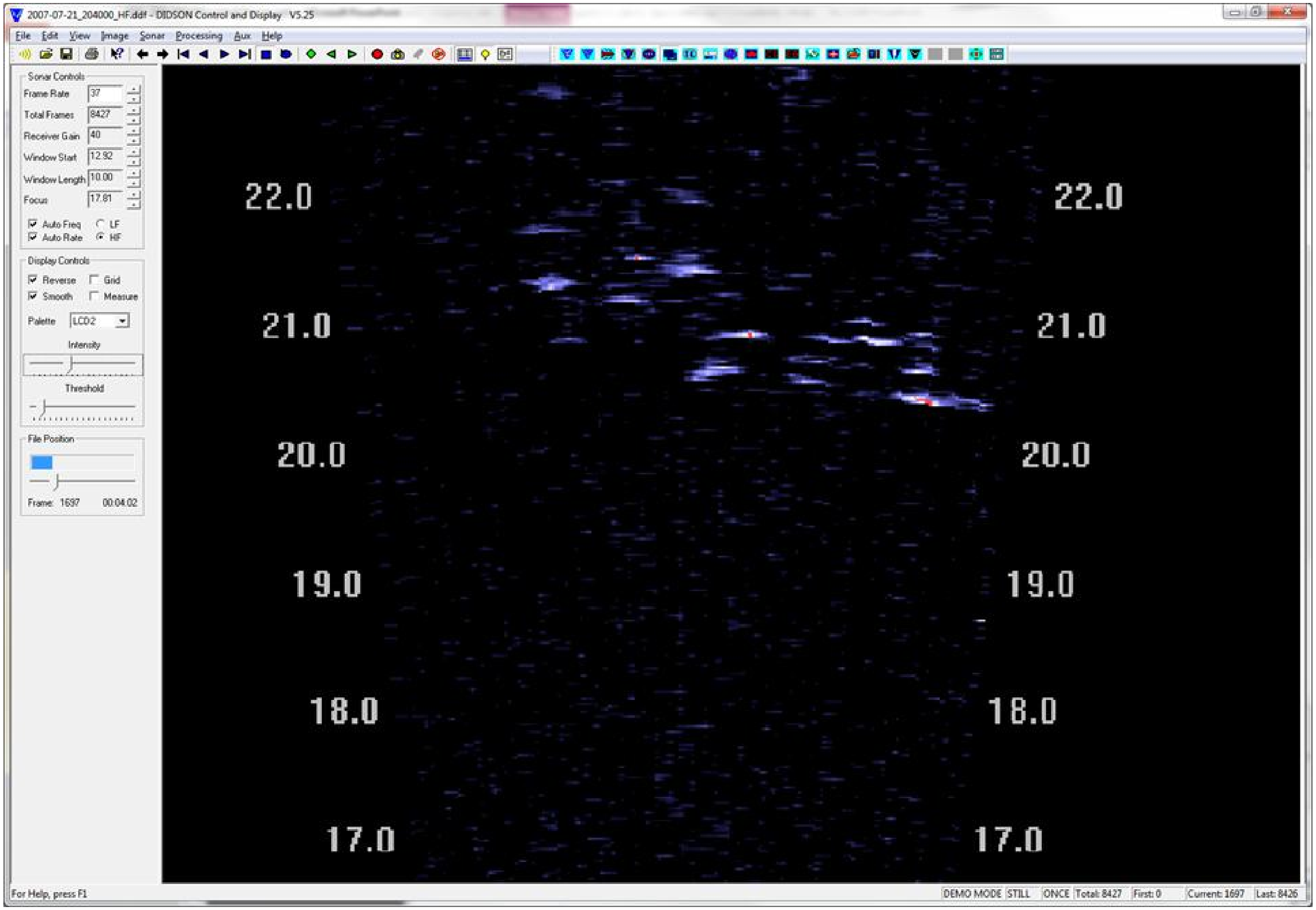


Figure 57.–DIDSON video frame showing approximately 15 smaller fish swimming in a school (see Example 1 in Figure 56).

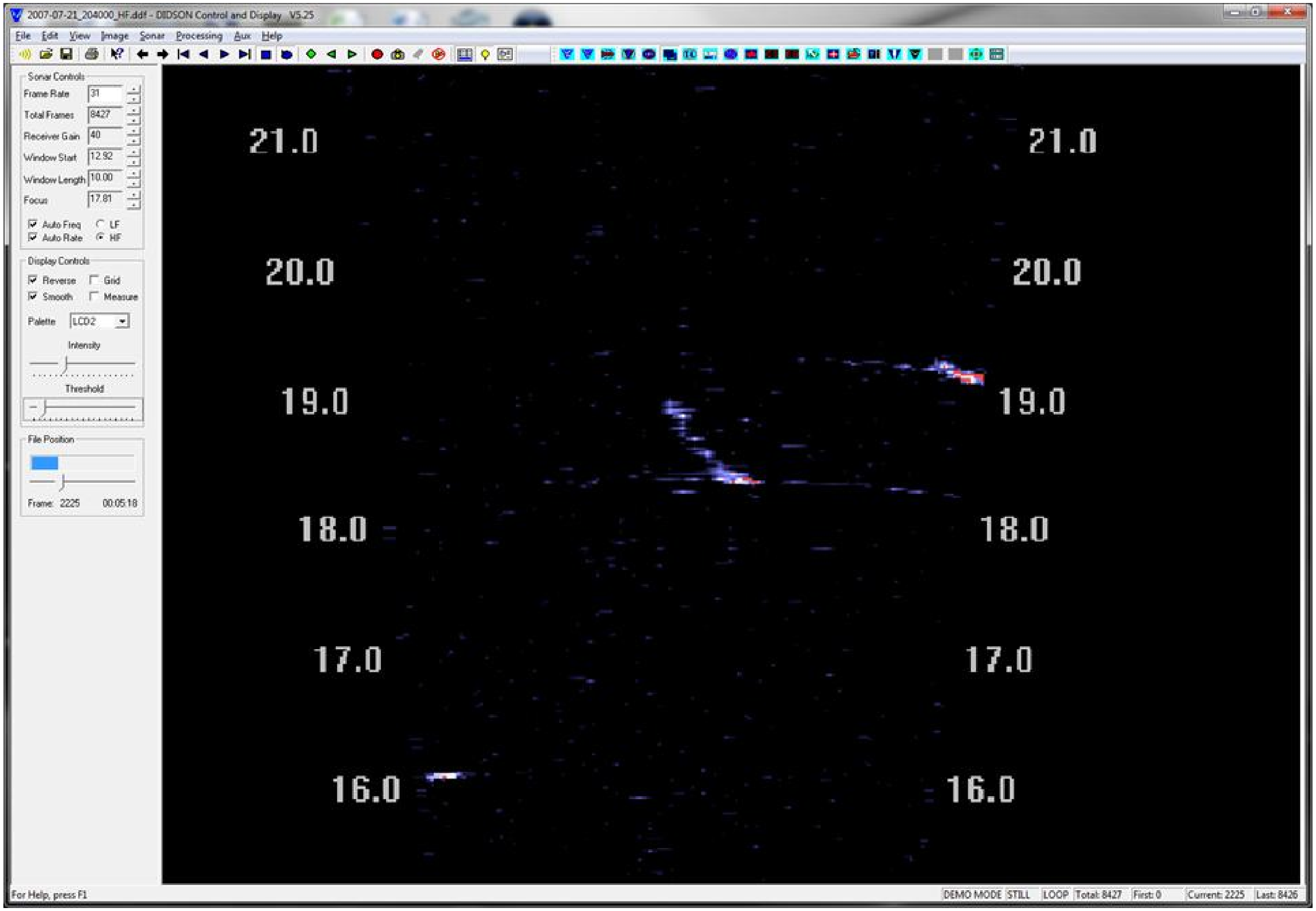


Figure 58.–DIDSON video frame captures a downstream-drifting Chinook salmon (99 cm) that drifts through at such a steep aspect angle (very little surface area presented to sonar) that it is undetected by split-beam sonar (see Example 7 in Figure 56).

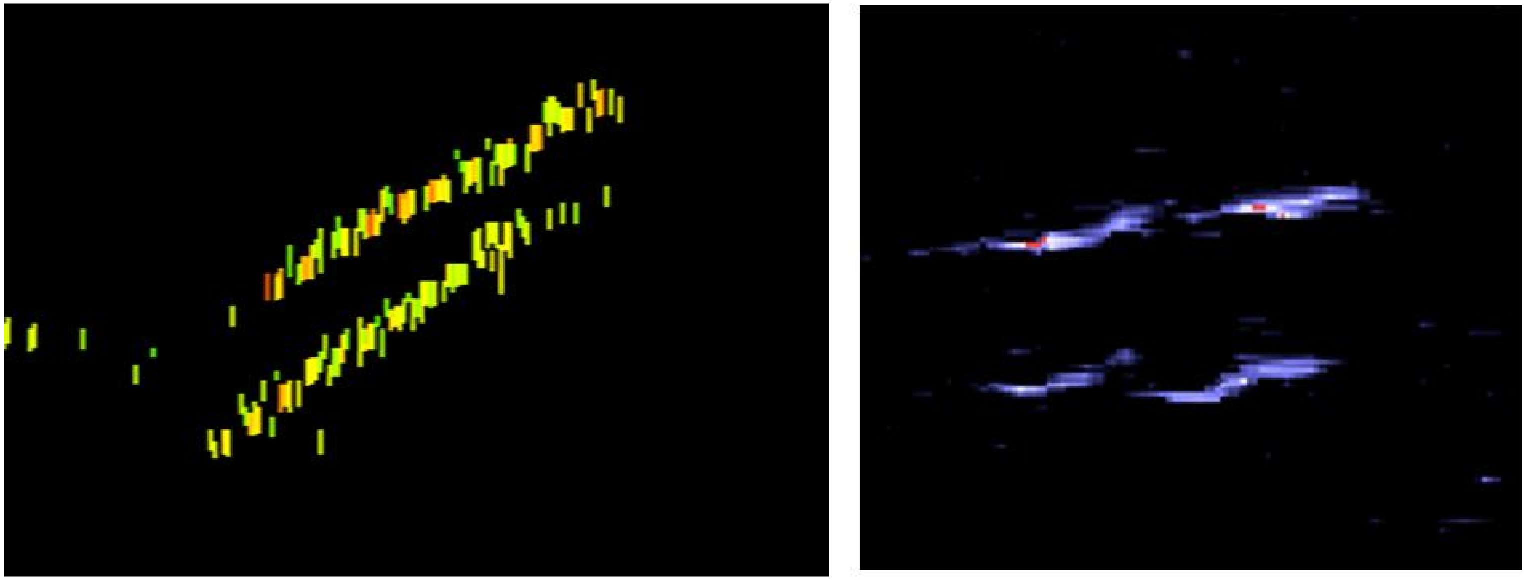


Figure 59.–Paired split-beam (left) and DIDSON (right) data reveal that the two fish tracks shown on the split-beam echogram are actually four smaller fish when played on the DIDSON video (see Example 4 in Figure 56).

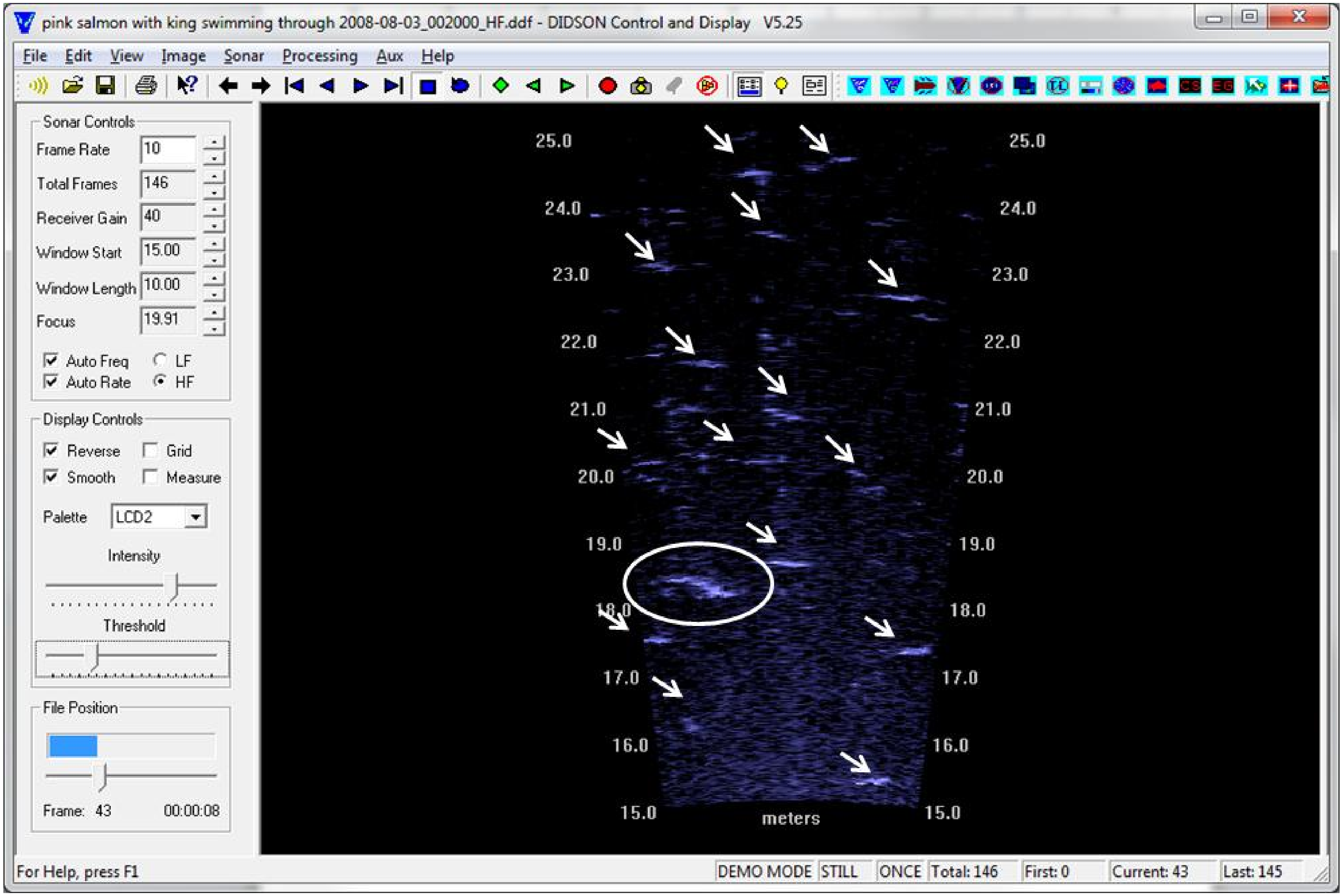


Figure 60.–A 108-cm Chinook salmon (inside circle) swims upstream past approximately 15 pink salmon (arrows) that are holding a stationary position in the beam until a change in the tide cycle (from low to rising) causes them to continue migrating upstream.

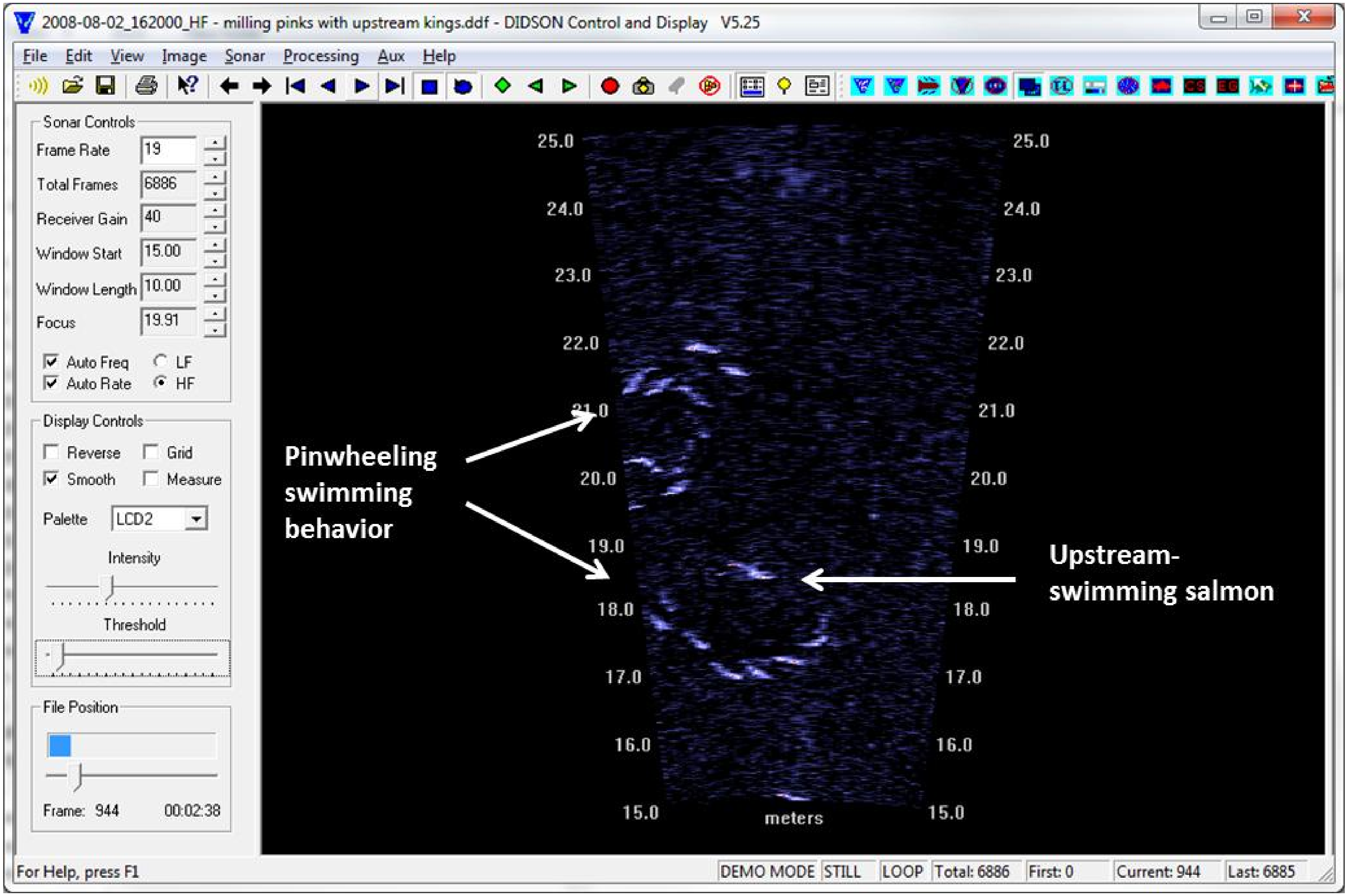


Figure 61.–DIDSON image showing a single upstream-swimming salmon amid two schools of fish milling in a circular pin-wheeling pattern.

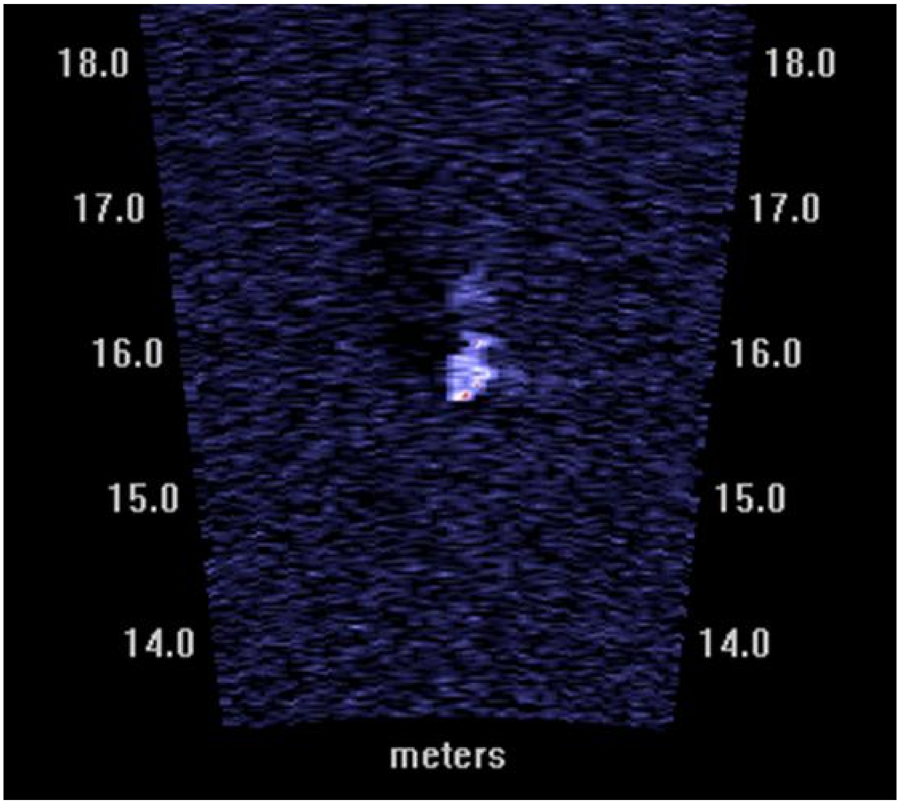


Figure 62.–The triangular shape and swimming motion of flounders make them easily distinguishable from salmon on DIDSON images, but not by split-beam sonar.

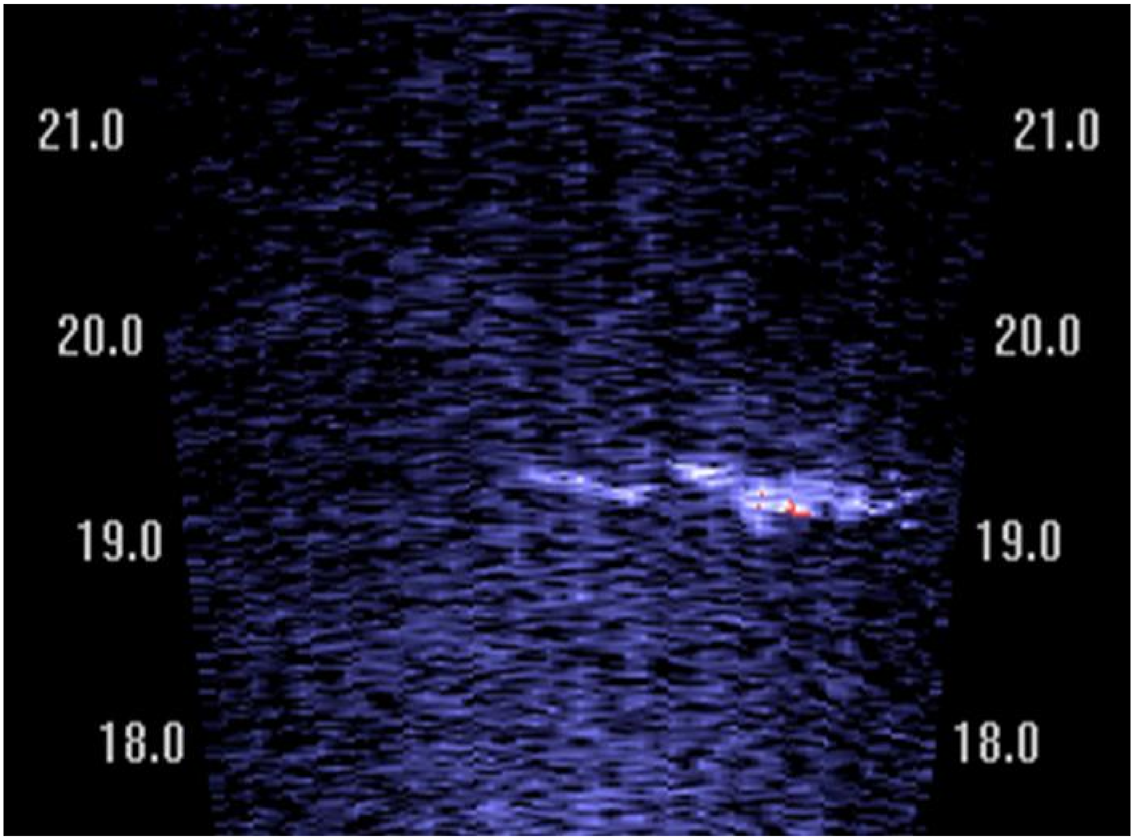


Figure 63.–DIDSON image of a small seal (at right) attempting to prey on a tethered salmon.

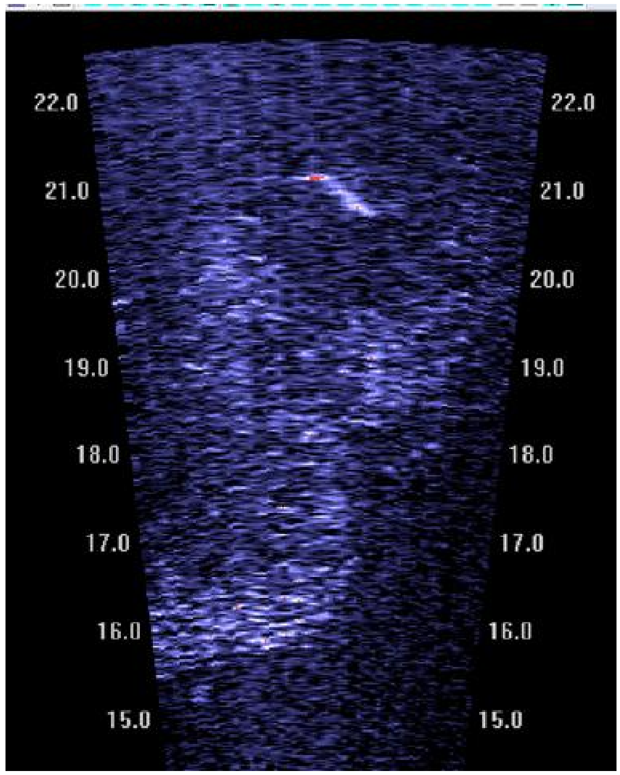


Figure 64.–DIDSON image of a Chinook salmon swimming through a school of eulachon.

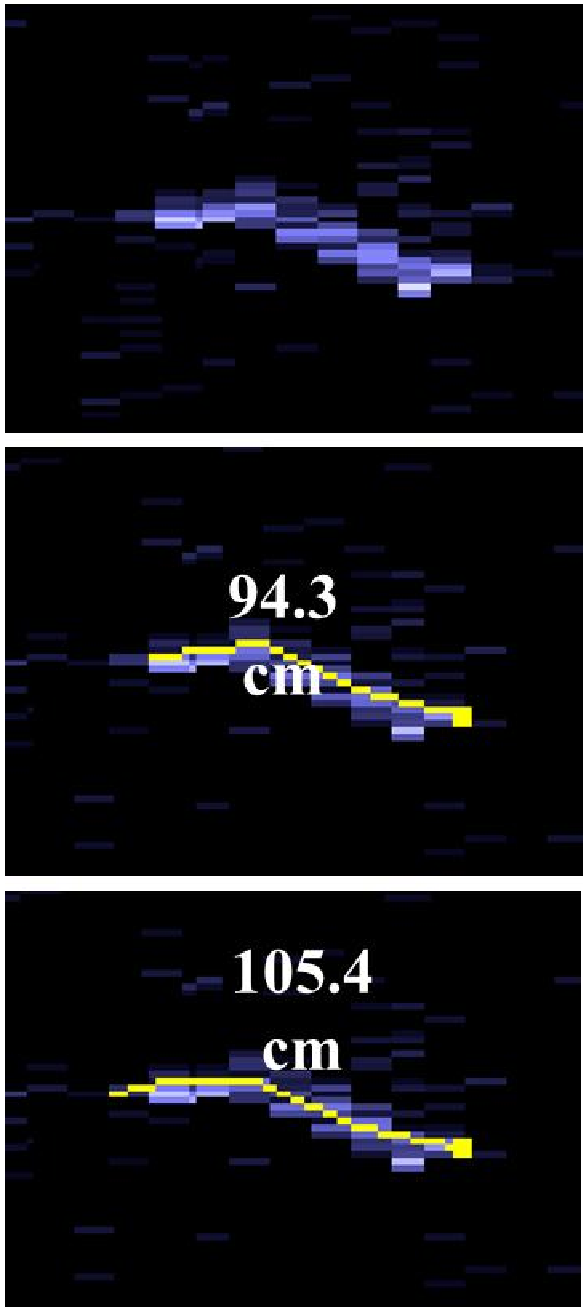


Figure 65.–DIDSON image of migrating fish (top) is measured at 94.3 cm (middle) and 105.4 cm (bottom) depending on whether the dimmer pixels in the tail region (on image left) are included in the measurement (frame 5833 from file 2008-07-27222000_HF.ddf).

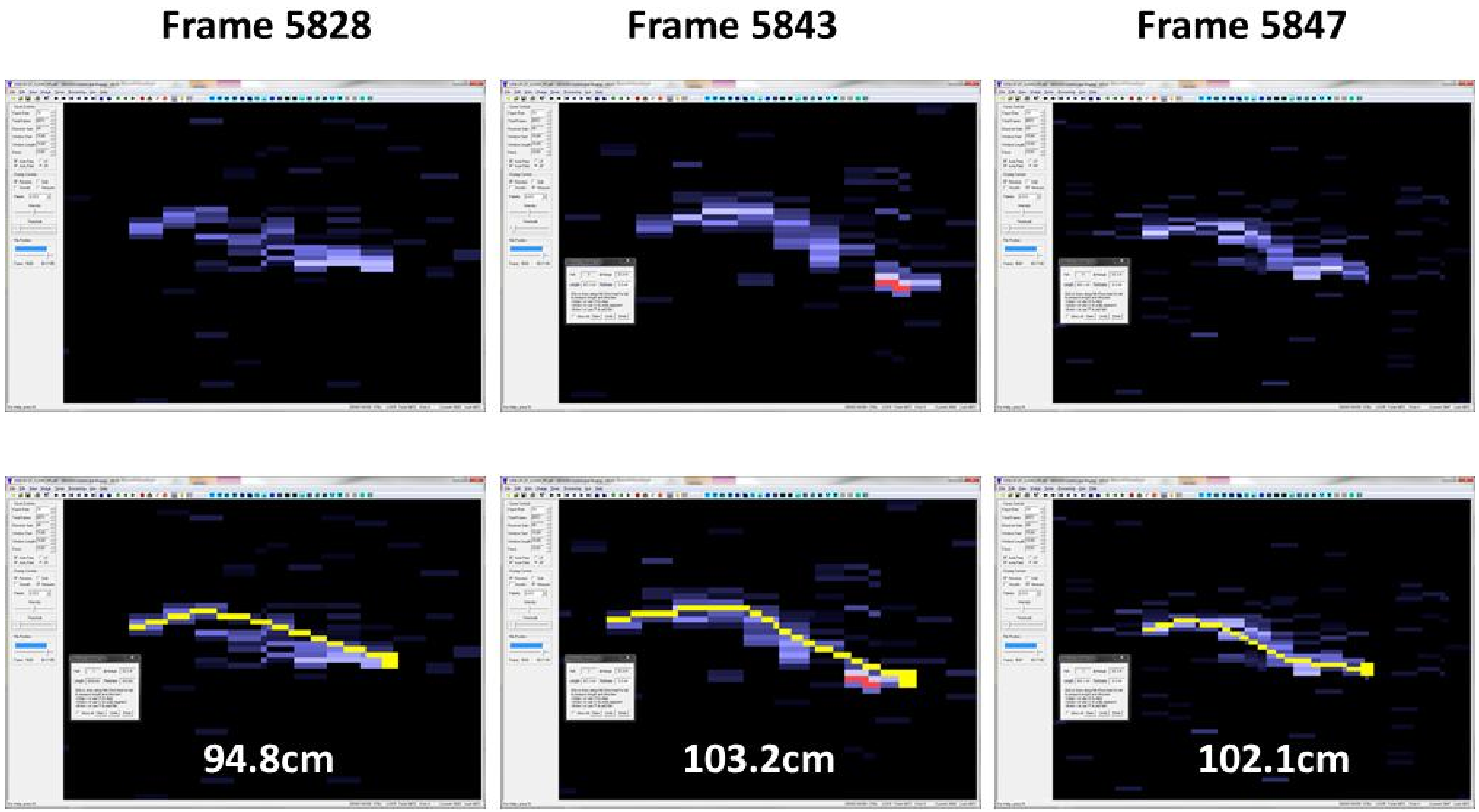


Figure 66.–DIDSON image of the same fish measured on three different frames. Each frame would be considered a good choice in that each shows little ambiguity in which pixels to include in the measurement and because the fish appears to be displaying its entire length based on the appearance of the snout, body, and tail (Frames 5828, 5843, and 5847) from file 2008-07-27222000_HF.ddf.

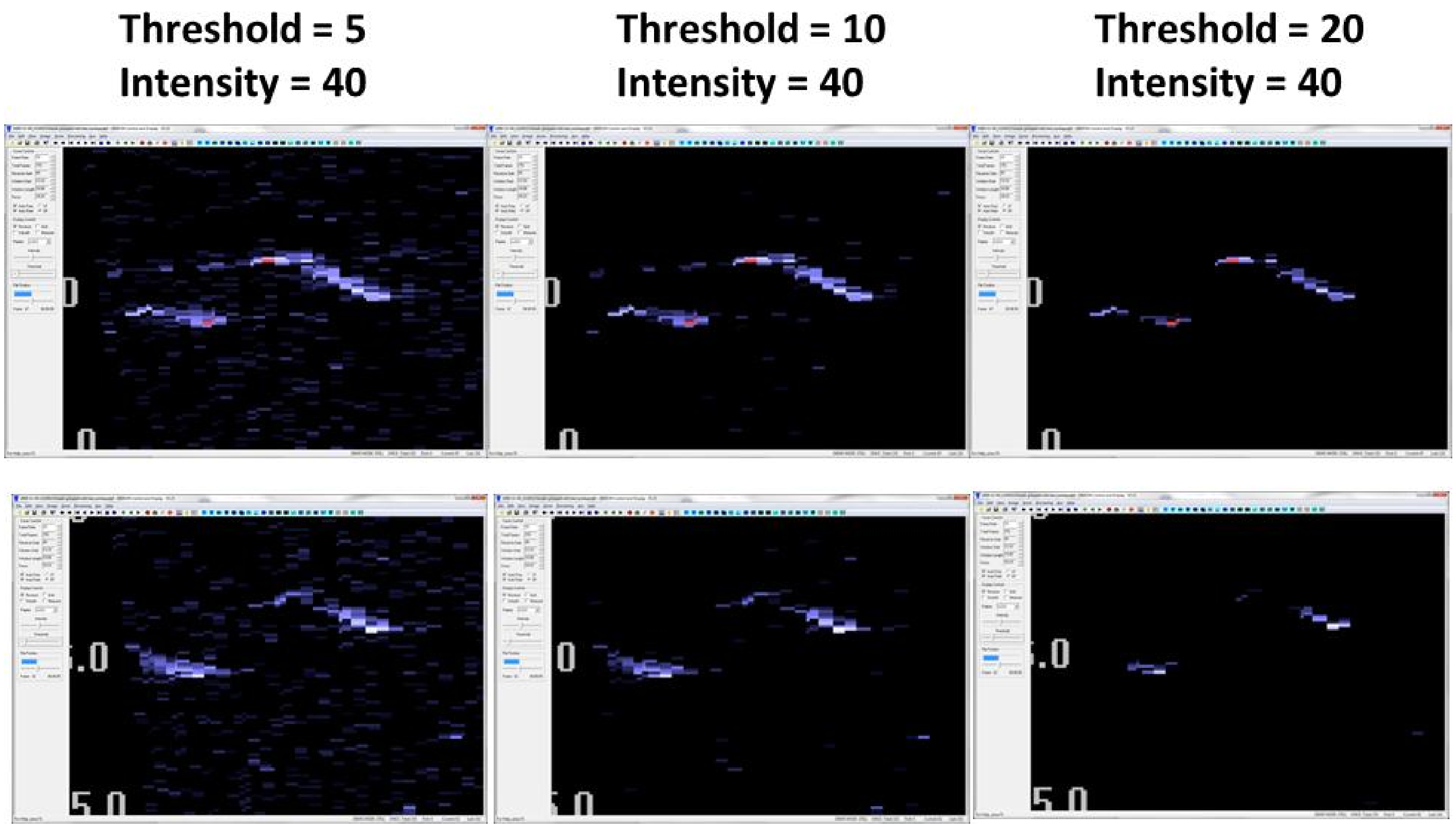


Figure 67.–The same DIDSON image of two fish viewed at a constant intensity but with an increasing threshold of 5 (left column), 10 (middle column), and 20 (right column). The top row shows an example of a well-chosen frame where the length measurement is robust to varying threshold settings and the images yield similar measurements even when the threshold is increased. The bottom row shows a poorly chosen frame where the length measurements on both fish images decreases with increasing threshold.

APPENDIX A: TARGET STRENGTH ESTIMATION

Appendix A1.–The sonar equation used to estimate target strength in decibels with dual- and split-beam applications.

Target strength (TS) in decibels (dB) of an acoustic target located at range R (in m), θ degrees from the maximum response axis (MRA) in one plane and ϕ degrees from the MRA in the other plane, was estimated as follows:

$$TS = 20 \log_{10}(V_o) - SL - G_r + 40 \log_{10}(R) + 2\alpha R - G_{TVG} - 2B(\theta,\phi),$$

where:

V_o	= voltage of the returned echo, output by the echo sounder;
SL	= source level of transmitted signal in dB;
G_r	= receiver gain in dB;
$40\log_{10}(R)$	= two-way spherical spreading loss in dB;
$2\alpha R$	= two-way absorption loss in dB;
G_{TVG}	= time-varied-gain correction of the echo sounder; and
$2B(\theta,\phi)$	= two-way loss due to position of the target off of the MRA.

The source level and gain were measured during calibration and confirmed using *in situ* standard sphere measurements. The time-varied-gain correction compensates for spherical spreading loss. Absorption loss ($2\alpha R$) was ignored in this study.

In practice, the location of the target in the beam (θ and ϕ) is not known, so $B(\theta,\phi)$ must be estimated in order to estimate target strength. Dual-beam and split-beam sonar differ in how they estimate $B(\theta,\phi)$, also called the beam pattern factor.

Dual-beam sonar (Ehrenberg 1983) uses 1 wide and 1 narrow beam. The system transmits on the narrow beam only and receives on both. The ratio between the voltages of the received signals is used to estimate beam pattern factor:

$$B(\theta,\phi) = 20 \log(V_N/V_W) \bullet WBDO,$$

where V_N is the voltage of the returned echo on the narrow beam, V_W is the voltage of the echo on the wide beam, WBDO is the wide beam drop-off correction, specific to each transducer, and estimated at calibration.

Split-beam sonar (MacLennan and Simmonds 1992) estimates target location (angles θ and ϕ of the target from the MRA) directly, not just the beam pattern factor ($B(\theta,\phi)$). Split-beam transducers are divided into 4 quadrants, and θ and ϕ are estimated by comparing the phases of signals received by opposing pairs of adjacent quadrants. The beam pattern factor is a function of θ and ϕ, determined during laboratory calibration.

APPENDIX B: SYSTEM PARAMETERS

Appendix B1.–Example of system parameters used for data collection on the right bank (transducer 733).

Parameter number	Subfield number[a]	Parameter value	Parameter description
100	-1	1	MUX argument #1—multiplexer port to activate
101	-1	0	percent—sync pulse switch, ping rate determiner NUS
102	-1	13201	maxp—maximum number of pings in a block NUS
103	-1	32767	maxbott—maximum bottom range in samples NUS
104	-1	13	N_th_layer—number of threshold layers
105	-1	5	max_tbp—maximum time between pings in pings
106	-1	5	min_pings—minimum number of pings per fish
507	-1	FED5	timval—0xFED5 corresponds to about 20 kHz NUS
108	-1	1	mux_on—means multiplexing enabled on board NUS
109	-1	200	mux_delay—samples delay between sync and switching NUS
110	-1	0	decimate_mask—decimate input samples flag NUS
112	-1	1	echogram_on—flag for DEP echogram enable 0=off, 1=on
113	-1	1	Hourly Sampling flag 1=On 0=Off
118	-1	5	maxmiss—maximum number of missed pings in auto bottom
119	-1	0	bottom—
120	-1	0	sb_int_code—sb only=0, sb-int: 40log a bot=1, 20log=2
121	-1	0	sb_int_code2—sb only=0, sb-int 40log eg=0, 20log=2
122	-1	13	N_int_layers—number of integration strata
123	-1	13	N_int_th_layers—number of integration threshold strata
124	-1	0	int_print—print integrator interval results to printer
125	-1	0	circular element transducer flag for bpf calculation
126	-1	80	grid spacing for Model 404 DCR (in samples, 16 s/m)
127	-1	1	TRIG argument #1—trigger source
128	-1	0	TRIG argument #2—digital data routing
130	-1	0	TVG Blank (0=Both Start/End,1=Stop Only,2=Start Only,3=None)
200	-1	20	sigma flag 0.0 = no sigma, else sigma is output
201	-1	221.02	sl—transducer source level
202	-1	-170.21	gn—transducer through system gain at one meter
203	-1	-18	rg—receiver gain used to collect data
204	-1	2.8	narr_ax_bw—vertical nominal beam width
205	-1	10	wide_ax_bw—horizontal axis nominal beam width
206	-1	0	narr_ ax_corr—vertical axis phase correction
207	-1	0	wide_ax_corr—horizontal axis phase correction
208	-1	11.0011	ping_rate—pulses per second
209	-1	0	echogram start range in meters
210	-1	37.5	echogram stop range in meters
211	-1	777	echogram threshold in millivolts
212	-1	13.2	print width in inches
213	-1	0	Chirp Bandwidth (0.0 = CHIRP OFF)
214	-1	20	Sampling within Hour Ending Time (in Decimal Minutes)
215	-1	1500	Speed of Sound (m/s)
216	-1	200	The Transducer's Frequency (kHz)
217	-1	-2.5	min_angoff_v—minimum angle off axis vertical
218	-1	2	max_angoff_v—maximum angle off axis vertical
219	-1	-5	min_angoff_h—minimum angle off axis horiz.

-continued-

Appendix B1.–Part 2 of 3.

Parameter number	Subfield number[a]	Parameter value	Parameter description
220	-1	5	max_angoff_ h—maximum angle off axis horiz.
221	-1	-24	max_dB_off—maximum angle off in dB
222	-1	-16.2537	ux—horizontal electrical to mechanical angle ratio
223	-1	-31.0378	uy—vertical electrical to mechanical angle ratio
224	-1	0	ud_coef_a—a coeff. for up-down beam pattern eq.
225	-1	-0.0069	ud_coef_b—b coeff. for up-down beam pattern eq.
226	-1	-2.2457	ud_coef_c—c coeff. for up-down beam pattern eq.
227	-1	0.0707	ud_coef_d—d coeff. for up-down beam pattern eq.
228	-1	-0.1249	ud_coef_e—e coeff. for up-down beam pattern eq.
229	-1	0	lr_coef_a—a coeff. for left-rt beam pattern eq.
230	-1	-0.0003	lr_coef_b—b coeff. for left-rt beam pattern eq.
231	-1	-0.2185	lr_coef_c—c coeff . for left-rt beam pattern eq.
232	-1	0.0007	lr_coef_d—d coeff. for left-rt beam pattern eq.
233	-1	-0.0002	lr_coef_e—ecoeff. for left-rt beam pattern eq.
234	-1	4	maximum fish velocity in meters per second
235	-1	1	Echo Scope Bottom Location
236	-1	0.4	maxpw—pulse width search window size
238	-1	35.4	bottom—bottom depth in meters
239	-1	0	init_slope—initial slope for tracking in m/ping
240	-1	0.2	exp_cont—exponent for expanding tracking window
241	-1	0.2	max_ch_rng—maximum change in range in m/ping
242	-1	0.04	pw_criteia->min_pw_6—min -6 dB pulse width
243	-1	10	pw_criteria->max_pw_6—max -6 dB pulse width
244	-1	0.04	pw_criteria->min_pw_12—min -12 dB pulse width
245	-1	10	pw_criteria->max_pw_12—max -12 dB pulse width
246	-1	0.04	pw_criteria->min_pw_18—min -18 dB pulse width
247	-1	10	pw_criteria->max_pw_18—max -18 dB pulse width
249	-1	10	maximum voltage to allow in .RAW file
250	-1	0.2	TX argument #1—pulse width in milliseconds
251	-1	25	TX argument #2—transmit power in dB-watts
252	-1	-12	RX argument #1—receiver gain
253	-1	90.9	REP argument #1—ping rate in ms per ping
254	-1	10	REP argument #2—pulsed cal tone separation
255	-1	1	TVG argument #1—TVG start range in meters
256	-1	100	TVG argument #2—TVG end range in meters
257	-1	40	TVG argument #3—TVG function (XX Log Range)
258	-1	-6	TVG argument #4—TVG gain
259	-1	0	TVG argument #5—alpha (spreading loss) in dB/Km
260	-1	0.2	minimum absolute distance fish must travel in x plane
261	-1	0.2	minimum absolute distance fish must travel in y plane
262	-1	0.2	minimum absolute distance fish must travel in z plane
263	-1	2	bottom_window—auto tracking bottom window (m)
264	-1	3	bottom_threshold—auto tracking bottom threshold (V)
265	-1	11.2	TVG argument #7—20/40 log crossover (meters)
266	-1	0	rotator—which rotator to aim
267	-1	0	aim_pan—transducer aiming angle in pan (x, lf/rt)
268	-1	0	aim_tilt—transducer aiming angle in tilt (y, u/d)

-continued-

Appendix B1.–Part 3 of 3.

Parameter number	Subfield number[a]	Parameter value	Parameter description
401	401	0	th_layer[0]—bottom of first threshold layer (m)
401	401	1	th_layer[1]—bottom of second threshold layer (m)
401	401	2	th_layer[2]—bottom of third threshold layer (m)
401	401	3	th_layer[3]—bottom of fourth threshold layer (m)
401	401	4	th_layer[4]—bottom of fifth threshold layer (m)
401	401	5	th_layer[5]—bottom of sixth threshold layer (m)
401	401	6	th_layer[6]—bottom of seventh threshold layer (m)
401	401	7	th_layer[7]—bottom of eighth threshold layer (m)
401	401	8	th_layer[8]—bottom of ninth threshold layer (m)
401	401	9	th_layer[9]—bottom of tenth threshold layer (m)
401	401	10	th_layer[10]—bottom of eleventh threshold layer (m)
401	401	11	th_layer[11]—bottom of twelfth threshold layer (m)
401	401	12	th_layer[12]—bottom of thirteenth threshold layer (m)
402	402	0	th_val[0], threshold for 1st layer in millivolts
402	402	1	th_val[1], threshold for 2nd layer in millivolts
402	402	2	th_val[2], threshold for 3rd layer in millivolts
402	402	3	th_val[3], threshold for 4th layer in millivolts
402	402	4	th_val[4], threshold for 5th layer in millivolts
402	402	5	th_val[5], threshold for 6th layer in millivolts
402	402	6	th_val[6], threshold for 7th layer in millivolts
402	402	7	th_val[7], threshold for 8th layer in millivolts
402	402	8	th_val[8], threshold for 9th layer in millivolts
402	402	9	th_val[9], threshold for 10th layer in millivolts
402	402	10	th_val[10], threshold for 11th layer in millivolts
402	402	11	th_val[11], threshold for 12th layer in millivolts
402	402	12	th_val[12], threshold for 13th layer in millivolts
405	405	0	Integration threshold value for layer 1 (mV)
405	405	1	Integration threshold value for layer 2 (mV)
405	405	2	Integration threshold value for layer 3 (mV)
405	405	3	Integration threshold value for layer 4 (mV)
405	405	4	Integration threshold value for layer 5 (mV)
405	405	5	Integration threshold value for layer 6 (mV)
405	405	6	Integration threshold value for layer 7 (mV)
405	405	7	Integration threshold value for layer 8 (mV)
405	405	8	Integration threshold value for layer 9 (mV)
405	405	9	Integration threshold value for layer 10 (mV)
405	405	10	Integration threshold value for layer 11 (mV)
405	405	11	Integration threshold value for layer 12 (mV)
405	405	12	Integration threshold value for layer 13 (mV)
602	602	-1	Echo sounder serial number
604	604	-1	Transducer serial number
605	605	-1	Echogram paper speed
606	606	-1	Echogram resolution
607	607	-1	Trigger option
608	608	-1	River flow direction

Note: Start processing at Port 1 -FILE_PARAMETERS- Tuesday 1 July 12:00:08:2008. Data processing parameters are used in collecting this file for Port 1.

[a] -1 = unique record/ field; other values represent the threshold layer number.

Appendix B2.–Example of system parameters used for data collection on the left bank (transducer 738).

Parameter number	Subfield number[a]	Parameter value	Parameter description
100	-1	2	MUX argument #1—multiplexer port to activate
101	-1	0	percent—sync pulse switch, ping rate determiner NUS
102	-1	19200	maxp—maximum number of pings in a block NUS
103	-1	32767	maxbott—maximum bottom range in samples NUS
104	-1	293	N_th_layer—number of threshold layers
105	-1	5	max_tbp—maximum time between pings in pings
106	-1	5	min_pings—minimum number of pings per fish
507	-1	FED5	timval—0xFED5 corresponds to about 20 kHz NUS
108	-1	1	mux_on—means multiplexing enabled on board NUS
109	-1	200	mux_delay—samples delay between sync and switching NUS
110	-1	0	decimate_mask—decimate input samples flag NUS
112	-1	1	echogram_on—flag for DEP echogram enable 0=off, 1=on
113	-1	1	Hourly Sampling flag 1=On 0=Off
118	-1	5	maxmiss—maximum number of missed pings in auto bottom
119	-1	0	bottom-0=fix,1=man,2=scope,3=acq_chan1,4=acq_chan2,5=auto_1,6=auto_chan2
120	-1	0	sb_int_code—sb only=0, sb-int: 40log a bot=1, 20log=2
121	-1	0	sb_int_code2—sb only=0, sb-int 40log eg=0, 20log=2
122	-1	293	N_int_layers—number of integration strata
123	-1	293	N_int_th_layers—number of integration threshold strata
124	-1	0	int_print—print integrator interval results to printer
125	-1	0	circular element transducer flag for bpf calculation
126	-1	80	grid spacing for Model 404 DCR (in samples, 16 s/m)
127	-1	1	TRIG argument #1—trigger source
128	-1	0	TRIG argument #2—digital data routing
130	-1	0	TVG Blank (0=Both Start/End,1=Stop Only,2=Start Only,3=None)
200	-1	20	sigma flag 0.0 = no sigma, else sigma is output
201	-1	218.21	sl—transducer source level
202	-1	-171.67	gn—transducer through system gain at one meter
203	-1	-18	rg—receiver gain used to collect data
204	-1	2.8	narr_ax_bw—vertical nominal beam width
205	-1	10	wide_ax_bw—horizontal axis nominal beam width
206	-1	0	narr_ ax_corr—vertical axis phase correction
207	-1	0	wide_ax_corr—horizontal axis phase correction
208	-1	16	ping_rate—pulses per second
209	-1	0	echogram start range in meters
210	-1	28	echogram stop range in meters
211	-1	475	echogram threshold in millivolts
212	-1	13.2	print width in inches
213	-1	0	Chirp Bandwith (0.0 = CHIRP OFF)
214	-1	40	Sampling within Hour Ending Time (in Decimal Minutes)
215	-1	1500	Speed of Sound (m/s)
216	-1	200	The Transducer's Frequency (kHz)
217	-1	-2.5	min_angoff_v—minimum angle off axis vertical
218	-1	2	max_angoff_v—maximum angle off axis vertical
219	-1	-5	min_angoff_h—minimum angle off axis horiz.

-continued-

Appendix B2.–Part 2 of 3.

Parameter number	Subfield number[a]	Parameter value	Parameter description
220	-1	5	max_angoff_ h—maximum angle off axis horiz.
221	-1	-24	max_dB_off—maximum angle off in dB
222	-1	-16.1638	ux—horizontal electrical to mechanical angle ratio
223	-1	-53.1208	uy—vertical electrical to mechanical angle ratio
224	-1	0	ud_coef_a—a coeff. for up-down beam pattern eq.
225	-1	-0.0001	ud_coef_b—b coeff. for up-down beam pattern eq.
226	-1	-2.56	ud_coef_c—c coeff. for up-down beam pattern eq.
227	-1	-0.0664	ud_coef_d—d coeff. for up-down beam pattern eq.
228	-1	-0.1197	ud_coef_e—e coeff. for up-down beam pattern eq.
229	-1	0	lr_coef_a—a coeff. for left-rt beam pattern eq.
230	-1	0	lr_coef_b—b coeff. for left-rt beam pattern eq.
231	-1	-0.2222	lr_coef_c—c coeff . for left-rt beam pattern eq.
232	-1	0.0001	lr_coef_d—d coeff. for left-rt beam pattern eq.
233	-1	-0.0002	lr_coef_e—ecoeff. for left-rt beam pattern eq.
234	-1	4	maximum fish velocity in meters per second
235	-1	1	Echo Scope Bottom Location
236	-1	0.4	maxpw—pulse width search window size
238	-1	26.4	bottom—bottom depth in meters
239	-1	0	init_slope—initial slope for tracking in m/ping
240	-1	0.2	exp_cont—exponent for expanding tracking window
241	-1	0.2	max_ch_rng—maximum change in range in m/ping
242	-1	0.04	pw_criteria->min_pw_6—min -6 dB pulse width
243	-1	10	pw_criteria->max_pw_6—max -6 dB pulse width
244	-1	0.04	pw_criteria->min_pw_12—min -12 dB pulse width
245	-1	10	pw_criteria->max_pw_12—max -12 dB pulse width
246	-1	0.04	pw_criteria->min_pw_18—min -18 dB pulse width
247	-1	10	pw_criteria->max_pw_18—max -18 dB pulse width
249	-1	10	maximum voltage to allow in .RAW file
250	-1	0.2	TX argument #1—pulse width in milliseconds
251	-1	25	TX argument #2—transmit power in dB-watts
252	-1	-12	RX argument #1—receiver gain
253	-1	62.5	REP argument #1—ping rate in ms per ping
254	-1	10	REP argument #2—pulsed cal tone separation
255	-1	2	TVG argument #1—TVG start range in meters
256	-1	100	TVG argument #2—TVG end range in meters
257	-1	40	TVG argument #3—TVG function (XX Log Range)
258	-1	-6	TVG argument #4—TVG gain
259	-1	0	TVG argument #5—alpha (spreading loss) in dB/Km
260	-1	0.2	minimum absolute distance fish must travel in x plane
261	-1	0.2	minimum absolute distance fish must travel in y plane
262	-1	0.2	minimum absolute distance fish must travel in z plane
263	-1	2	bottom_window—auto tracking bottom window (m)
264	-1	3	bottom_threshold—auto tracking bottom threshold (V)
265	-1	11.2	TVG argument #7—20/40 log crossover (meters)
266	-1	0	rotator—which rotator to aim
267	-1	0	aim_pan—transducer aiming angle in pan (x, lf/rt)
268	-1	0	aim_tilt—transducer aiming angle in tilt (y, u/d)

-continued-

Appendix B2.–Part 3 of 3.

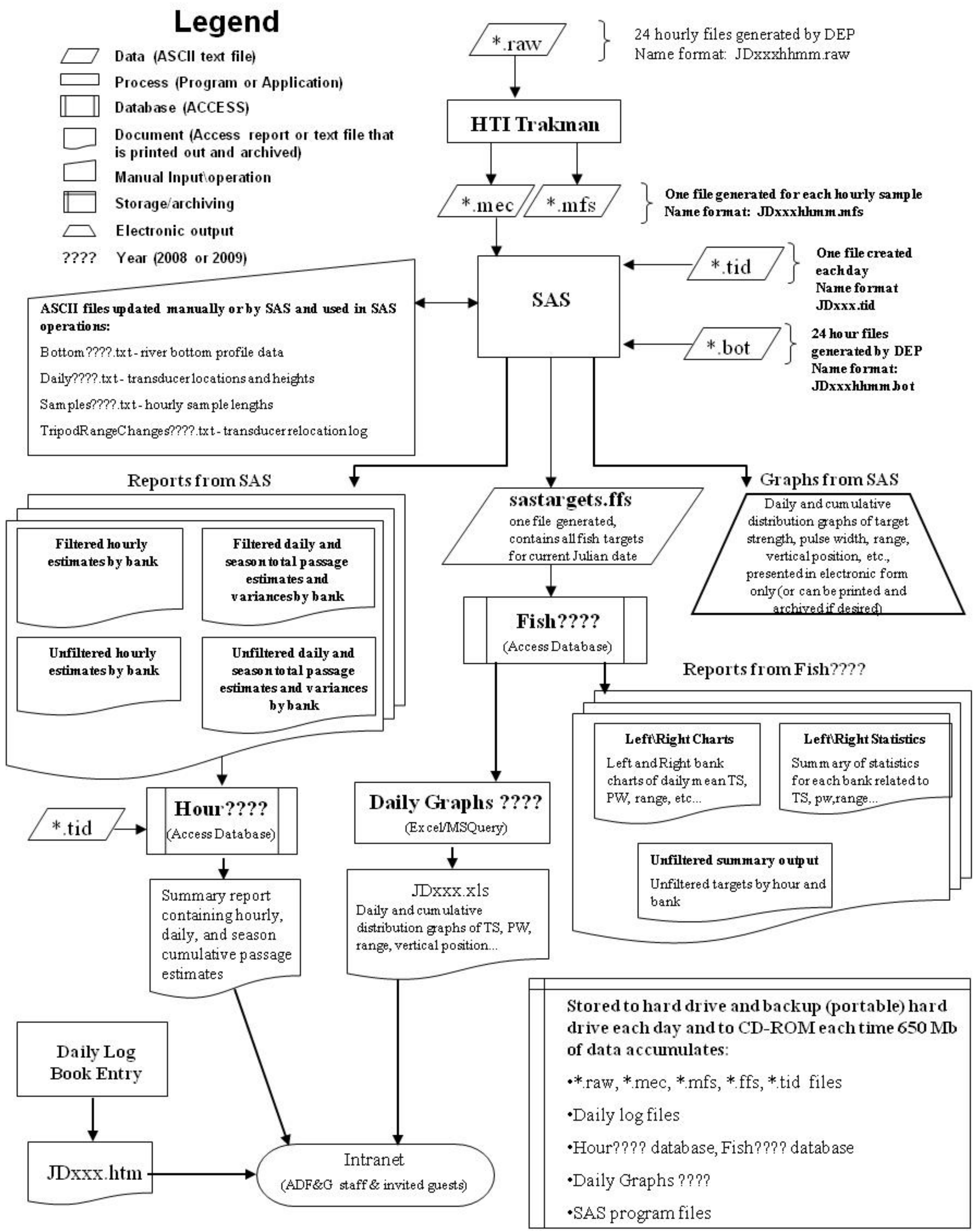
Parameter number	Subfield number[a]	Parameter value	Parameter description
401	0-292	1-30.2	th_layer[0-292], bottom of 1st threshold layer—bottom of 293rd threshold layer (i.e., 293 threshold layers in 0.1 m increments and numbered 0 through 292)
402	0-291	475	th_val[0-291], threshold for 1st through 292nd layer in millivolts
402	292	9999	th_val[292], threshold for 293rd layer in millivolts
405	0-291	100	Integration threshold value for layer 1-292 (mV)
405	292	9999	Integration threshold value for layer 293 (mV)
602	-1	1017536	Echo sounder serial number
604	-1	306738	Transducer serial number
605	-1	Spd-4	Echogram paper speed
606	-1	9_pin	Echogram resolution
607	-1	Board_Ext	Trigger option
608	-1	LeftToRight	River flow direction

Note: Start processing at Port 2 -FILE_PARAMETERS- Tuesday 1 July 12:00:08:2008. Data processing parameters are used in collecting this file for Port 2.

[a] -1 = unique record/ field; other values represent the threshold layer number.

APPENDIX C: DATA FLOW

Appendix C1.–Data flow diagram for the Kenai River Chinook salmon sonar project, 2008–2009.



APPENDIX D: EXCLUDED HOURLY SAMPLES

Appendix D1.–Hourly samples excluded by bank from calculation of early- and late-run Chinook salmon daily passage estimates (TS-based), Kenai River, 2008.

	Excluded sample hours	
Date	Left bank	Right bank
Early run		
7 Jun	1520–1720	1700
8 Jun	0520, 1520	-
9 Jun	1320	-
10 Jun	1220	2100
11 Jun	0920–1020, 2120, 2320	1000, 2100–2200
12 Jun	1120–1220, 2120–2220	2300
13 Jun	1320, 1520, 2320	1300, 1500, 2300
14 Jun	1320–1420, 2320	0000, 1300–1400, 2300
15 Jun	0020, 2320	0000, 2300
17 Jun	-	1300
27 Jun	2120–2220	2300
28 Jun	2120–2220	2200–2300
29 Jun	2320	1500–1600
30 Jun	1720	1800
Late run		
2 Jul	0520	0500, 1800
13 Jul	1420	1400
15 Jul	0820, 1520	1500, 1600, 2000
16 Jul	0720–0920, 1520–1720, 2020	0700–0800, 1000, 1500–1800
17 Jul	-	0200, 0500, 1600
20 Jul	2020–2120	2000
21 Jul	-	2000
22 Jul	0620	0600–0700
23 Jul	1820	0700, 1900
24 Jul	0820, 1920	0800, 1900–2000
25 Jul	1920–2020	2000–2200
26 Jul	1120, 2120–2320	1000–1200, 2100–2300
27 Jul	1120–1420, 2220–2320	1200–1500, 2200–2300
28 Jul	0020, 0220	0200, 1400
29 Jul	-	1400–1500
30 Jul	1420, 2020	1400–1600
31 Jul	1920, 2220	0200, 1500
1 Aug	0220, 1520, 1920, 2020	0200, 1800
2 Aug	0220, 0320, 1520, 1920–2120, 2320	0300, 1600
3 Aug	0320, 0720–1320, 2120–2320	0400, 0900–1300, 2100–2300

Appendix D2.–Hourly samples excluded by bank from calculation of early- and late-run Chinook salmon daily passage estimates (TS-based), Kenai River, 2009.

	Excluded sample hours	
Date	Left bank	Right bank
Early run		
13 Jun	0920, 2120–2220	2200
14 Jun	0720–0820	0800
15 Jun	1520, 2320	2300
20 Jun	1620–1720	1700
23 Jun	0720	-
24 Jun	1120	1100
25 Jun	0820, 1120	0800
26 Jun	1220–1420	1100–1300
27 Jun	1320	1200–1300, 2200
28 Jun	1120	0100
30 Jun	1020, 1320	1000
Late run		
1 Jul	0120, 0720, 1120–1220, 1520	0000–0100, 1100, 1600–1700, 2200
2 Jul	0320–0420, 1220–1320, 1520–1620	0400, 1300, 1500–1800, 2300
3 Jul	0020, 0520–0720, 1320–1420, 1820	0000–0100, 0400–0600, 1300, 1500–1800
4 Jul	0020–0120, 0520, 1420, 1720–2020	0000–0300, 0500, 0800, 1400–1500, 1700–2000
5 Jul	0120, 0320, 1520, 1820–1920	0500–0600, 1500–1600, 1800, 2000
6 Jul	0520–0820, 2020	0200, 0500–0700, 1800
7 Jul	1920–2020	1600, 1900
8 Jul	0620, 0820	0600
9 Jul	0820–0920	1700, 1900
10 Jul	2220	-
11 Jul	0920–1320, 1820–1920, 2120–2320	1000–1300, 1700–2000, 2300
12 Jul	0020–0120, 0620, 1020–1220, 1920–2020	0000–0100, 0600–0700, 1100–1300, 1900–2000
13 Jul	0720–0820, 2020–2120	0700–0800, 1200–1300, 2000–2100
14 Jul	0720–1020	0700–1000

APPENDIX E: WINBUGS CODE FOR ECHO-LENGTH STANDARD DEVIATION (ELSD) MIXTURE MODEL ESTIMATES OF SPECIES COMPOSITION

Appendix E1.–WinBUGS code for hierarchical age-composition model for development of prior distributions for ELSD mixture model.

```
# Age Mixture.odc  version 6a:
model {
 #Overall means and std deviations
 for (a in 1:A) {
   sigma[a] ~ dnorm(0,1.0E-4)I(0,)
   tau[a] <- 1 / sigma[a] / sigma[a]
   mu[a] ~ dnorm(0,1.0E-12)I(0,)
   }
 #Dirichlet distributed age proportions across years within weeks
 D.scale ~ dunif(0,1)
 D.sum <- 1 / (D.scale * D.scale)
 for (w in 1:W) {
   pi[w,1] ~ dbeta(0.2,0.4)
   pi.2p[w] ~ dbeta(0.2,0.2)
   pi[w,2] <- pi.2p[w] * (1 - pi[w,1])
   pi[w,3] <- 1 - pi[w,1] - pi[w,2]    for (y in 1:Y) {
     for (a in 1:A) {
       D[w,y,a] <- D.sum * pi[w,a]
       g[w,y,a] ~ dgamma(D[w,y,a],1)
       pi.wy[w,y,a] <- g[w,y,a]/sum(g[w,y,])
       }
     }
   }
 for (i in 1:nfish) {
   age[i] ~ dcat(pi.wy[week[i],year[i],1:A])
   length[i] ~ dnorm(mu[age[i]],tau[age[i]])
   }
}
```

Appendix E2.–WinBUGS code for ELSD mixture model fit to 2008 and 2009 early- and late-run Kenai River Chinook salmon sonar, gillnetting, and tethered fish data.

```
# ELSD 07 version 4:
# fish with neighbors < 1m in range excluded,
model{
 beta0 ~ dnorm(0,1.0E-4)
 beta1 ~ dnorm(0,1.0E-4)
 gamma ~ dnorm(0,1.0E-4)
 sigma.elsd ~ dunif(0,2)
 sigma.beta0 ~ dunif(0,2)
 tau.elsd  <- 1 / sigma.elsd / sigma.elsd
 tau.beta0 <- 1 / sigma.beta0 / sigma.beta0
 ps[1:2] ~ ddirch(D.species[])
 pa[1,1] ~ dbeta(B1,B2)
 theta1 ~ dbeta(B3,B4)
 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]
 p.chin <- ps[1] * p_n * p_i
 Lsig[1] <- 75
 Lsig[2] <- 25   #CHANGED FROM 34 in 2006, BASED ON AGE MIXTURE.ODC V5D SOCKEYE
 Ltau[1] <- 1 / Lsig[1] / Lsig[1]
 Ltau[2] <- 1 / Lsig[2] / Lsig[2]
 mu[1,1] ~ dnorm(636,0.0006)
 mu[1,2] ~ dnorm(816,0.0070)
 mu[1,3] ~ dnorm(1032,0.0006)
 mu[2,1] ~ dnorm(380,0.003)
 mu[2,2] ~ dnorm(500,0.006)
 mu[2,3] ~ dnorm(580,0.006)
 D.age.sockeye[1] <- 0.01
 D.age.sockeye[2] <- 0.5
 D.age.sockeye[3] <- 3.5
 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 (y in 1:3) {
  beta0.y[y] ~ dnorm(beta0,tau.beta0)
  }
 beta0.predict ~ dnorm(beta0,tau.beta0)
 for (k in 1:141) {
  elsd1[k] ~ dnorm(mu.elsd1[k],tau.elsd)
  mu.elsd1[k] <- beta0.y[year[k]] + beta1 * cm75[k] + gamma * sock.indic[k]
  }
    for (i in 1:nfish) {
     age[i] ~ dcat(pa.effective[species[i],1:3])
     mefl[i] ~ dnorm(mu[species[i],age[i]],Ltau[species[i]])
     }
    for (j in 1:ntgts) {
     species2[j] ~ dcat(ps[])
     age2[j] ~ dcat(pa[species2[j],1:3])
     mefl2[j] ~ dnorm(mu[species2[j],age2[j]],Ltau[species2[j]])
     elsd2[j] ~ dt(mu.elsd2[j],tau.elsd,8)
     cm75t[j] <- (mefl2[j] / 10) - 75;
     sock.indic2[j] <- species2[j] - 1;
     mu.elsd2[j] <- beta0.predict + gamma*sock.indic2[j] + beta1 * cm75t[j]
     } }
```

Appendix E3.–WinBUGS code for DIDSON-length mixture model. Prior distributions are in green font, likelihoods in blue.

```
model{
 beta0 ~ dnorm(75,0.0025)    #subjective prior sd=20cm
 beta1 ~ dnorm(1,25)         #subjective prior sd=0.2
 sigma.DL ~ dunif(0,20)
 tau.DL  <- 1 / sigma.DL / sigma.DL
 ps[1:2] ~ ddirch(D.species[])
 pa[1,1] ~ dbeta(B1,B2)
 theta1 ~ dbeta(B3,B4)
 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] <- 75
 Lsig[2] <- 25
 Ltau[1] <- 1 / Lsig[1] / Lsig[1]
 Ltau[2] <- 1 / Lsig[2] / Lsig[2]
 mu[1,1] ~ dnorm(636,0.0006)
 mu[1,2] ~ dnorm(816,0.0070)  mu[1,3] ~ dnorm(1032,0.0006)
 mu[2,1] ~ dnorm(380,0.003)
 mu[2,2] ~ dnorm(500,0.006)
 mu[2,3] ~ dnorm(580,0.006)
 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]])
  }
 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]])
  TL2.cm.75[j] <- (1.1*mefl.mm.2[j] + 2) / 10 - 75
  mu.DL2[j] <- beta0 + beta1 * TL2.cm.75[j]
  DL2[j] ~ dnorm(mu.DL2[j],tau.DL)
  }
```

APPENDIX F: DIDSON CONFIGURATION FOR KENAI RIVER CHINOOK SONAR STUDY, 2008–2009.

Dual-frequency identification sonars (DIDSONs) operate at two discrete 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. The long-range model (DIDSON-LR) used in this study was operated in high frequency mode (1.2 MHz) to achieve maximum image resolution. Additionally the DIDSON-LR was fitted with an ultra high-resolution lens to further enhance the image resolution of the DIDSON-LR system (DIDSON-LR+HRL). The high-resolution lens increases the image resolution by approximately a factor of two over the standard lens.

Overall nominal beam dimensions for a DIDSON-LR without a high-resolution lens are approximately 29° in the horizontal axis and 14° in the vertical axis. 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. The larger aperture of the high-resolution lens reduces the width of the individual beams of the standard lens and spreads them across a narrower field of view. Consequently, 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 (Appendix F2). The combined concentration of horizontal and vertical beam widths also increases the returned signal from a given target by 10 dB.

The resolution of a DIDSON image is defined in terms of down-range and cross-range resolution where cross-range resolution refers to the width and down-range resolution refers to the height of the individual pixels that make up the DIDSON image (Appendix F3). Each image pixel in a DIDSON frame has (x, y) rectangular coordinates that are mapped back to a beam and sample number defined by polar coordinates. The pixel height defines the down-range resolution and the pixel width defines the cross-range resolution of the image. Appendix F3 shows that image pixels are sometimes broken down into smaller screen pixels (e.g., pixels immediately to the right of the enlarged pixels), an artifact of conversions between rectangular and polar coordinates.

"Window Length," i.e., the range interval sampled by the sonar, controls the down-range resolution of the DIDSON image. Because the DIDSON image is composed of 512 samples 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. For this study, window length was set at 10 m, a compromise which allowed a reasonable distance to be covered while still operating in high frequency mode for optimal resolution. The down-range resolution (or pixel height) 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 F2). Targets at closer range are better resolved because the individual beam widths and corresponding image pixels increase with range following the formula below:

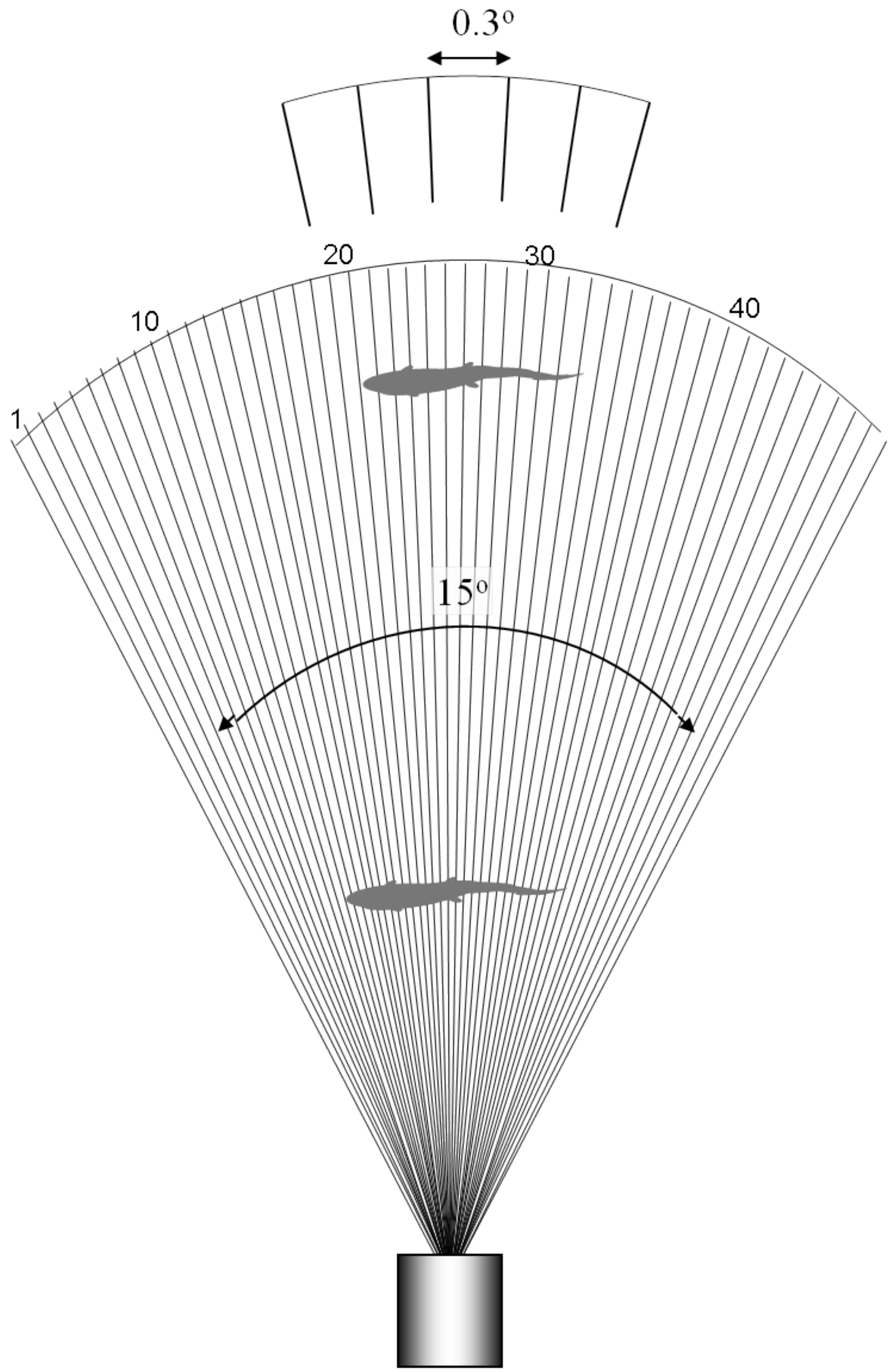
$$X = 2R\tan(\theta/2) \qquad (1)$$

where

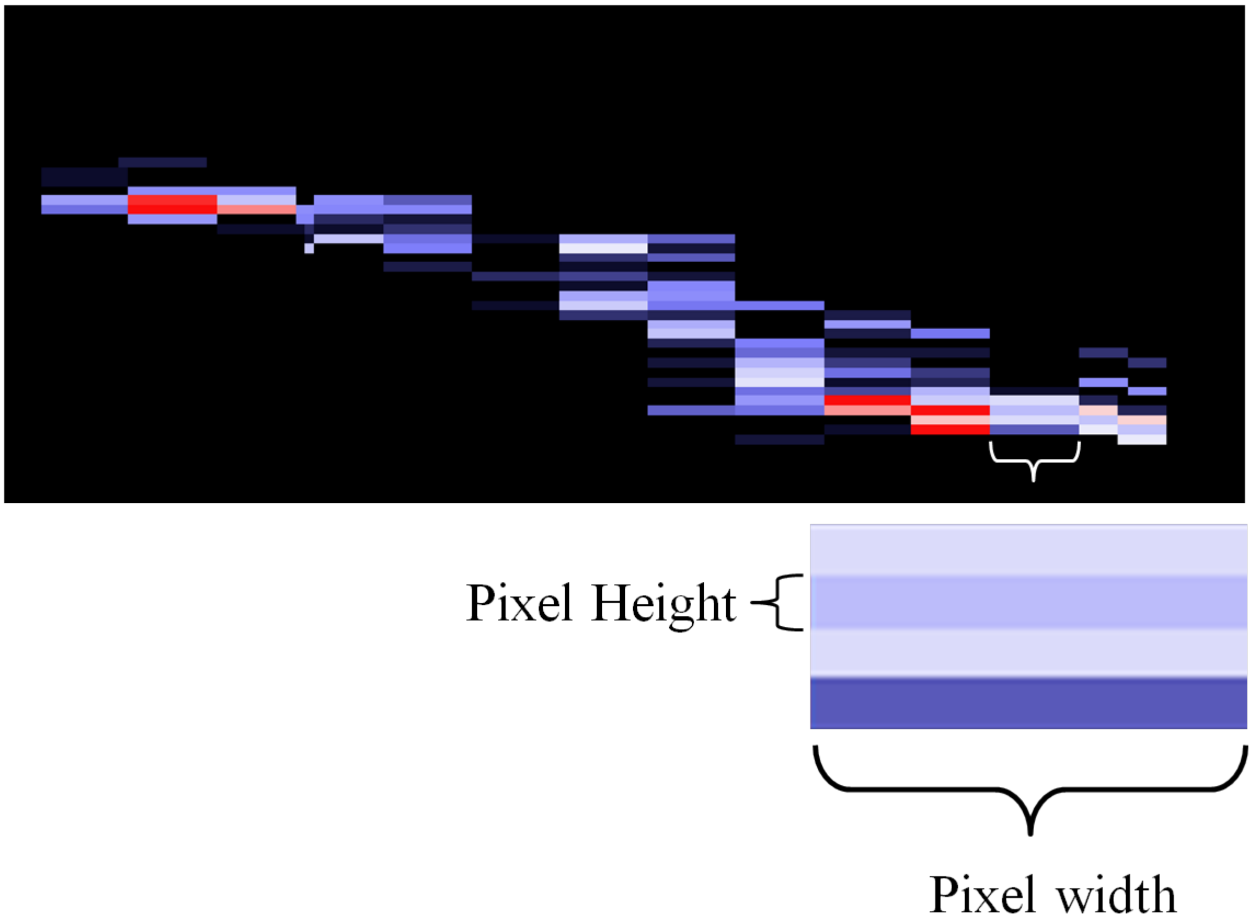
X = width of the individual beam or "image pixel" in meters,
R = range of interest in meters, and
θ = individual beam angle in degrees (approximately 0.3°).

The transmit power of the DIDSON sonar is fixed and 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 mid-range of the selected display window (e.g., for a window length of 10 m that started at 5 m, the focus range would be 15 m – [5 m/2]). The image smoothing feature was disabled.

Appendix F2.–Diagram showing the horizontal plane of a DIDSON-LR sonar with a high resolution lens (DIDSON-LR+HRL). The overall horizontal beam width of 15° is comprised of 48 sub-beams with approximately 0.3° beam widths. Note that because the beam widths grow wider with range, fish at close range are better resolved than fish at far range (Adapted from Burwen et al. [2007]).



Appendix F3.–Enlargement of a DIDSON video of a tethered Chinook salmon showing the individual pixels that comprise the image. Each image pixel in a DIDSON frame has (x, y) rectangular coordinates that are mapped back to a beam and sample number defined by polar coordinates range (Adapted from Burwen et al. [2010]).



APPENDIX G: DAILY PERCENTAGE OF UPSTREAM- AND DOWNSTREAM-MOVING FILTERED TARGETS FOR THE EARLY AND LATE RUNS, KENAI RIVER, 2008–2009.

Appendix G1.–Daily percentage of upstream- and downstream-moving filtered targets for the early run, Kenai River, 2008.

Date	% Downstream	% Upstream
16 May	27%	73%
17 May	22%	78%
18 May	26%	74%
19 May	39%	61%
20 May	13%	87%
21 May	18%	82%
22 May	7%	93%
23 May	2%	98%
24 May	0%	100%
25 May	6%	94%
26 May	7%	93%
27 May	4%	96%
28 May	3%	97%
29 May	3%	97%
30 May	2%	98%
31 May	0%	100%
1 Jun	0%	100%
2 Jun	0%	100%
3 Jun	1%	99%
4 Jun	2%	98%
5 Jun	3%	97%
6 Jun	4%	96%
7 Jun	1%	99%
8 Jun	1%	99%
9 Jun	1%	99%
10 Jun	0%	100%
11 Jun	1%	99%
12 Jun	1%	99%
13 Jun	1%	99%
14 Jun	1%	99%
15 Jun	1%	99%
16 Jun	0%	100%
17 Jun	3%	97%
18 Jun	1%	99%
19 Jun	2%	98%
20 Jun	3%	97%
21 Jun	3%	97%
22 Jun	1%	99%
23 Jun	6%	94%
24 Jun	0%	100%
25 Jun	2%	98%
26 Jun	2%	98%
27 Jun	1%	99%
28 Jun	2%	98%
29 Jun	3%	97%
30 Jun	2%	98%
Total	2%	98%

Appendix G2.–Daily percentage of upstream- and downstream-moving filtered targets for the late run, Kenai River, 2008.

Date	% Downstream	% Upstream
1 Jul	1%	99%
2 Jul	2%	98%
3 Jul	4%	96%
4 Jul	4%	96%
5 Jul	4%	96%
6 Jul	13%	87%
7 Jul	2%	98%
8 Jul	2%	98%
9 Jul	1%	99%
10 Jul	2%	98%
11 Jul	1%	99%
12 Jul	0%	100%
13 Jul	3%	97%
14 Jul	2%	98%
15 Jul	1%	99%
16 Jul	1%	99%
17 Jul	1%	99%
18 Jul	3%	97%
19 Jul	4%	96%
20 Jul	2%	98%
21 Jul	2%	98%
22 Jul	5%	95%
23 Jul	3%	97%
24 Jul	0%	100%
25 Jul	1%	99%
26 Jul	2%	98%
27 Jul	3%	97%
28 Jul	2%	98%
29 Jul	4%	96%
30 Jul	6%	94%
31 Jul	9%	91%
1 Aug	17%	83%
2 Aug	23%	77%
3 Aug	30%	70%
Total	6%	94%

Appendix G3.–Daily percentage of upstream- and downstream-moving filtered targets for the early run, Kenai River, 2009.

Date	% Downstream	% Upstream
16 May	4%	96%
17 May	79%	21%
18 May	24%	76%
19 May	19%	81%
20 May	23%	77%
21 May	10%	90%
22 May	0%	100%
23 May	0%	100%
24 May	25%	75%
25 May	0%	100%
26 May	4%	96%
27 May	7%	93%
28 May	3%	97%
29 May	2%	98%
30 May	4%	96%
31 May	0%	100%
1 Jun	0%	100%
2 Jun	0%	100%
3 Jun	5%	95%
4 Jun	1%	99%
5 Jun	1%	99%
6 Jun	1%	99%
7 Jun	1%	99%
8 Jun	1%	99%
9 Jun	1%	99%
10 Jun	1%	99%
11 Jun	0%	100%
12 Jun	0%	100%
13 Jun	0%	100%
14 Jun	0%	100%
15 Jun	0%	100%
16 Jun	0%	100%
17 Jun	0%	100%
18 Jun	6%	94%
19 Jun	2%	98%
20 Jun	3%	97%
21 Jun	1%	99%
22 Jun	3%	97%
23 Jun	7%	93%
24 Jun	2%	98%
25 Jun	3%	97%
26 Jun	2%	98%
27 Jun	2%	98%
28 Jun	4%	96%
29 Jun	6%	94%
30 Jun	5%	95%
Total	3%	97%

Appendix G4.–Daily percentage of upstream- and downstream-moving filtered targets for the late run, Kenai River, 2009.

Date	% Downstream	% Upstream
1 Jul	2%	98%
2 Jul	2%	98%
3 Jul	1%	99%
4 Jul	2%	98%
5 Jul	2%	98%
6 Jul	3%	97%
7 Jul	3%	97%
8 Jul	3%	97%
9 Jul	2%	98%
10 Jul	1%	99%
11 Jul	0%	100%
12 Jul	1%	99%
13 Jul	1%	99%
14 Jul	1%	99%
15 Jul	1%	99%
16 Jul	1%	99%
17 Jul	2%	98%
18 Jul	1%	99%
19 Jul	1%	99%
20 Jul	3%	97%
21 Jul	2%	98%
22 Jul	2%	98%
23 Jul	3%	97%
24 Jul	1%	99%
25 Jul	3%	97%
26 Jul	3%	97%
27 Jul	8%	92%
28 Jul	7%	93%
29 Jul	9%	91%
30 Jul	8%	92%
31 Jul	7%	93%
1 Aug	9%	91%
2 Aug	7%	93%
3 Aug	7%	93%
4 Aug	1%	99%
Total	2%	98%

APPENDIX H: AVERAGE VERTICAL ANGLE OF FILTERED TARGETS BY TIDE STAGE, RUN, BANK, AND DIRECTION OF TRAVEL (UPSTREAM OR DOWNSTREAM) FOR THE EARLY AND LATE RUNS, KENAI RIVER, 2008–2009

Appendix H1.–Average vertical angle of filtered targets by tide stage and direction of travel (upstream or downstream) for the early run, Kenai River, 2008.

Bank	Tide stage	Fish orientation	Average vertical angle (°)	Standard deviation	Sample size
Left bank					
	Falling				
		Downstream	–0.05	0.42	12
		Upstream	–0.11	0.30	1,939
		Tide stage total	–0.11	0.30	1,951
	Low				
		Downstream	–0.01	0.14	2
		Upstream	–0.22	0.26	706
		Tide stage total	–0.22	0.26	708
	Rising				
		Downstream	0.37	0.52	13
		Upstream	–0.21	0.50	1,080
		Tide stage total	–0.21	0.50	1,093
	All Tides				
		Downstream	0.15	0.50	27
		Upstream	–0.04	0.40	3,725
		Total	–0.04	0.40	3,752
Right bank					
	Falling				
		Downstream	0.19	0.44	59
		Upstream	–0.08	0.31	1,040
		Tide stage total	–0.06	0.33	1,099
	Low				
		Downstream	–0.32	0.24	12
		Upstream	–0.23	0.23	381
		Tide stage total	–0.23	0.23	393
	Rising				
		Downstream	–0.01	0.28	27
		Upstream	0.11	0.37	748
		Tide stage total	0.11	0.36	775
	All Tides				
		Downstream	0.07	0.42	98
		Upstream	–0.04	0.34	2,169
		Total	–0.03	0.35	2,267

Appendix H2.–Average vertical angle of filtered targets by tide stage and direction of travel (upstream or downstream) for the late run, Kenai River, 2008.

Bank	Tide stage	Fish orientation	Average vertical angle (°)	Standard deviation	Sample size
Left bank					
	Falling				
		Downstream	–0.14	0.34	270
		Upstream	–0.14	0.33	4,036
		Tide stage total	–0.14	0.33	4,306
	Low				
		Downstream	–0.08	0.36	47
		Upstream	–0.17	0.32	844
		Tide stage total	–0.17	0.32	891
	Rising				
		Downstream	–0.01	0.49	188
		Upstream	–0.05	0.46	1,996
		Tide stage total	–0.04	0.46	2,184
	All Tides				
		Downstream	–0.09	0.41	505
		Upstream	–0.09	0.38	6,876
		Total	–0.09	0.38	7,381
Right bank					
	Falling				
		Downstream	0.10	0.29	128
		Upstream	–0.00	0.19	2,814
		Tide stage total	–0.00	0.20	2,942
	Low				
		Downstream	0.11	0.18	42
		Upstream	–0.00	0.17	341
		Tide stage total	–0.01	0.17	383
	Rising				
		Downstream	0.10	0.23	238
		Upstream	0.07	0.20	2,952
		Tide stage total	0.07	0.21	3,190
	All Tides				
		Downstream	0.11	0.25	408
		Upstream	0.03	0.20	6,107
		Total	0.04	0.20	6,515

Appendix H3.–Average vertical angle of filtered targets by tide stage and direction of travel (upstream or downstream) for the early run, Kenai River, 2009.

Bank	Tide stage	Fish orientation	Average vertical angle (°)	Standard deviation	Sample size
Left bank					
	Falling				
		Downstream	–0.25	0.80	14
		Upstream	–0.11	0.33	1,531
		Tide stage total	–0.11	0.34	1,545
	Low				
		Downstream	0.03	N/A	1
		Upstream	–0.16	0.38	580
		Tide stage total	–0.16	0.38	581
	Rising				
		Downstream	0.39	0.28	3
		Upstream	0.23	0.55	399
		Tide stage total	0.24	0.55	402
	All Tides				
		Downstream	–0.13	0.75	18
		Upstream	–0.07	0.41	2,510
		Total	–0.06	0.41	2,528
Right bank					
	Falling				
		Downstream	–0.43	0.42	55
		Upstream	–0.28	0.24	972
		Tide stage total	–0.29	0.26	1,027
	Low				
		Downstream	–0.48	0.38	22
		Upstream	–0.37	0.41	266
		Tide stage total	–0.38	0.41	288
	Rising				
		Downstream	–0.06	0.55	16
		Upstream	–0.01	0.47	318
		Tide stage total	–0.01	0.47	334
	All Tides				
		Downstream	–0.38	0.45	93
		Upstream	–0.24	0.38	1,556
		Total	–0.25	0.36	1,649

Appendix H4.–Average vertical angle of filtered targets by tide stage and direction of travel (upstream or downstream) for the late run, Kenai River, 2009.

Bank	Tide stage	Fish orientation	Average vertical angle (˚)	Standard deviation	Sample size
Left bank					
	Falling				
		Downstream	–0.18	0.58	52
		Upstream	–0.23	0.32	3,454
		Tide stage total	–0.23	0.33	3,506
	Low				
		Downstream	0.06	0.51	7
		Upstream	–0.25	0.35	733
		Tide stage total	–0.24	0.35	740
	Rising				
		Downstream	0.08	0.43	24
		Upstream	–0.09	0.50	1,745
		Tide stage total	–0.09	0.50	1,769
	All Tides				
		Downstream	–0.08	0.54	83
		Upstream	–0.19	0.39	5,932
		Total	–0.19	0.39	6,015
Right bank					
	Falling				
		Downstream	0.23	0.39	115
		Upstream	0.03	0.33	3,525
		Tide stage total	0.03	0.33	3,640
	Low				
		Downstream	-0.07	0.30	37
		Upstream	0.01	0.35	711
		Tide stage total	0.01	0.35	748
	Rising				
		Downstream	0.06	0.40	70
		Upstream	0.08	0.31	4,096
		Tide stage total	0.08	0.31	4,166
	All Tides				
		Downstream	0.12	0.40	222
		Upstream	0.19	0.32	8,332
		Total	0.05	0.32	8,554

APPENDIX I: HISTORIC TS-BASED PASSAGE BY YEAR AND DATE (1987–2009)

Appendix I1.–Kenai River early-run Chinook salmon TS-based sonar passage estimates, 1987–2009.

Date	1987[a]	1988	1989	**1990**	**1991**	**1992**	1993	1994	1995	1996	**1997**	**1998**[bc]
7 May												6
8 May												18
9 May												3
10 May												3
11 May												12
12 May												12
13 May												27
14 May												43
15 May												63
16 May		188	180	78	30	54	64	238	98	60	114	48
17 May		415	319	57	12	48	85	342	99	91	99	45
18 May		259	264	93	65	88	91	260	78	63	93	57
19 May		260	180	136	55	40	66	302	149	96	165	36
20 May		406	147	93	68	78	69	369	228	177	84	54
21 May		184	245	69	51	90	165	327	465	165	129	33
22 May		182	164	75	111	108	117	246	265	156	114	15
23 May		231	186	63	66	150	160	212	286	159	162	12
24 May		288	279	51	66	126	141	303	265	159	138	33
25 May		351	300	76	57	79	150	170	198	153	165	81
26 May		393	270	70	81	93	168	150	189	240	220	43
27 May		387	419	87	81	66	150	267	165	204	325	60
28 May		483	357	61	78	78	361	258	159	330	317	63
29 May		713	269	221	51	45	538	347	222	512	288	63
30 May		333	164	154	51	111	388	321	351	348	350	129
31 May		501	157	175	69	114	266	369	282	474	318	93
1 Jun		556	258	153	150	106	187	321	357	603	213	111
2 Jun		545	194	294	240	107	412	266	369	741	241	189
3 Jun		598	233	225	362	232	324	298	549	873	376	192
4 Jun	1,059	755	246	178	177	190	255	304	693	1,051	324	186
5 Jun	552	782	280	192	316	166	276	351	429	943	427	**162**
6 Jun	1,495	493	384	156	**296**	319	327	198	807	741	327	**150**
7 Jun	1,145	506	545	**304**	**215**	515	198	384	843	773	591	**283**
8 Jun	602	771	890	**414**	**243**	375	297	306	999	918	441	**300**
9 Jun	1,024	569	912	**339**	**444**	**486**	378	462	789	1,140	391	**234**
10 Jun	985	333	913	**272**	**275**	**264**	453	432	876	684	527	**327**
11 Jun	1,004	320	710	**453**	**334**	**234**	549	423	774	882	512	**600**
12 Jun	1,044	302	577	**568**	**400**	**394**	600	329	417	864	537	**1,168**
13 Jun	2,168	188	599	**445**	**369**	**236**	951	376	492	1,071	681	**719**
14 Jun	1,297	289	458	**330**	**268**	**174**	811	514	691	1,111	424	**912**
15 Jun	975	510	335	**658**	**441**	**312**	407	306	636	1,116	318	**951**
16 Jun	786	808	397	**485**	**615**	**239**	616	453	648	420	348	**770**
17 Jun	612	535	514	**267**	**330**	**339**	567	315	750	495	**405**	**675**
18 Jun	783	533	464	**238**	**493**	**320**	606	435	808	697	**315**	**498**
19 Jun	771	200	295	**331**	**437**	**390**	422	636	419	657	**399**	**510**
20 Jun	682	175	498	**369**	**314**	**548**	504	402	594	315	**408**	**351**
21 Jun	517	373	520	**257**	**457**	**372**	621	570	438	351	**252**	**309**
22 Jun	487	312	614	**267**	**433**	**297**	399	366	375	396	**390**	**273**
23 Jun	529	375	547	**240**	**396**	**213**	607	550	178	401	**225**	**294**
24 Jun	303	674	564	**322**	**251**	**337**	720	696	450	573	**285**	**288**
25 Jun	564	582	374	**258**	**235**	**362**	808	734	429	684	**332**	**228**
26 Jun	731	436	369	**322**	**261**	**330**	1,051	597	334	504	**381**	**219**
27 Jun	452	549	309	**231**	**340**	**291**	1,158	639	946	228	**363**	**207**
28 Jun	587	827	425	**240**	**327**	**253**	798	681	696	303	**297**	**308**
29 Jun	371	495	376	**208**	**258**	**121**	728	929	984	234	**570**	**363**
30 Jun	388	915	292	**193**	**270**	**197**	660	649	615	351	**582**	**276**
Total	21,913[a]	20,880	17,992	**10,768**	**10,939**	**10,087**	19,669	18,403	21,884	23,505	**14,963**	**13,103**

-continued-

Appendix I1.–Part 2 of 3.

Date	1999[c]	**2000[c]**	2001[c]	**2002[c]**	2003[c]	2004[c]	2005[c]	2006[c]	2007[c]	2008[c]	2009[c]
7 May											
8 May											
9 May											
10 May											
11 May											
12 May											
13 May											
14 May											
15 May											
16 May	33	18	62	24	35	24	54	40	62[d]	33	69
17 May	63	49	111	21	35	30	51	30	75[d]	52	15
18 May	66	54	117	54	63	31	27	39	84[d]	60	39
19 May	39	84	133	60	81	57	21	66	92[d]	42	39
20 May	116	64	156	66	123	48	66	57	18	39	72
21 May	186	84	101	42	162	84	108	48	66	69	57
22 May	192	123	128	36	174	61	78	72	60	114	21
23 May	243	132	81	36	237	153	96	51	51	147	45
24 May	159	147	147	33	168	129	76	69	91	154	36
25 May	141	234	175	48	129	138	93	96	88	135	45
26 May	330	186	278	65	195	240	75	81	72	207	72
27 May	342	177	314	75	192	324	97	152	81	270	140
28 May	402	84	291	103	180	452	140	135	117	353	272
29 May	378	204	323	57	248	233	203	242	144	287	353
30 May	273	105	440	90	183	156	195	401	164	267	245
31 May	459	117	276	85	225	128	244	469	252	361	239
1 Jun	633	192	259	210	294	148	342	820	225	213	153
2 Jun	444	250	316	216	195	91	335	702	186	210	205
3 Jun	540	282	328	119	389	72	255	334	277	288	159
4 Jun	924	266	255	144	435	143	551	326	303	343	266
5 Jun	876	139	519	120	381	301	671	231	519	423	344
6 Jun	807	186	432	165	464	239	908	297	605	563	466
7 Jun	672	237	427	140	422	474	784	343	996	373	371
8 Jun	609	108	486	202	615	665	1,063	357	1,146	363	305
9 Jun	504	135	591	466	605	730	969	495	731	374	533
10 Jun	439	207	639	246	395	784	861	684	647	601	445
11 Jun	596	315	575	211	446	754	1,135	832	488	975	603
12 Jun	723	165	1,357	118	284	525	939	727	724	1,047	452
13 Jun	393	**337**	939	**142**	153	438	587	835	716	824	514
14 Jun	610	**309**	647	**118**	292	282	712	688	666	956	357
15 Jun	436	**571**	600	**138**	291	446	548	1,196	698	610	116
16 Jun	696	**441**	499	**110**	204	440	594	1,099	494	302	290
17 Jun	807	**765**	364	**251**	205	422	443	1,730	470	288	298
18 Jun	742	**591**	607	**243**	137	383	636	1,167	270	212	136
19 Jun	771	**348**	559	**201**	313	581	597	901	486	284	156
20 Jun	1,247	**319**	418	**187**	365	461	661	1,046	282	267	193
21 Jun	1,192	**522**	417	**228**	474	461	394	612	283	196	238
22 Jun	819	**456**	345	**213**	428	532	440	797	320	273	355
23 Jun	935	**462**	272	**153**	386	552	344	657	485	144	285
24 Jun	1,151	**408**	240	**193**	522	666	344	763	276	245	453
25 Jun	1,292	**186**	213	**330**	450	520	557	562	195	288	443
26 Jun	731	**359**	203	**381**	414	240	479	369	250	303	488
27 Jun	678	615	220	**310**	237	255	380	553	320	328	276
28 Jun	537	489	224	**186**	231	426	459	578	641	343	277
29 Jun	753	516	191	**231**	362	530	687	873	434	632	201
30 Jun	687	441	403	**295**	506	649	1,151	704	567	497	197
Total	25,666	**12,479**	16,676	**7,162**	13,325	15,498	20,450	23,326	16,217	15,355	11,334

-continued-

Note: Bold and outline numbers represent the dates that the Chinook fishery was restricted due to low inriver runs.

[a] Sonar operations did not begin until 4 June, so the early run total passage estimate for 1987 is incomplete.

[b] Sonar operations began early (7 May) to determine the proportion of early run fish that may pass the site prior to the normal start date (16 May).

[c] Only upstream-moving fish reported.

[d] Extreme tides and debris prevented sampling 16–19 May. Values for 16–19 May were inferred from previous years.

Appendix I2.–Kenai River late-run Chinook salmon TS-based sonar passage estimates, 1987–2009.

Date	1987	1988	1989	**1990**	1991	**1992**	1993[a]	1994[a]	1995	1996	1997	**1998**[f]
1 Jul	507	526	769	578	267	364	619	663	350	341	486	491
2 Jul	429	404	489	305	300	297	525	342	398	240	642	597
3 Jul	405	398	353	486	333	320	404	625	353	303	600	480
4 Jul	628	292	566	436	519	198	468	858	439	393	633	450
5 Jul	596	482	1,106	853	316	225	429	705	667	1,067	657	606
6 Jul	523	654	879	795	242	331	996	975	720	879	627	612
7 Jul	769	379	680	929	186	247	1,746	1,050	931	780	1,158	660
8 Jul	483	725	776	432	139	170	2,142	655	417	867	1,221	462
9 Jul	384	471	1,404	309	393	205	2,078	744	519	768	1,618	480
10 Jul	314	1,732	560	359	481	221	955	1,289	450	1,023	3,486	450
11 Jul	340	1,507	2,010	778	403	143	1,402	509	325	1,146	5,649	171
12 Jul	751	1,087	2,763	557	330	1,027	671	828	276	714	4,497	192
13 Jul	747	2,251	910	1,175	308	605	3,572	1,072	570	1,128	5,373	262
14 Jul	761	2,370	2,284	1,481	572	689	3,425	1,332	714	4,437	2,031	368
15 Jul	913	2,405	1,111	1,149	542	745	2,353	2,221	750	3,222	4,042	1,118
16 Jul	1,466	1,259	1,344	1,011	1,029	703	2,421	3,802	1,962	3,494	3,420	1,416
17 Jul	1,353	1,520	963	2,395	2,052	570	2,098	4,692	1,128	2,253	4,584	1,424
18 Jul	841	2,180	1,382	2,113	3,114	853	1,472	2,157	3,942	2,820	2,334	1,638
19 Jul	2,071	1,724	425	1,363	1,999	1,128	714	3,504	4,692	2,236	1,146	1,146
20 Jul	3,709	2,670	820	1,499	1,422	1,144	1,383	2,328	4,779	2,609	1,578	741
21 Jul	3,737	3,170	916	787	1,030	799	959	1,695	3,132	3,435	894	1,608
22 Jul	1,835	1,302	583	573	1,050	619	1,140	1,386	3,465	2,250	1,840	1,411
23 Jul	1,700	1,502	756	642	2,632	1,449	1,146	1,050	2,421	3,050	1,441	808
24 Jul	2,998	1,386	783	1,106	2,204	**711**	1,376	1,320	831	3,634	1,080	933
25 Jul	1,915	999	495	810	1,306	**1,713**	2,253	1,444	840	3,240	532	542
26 Jul	1,968	924	432	671	1,216	**1,296**	1,421	1,432	1,683	2,319	519	723
27 Jul	1,523	960	618	755	1,195	**1,561**	1,945	1,289	1,806	1,782	438	807
28 Jul	2,101	1,398	538	**603**	1,901	**1,957**	1,906	2,226	789	861	333	**954**
29 Jul	1,923	1,400	441	**546**	1,146	**1,533**	1,400	1,333	558	474	401	**1,255**
30 Jul	2,595	1,158	391	**382**	791	**1,198**	1,680	1,769	510	621	450	**1,556**
31 Jul	2,372	910	383	**316**	974	**951**	873	1,808	480	1,548	420	**1,344**
1 Aug	470	925	351	**393**	897	**921**	776	1,037	474		247	**909**
2 Aug	314	781	201	**388**	867	**1,018**	626	1,223	369		291	**1,512**
3 Aug	263	989	132	**533**	392	**837**	350	1,078	447		213	**1,006**
4 Aug	835	1,524	142	**717**	331	**862**	467	658	519			**1,131**
5 Aug	904	1,091	107	**723**	174	**861**	711	536	404			**1,094**
6 Aug	648	1,333	107	**552**	343	**654**	1,076	1,042	408			**864**
7 Aug	694	1,186	65	**516**	618	**558**	655	797	279			**843**
8 Aug	658	1,449		**682**	600	**217**	682		267			**750**
9 Aug	368	1,132		**679**		**165**	424		272			**570**
10	312	755		**678**		**249**	252					**496**
11		698		**547**								
12				**362**								
13				**221**								
14				**139**								
15				**150**								
Total	48,123	52,008	29,035[b]	**33,474**	34,614	**30,314**	51,991	53,474[c]	44,336[d]	53,934[e]	54,881[i]	**34,878**

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Appendix I2.–Part 2 of 3.

Date	1999[f]	2000[f]	2001[f]	2002[f]	2003[f]	2004[f]	2005[f]	2006[f]	2007[f]	2008[f]	2009[f]
1 Jul	453	461	697	563	727	1,167	1,283	580	609	527	631
2 Jul	612	373	766	1,596	735	1,125	1,109	343	401	520	755
3 Jul	486	370	1,075	2,456	982	1,053	1,204	269	450	461	956
4 Jul	396	488	714	1,855	1,212	715	778	844	501	257	751
5 Jul	369	787	676	1,949	1,684	842	1,454	953	506	221	656
6 Jul	683	778	645	1,205	1,462	1,231	1,020	718	510	188	419
7 Jul	936	1,020	887	1,241	1,322	1,932	863	828	578	242	751
8 Jul	1,030	1,713	751	1,069	1,666	1,287	882	1,269	1,051	260	666
9 Jul	1,047	1,632	568	1,618	1,183	815	1,687	814	601	718	610
10 Jul	717	1,461	908	1,533	1,880	757	1,616	446	500	899	674
11 Jul	1,059	1,038	858	1,369	1,693	1,061	1,475	310	927	482	1,091
12 Jul	560	1,506	575	1,245	1,289	1,208	2,557	431	710	892	1,114
13 Jul	401	2,327	1,148	1,288	1,227	2,567	1,643	376	527	632	822
14 Jul	969	2,709	1,448	1,034	697	2,577	1,203	644	1,037	414	1,400
15 Jul	636	2,808	1,338	450	1,212	1,943	1,427	1,925	1,282	1,636	1,099
16 Jul	927	2,264	1,201	1,253	1,107	2,718	1,811	2,266	667	1,297	1,136
17 Jul	3,558	1,915	2,415	1,481	1,482	2,262	1,710	1,116	776	1,349	1,249
18 Jul	2,784	2,154	2,065	1,001	1,731	2,008	1,142	1,207	1,729	829	924
19 Jul	1,869	1,919	1,568	915	1,773	1,753	1,786	1,307	1,754	791	1,149
20 Jul	3,471	1,155	994	964	1,384	1,566	1,091	1,575	2,153	809	1,009
21 Jul	3,354	933	786	970	1,153	1,757	847	1,259	1,677	1,257	914
22 Jul	1,998	702	497	845	2,159	1,401	752	1,017	2,751	1,292	1,052
23 Jul	1,875	760	526	1,637	1,693	1,812	712	933	1,901	1,160	826
24 Jul	1,748	1,868	529	1,175	1,774	2,044	662	639	3,008	1,081	527
25 Jul	1,937	1,761	676	974	1,525	1,107	782	958	3,490	876	579
26 Jul	1,098	1,034	667	930	1,149	941	1,050	874	2,659	1,035	959
27 Jul	3,066	992	775	591	1,449	2,277	985	1,073	3,357	1,577	390
28 Jul	1,358	999	1,070	707	909	1,540	814	1,291	1,779	1,395	441
29 Jul	1,185	1,029	928	406	808	1,724	989	1,602	859	1,277	452
30 Jul	969	577	508	571	691	1,523	1,059	1,225	922	1,408	432
31 Jul	1,308	549	883	540	751	1,480	819	762	1,340	1,586	344
1 Aug	591	695	455	642	377	1,078	689	669	866	1,385	216
2 Aug	468	421	459	553	394	688	682	605	330	1,177	194
3 Aug	642	294	504	752	379	722	660	576	397	1,009	156
4 Aug	444	453	840	995		754	587	769	374	683[l]	344
5 Aug	436	489	581	575		940	464	1,632		643[l]	
6 Aug	654	504	417	754[c]		1,009[g]	776[g]	912		621[l]	
7 Aug	678	366	618	676[c]		905[g]	696[g]	880		554[l]	
8 Aug	804	417	467	636[c]		854[g]	657[g]	1,095		537[l]	
9 Aug	328	399	232	456[c]		611[g]	470[g]	444[h]		382[l]	
10 Aug	165	397	200	337[c]		451[g]	347[g]	307[h]		282[l]	
11 Aug											
12 Aug											
13 Aug											
14 Aug											
15 Aug											
Total	48,069	44,517	33,916	41,807	41,659[j]	56,205	43,240	37,743	42,979[k]	34,641	25,688[k]

Note: Bold and outlined numbers represent dates when the Chinook salmon fishery was restricted because of low inriver runs.

[a] Late run daily and total passage estimates for the years 1993 and 1994 were incorrectly reported in historical tables presented in previous reports (i.e., Bosch and Burwen 2000, Miller and Burwen 2002, Miller et al. 2002, and Miller et al. 2003). Estimates presented in this current table are correct and were originally reported by Burwen and Bosch (1995a; 1995b).

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[b] Sampling was terminated on 7 August following several consecutive days of passage less than 1% of the cumulative passage.

[c] Sampling was terminated on 7 August due to pink salmon spawning in the insonified area.

[d] Sampling was terminated on 9 August following several consecutive days of passage less than 1% of the cumulative passage.

[e] Sampling was terminated on 31 July due to pink salmon spawning in the insonified area.

[f] Only upstream-moving fish reported.

[g] Sampling was terminated on 5 August due to budget constraints. Values for 6–10 August were inferred from previous years.

[h] Sampling was terminated on 8 August due to fish holding in the sonar beam. Values for 9–10 August were inferred from previous years.

[i] Sampling was terminated on 3 August following several consecutive days of passage less than 1% of the cumulative passage.

[j] Sampling was terminated on 3 August following three consecutive days of passage less than 1% of the cumulative passage.

[k] Sampling was terminated on 4 August following three consecutive days of passage less than 1% of the cumulative passage.

[l] Sampling was terminated on 3 August due to fish holding in the sonar beam. Values for 4–10 August were inferred from previous years.

APPENDIX J: ESTIMATED UPSTREAM FISH PASSAGE IN MIDRIVER (ALL SPECIES), TS-BASED (CHINOOK SALMON ONLY), NET-APPORTIONED (ALTERNATIVE ESTIMATE, CHINOOK SALMON ONLY), AND BEHAVIOR-CENSORED ELSD (ALTERNATIVE ESTIMATE, CHINOOKSALMON ONLY), KENAI RIVER SONAR, EARLY AND LATE RUNS, 2008–2009

Appendix J1.–Estimated upstream fish passage in midriver (all species), TS-based (Chinook salmon only), net-apportioned (alternative estimate, Chinook salmon only), and behavior-censored ELSD-based (alternative estimate, Chinook salmon only), Kenai River, early run, 2008.

	Unfiltered		TS-based		Behavior-censored ELSD Mixture Model		Net Apportioned	
Date	Passage	SE	Passage	SE	Passage	SE	Passage	SE
16 May	69	28	33	14	32	13	69	28
17 May	76	25	52	23	36	12	0	0
18 May	81	25	60	18	38	12	0	0
19 May	57	11	42	7	27	6	0	0
20 May	78	15	39	8	37	8	52	26
21 May	84	11	69	9	39	6	29	20
22 May	189	45	114	18	89	23	41	46
23 May	218	26	147	19	73	20	47	28
24 May	268	36	154	25	74	20	15	17
25 May	246	21	135	17	44	13	21	20
26 May	290	23	207	22	77	24	102	43
27 May	353	52	270	41	94	23	116	75
28 May	506	48	353	40	108	25	36	25
29 May	422	41	287	34	95	22	24	16
30 May	396	51	267	34	113	29	39	15
31 May	514	58	361	46	82	24	73	38
1 Jun	309	34	213	25	52	19	22	16
2 Jun	297	32	210	30	48	16	20	18
3 Jun	465	63	288	44	59	18	46	26
4 Jun	469	46	343	44	68	20	70	19
5 Jun	573	34	423	35	90	22	72	29
6 Jun	674	89	563	78	157	35	57	25
7 Jun	948	198	373	46	121	35	298	135
8 Jun	692	116	363	43	173	46	135	23
9 Jun	635	113	374	62	164	41	251	59
10 Jun	840	88	601	83	234	39	286	93
11 Jun	1,860	156	975	103	421	81	277	87
12 Jun	1,947	171	1,047	82	335	64	227	139
13 Jun	1,607	109	824	80	345	52	186	82
14 Jun	2,326	186	956	85	397	88	157	40
15 Jun	1,230	131	610	53	282	65	152	42
16 Jun	524	55	302	30	137	34	82	42
17 Jun	650	80	288	45	153	36	146	41
18 Jun	491	69	212	33	110	30	115	64
19 Jun	593	52	284	29	207	37	139	50
20 Jun	568	55	267	29	176	33	103	13
21 Jun	448	40	196	27	138	29	112	37
22 Jun	462	34	273	25	135	27	125	16
23 Jun	302	25	144	17	85	24	61	9
24 Jun	440	37	245	23	161	34	375	76
25 Jun	572	34	288	25	165	35	92	87
26 Jun	519	48	303	36	177	36	172	52
27 Jun	595	74	328	39	193	44	123	45
28 Jun	1,010	154	343	32	257	61	79	44
29 Jun	1,215	70	632	40	236	53	111	53
30 Jun	1,008	72	497	35	226	54	67	33
Total	28,116	54	15,355	296	6,560	252	4,822	350

Appendix J2.–Estimated upstream fish passage in midriver (all species), TS-based (Chinook salmon only), net-apportioned (alternative estimate, Chinook salmon only), and behavior-censored ELSD-based (alternative estimate, Chinook salmon only), Kenai River, late run, 2008.

	Unfiltered		TS-based		Behavior-censored ELSD Mixture Model		Net Apportioned	
Date	Passage	SE	Passage	SE	Passage	SE	Passage	SE
1 Jul	1,066	77	527	46	237	49	87	58
2 Jul	1,334	106	520	41	399	69	143	22
3 Jul	920	103	461	52	335	80	90	39
4 Jul	605	62	257	35	176	38	88	22
5 Jul	444	37	221	25	95	24	99	24
6 Jul	425	38	188	16	169	48	147	33
7 Jul	511	56	242	30	232	45	131	46
8 Jul	487	31	260	24	213	37	210	21
9 Jul	1,314	107	718	64	450	81	306	124
10 Jul	1,721	168	899	103	615	143	406	83
11 Jul	1,072	120	482	45	495	78	628	118
12 Jul	2,229	111	892	60	693	134	615	116
13 Jul	1,711	106	632	48	762	108	825	62
14 Jul	877	83	414	45	456	65	228	85
15 Jul	3,848	357	1,636	127	1,078	223	670	142
16 Jul	5,994	629	1,297	151	1,033	278	611	369
17 Jul	4,389	317	1,349	76	677	169	808	269
18 Jul	1,899	144	829	68	648	115	480	116
19 Jul	1,958	116	791	51	485	81	433	149
20 Jul	2,574	244	809	62	821	150	932	151
21 Jul	3,069	219	1,257	64	944	162	1,274	123
22 Jul	3,656	256	1,292	81	990	152	1,477	220
23 Jul	3,060	250	1,160	74	827	137	1,949	193
24 Jul	3,906	324	1,081	72	577	126	1,656	370
25 Jul	3,340	341	876	46	752	134	1,460	247
26 Jul	4,529	432	1,035	78	1,210	210	2,228	585
27 Jul	6,710	387	1,577	105	1,331	259	2,322	186
28 Jul	4,796	354	1,395	80	847	157	1,635	279
29 Jul	4,917	203	1,277	70	854	156	1,436	317
30 Jul	7,244	666	1,408	103	1,055	198	1,883	464
31 Jul	10,504	1,776	1,586	115	1,418	338	4,454	1,040
1 Aug	5,410	793	1,385	102	1,252	251	3,327	679
2 Aug	5,394	809	1,177	90	1,269	278	1,812	283
3 Aug	4,176	345	1,009	84	1,162	168	1,161	289
Total	106,089	2,596	30,939	438	24,557	933	36,012	1,770

Appendix J3.–Estimated upstream fish passage in midriver (all species), TS-based (Chinook salmon only), net-apportioned (alternative estimate, Chinook salmon only), and behavior-censored ELSD-based (alternative estimate, Chinook salmon only), Kenai River, early run, 2009.

	Unfiltered		TS-based		Behavior-censored ELSD Mixture Model		Net Apportioned	
Date	Passage	SE	Passage	SE	Passage	SE	Passage	SE
16 May	78	14	69	12	44	11	0	0
17 May	18	8	15	7	10	5	0	0
18 May	42	12	39	12	24	8	42	12
19 May	51	12	39	9	29	8	0	0
20 May	76	18	72	17	43	13	76	18
21 May	60	12	57	10	34	9	60	12
22 May	21	6	21	6	12	4	0	0
23 May	48	8	45	8	27	7	0	0
24 May	45	8	36	7	25	6	26	5
25 May	51	8	45	7	29	7	24	4
26 May	78	12	72	10	44	10	0	0
27 May	143	17	140	19	49	13	34	4
28 May	353	41	272	30	128	27	58	7
29 May	425	50	353	46	164	53	41	5
30 May	308	43	245	43	108	24	92	13
31 May	305	33	239	32	67	28	48	5
1 Jun	210	22	153	22	69	20	39	4
2 Jun	259	39	205	33	71	22	30	5
3 Jun	216	22	159	21	63	17	40	4
4 Jun	353	60	266	48	32	22	84	14
5 Jun	452	63	344	56	120	36	33	5
6 Jun	697	93	466	58	195	52	18	2
7 Jun	539	89	371	62	99	29	23	4
8 Jun	416	66	305	56	105	33	44	7
9 Jun	740	68	533	54	134	29	61	6
10 Jun	715	71	445	48	189	55	25	2
11 Jun	816	107	603	92	246	55	33	4
12 Jun	656	70	452	58	176	39	128	14
13 Jun	914	132	514	45	136	37	103	15
14 Jun	696	117	357	62	166	53	42	7
15 Jun	239	39	116	19	47	16	69	11
16 Jun	398	54	290	40	84	25	175	24
17 Jun	423	61	298	38	101	25	82	12
18 Jun	208	29	136	19	49	18	45	6
19 Jun	243	49	156	37	14	10	89	18
20 Jun	353	58	193	36	97	25	108	18
21 Jun	340	45	238	28	84	30	0	0
22 Jun	526	57	355	38	139	33	39	4
23 Jun	452	63	285	39	88	40	59	8
24 Jun	841	94	453	48	219	41	98	11
25 Jun	766	80	443	51	148	36	126	13
26 Jun	955	69	488	34	155	32	60	4
27 Jun	531	67	276	31	133	50	145	18
28 Jun	431	39	277	34	172	28	188	17
29 Jun	269	26	201	23	146	22	194	19
30 Jun	323	55	197	46	114	25	153	26
Total	17,079	388	11,334	263	4,428	201	2,834	73

Appendix J4.–Estimated upstream fish passage in midriver (all species), TS-based (Chinook salmon only), net-apportioned (alternative estimate, Chinook salmon only), and behavior-censored ELSD-based (alternative estimate, Chinook salmon only), Kenai River, late run, 2009.

	Unfiltered		TS-based		Behavior-censored ELSD Mixture Model		Net Apportioned	
Date	Passage	SE	Passage	SE	Passage	SE	Passage	SE
1 Jul	1,585	166	631	71	401	63	827	87
2 Jul	1,878	183	755	42	432	70	366	36
3 Jul	2,197	134	956	94	292	64	373	23
4 Jul	2,291	170	751	72	426	78	408	30
5 Jul	1,635	127	656	50	343	73	714	55
6 Jul	1,199	110	419	43	408	64	414	38
7 Jul	1,773	164	751	53	369	98	450	42
8 Jul	1,502	139	666	65	482	92	580	54
9 Jul	1,640	118	610	59	477	109	510	37
10 Jul	1,309	111	674	60	448	93	635	54
11 Jul	5,229	604	1,091	120	544	173	716	83
12 Jul	4,428	425	1,114	133	463	135	602	58
13 Jul	2,483	303	822	68	596	165	536	66
14 Jul	5,391	313	1,400	153	954	477	1,279	74
15 Jul	4,154	500	1,099	90	785	216	673	81
16 Jul	2,754	259	1,136	86	625	162	918	86
17 Jul	7,192	707	1,249	92	1,612	391	906	89
18 Jul	3,349	347	924	76	496	143	519	54
19 Jul	5,913	583	1,149	81	757	326	337	33
20 Jul	2,498	262	1,009	69	442	137	320	34
21 Jul	1,770	123	914	86	299	84	416	29
22 Jul	2,032	180	1,052	113	234	62	140	12
23 Jul	2,395	181	826	84	117	63	261	20
24 Jul	1,311	83	527	52	146	39	256	16
25 Jul	1,413	149	579	69	138	43	343	36
26 Jul	1,969	173	959	75	284	75	181	16
27 Jul	1,229	115	390	37	288	48	280	26
28 Jul	1,727	118	441	42	551	86	773	53
29 Jul	1,576	129	452	39	405	84	514	42
30 Jul	1,401	114	432	39	394	68	651	53
31 Jul	964	66	344	30	287	46	408	28
1 Aug	643	38	216	19	267	35	430	25
2 Aug	542	35	194	21	309	44	329	21
3 Aug	414	44	156	23	196	35	162	17
4 Aug	747	94	344	64	389	65	498	63
Total	80,533	1,582	25,688	440	15,656	893	17,725	297

APPENDIX K: COMPARISON OF BEHAVIOR-CENSORED ELSD MIXTURE MODEL ESTIMATES AND ADAPTIVE ELSD THRESHOLD ESTIMATES OF CHINOOK SALMON PASSAGE, KENAI RIVER, 2008–2009

Appendix K1.–Estimated daily fish passage based on behavior-censored ELSD mixture model (Chinook only) and the adaptive ELSD threshold (Chinook only), Kenai River, early run, 2008.

Date	Behavior-censored ELSD Mixture Model	Adaptive ELSD Threshold
16 May	32	57
17 May	36	57
18 May	38	66
19 May	27	39
20 May	37	27
21 May	39	42
22 May	89	72
23 May	73	85
24 May	74	102
25 May	44	51
26 May	77	106
27 May	94	102
28 May	108	120
29 May	95	99
30 May	113	93
31 May	82	96
1 Jun	52	51
2 Jun	48	54
3 Jun	59	54
4 Jun	68	69
5 Jun	90	83
6 Jun	157	123
7 Jun	121	117
8 Jun	173	138
9 Jun	164	147
10 Jun	234	210
11 Jun	421	414
12 Jun	335	321
13 Jun	345	296
14 Jun	397	377
15 Jun	282	233
16 Jun	137	84
17 Jun	153	163
18 Jun	110	120
19 Jun	207	177
20 Jun	176	158
21 Jun	138	149
22 Jun	135	129
23 Jun	85	87
24 Jun	161	161
25 Jun	165	186
26 Jun	177	173
27 Jun	193	194
28 Jun	257	280
29 Jun	236	371
30 Jun	226	305

Appendix K2.–Estimated daily fish passage based on behavior-censored ELSD mixture model (Chinook only) and the adaptive ELSD threshold (Chinook only), Kenai River, late run, 2008.

Date	Behavior-censored ELSD Mixture Model	Adaptive ELSD Threshold
1 Jul	237	329
2 Jul	399	411
3 Jul	335	282
4 Jul	176	151
5 Jul	95	107
6 Jul	169	153
7 Jul	232	197
8 Jul	213	205
9 Jul	450	513
10 Jul	615	722
11 Jul	495	455
12 Jul	693	695
13 Jul	762	663
14 Jul	456	423
15 Jul	1,078	1,234
16 Jul	1,033	1,554
17 Jul	677	913
18 Jul	648	617
19 Jul	485	572
20 Jul	821	788
21 Jul	944	915
22 Jul	990	941
23 Jul	827	781
24 Jul	577	633
25 Jul	752	711
26 Jul	1,210	1,038
27 Jul	1,331	1,329
28 Jul	847	804
29 Jul	854	845
30 Jul	1,055	1,033
31 Jul	1,418	1,268
1 Aug	1,252	1,188
2 Aug	1,269	1,228
3 Aug	1,162	1,115

Appendix K3.–Estimated daily fish passage based on behavior-censored ELSD mixture model (Chinook only) and the adaptive ELSD threshold (Chinook only), Kenai River, early run, 2009.

Date	Behavior-censored ELSD Mixture Model	Adaptive ELSD Threshold
16 May	44	69
17 May	10	15
18 May	24	36
19 May	29	30
20 May	43	46
21 May	34	24
22 May	12	6
23 May	27	27
24 May	25	30
25 May	29	24
26 May	44	36
27 May	49	47
28 May	128	152
29 May	164	156
30 May	108	114
31 May	67	138
1 Jun	69	66
2 Jun	71	72
3 Jun	63	60
4 Jun	32	111
5 Jun	120	149
6 Jun	195	251
7 Jun	99	144
8 Jun	105	126
9 Jun	134	207
10 Jun	189	168
11 Jun	246	216
12 Jun	176	151
13 Jun	136	126
14 Jun	166	132
15 Jun	47	48
16 Jun	84	72
17 Jun	101	82
18 Jun	49	35
19 Jun	14	15
20 Jun	97	78
21 Jun	84	60
22 Jun	139	111
23 Jun	88	80
24 Jun	219	156
25 Jun	148	129
26 Jun	155	138
27 Jun	133	106
28 Jun	172	156
29 Jun	146	132
30 Jun	114	93

Appendix K4.–Estimated daily fish passage based on behavior-censored ELSD mixture model (Chinook only) and the adaptive ELSD threshold (Chinook only), Kenai River, late run, 2009.

Date	Behavior-censored ELSD Mixture Model	Adaptive ELSD Threshold
1 Jul	401	309
2 Jul	432	362
3 Jul	292	313
4 Jul	426	324
5 Jul	343	261
6 Jul	408	270
7 Jul	369	395
8 Jul	482	377
9 Jul	477	377
10 Jul	448	438
11 Jul	544	863
12 Jul	463	891
13 Jul	596	741
14 Jul	954	1,753
15 Jul	785	1,280
16 Jul	625	988
17 Jul	1,611	1,832
18 Jul	496	730
19 Jul	757	911
20 Jul	442	642
21 Jul	299	414
22 Jul	234	380
23 Jul	117	386
24 Jul	146	230
25 Jul	138	202
26 Jul	284	380
27 Jul	288	267
28 Jul	551	511
29 Jul	405	527
30 Jul	394	404
31 Jul	287	295
1 Aug	267	265
2 Aug	309	264
3 Aug	196	171
4 Aug	389	348