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Estimates of Chinook Salmon Abundance in the Kenai River Using Split-Beam Sonar, 2005

by

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December 2007

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)

Measures (fisheries)

fork length	FL
mideye-to-fork	MEF
mideye-to-tail-fork	METF
standard length	SL
total length	TL

Mathematics, statistics

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

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TABLE OF CONTENTS

Page

TABLE OF CONTENTS (Continued)

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

ABSTRACT

Chinook salmon *Oncorhynchus tshawytscha* abundance in the Kenai River in 2005 was estimated using side-looking 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 2005, the sonar project operated 16 May through 5 August. The total estimated upstream Chinook salmon passage in 2005 was 60,744 (SE = 533) fish: 20,450 (SE = 295) fish during the early run and 40,294 (SE = 445) fish during the late run. Total late-run passage estimate extrapolated through 10 August was 43,240 (SE = 1,370) fish. The standard errors associated with these estimates reflect only sampling error and not other sources of uncertainty including target detection, species composition, direction of travel, and target tracking. The early-run peak daily passage occurred on 11 and 30 June with 50% of the run having passed by 12 June. The late-run peak daily passage occurred on 13 July, with 50% of the late run having passed by 16 July.

Key words: split-beam sonar, dual-beam sonar, 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 (Nelson et al. 1999). 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 (Howe et al. 1995-1996, 2001a-d; Jennings et al. 2004, 2006 a, b; Mills 1979-1980, 1981a-b, 1982-1994; Walker et al. 2003). 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 are harvested primarily by sport anglers; late-run Chinook 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, the BOF adopted new escapement goals based in part on Chinook salmon passage estimated by sonar and our best understanding of biases associated with the sonar (Bosch and Burwen 1999; Hammarstrom and Hasbrouck 1998, 1999). The revised escapement goals defined a range of escapement levels desired: 7,200 to 14,400 for early-run Chinook salmon and 17,800 to 35,700 for late-run Chinook salmon. In January 2005, based in part on additional brood year information, the BOF lowered the early-run escapement goal range to 5,000-9,000 Chinook salmon. By providing flexible management it is anticipated that these escapement goal ranges (as defined by 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) will provide a stable fishing season without compromising either run.

Sonar estimates of inriver 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 on the sport fishery were imposed each year from 1989 to 1992 to ensure spawning escapement goals were met. Since 1993, the 1997, 1998, 2000 and

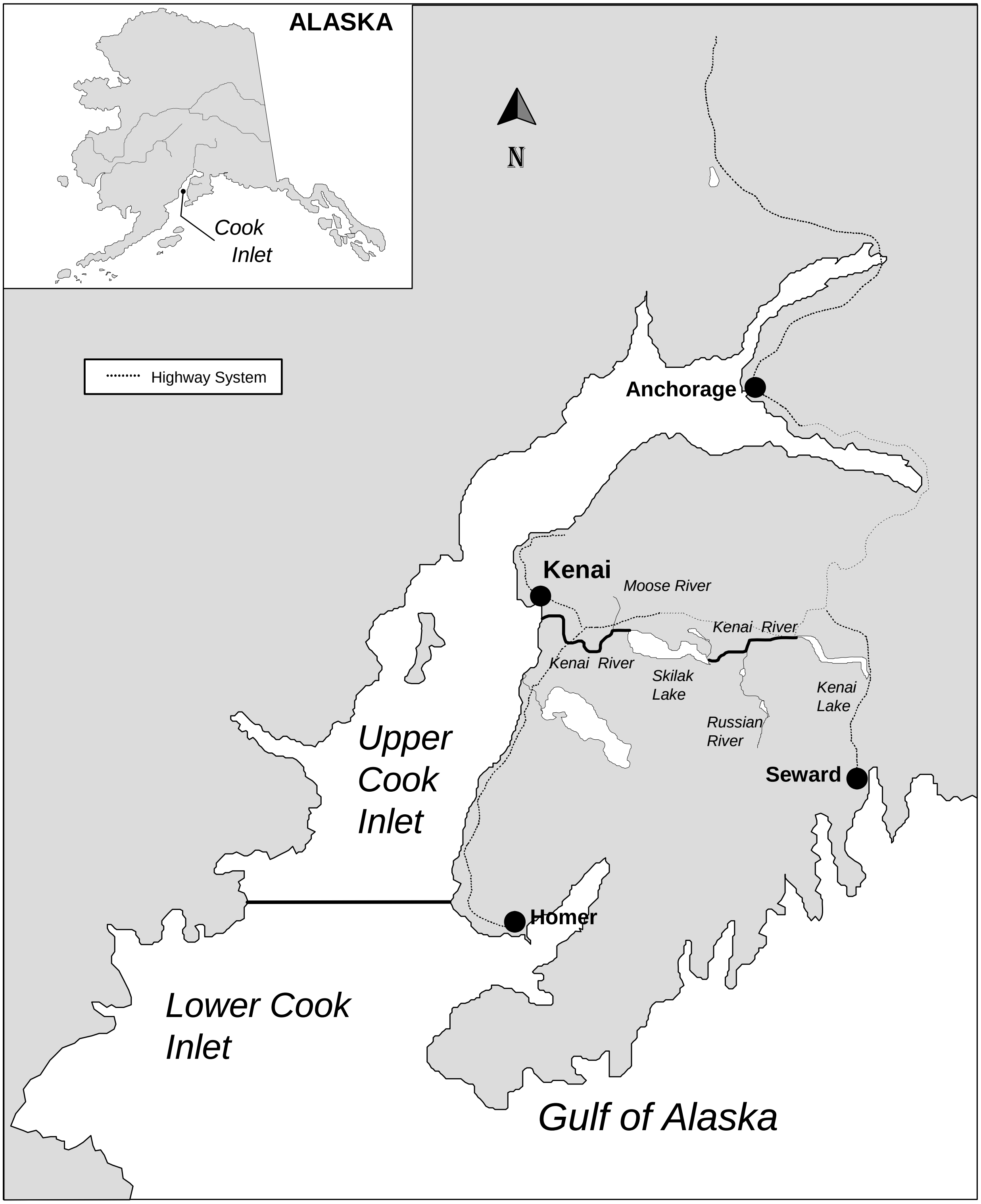


Figure 1.-Cook Inlet showing location of Kenai River.

2002 early runs, and the 1998 late run required a restriction of the sport fishery to meet escapement goals.

The first estimates of Chinook salmon abundance were generated for the 1984 late run with a mark-recapture project using drift gillnets (Hammarstrom et al. 1985). The mark-recapture project produced estimates of riverine abundance through 1990 (Alexandersdottir and Marsh 1990; Carlon and Alexandersdottir 1989; Conrad 1988; Conrad and Larson 1987; Hammarstrom and Larson 1986). These estimates had low precision and appeared to be biased high, particularly during the late run (Bernard and Hansen 1992).

To obtain timely and accurate estimates of Chinook salmon passage, the Alaska Department of Fish and Game initiated studies to determine whether an acoustic assessment program could be developed to provide daily estimates of Chinook salmon 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 2004, sockeye salmon escapement estimates generated by the river mile-19 sockeye sonar project ranged from 625,000 to 1,600,000 (Westerman and Willette 2006) while late-run Chinook salmon escapement estimates generated by the Chinook sonar project ranged from 29,000 to 55,000. Dual-beam sonar was initially chosen for the Chinook 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) and estimate their numbers returning to the river.

Early studies indicated that Chinook salmon could be distinguished from sockeye salmon based on target strength and spatial separation in the river. Sockeye salmon migrate primarily near the bank and were believed to have a smaller target strength than Chinook salmon, which primarily migrate near the mid-channel of the river. A target strength threshold was established to censor "counts" based on acoustic size. A range threshold was also used when sockeye salmon were abundant, that is, targets within a designated distance from the transducer were interpreted to be sockeye salmon and not counted. These two criteria have been the basis for discriminating between species and estimating the number of Chinook salmon returning to the Kenai River.

Daily and seasonal acoustic estimates of Chinook salmon have been generated since 1987. Estimates of total passage made with sonar were consistently lower than the 1987 through 1990 mark-recapture estimates (Eggers et al. 1995). The inconsistencies between sonar and mark-recapture estimates were highest during the late run, presumably because of 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 3-dimensional position of an acoustic target in the sonar beam. Consequently, the direction of travel for each target and the spatial distribution (three-dimensional) of fish in the acoustic beam could be determined for the first time. The split-beam system operated at a lower frequency that provided a higher (improved) signal-to-noise ratio (SNR) (Simmonds and MacLennan 2005). It also interfaced with improved fish-tracking software, which reduced the interference from boat wake, and improved fish-tracking capabilities (Burwen and Bosch 1996). The split-beam system was deployed side-by-side and run concurrently with the dual-beam for much of the 1994 season (Burwen et al. 1995). Both systems performed similarly, detecting comparable numbers of fish. The split-beam data confirmed earlier studies showing that fish were strongly oriented to the river bottom. However, experiments conducted with the split-beam system could not confirm the validity of discriminating Chinook salmon from sockeye salmon based on acoustic size. These results supported modeling exercises performed by Eggers (1994) that 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 spatial segregation of the species (sockeye salmon migrating near shore and Chinook salmon migrating mid-river; 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.

Two ancillary studies (Burwen et al. 1998) conducted in 1995 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 site; and (2) the utility of using target strength and/or other acoustic parameters as discriminatory variables 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, and in a concurrent tethered, live-fish experiment, most sockeye salmon tethered in front of the split-beam sonar had mean target strengths exceeding the target strength threshold.

Radiotelemetry projects were implemented in 1996 and 1997 to estimate the magnitude of bias introduced during periods of high sockeye passage (Hammarstrom and Hasbrouck 1998, 1999). These studies were designed to provide an independent and accurate estimate of inriver Chinook salmon abundance during the late run when the potential to misclassify sockeye salmon is greatest. Although the precision was similar, the use of radiotelemetry avoided certain biases introduced in previous mark-recapture estimates. Sonar estimates of late-run Chinook abundance were 26% greater in 1996 and 28% greater in 1997 than the telemetry estimates.

The inriver drift gillnetting project, originally designed to collect age, sex, and length (ASL) samples (Marsh 2000), was modified in 1998 to produce standardized estimates of Chinook catch per unit effort (CPUE) for use as an alternative index of Chinook salmon abundance (Reimer et al. 2002). A drift zone was established just downstream from the sonar site and crews fished relative to the tide cycles. 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 passage estimates were potentially high because of inclusion of sockeye or other species (Bosch and Burwen 2000; Miller et al. 2002; Miller et al. 2003, 2004; 2005 ; Miller and Burwen 2002).

Analysis of the 1998-2000 standardized CPUE data suggested the gillnetting data were better suited for determining species apportionment than for abundance estimation (Reimer et al. 2002). In 2001, Chinook salmon abundance was estimated for the first time using a combination of Chinook catch proportions from the gillnetting project and unfiltered passage estimates from the sonar project (Miller et al. 2003). Net-apportioned estimates of Chinook passage tracked well with conventional sonar passage estimates during the 2001 early run, but were substantially higher than the sonar estimates during the 2001 late run. The apparent under-representation of sockeye salmon in the gillnet catches during the 2001 late run led to changes in the gillnetting project beginning in 2002 that included using multiple mesh sizes (Reimer 2003, 2004). For now, we assume these gillnets are not size selective.

In addition to developing an alternative index of Chinook abundance, we continued to pursue improved techniques for discriminating Chinook and sockeye salmon. An investigation conducted in 1999 (Burwen et al. 2000) attempted to identify alternative sites above tidal influence with stronger bank-orientation of sockeye salmon, where range thresholds would be more effective. The investigation concentrated on a site located at river km 21.2 (river mile 13.2) that was above 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 greater boat traffic, less acoustically favorable bottom topography, and increased background noise resulting in difficult fish tracking conditions.

Alternative methods for separating Chinook and sockeye salmon using acoustic information are also being pursued. Studies with tethered and free-swimming fish indicate that variables based on echo envelope length may provide higher discriminatory power than target strength for separating sockeye and Chinook salmon (Burwen and Fleischman 1998; Burwen et al. 2003). Statistical methods have been developed which enable robust estimates of species composition even when species overlap in size (Fleischman and Burwen 2003). In addition, ongoing experiments using DIDSON imaging sonar (Burwen et al. 2007) may provide a means to evaluate species classification techniques through comparison of split-beam generated fish traces with high-resolution images of fish provided by the DIDSON sonar.

PROJECT OBJECTIVES

Objectives for 2005 were to generate daily and seasonal estimates of early-run (16 May-30 June) and late-run (1 July-5 August) Chinook salmon passage into the Kenai River using a split-beam sonar system.

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/or 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 (1971-2000) precipitation for the City of Kenai, located at the mouth of the Kenai River, is 48 cm. Average summer (June, July, and August) temperature for the City of Kenai is 12°C (WRCC 2003).

SITE DESCRIPTION

The 2005 sonar site was located 14 km (8.5 mi) 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 relative to the sport fishery and known Chinook salmon spawning habitat.

The river bottom in this area has remained stable for the past 20 years despite a 140-year flood event during September 1995 (Bosch and Burwen 1999). The slope from both banks has remained 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 SNR ratio when the beam is aimed along the river bottom. The left-bank bottom gradient is steeper and consists of more acoustically reflective small rounded cobble and gravel.

The sonar site is located downstream of the lowest suspected Chinook salmon spawning sites, yet far enough from the mouth that most of the fish counted are probably committed to the Kenai River (Alexandersdottir and Marsh 1990). Initially, almost all sport fishing occurred some distance upstream of this site. However, fishing activity near the site has increased over the past several years, mostly during the late run.

ACOUSTIC SAMPLING

A Hydroacoustic Technology Inc. (HTI) split-beam sonar system was operated from 16 May through 5 August 2005. Components of the system are listed in Table 1 and 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

Sampling on both banks was controlled by electronics housed in a tent located on the right bank of the river. Communication cables were connected to transducers and their aiming devices 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. From 16 May to 5 August, water level at low tide rose approximately 1.3 m. Rising water level throughout the season and heavy debris accumulation on the gear resulted in occasional relocation of transducer tripods. Total range insonified by both (right and left) sonar beams ranged from approximately 60.5 m on 25 May to 76.8 m on 22-24 July (Figure 4).

Vertical and horizontal aiming of each transducer was remotely controlled by a dual-axis electronic pan and tilt system. A digital readout displayed 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 included the river bottom. In the horizontal plane, the transducer was aimed perpendicular to the flow of the river 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.

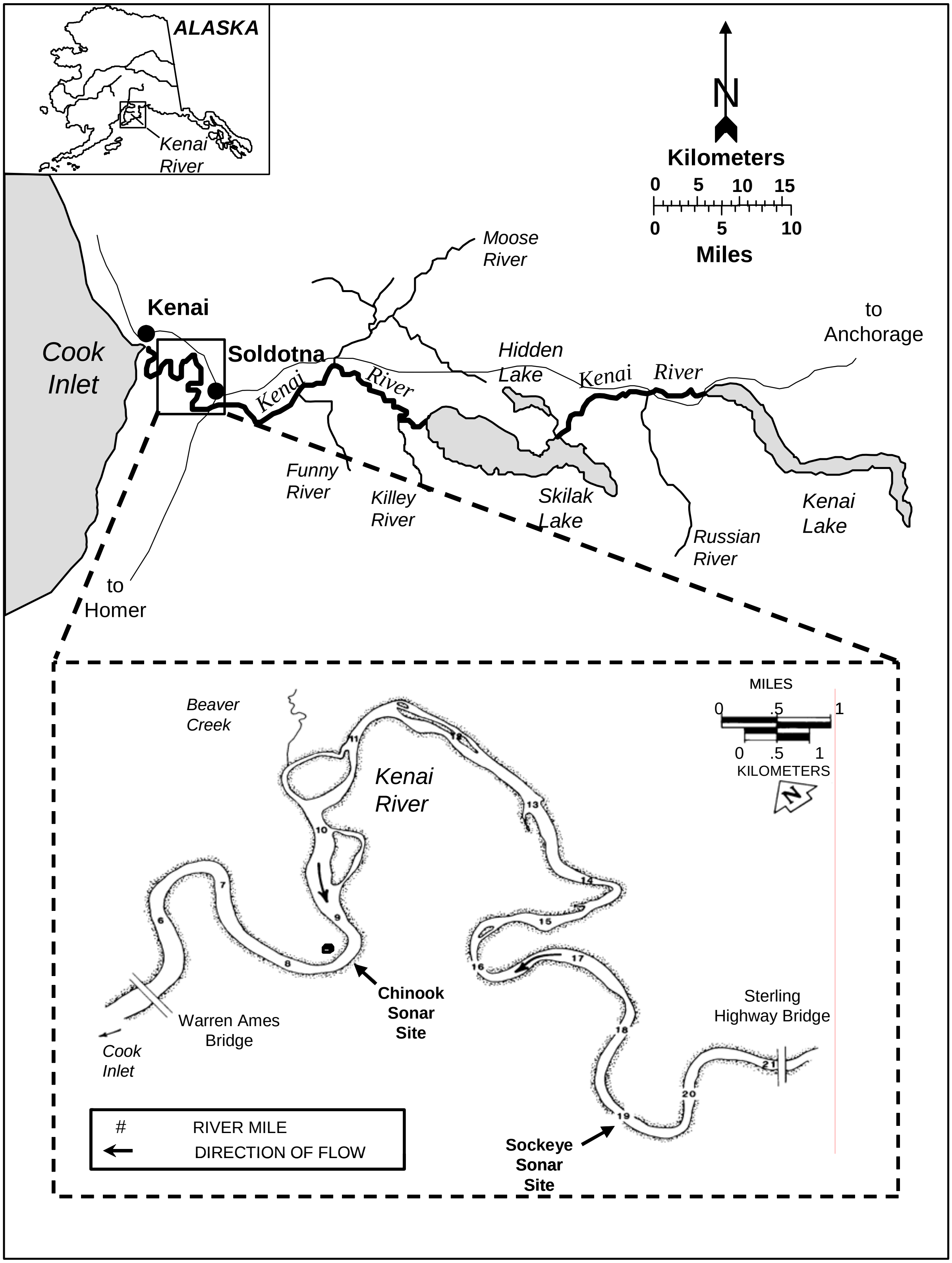


Figure 2.-Kenai River sonar site locations, 2005.

Table 1.-Main components of the split-beam sonar system used in 2005.

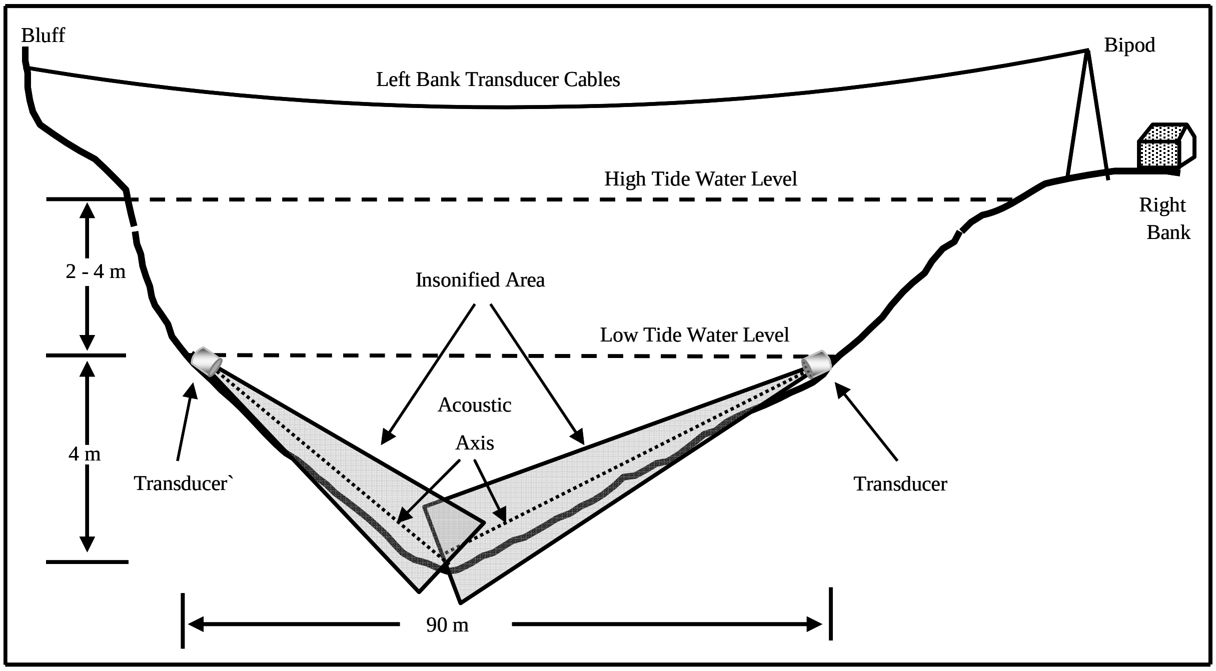
System Component	Description
Sounder	Hydroacoustics Technology Inc. (HTI) Model 244 Split-Beam Echo sounder operating at 200 kHz
Data Processing Computer	Dell Dimension 2350 personal computer
Transducers	(2) HTI Split-Beam transducers: Left Bank: nominal beam widths: 2.9^ox10.2^o Right Bank: nominal 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. Uwinstru Underwater Measurement Device.

Bottom Mapping and Beam Coverage

A detailed profile of the river bottom and the area encompassed by the sonar beams was produced prior to acoustic sampling. Depth readings from a Lowrance X-16 were paired with distance measurements from a fixed target on shore using a Bushnell Laser Ranger (±1 m accuracy). When bottom profile information is combined with information from the attitude sensor, a detailed visualization of how the water column above the bottom substrate was insonified by the acoustic beam could be generated (Figure 5).

Each time the 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. 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).



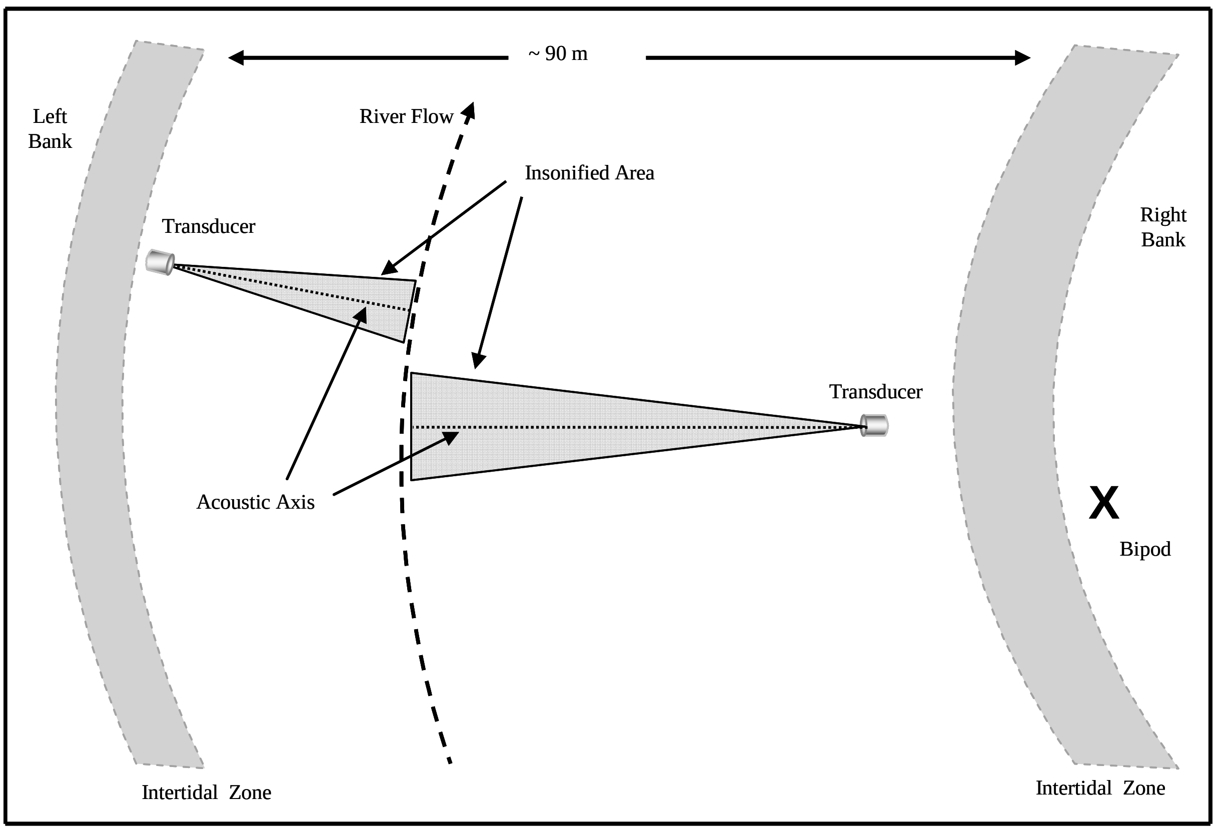


Figure 3.-Cross-sectional (top) and aerial (bottom) diagrams of sonar site illustrating insonified portions of the Kenai River, 2005.

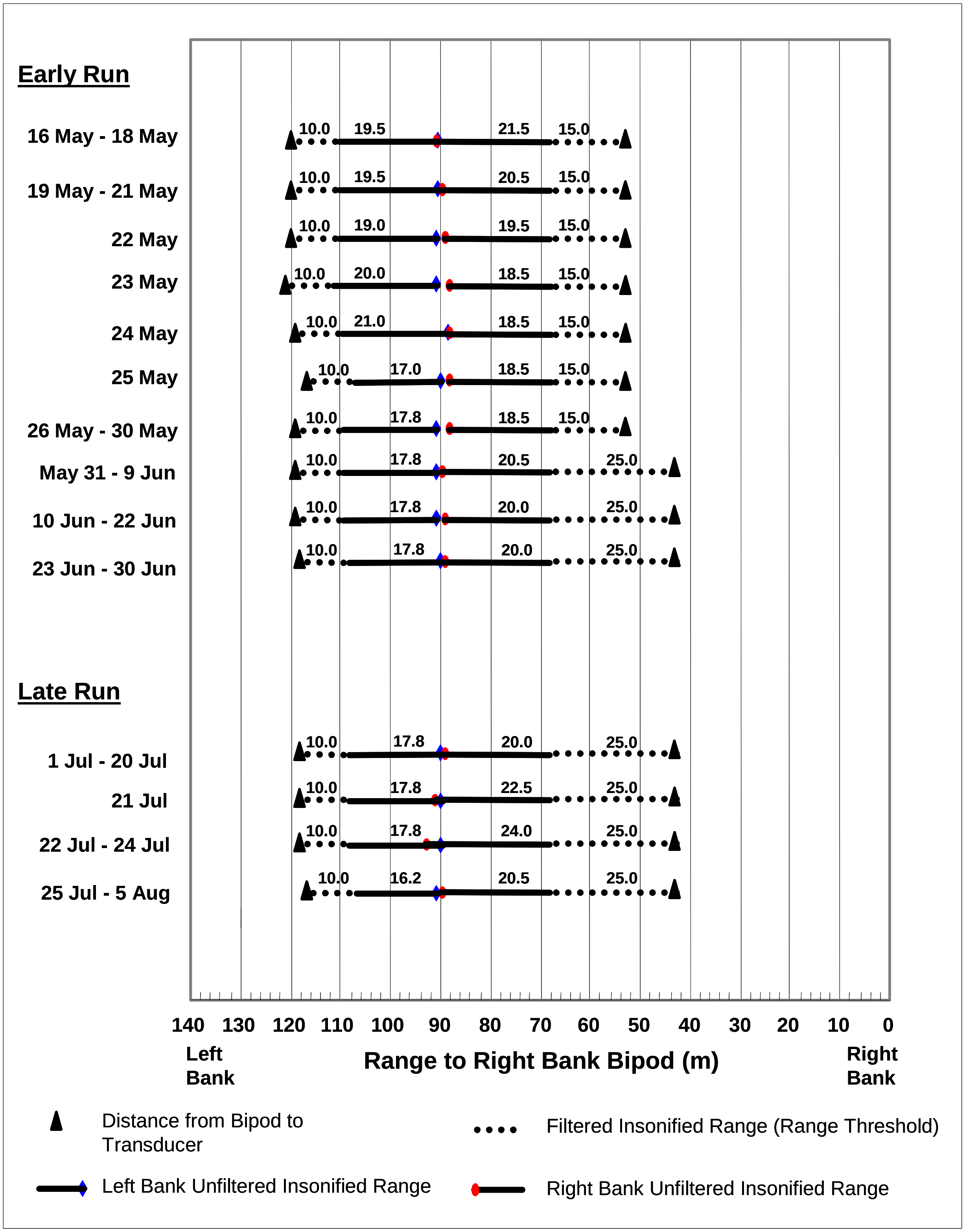


Figure 4.-Daily right- and left-bank transducer placement and insonified ranges relative to bipod tower located on the right bank, Kenai River, 2005. Distance from bipod to thalweg is approximately 88 m.

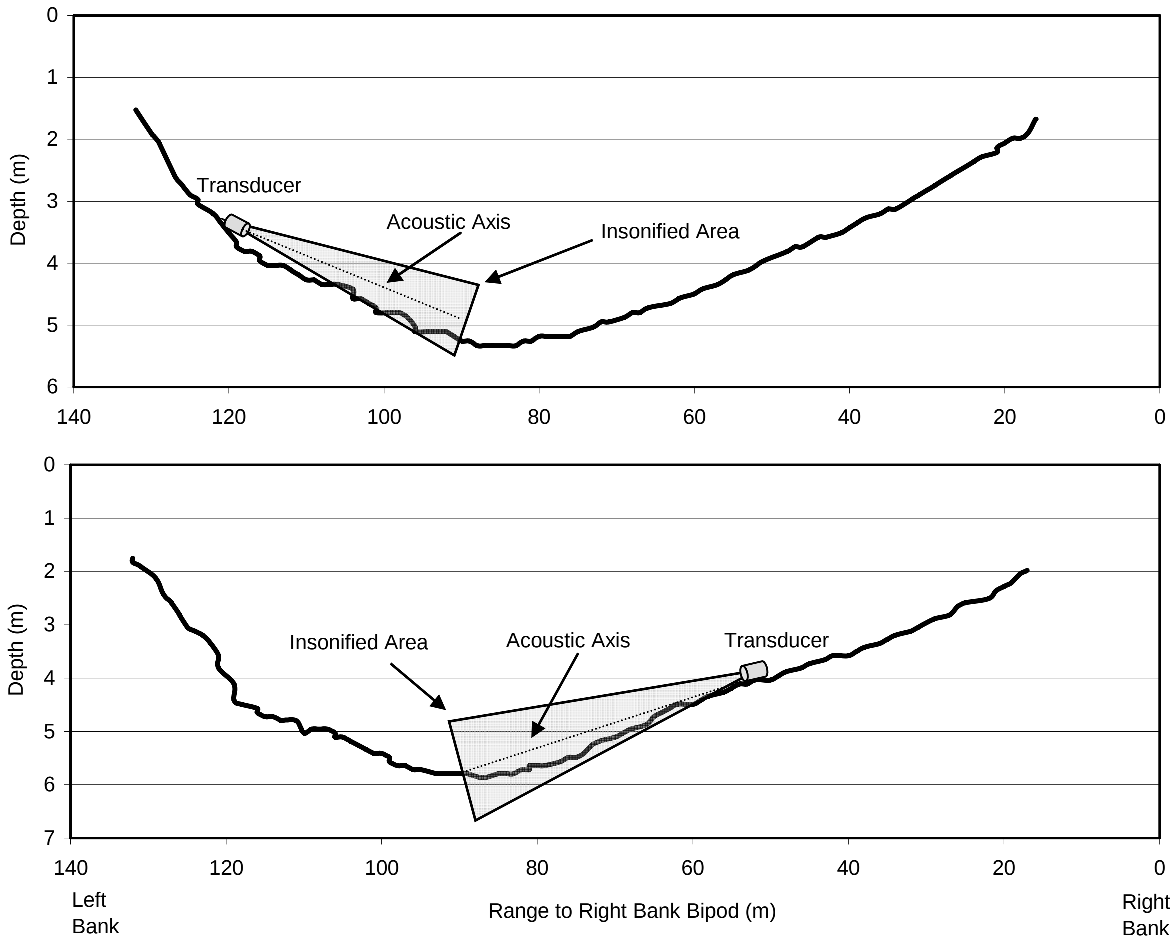


Figure 5.-Bottom profiles by bank for the Kenai River Chinook salmon sonar site with approximate transducer placement and sonar beam coverage for 16 May 2005.

System Calibration

HTI performed reciprocity calibrations with a naval standard transducer on 14 January 2005 and again on 22 November 2005. Calibrations were verified at the calibration facility with a 38.1-mm tungsten carbide sphere (Foote and MacLennan 1984). Further verification was obtained *in situ* by measuring the same standard sphere on 15 May, 28 July, and 1 August. 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 (see Data Acquisition).

Sampling Procedure

A systematic sample design (Cochran 1977) was used to sample from each bank for 20 min 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 produce daily fish passage estimates. 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 quiescent or activated for ancillary studies during the third 20-min period. This routine was followed 24 hours per day and 7 days per week unless one or both banks were inoperable.

A test of this sample design conducted 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 1 hour (Miller et al. 2002).

Because fish passage rates are related to tide stage (Eggers et al. 1995), tide stage was recorded at the top of each hour and at 20 minutes past each hour to coincide with the start of sonar sampling. Tide stage was recorded using water level measurements taken from a staff gauge at the sonar site.

Echo Sounder Settings

Relevant 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 sample 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.

Table 2.-HTI model 244 digital echo sounder settings used in 2005.

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

Data Acquisition

An HTI Model 244 digital echo sounder (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 6). The DES recorded the start time, date, and number of pings processed for each sample.

Echoes in the transducer near field (≤ 2.0 m) were excluded (Simmonds and MacLennan 2005), as were echoes that exceeded maximum vertical and horizontal angles off-axis. Angle filters were used to prevent consideration of unreliable data from transducer side lobes.

Voltage thresholds for data acquisition were set high enough to exclude most background noise from spurious sources such as boat wakes, 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. Since 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 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.

Table 3. -Echo acceptance criteria for digital echo processing, 2005.

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 – 5 Aug	0.04 to 10.0	-2.5 to 2.0	-5.0 to 5.0	733 (-35 dB)	2.0
Left					
16 May – 21 Jul	0.04 to 10.0	-2.5 to 2.0	-5.0 to 5.0	479 (-35 dB)	2.0
22 Jul – 5 Aug	0.04 to 10.0	-2.5 to 2.0	-5.0 to 5.0	446 (-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).

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[1] 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, echoes (in 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 following a sequential progression through the

[1] Use of a company's name does not constitute endorsement.

beam were selected by the user and classified into fish traces. TRAKMAN then produced three output files. The first file contained each echo that was tracked in a valid target (*.MEC file) and included the following data for each echo: 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: 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). The third file was identical to the *.RAW file described earlier except that it contained only those echoes combined into tracked targets. Direction of travel was estimated by calculating the simple linear regression of X-axis position (distance up- or down-river 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. A diagram illustrating data flow can be found in Appendix C1.

Downstream targets (and occasionally upstream 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. Obvious debris-like targets were excluded from consideration as valid fish targets during the tracking procedure and the remaining downstream targets were retained to adjust the total estimate of fish passage. 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 ANALYSES

Tidal and Temporal Distribution

Falling tide was defined as the period of decreasing staff-gauge 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 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

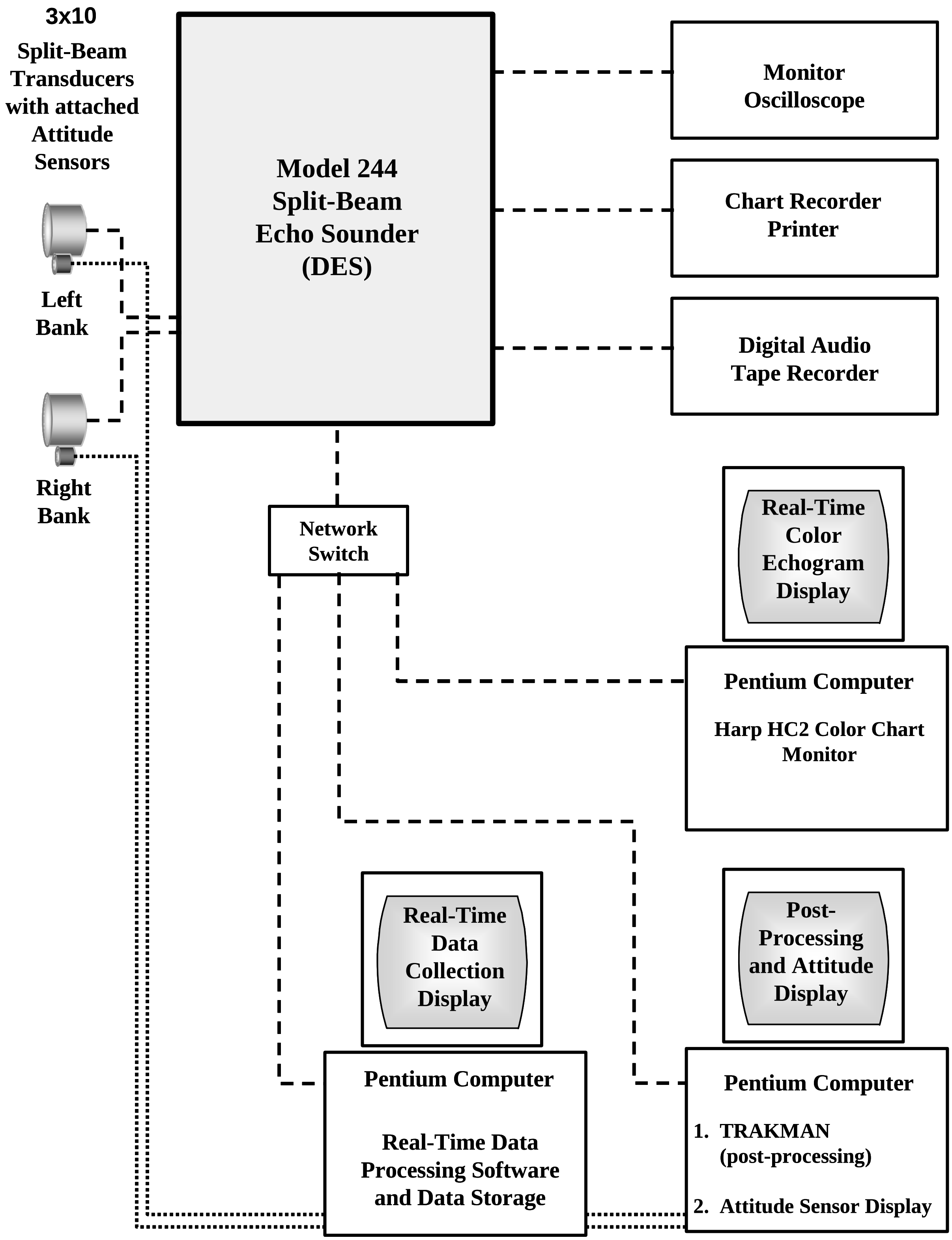


Figure 6.-Diagram of 2005 split-beam sonar system configuration and data flow.

comparisons provided information on distribution of fish targets from the face of the transducer, but because tripod/transducer locations change throughout the season the comparisons were poor descriptors of actual fish range distributions across the river. 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 and 4):

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

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.

Fish 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 (up- and downstream) and tide stage. Vertical distributions were calculated from the midpoint angle off-axis in the vertical plane as follows:

$$\theta_y = \arcsin \frac{y_s + \left(\frac{d_y}{2} \right)}{z_m}, \tag{2}$$

where:

θ_y = vertical angle-off-axis midpoint (degrees),

y_s = starting vertical coordinate (in meters), and

d_y = distance traveled in vertical direction (in meters).

Target Strength Distribution

Target strength was calculated for individual echoes (Appendix A1) and averaged for each tracked fish. Target strength distributions were plotted separately for early- and late-run fish and for upstream and downstream moving fish.

Species Discrimination

Tracked fish were filtered using criteria to minimize the number of sockeye salmon counted. Two parameters have been used historically on this project to separate large Chinook salmon from sockeye salmon and other species: target strength (-28 dB threshold) and distance from the transducer (range). The vast majority of sockeye salmon swim near shore, and can be excluded by counting only offshore targets. Although we know that filters based on target strength and range are not always effective at excluding all sockeye salmon (Burwen et al. 1995; Eggers 1994), we continue their use for historical comparability, while we investigate other means of discriminating between fish sizes.

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. The left-bank range threshold remained at 10 m all season. The right bank range threshold was 15 m from 16 to 30 May and 25 m thereafter (Figure 4).

Targets observed passing the sonar site in pairs or small groups were assumed to be sockeye salmon. During periods of high sockeye salmon passage, size and range filters failed to remove many of these targets. As a result, hourly samples containing substantial numbers of paired or grouped targets beyond the range thresholds were considered unreliable and were excluded from calculation of the Chinook passage estimate (Appendix D1). This reduced the potential for overestimating Chinook salmon passage, at the risk of underestimating passage. If Chinook passage was relatively high in the excluded samples, then Chinook passage estimates would be biased conservatively low.

Passage Estimates

Estimates of Chinook salmon passage for day *i* were generated as follows:

$$\hat{y}_i = 24\sum_{k=1}^{2}\bar{y}_{ik}\,, \qquad (3)$$

where the mean hourly passage past bank *k* during day *i* was:

$$\bar{y}_{ik} = \frac{1}{n_{ik}}\sum_{j}^{n_{ik}}\hat{y}_{ijk}\,, \qquad (4)$$

where n_{ik} was the number of hours during which passage was estimated on bank *k* for day *i*. Hourly Chinook salmon passage on bank *k* during hour *j* of day *i*, was estimated as follows:

$$\hat{y}_{ijk} = \frac{60}{t_{ijk}}c_{ijk}\,, \qquad (5)$$

where:

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

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

When the sonar system was functional on one bank but not the other, we estimated the passage on the non-functional bank *k*' from passage on the functional bank *k* with a ratio estimator:

$$\hat{y}_{ijk'} = \hat{R}_{ikt}\hat{y}_{ijk}\,, \qquad (6)$$

where the estimated bank-to-bank ratio R_{ikt}, for day *i* and tide stage *t* was calculated by pooling counts from all hours during the previous 2 days (to ensure adequate sample size) with tide stage *t*:

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

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

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

where *f* was the sampling fraction (approximately 0.33), and ϕ_{jk} was 1 if the sonar was operating on bank *k* during hour *j* or 0, if not. Uncertainty due to imperfect detection of fish, imperfect discrimination of species, missing hourly counts, and spatial expansion was not estimated. Therefore, variance estimates were biased low.

The cumulative estimate of Chinook salmon abundance, and its variance, was the sum of the daily estimates:

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

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

Late-run passage through 10 August ($\hat{Y}_e$) was estimated by dividing by the mean proportion of passage ($\bar{p}$) through 5 August for the 10 years (1987, 1988, 1990, 1992, 1993, 1995, and 1998-2001) when the sonar project operated through at least 9 August:

$$\hat{Y}_e = \frac{\hat{Y}}{\bar{p}}, \tag{11}$$

where:

$$\bar{p} = \frac{\sum_g p_g}{10}, \tag{12}$$

$$p_g = \frac{\sum_{i=1July}^{5Aug}\hat{y}_i}{\sum_{i=1July}^{10Aug}\hat{y}_i}, \tag{13}$$

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

$$\hat{V}\left[\hat{Y}_e\right] = \hat{V}\left[\hat{Y}\right]\bar{p}^{-2} + \hat{V}\left[\bar{p}^{-1}\right]\hat{Y}^2 - \hat{V}\left[\hat{Y}\right]\hat{V}\left[\bar{p}^{-1}\right], \tag{14}$$

where:

$$\hat{V}\left[\bar{p}^{-1}\right] = \frac{\sum_{g=1}^{10}\left(p^{-1}{}_g - \bar{p}^{-1}\right)^2}{10(10-1)}. \tag{15}$$

Unfiltered[1] daily passage estimates for day i, $\hat{x}_i$, were calculated by following equations 3-10 after substituting unfiltered counts c'_{jk} for c_{jk}, where:

c'_{jk} = 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 and hour j.

The "alternative" daily estimate (or net-apportioned estimate) of Chinook salmon abundance was calculated by multiplying the unfiltered sonar passage estimate by the proportion $\hat{q}_i$ of Chinook salmon in drift gillnet catches near the sonar site (Eskelin 2007):

$$\hat{y}'_i = \hat{x}_i \hat{q}_i . \tag{16}$$

The variance estimate of the alternative estimate follows Goodman 1960:

$$\hat{\text{var}}(\hat{y}'_i) = \hat{x}_i^2 \,\hat{\text{var}}(\hat{q}_i) + \hat{q}_i^{\,2} \,\hat{\text{var}}(\hat{x}_i) - \hat{\text{var}}(\hat{q}_i)\hat{\text{var}}(\hat{x}_i). \tag{17}$$

Note that variance of sonar estimates in this report reflects only the uncertainty associated with sampling error, as this is the only uncertainty we are currently able to quantify. Other sources of uncertainty associated with this type of project include target detection, species composition, direction of travel, and target tracking. Because we are only able to account for sampling error related to the systematic sample design, our approach has been to keep the methods as consistent as possible from year to year so that any bias will also be consistent.

RESULTS

SYSTEM CALIBRATION

During system calibration at the HTI calibration facility, the target strength of a 38.1-mm tungsten carbide standard sphere was measured at -40.0 dB for the right-bank transducer and -40.1 dB for the left-bank transducer (HTI 2005; Table 4). Although these measurements were similar to the theoretical value for the sphere (-39.5 dB; MacLennan and Simmonds 1992), the resulting voltage thresholds (872 mV for the right bank and 530 mV for the left bank) for a –35 dB echo were high compared to historic thresholds (Table 5), thus suggesting a shift in system sensitivity or an error in calibration. Results of *in situ* calibration checks conducted on 13 May (Table 4) indicated a calibration error had likely occurred and that the calibration parameters were in error by as much as 1.5 dB on the right bank and 1.0 dB on the left bank. Because of the apparent calibration error, the minimum voltage thresholds for data collection were set from the beginning of the season at 733 mV on the right bank and 479 mV on the left bank, or approximately 1.5 dB and 1.0 dB lower than the thresholds suggested by the system calibration. The left-bank voltage threshold was further reduced to 446 mV on 22 July when it became

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[1] Unfiltered with respect to target strength, but restricted to upstream-bound targets passing at a distance greater than the smallest range thresholds used during the season (15 m on right bank, 10 m on left bank).

obvious based on other passage indices that inseason passage on both banks was being underestimated and that a preseason calibration error had occurred.

Data from both runs were reprocessed postseason using minimum voltage thresholds resulting from a postseason system calibration conducted at the HTI calibration facility. Standard sphere target strength measurements collected at the facility following the postseason calibration were -39.5 dB for the right-bank transducer and -39.3 dB for the left-bank transducer (Table 4), very similar to the standard sphere theoretical value. The postseason calibration voltage thresholds (734 mV for right bank and 424 mV for left bank) were also similar to historic values (Table 5).

Table 4.-Results of 2005 *in situ* calibration verifications using a 38.1 mm tungsten carbide standard sphere.

Location	Date	Mean Target Strength (dB)	SD	N	Range (m)	Noise (mV)	Threshold (mV)
Right Bank							
HTI[a]	14 Jan 05	-40.0	0.89	824	6.2	N/A[b]	N/A[b]
Kenai River	13 May 05	-41.4	1.64	1,354	15.3	150	250
Kenai River	13 Jun 05	-39.4	2.11	1,346	17.7	300	300
Kenai River	4 Aug 05	-39.1	2.84	1,438	12.5	200	200
HTI[a]	22-Nov-05	-39.5	0.52	997	6.1	N/A[b]	N/A[b]
Left Bank							
HTI[a]	14 Jan 05	-40.1	0.93	1,020	6.2	N/A[b]	N/A[b]
Kenai River	13 May 05	-41.0	1.45	1,241	15.0	70	75
Kenai River	13 Jun 05	-40.8	1.53	1,065	17.7	70	75
Kenai River	4 Aug 05	-40.8	2.48	2,126	15.7	50	75
HTI[a]	22 Nov 05	-39.3	0.57	997	6.1	N/A[b]	N/A[b]

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

[b] Not available or not applicable.

TARGET TRACKING

In 2005, 84,950 targets were manually tracked, 21,016 during the early run and 63,934 during the late run. The proportion of fish classified as Chinook[1] salmon that were moving upstream was 98% for the early run and 93% for the late run (Appendices E1 and E2). Daily upstream proportions varied from 90 to 100% during the early run and from 83 to 98% during the late run.

The number of echoes tracked per fish (filtered for range and target strength criteria) varied by run, bank, and direction of travel. Upstream moving fish averaged 62 echoes (SD = 38) per fish on the left bank during the early run and 71 echoes (SD = 47) on the right bank. Downstream moving fish averaged 67 echoes (SD = 60) on the left bank and 87 echoes (SD = 86) on the right bank. During the late run, upstream fish averaged 84 echoes (SD = 58) on the left bank and 71

[1] Chinook salmon classifications were based on range and target strength criteria.

echoes (SD = 48) on the right bank. Downstream moving fish averaged 93 echoes (SD = 84) on the left bank and 80 echoes (SD = 71) per fish on the right bank.

Table 5.-Minimum voltage thresholds (-35 dB) from sonar system reciprocity calibrations, 1998-2005.

Year of Calibration	Right Bank Minimum Voltage Threshold (mV)	Left Bank Minimum Voltage Threshold (mV)
1998	662	413
1999	709	446
2000	653	419
2001	752	481
2002	708	420
2003	722	452
2004	713	451
2005 – 14 Jan (preseason)	872	530
2005 – 22 Nov (postseason)	734	424

TIDAL DISTRIBUTION

Upstream Chinook passage during both the early run (58.5%) and late run (53.7%) occurred mostly during the falling tide (Tables 6 and 7, Figure 7). Downstream passage also occurred primarily during the falling tide for both the early (55.2%) and late (50.3%) runs.

SPATIAL DISTRIBUTION

Distribution by Bank

Chinook salmon passage on the left bank was greater than on the right bank during both runs by an approximate 3:1 ratio (Tables 8 and 9). Fish passage by bank for all species combined was about equal.

Distribution by Range[1]

During the early run, upstream-traveling Chinook on the left bank were distributed throughout the insonified range, whereas downstream-traveling fish were distributed more mid-channel (Figure 8). During the early run on the right bank, upstream-traveling Chinook exhibited a bimodal range distribution, whereas downstream-traveling fish were distributed more uniformly across the channel (Figure 8).

[1] Because transducers were moved throughout the season in response to changing water levels (Figure 4), range measurements were standardized (Figures 8-11) to reflect distance from a fixed geographic reference point (see Methods). Hence, the left side of the distribution (in Figures 8-10) reflects the combined effects of range thresholds and the geographic standardization

Table 6.-Chinook salmon passage estimates by tide stage and direction of travel for the 2005 early run (16 May-30 June).

2005 Early Run	Total Number of Fish	Rising	Falling	Low
Upstream	20,450	4,507	11,957	3,986
Row %	100.0%	22.0%	58.5%	19.5%
Column %	97.6%	96.9%	97.7%	98.0%
Downstream	506	144	279	82
Row %	100.0%	28.5%	55.2%	16.3%
Column %	2.4%	3.1%	2.3%	2.0%

Test for Independence: chi-square = 12.76, df = 2, $P < 0.01$

Table 7.-Chinook salmon passage estimates by tide stage and direction of travel for the 2005 late run (1 July-5 August).

2005 Late Run	Total Number of Fish	Rising	Falling	Low
Upstream	40,294	11,746	21,654	6,890
Row %	100.0%	29.2%	53.7%	17.1%
Column %	93.1%	94.4%	93.6%	89.9%
Downstream	2,967	702	1,491	774
Row %	100.0%	23.7%	50.3%	26.1%
Column %	6.9%	5.6%	6.4%	10.1%

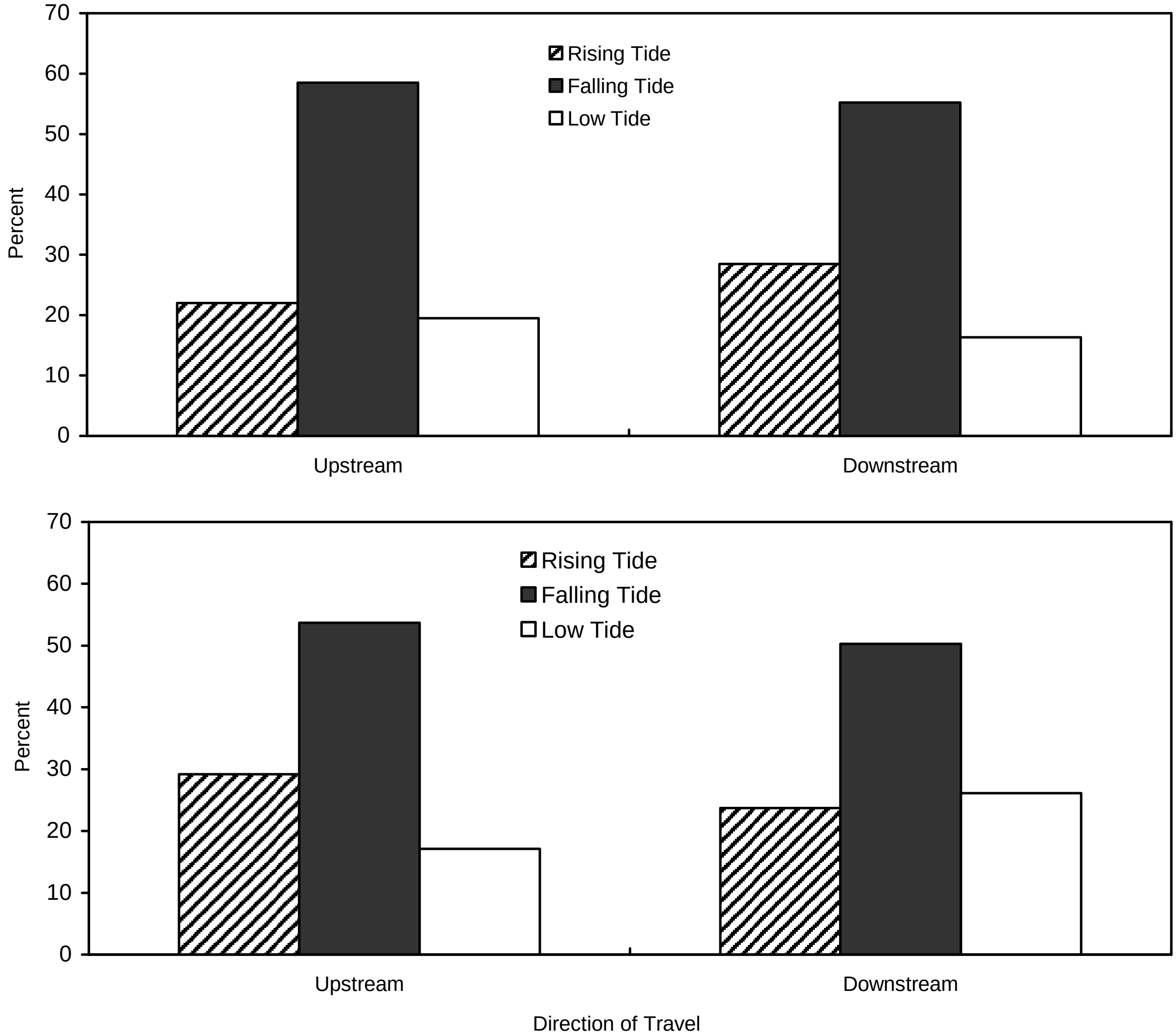
Test for Independence: chi-square = 161.29, df = 2, $P < 0.0001$

During the late run, upstream-traveling Chinook on the left bank were distributed throughout the insonified range, whereas downstream-traveling fish were distributed more mid-channel (Figure 9). During the late run on the right bank, upstream-traveling Chinook exhibited a bimodal range distribution, whereas downstream-traveling fish were concentrated offshore (Figure 9).

The effect of tide stage on range distribution (distance from shore) by Chinook salmon was small during both the early and late runs (Figures 10 and 11). On the left bank, range distribution was uniform for all tide stages. On the right bank, range distribution was bimodal during all tide stages, with low tide exhibiting a larger offshore peak range distribution.

Distribution by Vertical Position

Chinook salmon were bottom-oriented during both runs, although vertical distribution did vary by direction of travel, tide stage, and season (Appendices F1 and F2). During the early run, 94% of the upstream moving Chinook salmon on the left bank and 83% on the right bank were on or below the acoustic axis (Figure 12). Downstream moving Chinook salmon were less bottom-oriented (Appendix F1). Seventy-five percent of downstream moving fish on the left bank and 68% on the right bank were below the acoustic axis (Figure 12). Upstream moving fish on the left bank (mean = -0.47°, SD = 0.34, n = 5,619) were on average lower (t = 3.70, $P < 0.001$) in



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

Figure 7.-Percentage of upstream and downstream moving Chinook salmon by tide stage during the early (top) and late (bottom) runs, Kenai River, 2005.

Table 8.-Chinook salmon passage estimates by river bank and direction of travel for the 2005 early run (16 May-30 June).

	Estimate of Upstream Component		Estimate of Downstream Component		Estimate of Total Fish Passage[a]	
Bank	Number	Percent	Number	Percent	Number	Percent
Right	4,458	22%	354	70%	4,812	23%
Left	15,992	78%	152	30%	16,144	77%
Total	20,450	100%	506	100%	20,956	100%

[a] Total passage (upstream component plus downstream component) is provided to maintain comparability between recent (1998-2005) fish passage estimates derived from split-beam sonar and composed of only upstream targets, and past estimates generated by split-beam (1995-1997) and dual-beam (1987-1994) sonar and composed of both upstream and downstream targets.

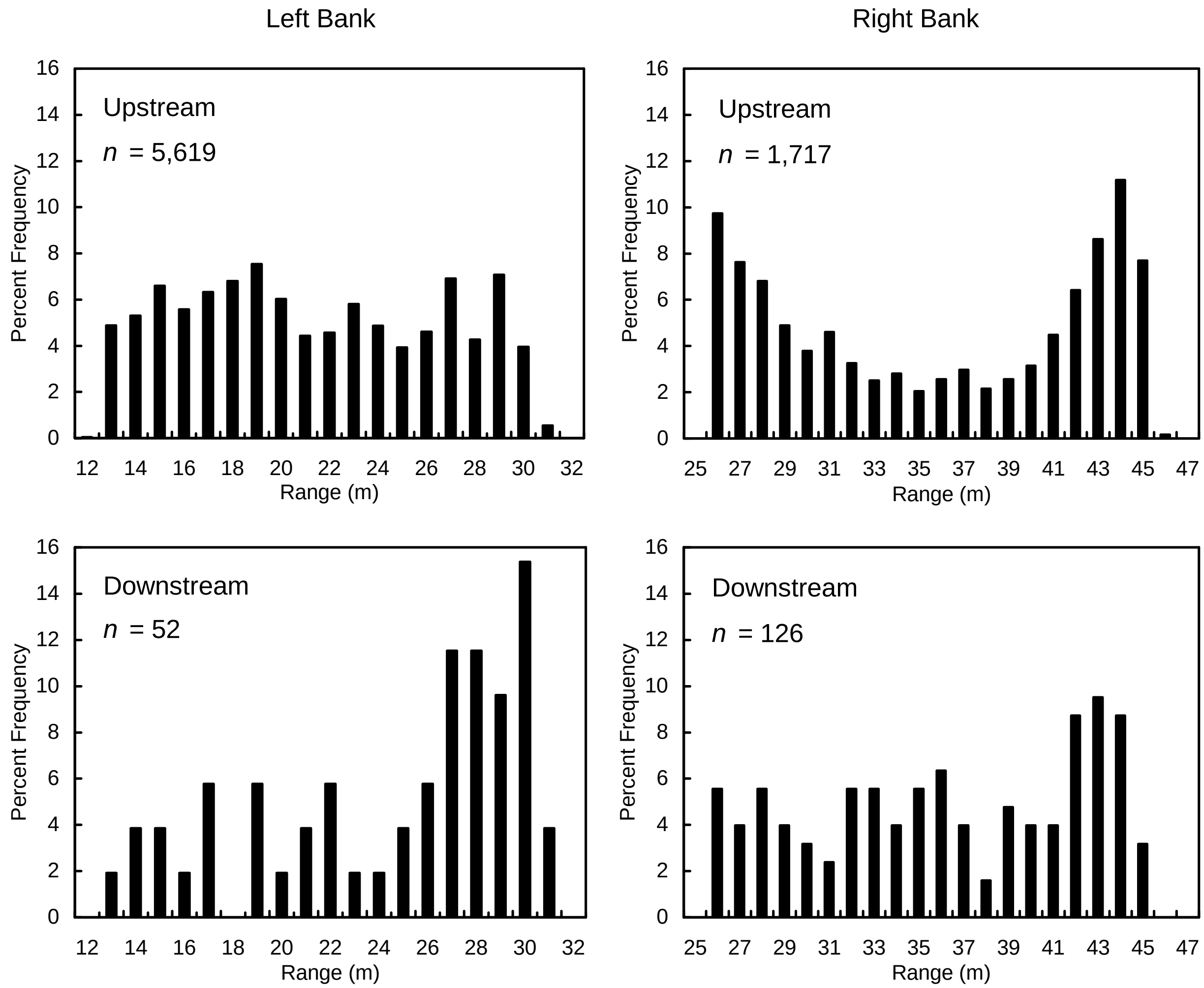
Table 9.-Chinook salmon passage estimates by river bank and direction of travel for the 2005 late run (1 July-5 August).

	Estimate of Upstream Component		Estimate of Downstream Component		Estimate of Total Fish Passage[a]	
Bank	Number	Percent	Number	Percent	Number	Percent
Right	10,676	26%	1,520	51%	12,196	28%
Left	29,618	74%	1,447	49%	31,065	72%
Total	40,294	100%	2,967	100%	43,261	100%

[a] Total passage (upstream component plus downstream component) is provided to maintain comparability between recent (1998-2005) fish passage estimates derived from split-beam sonar and composed of only upstream targets, and past estimates generated by split-beam (1995-1997) and dual-beam (1987-1994) sonar and composed of both upstream and downstream targets.

the water column than downstream moving fish (mean = -0.18°, SD = 0.56, n = 52). On the right bank, fish moving upstream (mean = -0.19°, SD = 0.32, n = 1,717) were also lower (t = 3.76, $P < 0.001$) in the water column than downstream moving fish (mean = -0.04°, SD = 0.41, n = 126). Upstream traveling fish on both banks were bottom-oriented during all tides, but left-bank fish were distributed slightly higher in the water column during rising tides (Figure 13).

Late-run Chinook salmon also showed a tendency to travel along the river bottom (Figure 14 and Appendix F2). Eighty-four percent of upstream moving fish on the left bank and 71% of upstream moving fish on the right bank were on or below the acoustic axis. Downstream traveling fish were slightly higher in the water column (Appendix F2). Seventy-four percent of downstream moving fish on the left bank and 61% on the right bank were on or below the acoustic axis. Upstream moving fish on the left bank (mean = -0.31°, SD = 0.38, n = 11,337)



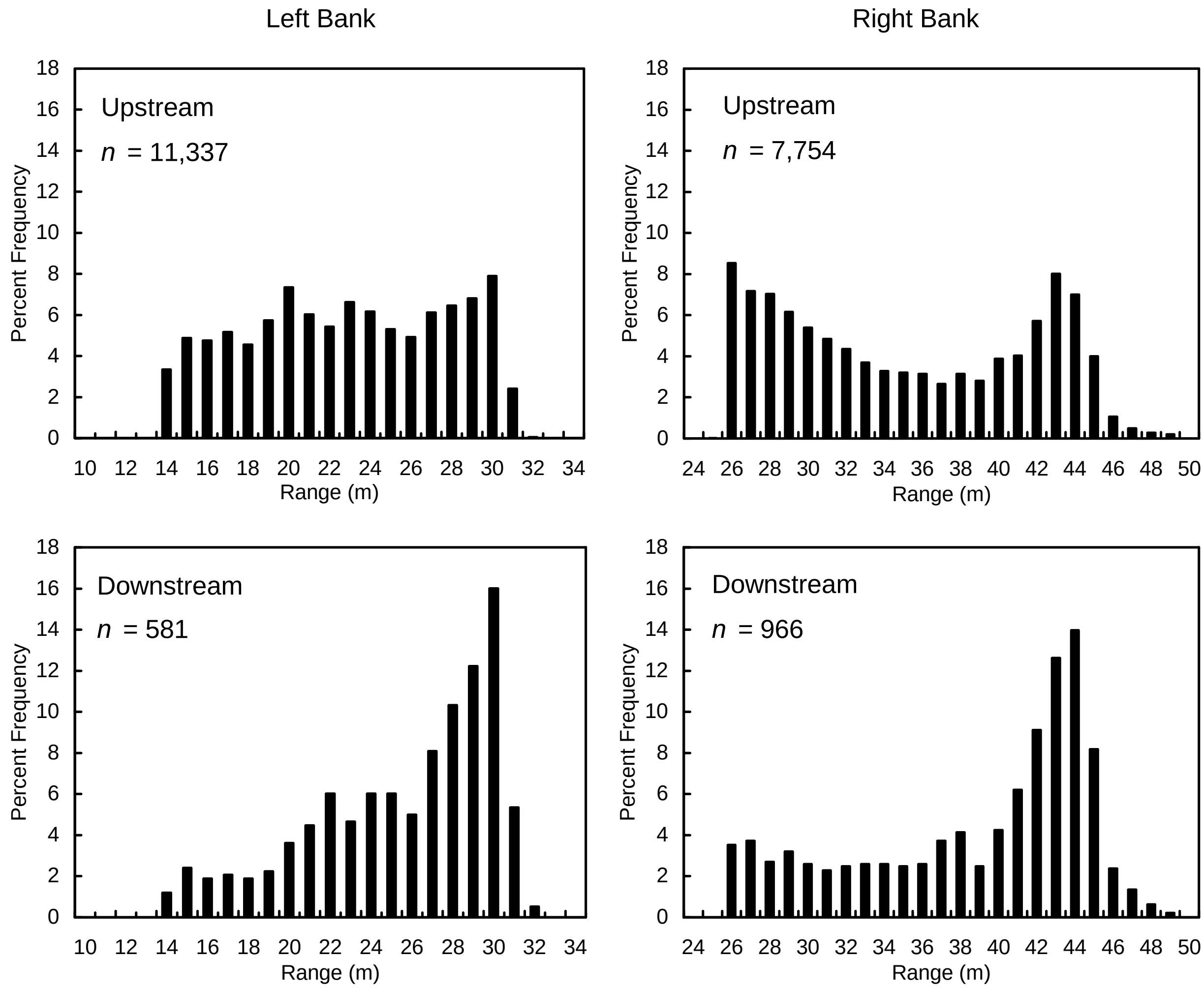
Note: Data have been filtered by range (distance from transducer) and target strength criteria.

Figure 8.-Standardized distance from transducer of early-run upstream and downstream moving Chinook salmon by bank, Kenai River, 2005.

traveled lower (t = 7.07, P < 0.001) in the water column than downstream fish (mean = -0.19°, SD = 0.40, n = 581). Similarly, upstream moving fish on the right bank (mean = -0.04°, SD = 0.27, n = 7,754) traveled lower (t = 5.43, P < 0.001) in the water column than downstream moving fish (mean = 0.01°, SD = 0.29, n = 966). Vertical distribution of upstream traveling fish was slightly higher during the low tide on the right bank and during the rising tide on the left bank (Figure 15).

TARGET STRENGTH

Target strength distributions varied by bank, direction of travel, and run. Mean target strength estimates for all upstream targets on the right bank during the early run averaged >1 dB higher than left bank estimates (Figure 16). During the late run, right-bank mean target strength estimates for all upstream targets averaged <1 dB higher than left-bank estimates (Figure 17). Mean target strength of all upstream and downstream targets varied more on the right bank than



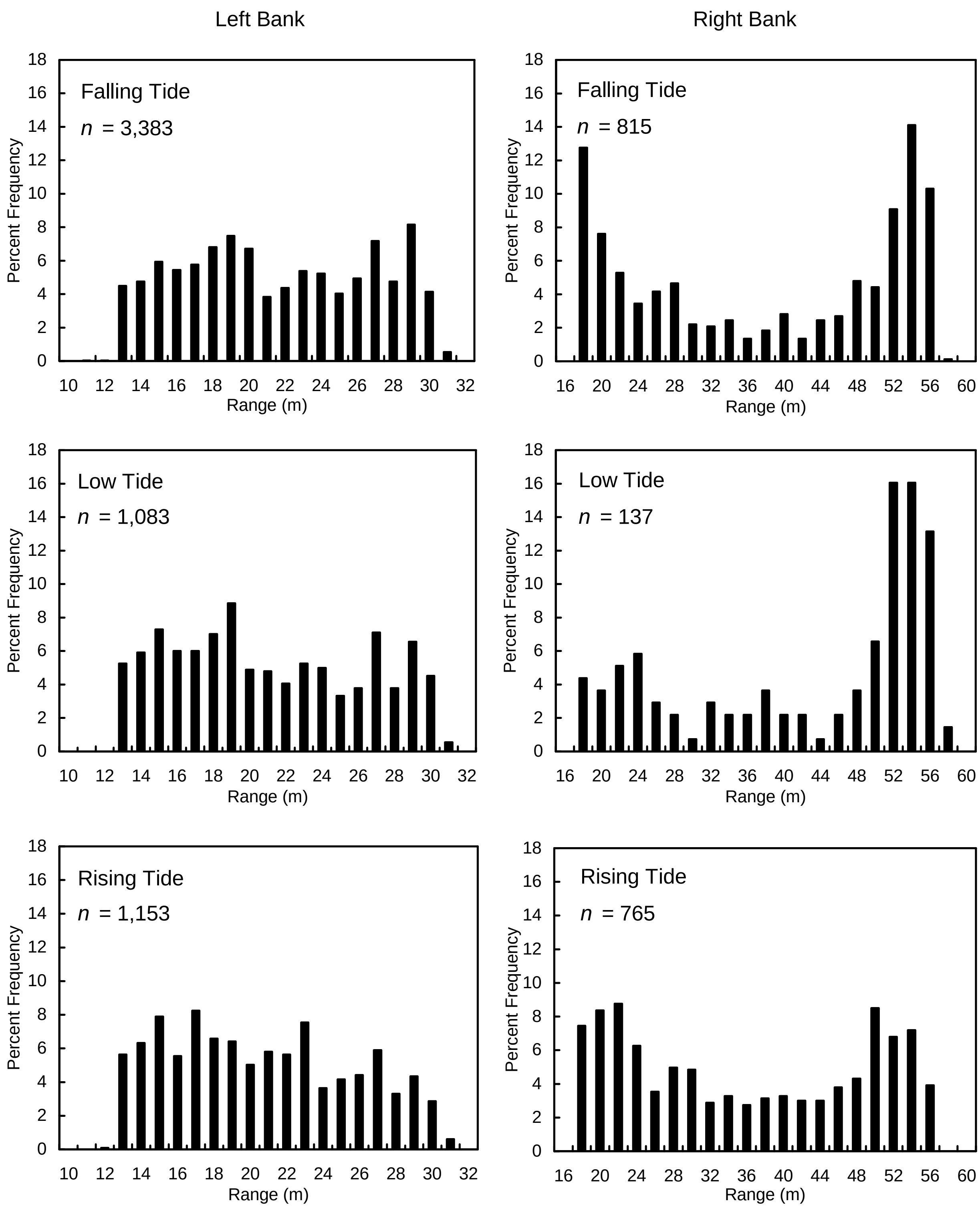
Note: Data have been filtered by range (distance from transducer) and target strength criteria.

Figure 9.-Standardized distance from transducer of late-run upstream and downstream moving Chinook salmon by bank, Kenai River, 2005.

on the left bank. Figure 16 and Figure 17 show target strength statistics and range distributions for all tracked targets.

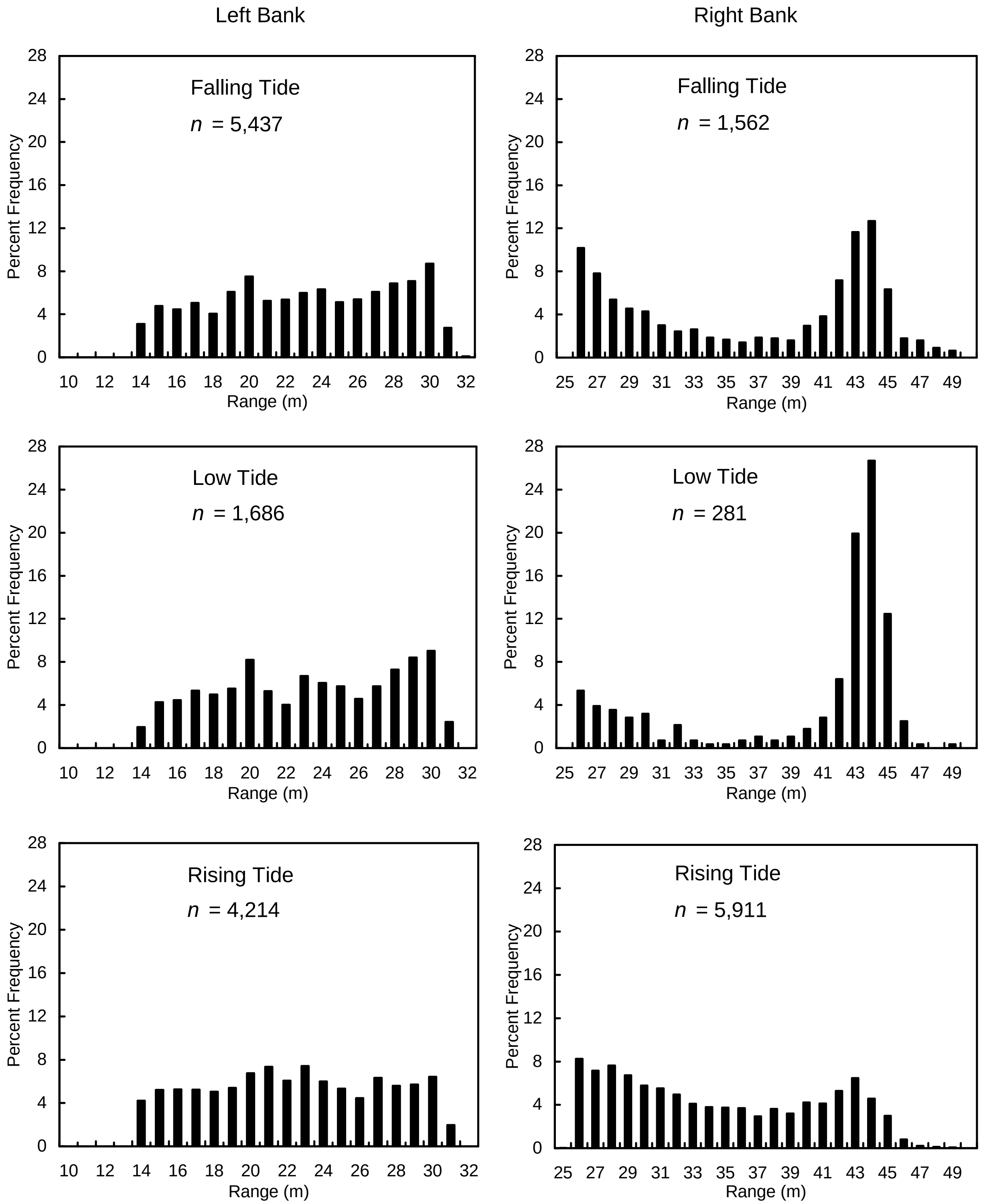
During the early run on the left bank, mean target strength of Chinook salmon was similar (t = -1.44 P = 0.07) among upstream and downstream traveling fish, as was mean target strength variability (F = 0.93, P = 0.38; Table 10). Mean target strength of Chinook salmon was also similar (t = 0.07, P = 0.47) on the right bank among upstream and downstream traveling fish, as was mean target strength variability (F = 0.82, P = 0.08; Table 10). Table 10 shows target strength statistics only for fish that met minimum range distribution and target strength criteria.

During the late run on the left bank, mean target strength of Chinook salmon was also similar (t = 0.42, P = 0.34) among upstream and downstream traveling fish, as was mean target strength



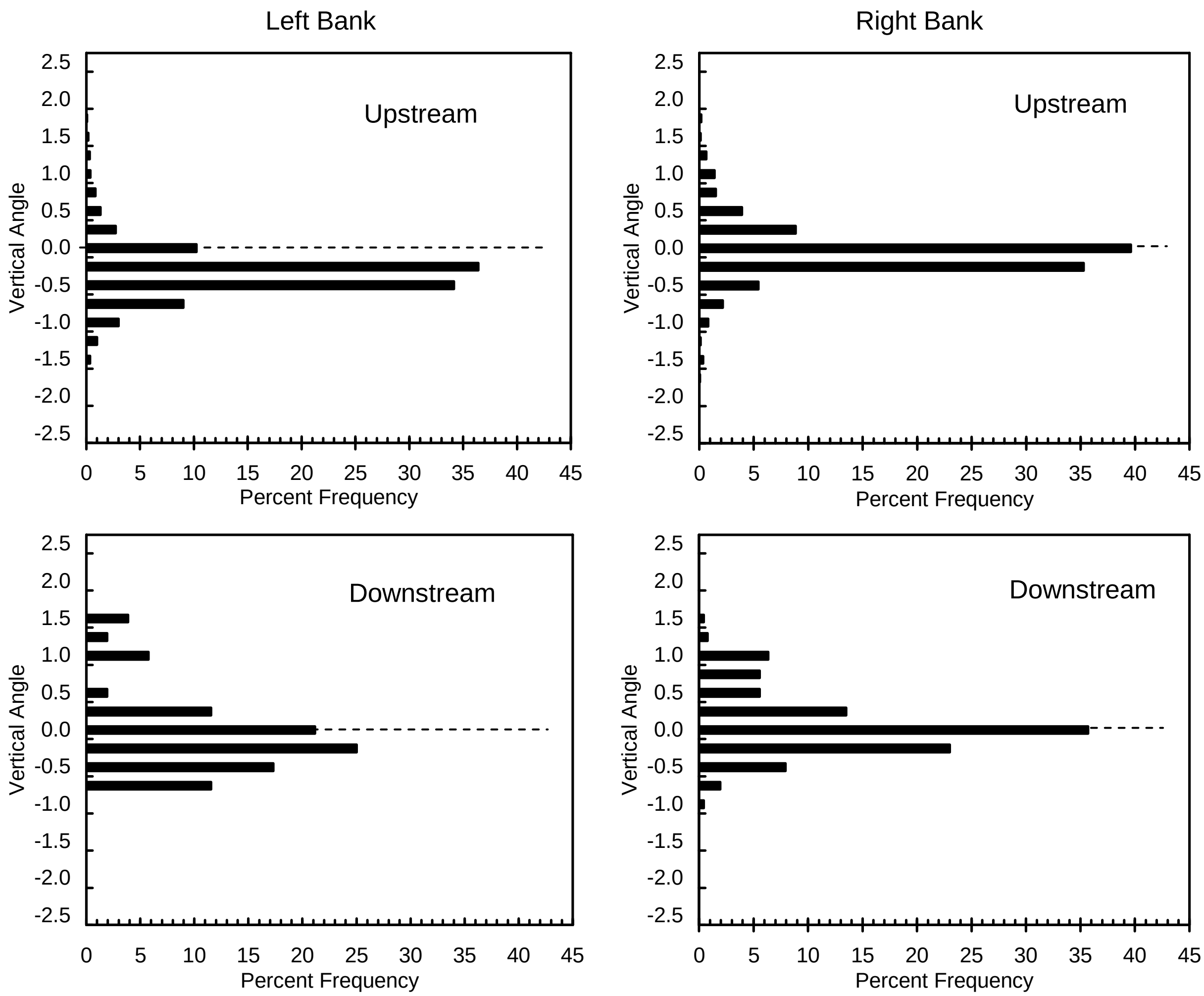
Note: Data have been filtered by range (distance from transducer) and target strength criteria.

Figure 10.-Standardized distance from transducer of early-run upstream moving Chinook salmon by tide stage and bank, Kenai River, 2005.



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

Figure 11.-Standardized distance from transducer of late-run upstream moving Chinook salmon by tide stage and bank, Kenai River, 2005.



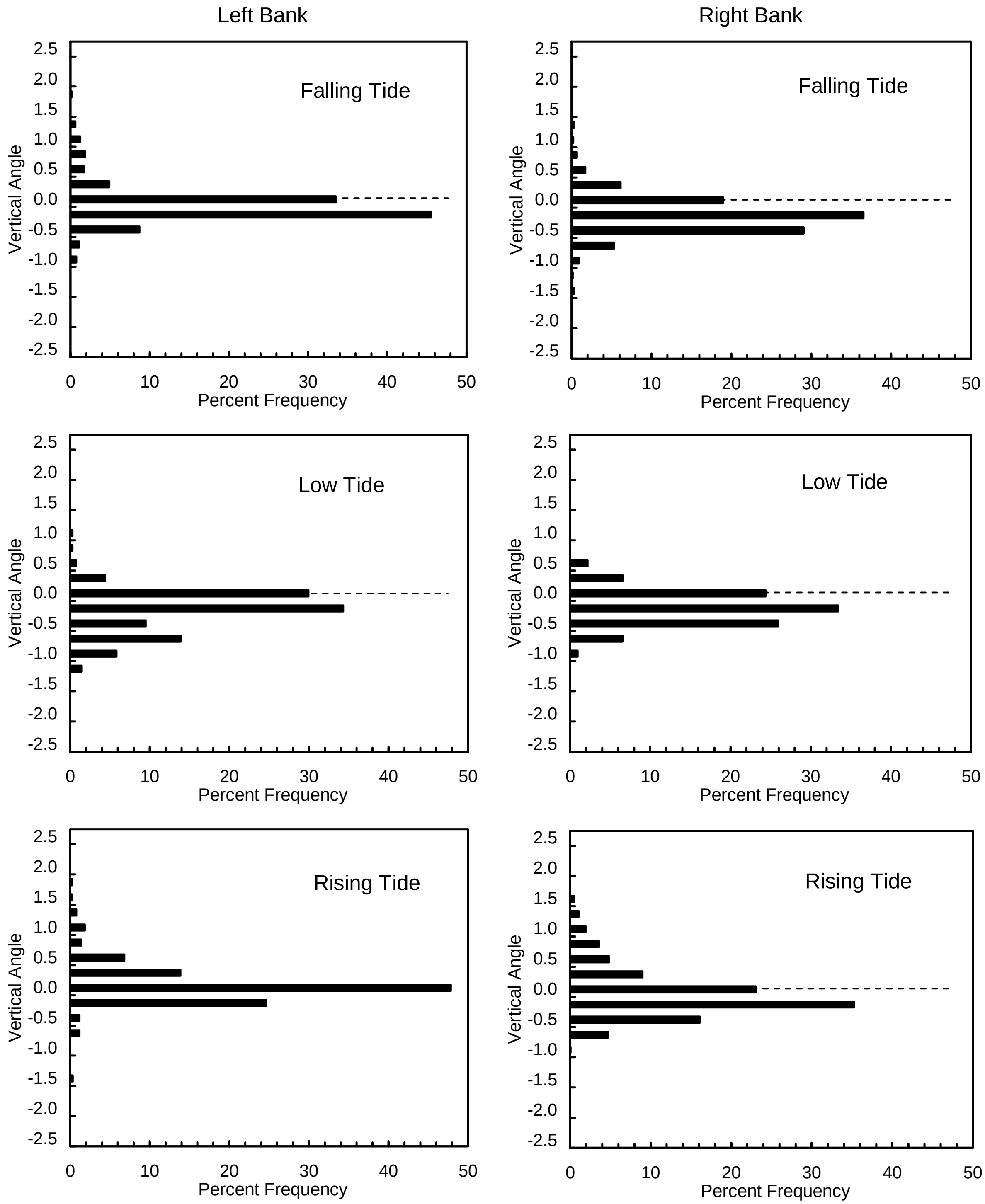
Note: Data have been filtered by range (distance from transducer) and target strength criteria. Acoustic axis = 0.0.

Figure 12.-Vertical distributions above and below the acoustic axis of early-run upstream and downstream moving Chinook salmon by bank, Kenai River, 2005.

variability (F = 1.03, P = 0.32; Table 10). On the right bank during the late run, mean target strength was slightly (0.3 dB) higher (t = -4.62, P < 0.01) among upstream traveling fish, as was mean target strength variability (F = 0.83, P < 0.01; Table 10). The difference observed in mean target strength between upstream and downstream traveling fish was likely an artifact of sample size.

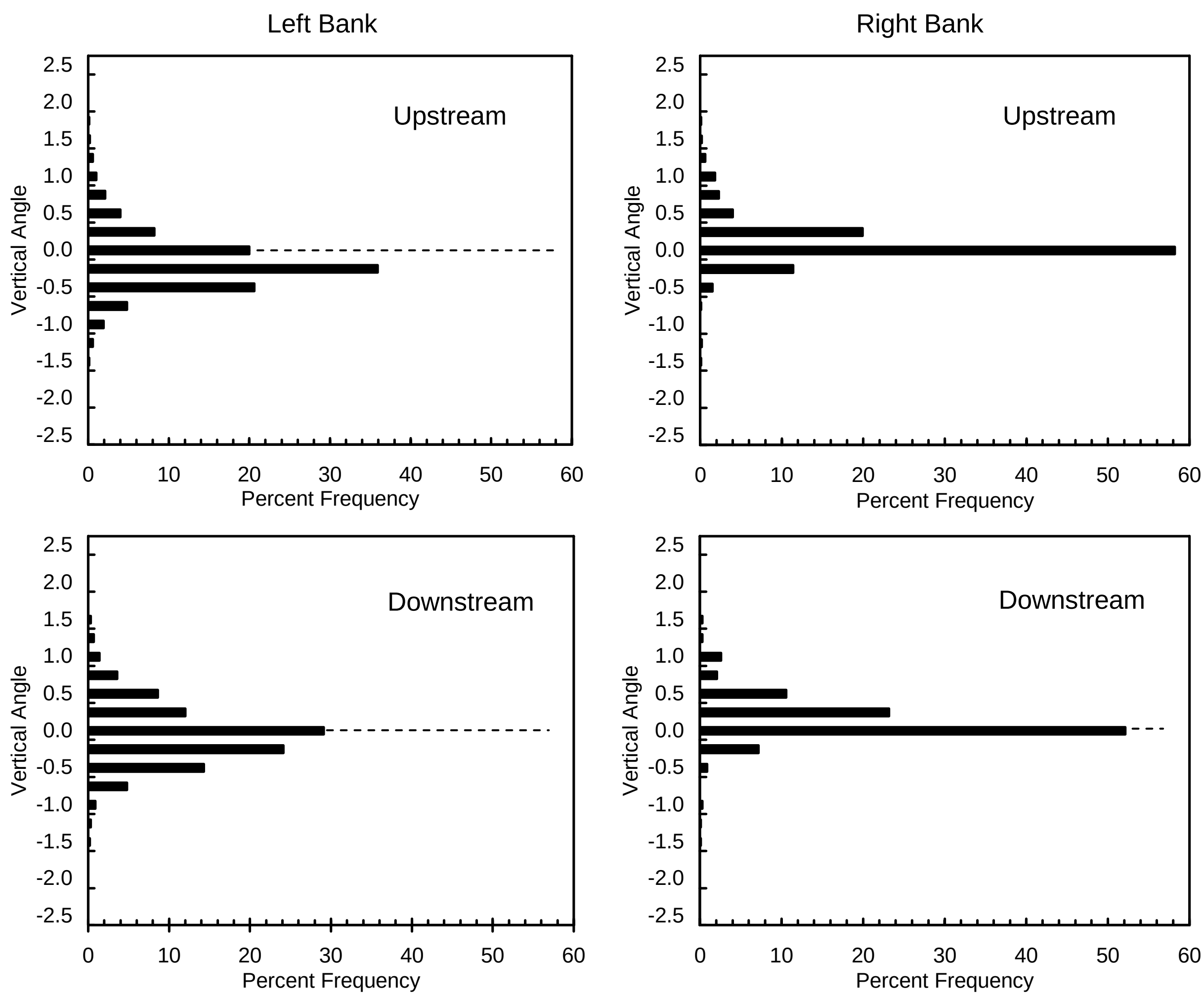
CHINOOK SALMON PASSAGE

Daily estimates of Chinook salmon passage were generated for 16 May through 5 August. A total of 618 hours of acoustic data were processed from the right bank and 608 hours from the left bank during the 82-day season. This represented 31% of the total available sample time (on average in a 24-hour period) for each bank.



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

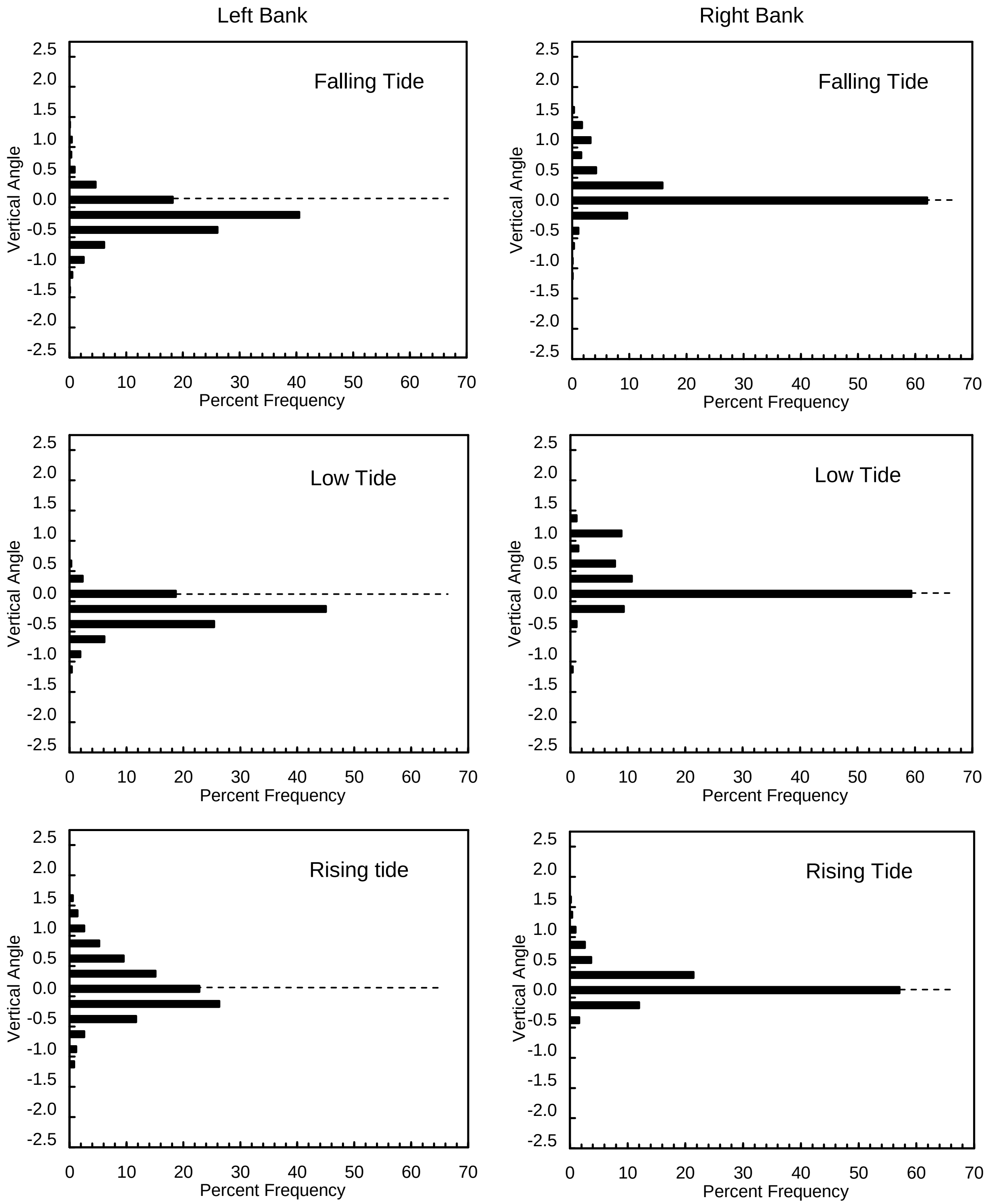
Figure 13.-Vertical distributions above and below the acoustic axis of early-run upstream moving Chinook salmon by tide stage and bank, Kenai River, 2005.



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

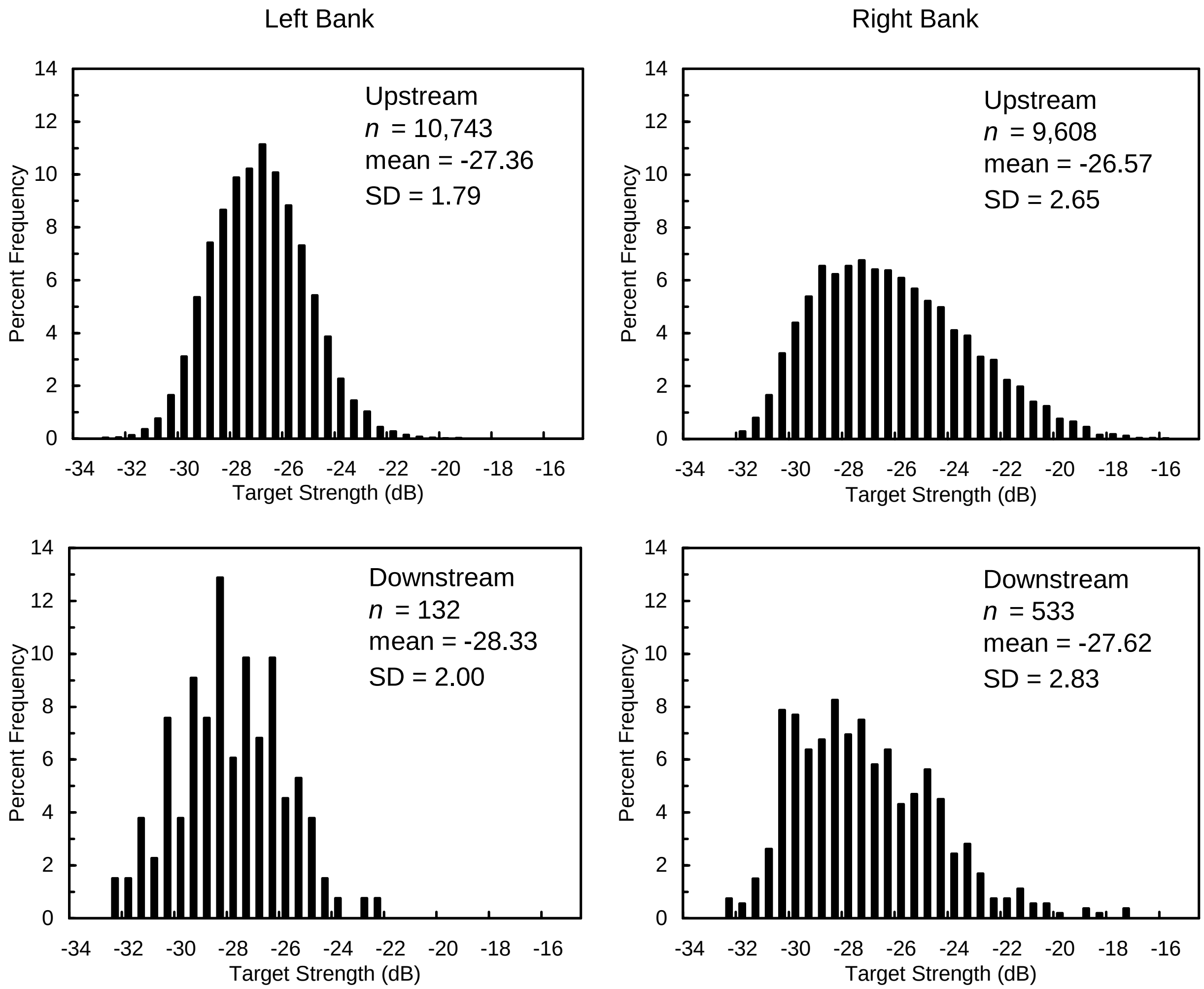
Figure 14.-Vertical distributions above and below the acoustic axis of late-run upstream and downstream moving Chinook salmon by bank, Kenai River, 2005.

Estimated upstream Chinook salmon passage from 16 May to 5 August was 60,744 (SE = 533) fish, composed of 20,450 (SE = 295) early-run fish and 40,294 (SE = 445) late-run fish (Tables 8, 9, 11, and 12). Estimated late-run passage through 10 August was 43,240 (SE = 1,370) fish. Peak daily passage during the early run occurred on 11 June and 30 June; 50% of the run passed by 12 June (Figure 18). The 2005 early run started slow when compared with historic mean escapement timing, but was average after the first week of June (Figure 18 and Appendix G1). The daily peak of the late run occurred on 13 July; 50% of the late run passed by 16 July (Figure 19). Timing of the late run was similar to the historic mean escapement (Figure 19 and Appendix G2).



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

Figure 15.-Vertical distributions above and below the acoustic axis of late-run upstream moving Chinook salmon by tide stage and bank, Kenai River, 2005.



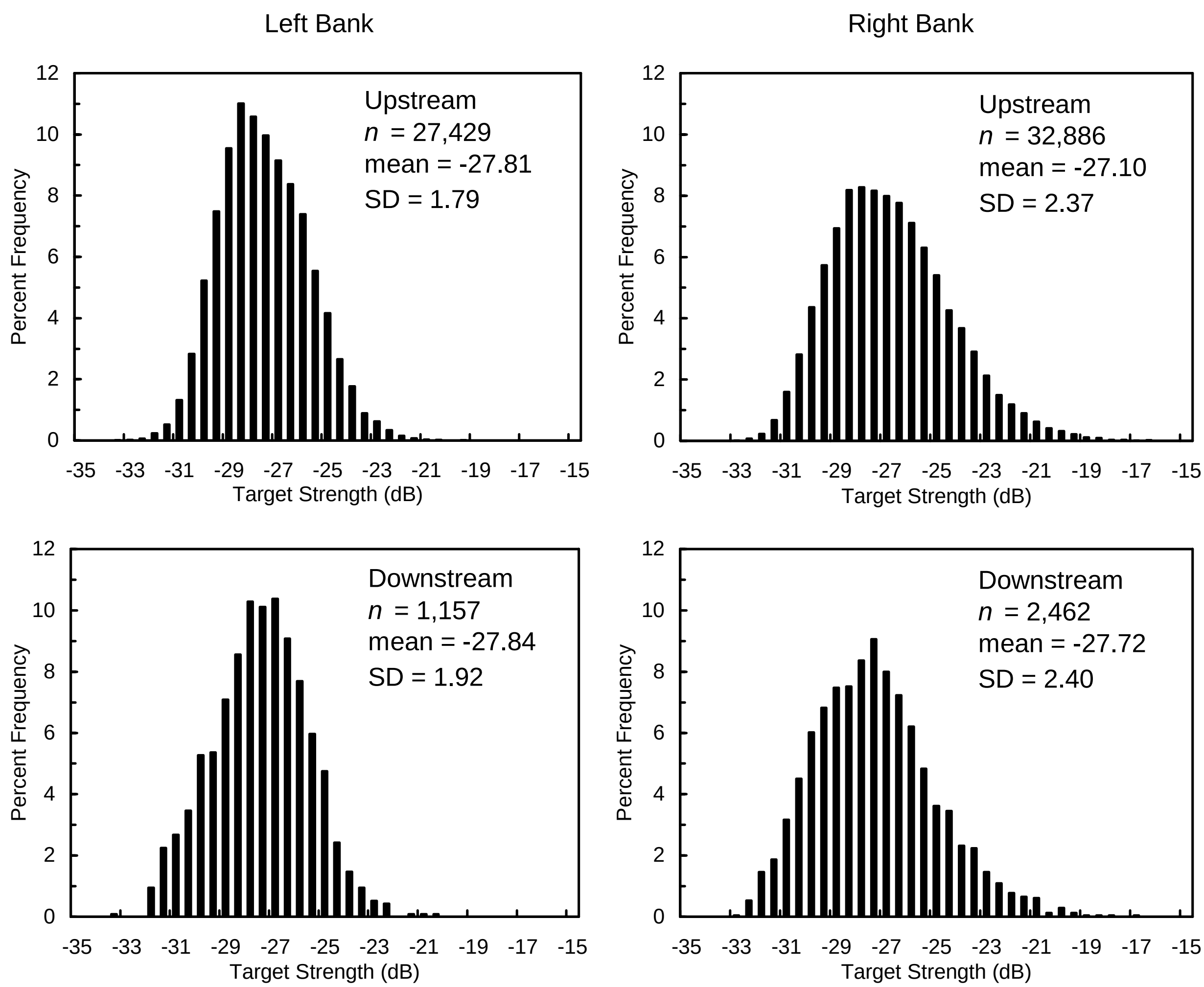
Note: Data have not been filtered by range (distance from transducer) and target strength criteria.

Figure 16.-Early-run target strength (acoustic size) for all upstream and downstream moving targets by bank, Kenai River, 2005.

DISCUSSION

ACCURACY OF PASSAGE ESTIMATES

Research indicates that sonar estimates of Chinook passage are subject to potential bias 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. Bias from target detection and tracking are generally small, consistent, or negative (resulting in conservative estimates). At present, we are more concerned about species discrimination errors, which can cause large biases (in either direction). For a discussion of target detection see Miller et al. (2007).



Note: Data have not been filtered by range (distance from transducer) and target strength criteria.

Figure 17.-Late-run target strength (acoustic size) for all upstream and downstream moving targets by bank, Kenai River, 2005.

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 outside of our range thresholds, they can comprise more than 50% of the mid-channel fish (Burwen et al. 1998). Under these circumstances range thresholds are ineffective, and Chinook abundance can be overestimated.

Table 10.-Mean target strength (dB) for upstream and downstream moving targets (Chinook salmon only) by riverbank during the early (16 May-30 June) and late (1 July-5 August) runs, 2005.

Location	Upstream Mean Target Strength (dB)	SD	N	Downstream Mean Target Strength (dB)	SD	N
Early Run						
Left Bank	-26.41	1.14	5,619	-26.64	1.08	52
Right Bank	-25.69	2.00	1,717	-25.67	1.82	126
Late Run						
Left Bank	-26.43	1.18	11,337	-26.41	1.19	581
Right Bank	-25.73	1.86	7,754	-26.00	1.69	966

In response to these shortcomings, we refined our species discrimination algorithm in 2000. Fish distribution and behavior made it evident when sockeye were abundant mid-river; episodes of abundant sockeye mid-river were often discrete and short-lived. Since 2000, we have censored the data from the associated 1-hour samples, and generated the Chinook passage estimate from the remaining hourly samples. This procedure has reduced the probability of grossly overestimating Chinook abundance, but it has the drawback of being somewhat subjective to implement, and may increase the probability of underestimating abundance. Inclusion of all available hourly samples in 2005, regardless of the presence of offshore sockeye, would have generated an early-run Chinook passage estimate of 22,176 (SE = 361) and a late-run Chinook passage estimate through 5 August of 57,546 (SE = 1,287), approximately 8% (20,452) and 43% (40,294) higher than corresponding censored estimates. However, uncensored estimates may overestimate Chinook passage, because minimum range thresholds before 2000 were extended more frequently than they are presently.

In 2002, we developed two alternative methods of estimating the species composition for the inriver return based on: (1) catches in the drift gillnets, and (2) echo-length ("pulse width") measurements, analyzed with a mixture model. The first alternative method (see Methods and Eskelin 2007) uses data from gillnets drifted immediately below the sonar site to estimate the species composition of fish counted by the sonar. The second alternative method (Appendix H) is based on echo-length standard deviation (ELSD), which is a better hydroacoustic index of fish size than target strength (Burwen et al. 2003). Both methods offer the advantage of objective species discrimination and the means to assess the associated uncertainty. Although these alternative methods are experimental, we are hopeful that they will lead to more accurate estimates of Chinook salmon passage. At present, we compare the alternative methods with the "standard" sonar method to help gauge its accuracy.

Historically, we have also compared sonar estimates of Chinook passage with several other indices of Chinook and sockeye abundance to aid in evaluating accuracy of the sonar estimates. These indices include CPUE from gillnets drifted at the sonar site, Chinook CPUE in the sport fishery, and daily estimates of sockeye salmon at the river mile-19 sonar site.

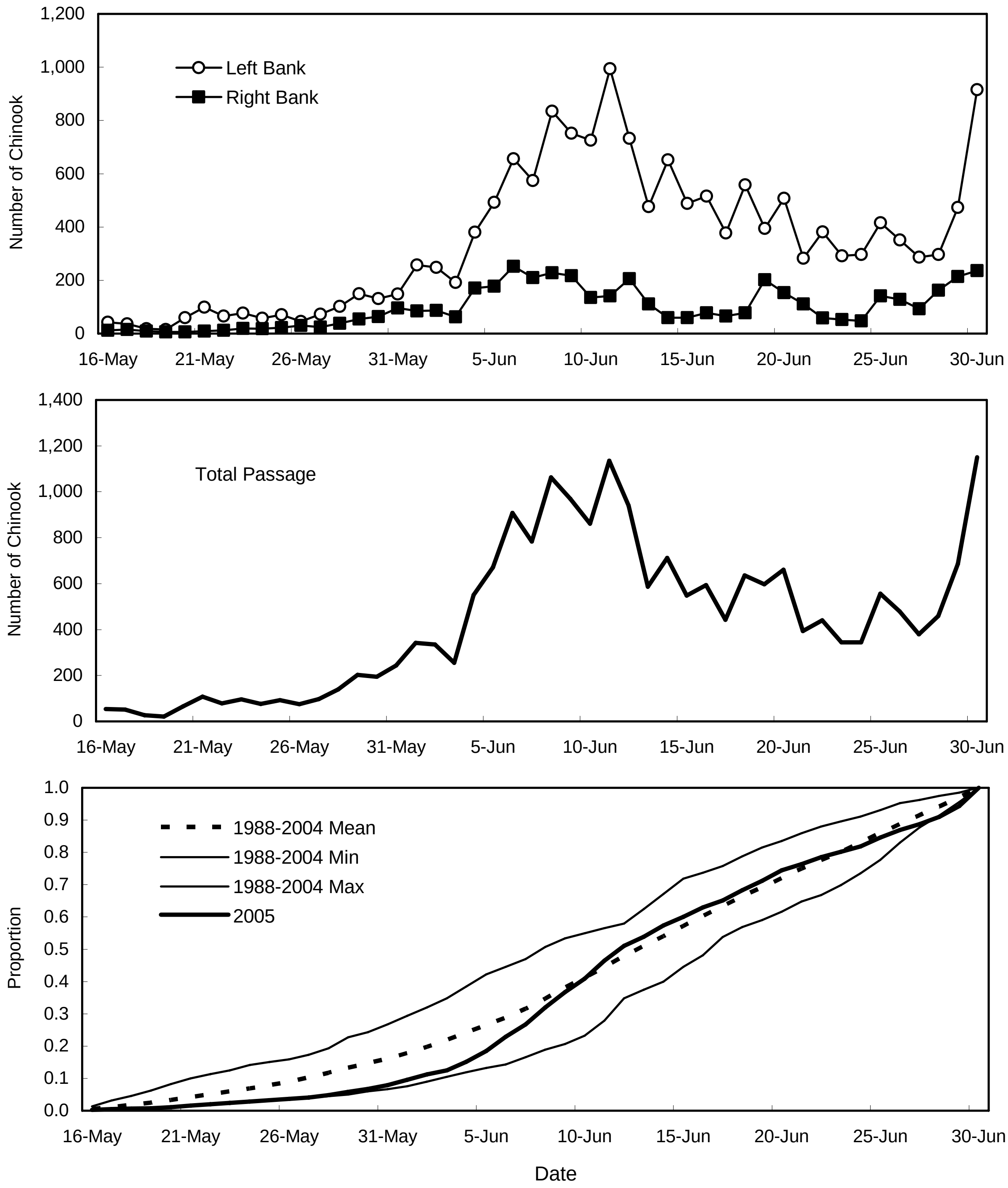
Table 11.-Daily upstream Chinook salmon passage estimates, Kenai River sonar, early run, 2005.

Date	Left Bank	Right Bank	Daily Total	Cumulative Total
16-May	42	12	54	54
17-May	36	15	51	105
18-May	18	9	27	132
19-May	15	6	21	153
20-May	60	6	66	219
21-May	99	9	108	327
22-May	66	12	78	405
23-May	77	19	96	501
24-May	58	18	76	577
25-May	71	22	93	670
26-May	45	30	75	745
27-May	73	24	97	842
28-May	102	38	140	982
29-May	149	54	203	1,185
30-May	131	64	195	1,380
31-May	148	96	244	1,624
1-Jun	257	85	342	1,966
2-Jun	248	87	335	2,301
3-Jun	192	63	255	2,556
4-Jun	380	171	551	3,107
5-Jun	493	178	671	3,778
6-Jun	656	252	908	4,686
7-Jun	574	210	784	5,470
8-Jun	835	228	1,063	6,533
9-Jun	752	217	969	7,502
10-Jun	726	135	861	8,363
11-Jun	994	141	1,135	9,498
12-Jun	733	206	939	10,437
13-Jun	476	111	587	11,024
14-Jun	652	60	712	11,736
15-Jun	488	60	548	12,284
16-Jun	516	78	594	12,878
17-Jun	377	66	443	13,321
18-Jun	558	78	636	13,957
19-Jun	395	202	597	14,554
20-Jun	508	153	661	15,215
21-Jun	283	111	394	15,609
22-Jun	381	59	440	16,049
23-Jun	292	52	344	16,393
24-Jun	297	47	344	16,737
25-Jun	416	141	557	17,294
26-Jun	351	128	479	17,773
27-Jun	287	93	380	18,153
28-Jun	297	162	459	18,612
29-Jun	473	214	687	19,299
30-Jun	915	236	1,151	20,450
Total	15,992	4,458	20,450	

Table 12.-Daily upstream Chinook salmon passage estimates, Kenai River sonar, late run, 2005.

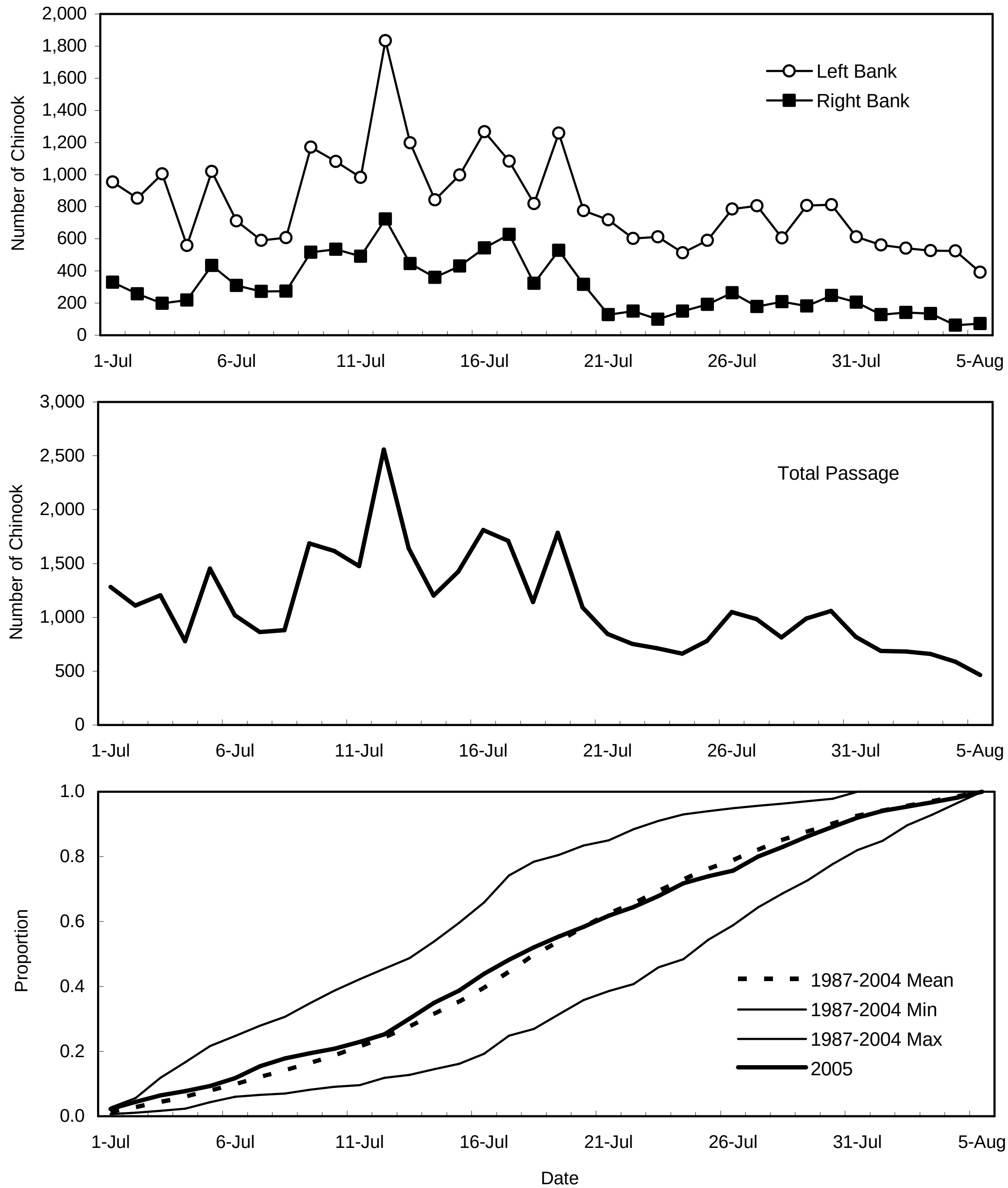
Date	Left Bank	Right Bank	Daily Total	Cumulative Total
1-Jul	954	329	1,283	1,283
2-Jul	852	257	1,109	2,392
3-Jul	1,005	199	1,204	3,596
4-Jul	559	219	778	4,374
5-Jul	1,020	434	1,454	5,828
6-Jul	711	309	1,020	6,848
7-Jul	591	272	863	7,711
8-Jul	607	275	882	8,593
9-Jul	1,170	517	1,687	10,280
10-Jul	1,081	535	1,616	11,896
11-Jul	983	492	1,475	13,371
12-Jul	1,834	723	2,557	15,928
13-Jul	1,198	445	1,643	17,571
14-Jul	843	360	1,203	18,774
15-Jul	997	430	1,427	20,201
16-Jul	1,267	544	1,811	22,012
17-Jul	1,083	627	1,710	23,722
18-Jul	819	323	1,142	24,864
19-Jul	1,258	528	1,786	26,650
20-Jul	775	316	1,091	27,741
21-Jul	719	128	847	28,588
22-Jul	602	150	752	29,340
23-Jul	612	100	712	30,052
24-Jul	513	149	662	30,714
25-Jul	590	192	782	31,496
26-Jul	786	264	1,050	32,546
27-Jul	806	179	985	33,531
28-Jul	605	209	814	34,345
29-Jul	807	182	989	35,334
30-Jul	812	247	1,059	36,393
31-Jul	613	206	819	37,212
1-Aug	562	127	689	37,901
2-Aug	541	141	682	38,583
3-Aug	526	134	660	39,243
4-Aug	525	62	587	39,830
5-Aug	392	72	464	40,294
6-Aug	-	-	776[a]	41,070
7-Aug	-	-	696[a]	41,766
8-Aug	-	-	657[a]	42,423
9-Aug	-	-	470[a]	42,893
10-Aug	-	-	347[a]	43,240
Total	-	-	43,240	

[a] Counting operations were terminated on 5 August. Daily passage for 6-10 August was estimated using total passage through 5 August and the mean proportion of passage from 6-10 August for years 1987-88, 1990, 1992-93, 1995, and 1998-2001.



Note: Mean in bottom panel is based on estimates of total passage for 1988-1997 and upstream passage for 1998-2004.

Figure 18.-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, 2005.



Note: Mean in bottom panel is based on passage through 5 August and on estimates of total passage for 1987-1997 and upstream passage for 1998-2004.

Figure 19.-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, 2005.

Gillnets have been drifted near the sonar site since the 1980s to estimate age composition (Reimer et al. 2002). In 1998, gillnetting methods were standardized to produce consistent estimates of CPUE, to compare within and between years as an index of Chinook salmon abundance. After analyzing 1998-2000 standardized data, we concluded that gillnet CPUE is an inconsistent index of abundance, because it is highly variable and is affected by river discharge and water clarity. Several changes to the gillnetting procedures were implemented in 2002: an additional mesh size (5.0 in) was added, 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).

Inriver sport fish CPUE, estimated with an intensive creel survey (Eskelin 2007), has historically been considered a useful index of Chinook salmon abundance. Recent observations indicate that this index has little or no predictive value, even after controlling for the effects of water clarity and discharge. However, we continue to present sport fish CPUE (Figures 20 and 21) for historical continuity.

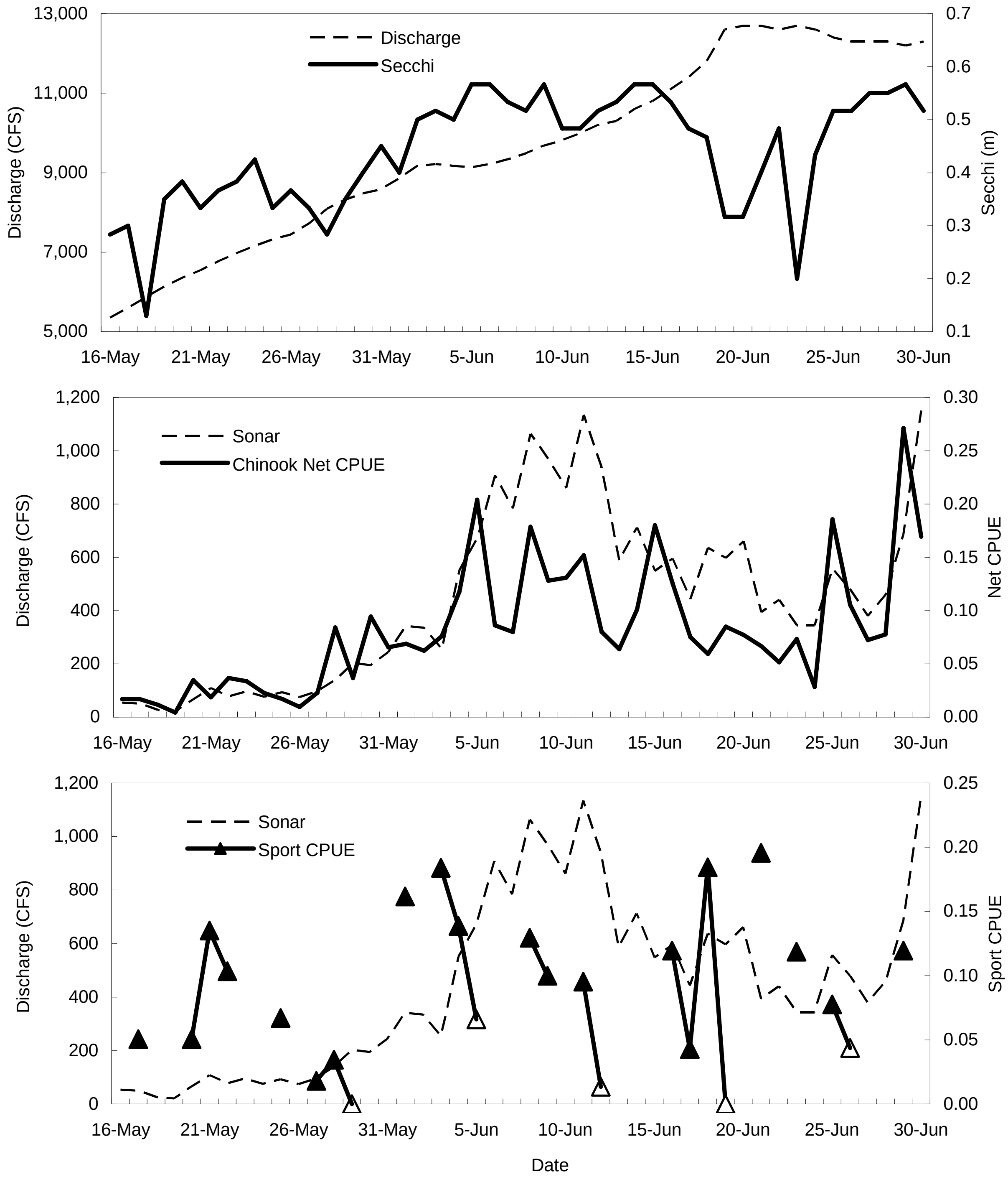
The river mile-19 sockeye sonar site, located upriver of the Chinook sonar site, provides an index of inriver sockeye salmon abundance. This sonar project is conducted from 1 July to mid August by the Commercial Fisheries Division and targets sockeye salmon near shore (Westerman and Willette 2007). Although travel time between the river mile-8.5 Chinook sonar site and the river mile-19 sockeye sonar site varies, we believe it averages 1 to 2 days. This project identifies periods when sockeye are abundant and when the potential for misclassifying sockeye as Chinook salmon may be high.

Early Run

The 2005 early-run standard sonar passage estimate of 20,450 Chinook salmon was above average (Appendix G1). Factors that may have influenced the early-run Chinook salmon passage estimate include the presence of eulachon *Thaleichthys pacificus* and sockeye salmon mid-river, a noise band on the right bank, and the preseason calibration error.

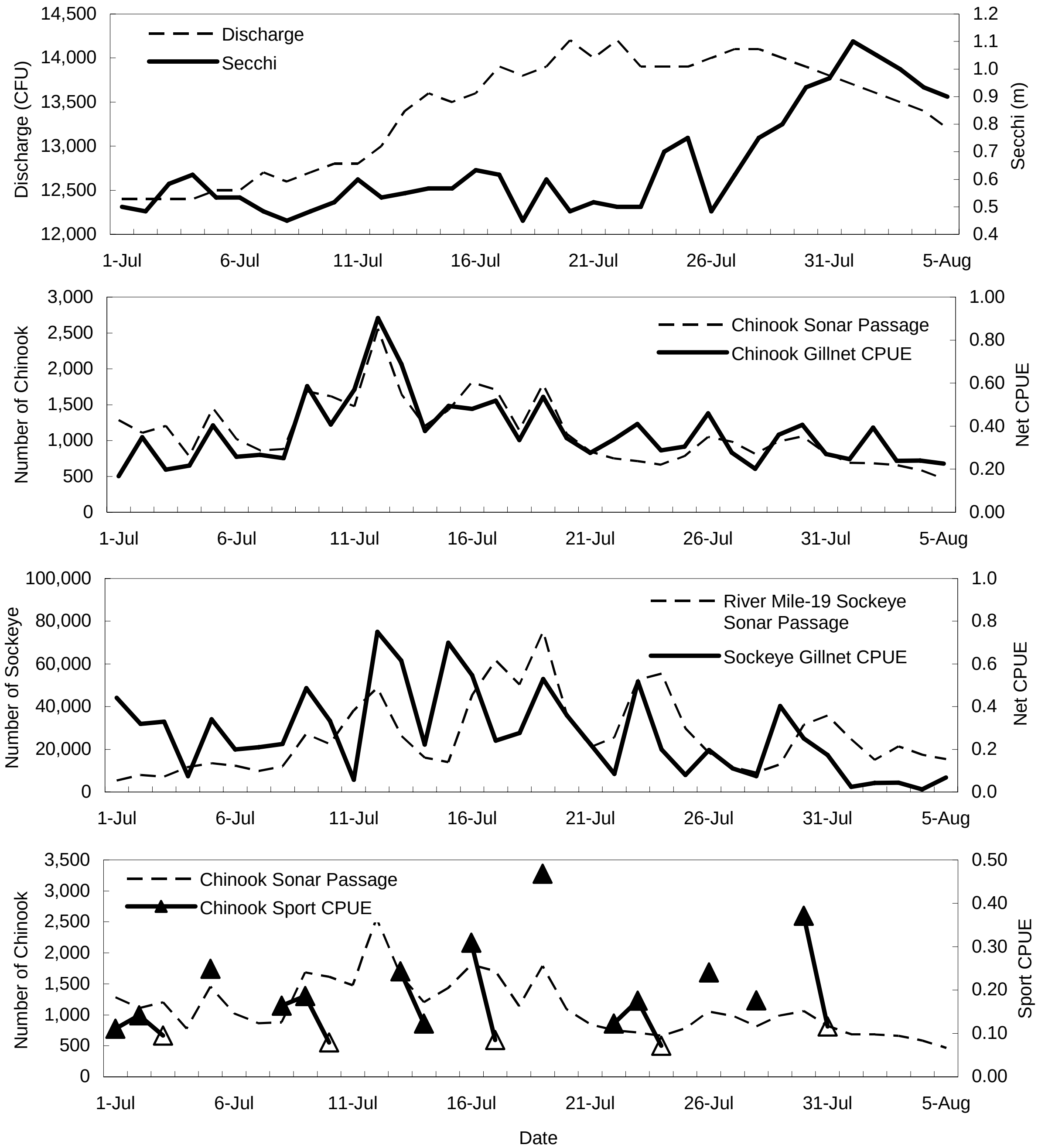
The upriver migration of eulachon in late May and early June resulted in some sound blockage, but the blockage did not appear severe enough to impact Chinook salmon passage estimates. A noise band observed occasionally on the right bank throughout the early run also caused some concern, but there were no indications that fish detection within or beyond the noise band was greatly affected. The noise band was similar to, but not as severe as, that observed in 2003 (Miller et al. 2005). If target detection were affected by the noise band or the eulachon schools, the result would be a reduced early-run Chinook salmon passage estimate.

In situ calibration verifications conducted on site indicated that voltage thresholds calculated from the preseason equipment calibration were too high. As a result, the right- and left-bank voltage thresholds were set lower at the beginning of the season than those suggested by the preseason calibration. The postseason calibration indicates the reduced threshold used during the season for the right bank was correct, but that the left bank threshold probably should have been set lower (by approximately 1 dB). The erroneously high voltage threshold on the left bank probably reduced the Chinook salmon passage estimate. There is no way to directly determine the magnitude of this error on the 2005 early-run estimate. However, when we applied a



Note: River discharge taken from USGS (2005). Net CPUE and sport fish CPUE taken from Eskelin (2007). Open triangles represent days on which only unguided anglers were allowed to fish.

Figure 20.-Daily discharge rates collected at the Soldotna Bridge, Secchi disk readings taken in front of the sonar site, Chinook salmon sonar passage estimates, inriver gillnet CPUE, and Chinook salmon sport fish CPUE, early run (16 May-30 June), Kenai River, 2005.



Note: River discharge taken from USGS (2005). River mile-19 sockeye sonar estimates taken from Westerman and Willette (2007). Net CPUE and sport fish CPUE taken from Eskelin (2007). The Chinook 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 21.-Daily discharge rates collected at the Soldotna Bridge, Secchi disk readings taken in front of the sonar site, Chinook salmon sonar passage estimates, inriver gillnet CPUE, river mile-19 sockeye sonar passage estimates, and Chinook salmon sport fish CPUE, late run (1 July-5 August), Kenai River, 2005.

hypothetical calibration error of similar magnitude to the 2004 early run, it reduced the passage estimate by 7%.

Conversely, net-apportioned estimates (Equation 16) tracked well with and were lower than the standard sonar estimates during most of the early run. The early-run total net-apportioned estimate of 12,413 (SE = 732) was 40% less than the standard early-run sonar estimate of 20,450 (Figure 22; Appendix I1). Likewise, the ELSD mixture model estimated 15,078 (SE = 577) Chinook salmon in the early run, approximately 26% lower than the standard estimate (Appendix H). The mixture model estimate was substantially lower than the standard estimate for 5 of the 7 weeks during the early run. The standard, ELSD, and net-apportioned estimates exhibited similar trends throughout the early run with the exception of the final week. In most cases, the net-apportioned estimate was the lowest of the three methods, while the standard estimate was the highest (Figure H4).

As in past years (Reimer et al. 2002) sonar estimates and gillnet CPUE tracked each other short-term, but the relationship appeared to change over time (Figure 20). General trends in increasing and decreasing passage were observed between the two methods, but the relative magnitude of the increases or decreases varied through time. Changes in discharge and water clarity may have influenced gillnet CPUE on 17-24 June (Figure 20).

Late Run

The 2005 late-run passage estimate of 40,294 Chinook salmon through 5 August was average (Appendix G2). As with the early run, the late-run passage estimate may have been influenced by the presence of sockeye salmon and the preseason calibration error.

The left-bank voltage threshold was lowered by 1 dB on 21 July when it became apparent that the left-bank threshold was set higher than it should have been because of the preseason calibration error. As with the early run, there is no way to determine the magnitude of the error on the 2005 late-run estimate. However, when we applied a hypothetical calibration error of similar magnitude to the 2004 late-run, it reduced the passage estimate by 6%.

Net-apportioned sonar estimates tracked the standard sonar estimates during the late run, but unlike the early run, were consistently higher than the standard sonar estimates (Figure 22, Appendix I2). The net-apportioned estimate was substantially higher than the standard sonar estimate for the third straight year. The cumulative net-apportioned estimate of 85,595 (SE = 3,456) Chinook salmon in 2005 was more than twice the standard sonar estimate. In 2003, the net-apportioned estimate was 48% higher than the standard sonar estimate, and was 43% higher in 2004 (Miller et al. 2005; Miller et al. 2007). The large net-apportioned estimate relative to sonar estimate in 2003 was partially attributed to the higher than average proportion of small Chinook observed that year (Miller et al. 2005). The proportion of small Chinook salmon (2-ocean age or less) in 2004 was less than in 2003 and was even smaller in 2005 (Eskelin 2007), so the difference in estimates may not be due to fish size.

Based on sockeye salmon gillnet CPUE and river mile-19 sockeye salmon sonar estimates (Figure 21), substantial numbers of sockeye salmon were present at the Chinook sonar site throughout much of July. Peak sockeye salmon gillnet CPUE occurred on 12 July, the same day as peak Chinook salmon sonar passage and peak Chinook gillnet CPUE. Throughout the late run, Chinook gillnet CPUE tracked well with the daily sonar estimates (Figure 21).

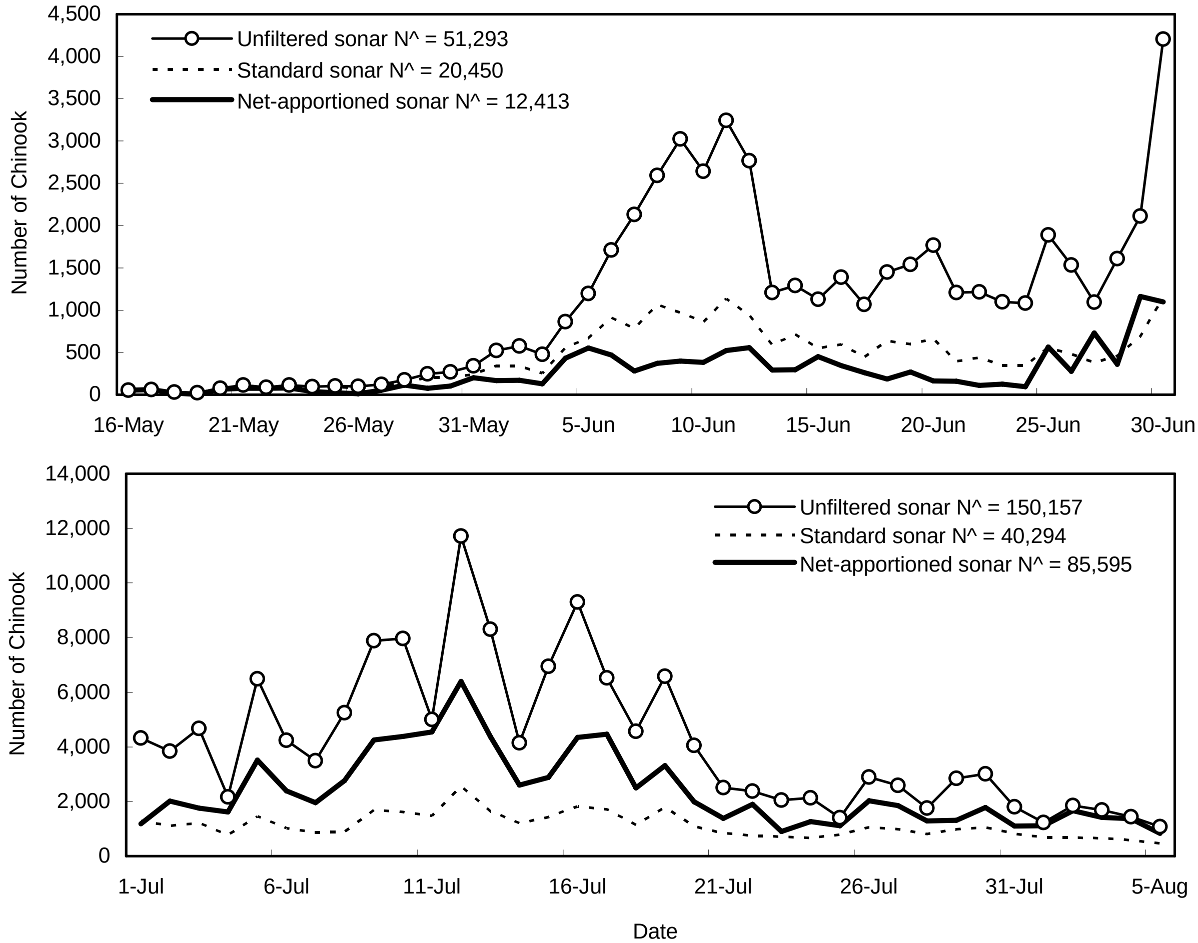


Figure 22.-Early- (top) and late-run (bottom) fish passage estimates based on unfiltered sonar (all species), standard filtered sonar (Chinook salmon only), and net-apportioned sonar (alternative Chinook salmon only), Kenai River, 2005.

OUTLOOK

Since the late 1990s, it is evident that species discrimination based on target strength is the weak link in our ability to accurately estimate Chinook salmon passage in the Kenai River. In 2005, the sensitivity of target strength to calibration errors was apparent, further underscoring its shortcoming as a species discriminator. Standard and alternative estimates of passage also contrasted sharply in 2005. For the first time, the alternative estimates were lower than the standard sonar estimate for the early run, and higher than the standard estimate for the late run. This suggests that there may be potential for occasionally misclassifying sockeye salmon as Chinook salmon in the early run.

The ELSD mixture model estimates, which fall between the standard and net-apportioned estimates, are arguably the most reasonable. Until now, we have produced these estimates only for the early run. ELSD measurements may be biased high during the late run because of interference from high fish densities. We will investigate ways to address this bias in 2006 using experimental paired split-beam and DIDSON data collected in 2005 (Burwen et al. *In prep*). We may then investigate the feasibility of producing ELSD mixture model estimates for the late run, or possibly replacing the target strength threshold with one based on ELSD. In 2006, any estimates will be tested on an experimental basis only, and compared to the standard sonar and net-apportioned estimates.

Finally, progress using DIDSON imaging sonar for species discrimination in the Kenai River is ongoing. The DIDSON manufacturers are currently developing a long-range model with improved resolution capabilities. It should be available for testing in 2007.

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APPENDIX A. TARGET STRENGTH ESTIMATION

Appendix A1.–The sonar equation used to estimate target strength (dB) 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 is estimated as:

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

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 are 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(θ,ϕ) must be estimated in order to estimate target strength. Dual-beam and split-beam sonar differ in how they estimate B(θ,ϕ), also called the beam pattern factor.

Dual-beam sonar (Ehrenberg 1983) uses one wide and one 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(θ,ϕ)). Split-beam transducers are divided into four 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-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	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	221.18	sl - transducer source level
202	-1	-169.37	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	47.3	echogram stop range in meters
211	-1	733	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.-Page 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	-16.1163	ux - horizontal electrical to mechanical angle ratio
223	-1	-28.8329	uy - vertical electrical to mechanical angle ratio
224	-1	0	ud_coef_a - a coeff. for up-down beam pattern eq.
225	-1	-0.0152	ud_coef_b - b coeff. for up-down beam pattern eq.
226	-1	-2.3219	ud_coef_c - c coeff. for up-down beam pattern eq.
227	-1	0.1387	ud_coef_d - d coeff. for up-down beam pattern eq.
228	-1	-0.168	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	0.0005	lr_coef_b - b coeff. for left-rt beam pattern eq.
231	-1	-0.2094	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	45	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.-Page 3 of 3.

Parameter Number	Subfield Number[a]	Parameter Value	Parameter Description
401	0	1	th_layer[0] – bottom of first threshold layer (m)
401	1	5	th_layer[1] – bottom of second threshold layer (m)
401	2	10	th_layer[2] – bottom of third threshold layer (m)
401	3	15	th_layer[3] – bottom of fourth threshold layer (m)
401	4	20	th_layer[4] – bottom of fifth threshold layer (m)
401	5	25	th_layer[5] – bottom of sixth threshold layer (m)
401	6	30	th_layer[6] – bottom of seventh threshold layer (m)
401	7	35	th_layer[7] – bottom of eighth threshold layer (m)
401	8	40	th_layer[8] – bottom of ninth threshold layer (m)
401	9	45	th_layer[9] – bottom of tenth threshold layer (m)
401	10	50	th_layer[10] – bottom of eleventh threshold layer (m)
401	11	55	th_layer[11] – bottom of twelfth threshold layer (m)
401	12	60	th_layer[12] – bottom of thirteenth threshold layer (m)
402	0	733	th_val[0], threshold for 1st layer in millivolts
402	1	733	th_val[1], threshold for 2nd layer in millivolts
402	2	733	th_val[2], threshold for 3rd layer in millivolts
402	3	733	th_val[3], threshold for 4th layer in millivolts
402	4	733	th_val[4], threshold for 5th layer in millivolts
402	5	733	th_val[5], threshold for 6th layer in millivolts
402	6	733	th_val[6], threshold for 7th layer in millivolts
402	7	733	th_val[7], threshold for 8th layer in millivolts
402	8	733	th_val[8], threshold for 9th layer in millivolts
402	9	733	th_val[9], threshold for 10th layer in millivolts
402	10	733	th_val[10], threshold for 11th layer in millivolts
402	11	733	th_val[11], threshold for 12th layer in millivolts
402	12	9999	th_val[12], threshold for 13th layer in millivolts
405	0	100	Integration threshold value for layer 1 (mV)
405	1	100	Integration threshold value for layer 2 (mV)
405	2	100	Integration threshold value for layer 3 (mV)
405	3	100	Integration threshold value for layer 4 (mV)
405	4	100	Integration threshold value for layer 5 (mV)
405	5	100	Integration threshold value for layer 6 (mV)
405	6	100	Integration threshold value for layer 7 (mV)
405	7	100	Integration threshold value for layer 8 (mV)
405	8	100	Integration threshold value for layer 9 (mV)
405	9	100	Integration threshold value for layer 10 (mV)
405	10	100	Integration threshold value for layer 11 (mV)
405	11	100	Integration threshold value for layer 12 (mV)
405	12	9999	Integration threshold value for layer 13 (mV)
602	-1	1017536	Echo sounder serial number
604	-1	306733	Transducer serial number
605	-1	Spd-4	Echogram paper speed
606	-1	9_pin	Echogram resolution
607	-1	Board_Exte	Trigger option
608	-1	LeftToRight	River flow direction

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

Note: Start Processing at Port 1 -FILE_PARAMETERS- Friday 1 July 12:00:08 2005

Note: Data processing parameters used in collecting this file for Port 1

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	69	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	69	N_int_layers-number of integration strata
123	-1	69	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	218.37	sl - transducer source level
202	-1	-170.89	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	29.5	echogram stop range in meters
211	-1	479	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-

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	-16.0303	ux - horizontal electrical to mechanical angle ratio
223	-1	-53.8422	uy - vertical electrical to mechanical angle ratio
224	-1	0	ud_coef_a - a coeff. for up-down beam pattern eq.
225	-1	0.0062	ud_coef_b - b coeff. for up-down beam pattern eq.
226	-1	-2.5614	ud_coef_c - c coeff. for up-down beam pattern eq.
227	-1	-0.1478	ud_coef_d - d coeff. for up-down beam pattern eq.
228	-1	-0.1434	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	-0.2238	lr_coef_c - c coeff . for left-rt beam pattern eq.
232	-1	-0.0004	lr_coef_d - d coeff. for left-rt beam pattern eq.
233	-1	-0.0001	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	27.8	bottom - bottom depth in meters
239	-1	0	init_slope - initial slope for tracking in m/ping
240	-1	1	exp_cont - exponent for expanding tracking window
241	-1	0	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)

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Appendix B2.-Page 3 of 3.

Parameter Number	Subfield Number[a]	Parameter Value	Parameter Description
401	0-68	1-35	th_layer[0-68], bottom of 1st threshold layer – bottom of 69th threshold layer (i.e. 69 threshold layers in 0.5 m increments and numbered 0 through 68)
402	0-67	479	th_val[0-67], threshold for 1st through 68th layer in millivolts
402	68	9999	th_val[68], threshold for 69th layer in millivolts
405	0-67	100	Integration threshold value for layer 1-68 (mV)
405	68	9999	Integration threshold value for layer 69 (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_Exte	Trigger option
608	-1	LeftToRight	River flow direction

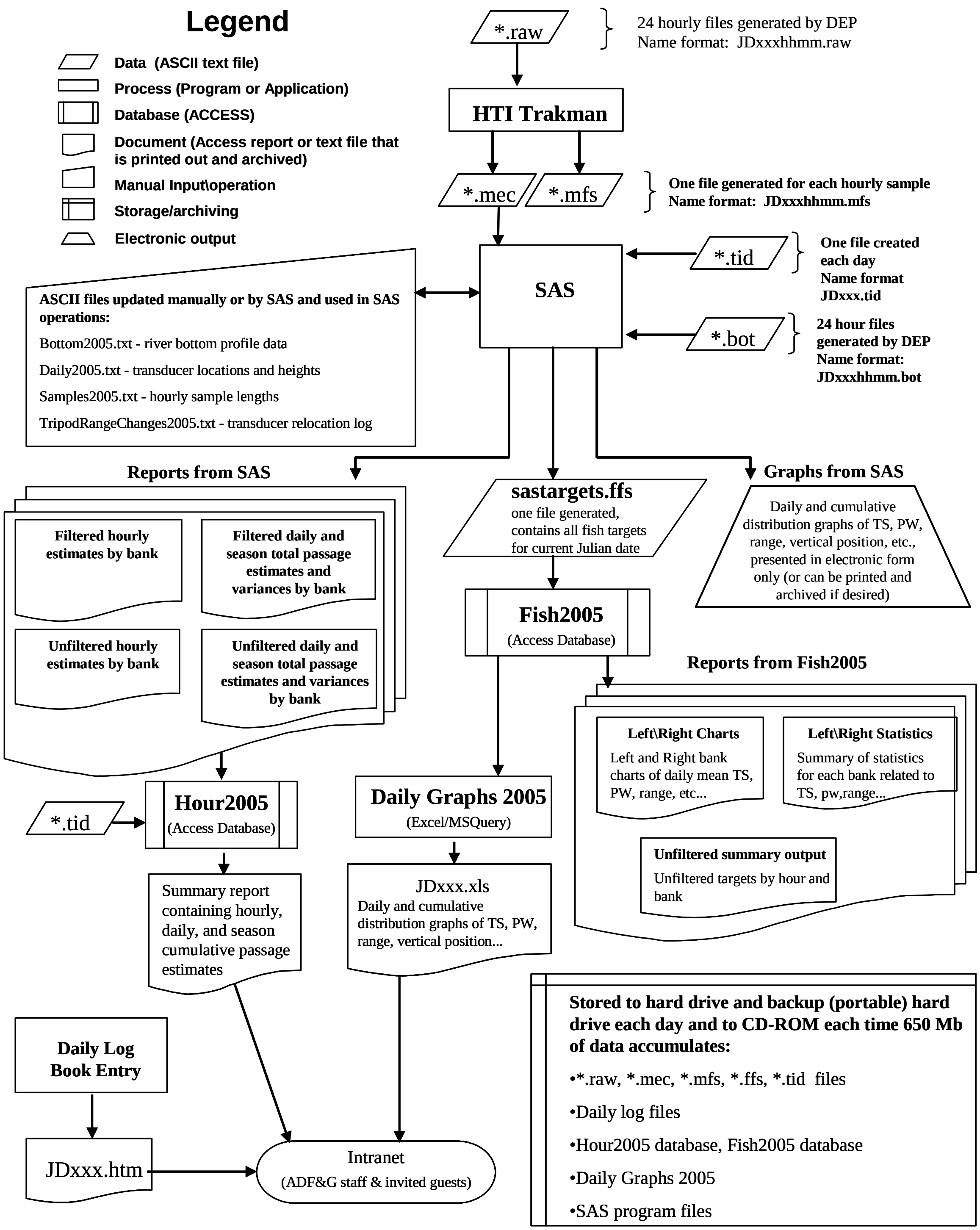
[a] -1 = unique record/field; other values represent the threshold layer number

Note: Start Processing at Port 2 -FILE_PARAMETERS- Friday 1 July 12:20:09 2005

Note: Data processing parameters used in collecting this file for Port 2

APPENDIX C. DATA FLOW

Appendix C1.–Data flow diagram for the Kenai River Chinook salmon sonar project, 2005.



APPENDIX D. EXCLUDED HOURLY SAMPLES

Appendix D1.–Hourly samples excluded by bank from calculation of early- and late-run Chinook salmon daily passage estimates, Kenai River, 2005.

Date	Excluded Sample Hours	
	Left Bank	Right Bank
EARLY RUN		
28-May	-	1000-1200, 1400, 1600-1800
30-May	-	1000-1300
7-June	1920-2020	-
8-June	1120, 2120	-
9-June	1120, 2120-2220	2100
10-June	1120, 2220-2320	1800
11-June	0520, 1820-1920	0500, 1900
12-June	0620, 1220, 1920-2020	1900-2000
15-June	0920-1020	-
16-June	1120	-
17-June	1220, 1720	-
18-June	1320, 1820, 2320	-
19-June	-	1700
23-June	1020, 1220	-
24-June	2100	2120
25-June	0920, 2120-2220	2100
26-June	-	1900
28-June	-	0900
29-June	-	1000, 2200
30-June	1220, 2320	1200, 2300
LATE RUN		
1-July	1320	1300
2-July	1320-1420	1300-1400
3-July	1420-1620, 1920	1400-1600, 1900
4-July	-	1500-1700
5-July	0220, 0520, 0820, 1520, 2120	1500-1600
6-July	1620	0300, 1600-1700
7-July	1620-1720	1700
8-July	0420, 1720	0400, 1700-1900
9-July	0420, 1720-1820	0400, 1800-1900
10-July	0520-0620, 1820-1920	0500-0700, 1800-2000
11-July	0620, 1120-1220, 1820-1920	0600-0700, 1900-2000
12-July	0720, 1220-1320, 1920	0700-0900, 2000-2100
13-July	0820-0920, 2020-2220	0800-0900, 2000-2200
14-July	2020-2120	1000, 2100-2200
15-July	1020, 2120-2220	2100-2300
16-July	1120-1420, 2220	1200-1400, 2200-2300
17-July	1320-1420, 2320	1300-1400, 2300
18-July	0020-0120	0000-0100, 1400-1600
19-July	0620-0720	0000, 1400-1600
20-July	1620	1500-1700
21-July	0220, 1520, 1820	0200, 1600, 1800
22-July	0720-0820, 1620	1600
23-July	0920	0800

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Appendix D1.-Page 2 of 2.

Date	Excluded Sample Hours	
	Left Bank	Right Bank
24-July	2220	1400-1700, 2200-2300
25-July	-	0500-0700, 1800
26-July	0720-0820, 1920	0700-0800, 1900
27-July	0820	0800-0900, 2000-2100
28-July	-	2100-2200
29-July	1220, 2220-2320	1200, 2200-2300
30-July	1320-1420	1300-1400, 2300
31-July	0020	0000
1-August	-	1600
2-August	1520, 2020	1500-1600
3-August	-	1500-1600
4-August	-	1600-1800
5-August	1620	1600

APPENDIX E. DAILY PROPORTION OF UPSTREAM AND DOWNSTREAM MOVING FISH FOR THE CHINOOK SALMON EARLY AND LATE RUNS, KENAI RIVER, 2005

Appendix E1.–Daily proportion of upstream and downstream moving fish for the Chinook salmon early run, Kenai River, 2005.

Date	Downstream Count	Upstream Count	Daily Total	% Downstream	% Upstream
16 May	3	54	57	5%	95%
17 May	0	51	51	0%	100%
18 May	0	27	27	0%	100%
19 May	0	21	21	0%	100%
20 May	3	66	69	4%	96%
21 May	6	108	114	5%	95%
22 May	0	78	78	0%	100%
23 May	2	96	98	2%	98%
24 May	2	76	78	3%	97%
25 May	4	93	97	4%	96%
26 May	3	75	78	4%	96%
27 May	9	97	106	8%	92%
28 May	16	140	156	10%	90%
29 May	21	203	224	9%	91%
30 May	3	195	198	2%	98%
31 May	27	244	271	10%	90%
1 June	12	342	354	3%	97%
2 June	15	335	350	4%	96%
3 June	12	255	267	4%	96%
4 June	30	551	581	5%	95%
5 June	56	671	727	8%	92%
6 June	30	908	938	3%	97%
7 June	14	784	798	2%	98%
8 June	9	1,063	1,072	1%	99%
9 June	0	969	969	0%	100%
10 June	5	861	866	1%	99%
11 June	2	1,135	1,137	0%	100%
12 June	6	939	945	1%	99%
13 June	9	587	596	2%	98%
14 June	3	712	715	0%	100%
15 June	6	548	554	1%	99%
16 June	9	594	603	1%	99%
17 June	6	443	449	1%	99%
18 June	15	636	651	2%	98%
19 June	7	597	604	1%	99%
20 June	18	661	679	3%	97%
21 June	6	394	400	2%	99%
22 June	0	440	440	0%	100%
23 June	7	344	351	2%	98%
24 June	9	344	353	3%	97%
25 June	3	557	560	1%	99%
26 June	12	479	491	2%	98%
27 June	42	380	422	10%	90%
28 June	34	459	493	7%	93%
29 June	12	687	699	2%	98%
30 June	18	1,151	1,169	2%	98%
Total	506	20,450	20,956	2%	98%

Appendix E2.–Daily proportion of upstream and downstream moving fish for the Chinook salmon late run, Kenai River, 2005.

Date	Downstream Count	Upstream Count	Daily Total	% Downstream	% Upstream
1 July	63	1,283	1,346	5%	95%
2 July	101	1,109	1,210	8%	92%
3 July	22	1,204	1,226	2%	98%
4 July	31	778	809	4%	96%
5 July	52	1,454	1,506	3%	97%
6 July	78	1,020	1,098	7%	93%
7 July	73	863	936	8%	92%
8 July	42	882	924	5%	95%
9 July	102	1,687	1,789	6%	94%
10 July	130	1,616	1,746	7%	93%
11 July	64	1,475	1,539	4%	96%
12 July	149	2,557	2,706	6%	94%
13 July	135	1,643	1,778	8%	92%
14 July	72	1,203	1,275	6%	94%
15 July	65	1,427	1,492	4%	96%
16 July	123	1,811	1,934	6%	94%
17 July	120	1,710	1,830	7%	93%
18 July	101	1,142	1,243	8%	92%
19 July	126	1,786	1,912	7%	93%
20 July	69	1,091	1,160	6%	94%
21 July	98	847	945	10%	90%
22 July	94	752	846	11%	89%
23 July	93	712	805	12%	88%
24 July	73	662	735	10%	90%
25 July	74	782	856	9%	91%
26 July	99	1,050	1,149	9%	91%
27 July	47	985	1,032	5%	95%
28 July	50	814	864	6%	94%
29 July	55	989	1,044	5%	95%
30 July	99	1,059	1,158	9%	91%
31 July	103	819	922	11%	89%
1 August	102	689	791	13%	87%
2 August	137	682	819	17%	83%
3 August	60	660	720	8%	92%
4 August	28	587	615	5%	95%
5 August	37	464	501	7%	93%
Total	2,967	40,294	43,261	7%	93%

APPENDIX F. AVERAGE VERTICAL ANGLE BY TIDE STAGE, RUN, BANK, AND FISH ORIENTATION (UPSTREAM OR DOWNSTREAM) FOR THE CHINOOK SALMON EARLY AND LATE RUNS, KENAI RIVER, 2005

Appendix F1.–Average vertical angle by tide stage and orientation for the Chinook salmon early run, Kenai River, 2005.

Tide Stage /Fish Orientation	Average Vertical Angle	Standard Deviation	Sample Size
	Left Bank		
Falling			
Downstream	-0.12	0.61	22
Upstream	-0.52	0.28	3,383
Tide Stage Total	-0.52	0.29	3,405
Low			
Downstream	-0.46	0.30	11
Upstream	-0.54	0.24	1,083
Tide Stage Total	-0.54	0.24	1,094
Rising			
Downstream	-0.10	0.59	19
Upstream	-0.26	0.45	1,153
Tide Stage Total	-0.25	0.46	1,172
Left Bank Total	-0.47	0.34	5,671
	Right Bank		
Falling			
Downstream	0.03	0.46	77
Upstream	-0.24	0.30	815
Tide Stage Total	-0.22	0.33	892
Low			
Downstream	-0.22	0.32	17
Upstream	-0.41	0.33	137
Tide Stage Total	-0.39	0.33	154
Rising			
Downstream	-0.13	0.27	32
Upstream	-0.08	0.31	765
Tide Stage Total	-0.09	0.31	797
Right Bank Total	-0.18	0.33	1,843

Appendix F2.–Average vertical angle by tide stage and orientation for the Chinook salmon late run, Kenai River, 2005.

Tide Stage /Fish Orientation	Average Vertical Angle	Standard Deviation	Sample Size
	Left Bank		
Falling			
Downstream	-0.27	0.35	248
Upstream	-0.42	0.28	5,437
Tide Stage Total	-0.41	0.28	5,685
Low			
Downstream	-0.26	0.29	136
Upstream	-0.43	0.24	1,686
Tide Stage Total	-0.41	0.24	1,822
Rising			
Downstream	-0.04	0.48	197
Upstream	-0.11	0.45	4,214
Tide Stage Total	-0.11	0.45	4,411
Left Bank Total	-0.30	0.38	11,918
	Right Bank		
Falling			
Downstream	0.01	0.30	377
Upstream	-0.03	0.31	1,562
Tide Stage Total	-0.02	0.31	1,939
Low			
Downstream	0.00	0.33	148
Upstream	0.02	0.36	281
Tide Stage Total	0.01	0.35	429
Rising			
Downstream	0.01	0.27	441
Upstream	-0.05	0.25	5,911
Tide Stage Total	-0.05	0.25	6,352
Right Bank Total	-0.04	0.27	8,720

APPENDIX G. HISTORIC PASSAGE BY YEAR AND DATE (1987–2005)

Appendix G1.–Kenai River early-run Chinook salmon sonar passage estimates, 1987-2005.

Date/Year	1987[a]	1988	1989	**1990**	**1991**	**1992**	1993	1994	1995	1996	**1997**	**1998[bc]**	1999[c]	**2000[c]**	2001[c]	**2002[c]**	2003[c]	2004[c]	2005[c]
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	33	18	62	24	35	24	54
17 May		415	319	57	12	48	85	342	99	91	99	45	63	49	111	21	35	30	51
18 May		259	264	93	65	88	91	260	78	63	93	57	66	54	117	54	63	31	27
19 May		260	180	136	55	40	66	302	149	96	165	36	39	84	133	60	81	57	21
20 May		406	147	93	68	78	69	369	228	177	84	54	116	64	156	66	123	48	66
21 May		184	245	69	51	90	165	327	465	165	129	33	186	84	101	42	162	84	108
22 May		182	164	75	111	108	117	246	265	156	114	15	192	123	128	36	174	61	78
23 May		231	186	63	66	150	160	212	286	159	162	12	243	132	81	36	237	153	96
24 May		288	279	51	66	126	141	303	265	159	138	33	159	147	147	33	168	129	76
25 May		351	300	76	57	79	150	170	198	153	165	81	141	234	175	48	129	138	93
26 May		393	270	70	81	93	168	150	189	240	220	43	330	186	278	65	195	240	75
27 May		387	419	87	81	66	150	267	165	204	325	60	342	177	314	75	192	324	97
28 May		483	357	61	78	78	361	258	159	330	317	63	402	84	291	103	180	452	140
29 May		713	269	221	51	45	538	347	222	512	288	63	378	204	323	57	248	233	203
30 May		333	164	154	51	111	388	321	351	348	350	129	273	105	440	90	183	156	195
31 May		501	157	175	69	114	266	369	282	474	318	93	459	117	276	85	225	128	244

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Date/Year	1987[a]	1988	1989	**1990**	**1991**	**1992**	1993	1994	1995	1996	**1997**	**1998[bc]**	1999[c]	**2000[c]**	2001[c]	**2002[c]**	2003[c]	2004[c]	2005[c]
1 June		556	258	153	150	106	187	321	357	603	213	111	633	192	259	210	294	148	342
2 June		545	194	294	240	107	412	266	369	741	241	189	444	250	316	216	195	91	335
3 June		598	233	225	362	232	324	298	549	873	376	192	540	282	328	119	389	72	255
4 June	1,059	755	246	178	177	190	255	304	693	1,051	324	186	924	266	255	144	435	143	551
5 June	552	782	280	192	316	166	276	351	429	943	427	**162**	876	139	519	120	381	301	671
6 June	1,495	493	384	156	**296**	319	327	198	807	741	327	**150**	807	186	432	165	464	239	908
7 June	1,145	506	545	**304**	**215**	515	198	384	843	773	591	**283**	672	237	427	140	422	474	784
8 June	602	771	890	**414**	**243**	375	297	306	999	918	441	**300**	609	108	486	202	615	665	1,063
9 June	1,024	569	912	**339**	**444**	**486**	378	462	789	1,140	391	**234**	504	135	591	466	605	730	969
10 June	985	333	913	**272**	**275**	**264**	453	432	876	684	527	**327**	439	207	639	246	395	784	861
11 June	1,004	320	710	**453**	**334**	**234**	549	423	774	882	512	**600**	596	315	575	211	446	754	1,135
12 June	1,044	302	577	**568**	**400**	**394**	600	329	417	864	537	**1,168**	723	165	1,357	118	284	525	939
13 June	2,168	188	599	**445**	**369**	**236**	951	376	492	1,071	681	**719**	393	**337**	939	**142**	153	438	587
14 June	1,297	289	458	**330**	**268**	**174**	811	514	691	1,111	424	**912**	610	**309**	647	**118**	292	282	712
15 June	975	510	335	**658**	**441**	**312**	407	306	636	1,116	318	**951**	436	**571**	600	**138**	291	446	548
16 June	786	808	397	**485**	**615**	**239**	616	453	648	420	348	**770**	696	**441**	499	**110**	204	440	594
17 June	612	535	514	**267**	**330**	**339**	567	315	750	495	**405**	**675**	807	**765**	364	**251**	205	422	443
18 June	783	533	464	**238**	**493**	**320**	606	435	808	697	**315**	**498**	742	**591**	607	**243**	137	383	636
19 June	771	200	295	**331**	**437**	**390**	422	636	419	657	**399**	**510**	771	**348**	559	**201**	313	581	597
20 June	682	175	498	**369**	**314**	**548**	504	402	594	315	**408**	**351**	1,247	**319**	418	**187**	365	461	661
21 June	517	373	520	**257**	**457**	**372**	621	570	438	351	**252**	**309**	1,192	**522**	417	**228**	474	461	394
22 June	487	312	614	**267**	**433**	**297**	399	366	375	396	**390**	**273**	819	**456**	345	**213**	428	532	440
23 June	529	375	547	**240**	**396**	**213**	607	550	178	401	**225**	**294**	935	**462**	272	**153**	386	552	344
24 June	303	674	564	**322**	**251**	**337**	720	696	450	573	**285**	**288**	1,151	**408**	240	**193**	522	666	344
25 June	564	582	374	**258**	**235**	**362**	808	734	429	684	**332**	**228**	1,292	**186**	213	**330**	450	520	557
26 June	731	436	369	**322**	**261**	**330**	1,051	597	334	504	**381**	**219**	731	**359**	203	**381**	414	240	479
27 June	452	549	309	**231**	**340**	**291**	1,158	639	946	228	**363**	**207**	678	615	220	**310**	237	255	380
28 June	587	827	425	**240**	**327**	**253**	798	681	696	303	**297**	**308**	537	489	224	**186**	231	426	459
29 June	371	495	376	**208**	**258**	**121**	728	929	984	234	**570**	**363**	753	516	191	**231**	362	530	687
30 June	388	915	292	**193**	**270**	**197**	660	649	615	351	**582**	**276**	687	441	403	**295**	506	649	1,151
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**	25,666	**12,479**	16,676	**7,162**	13,325	15,498	20,450

[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 before the normal start date (16 May).

[c] Only upstream moving fish are reported.

Note: Bold and outlined numbers represent the dates that the Chinook fishery was restricted because of low inriver return.

Appendix G2.–Kenai River late-run Chinook salmon sonar passage estimates, 1987-2005.

Date/Year	1987	1988	1989	**1990**	1991	**1992**	1993[a]	1994[a]	1995	1996	1997	**1998**[b]	1999[b]	2000[b]	2001[b]	2002[b]	2003[b]	2004[b]	2005[b]
1 July	507	526	769	578	267	364	619	663	350	341	486	491	453	461	697	563	727	1,167	1,283
2 July	429	404	489	305	300	297	525	342	398	240	642	597	612	373	766	1,596	735	1,125	1,109
3 July	405	398	353	486	333	320	404	625	353	303	600	480	486	370	1,075	2,456	982	1,053	1,204
4 July	628	292	566	436	519	198	468	858	439	393	633	450	396	488	714	1,855	1,212	715	778
5 July	596	482	1,106	853	316	225	429	705	667	1,067	657	606	369	787	676	1,949	1,684	842	1,454
6 July	523	654	879	795	242	331	996	975	720	879	627	612	683	778	645	1,205	1,462	1,231	1,020
7 July	769	379	680	929	186	247	1,746	1,050	931	780	1,158	660	936	1,020	887	1,241	1,322	1,932	863
8 July	483	725	776	432	139	170	2,142	655	417	867	1,221	462	1,030	1,713	751	1,069	1,666	1,287	882
9 July	384	471	1,404	309	393	205	2,078	744	519	768	1,618	480	1,047	1,632	568	1,618	1,183	815	1,687
10 July	314	1,732	560	359	481	221	955	1,289	450	1,023	3,486	450	717	1,461	908	1,533	1,880	757	1,616
11 July	340	1,507	2,010	778	403	143	1,402	509	325	1,146	5,649	171	1,059	1,038	858	1,369	1,693	1,061	1,475
12 July	751	1,087	2,763	557	330	1,027	671	828	276	714	4,497	192	560	1,506	575	1,245	1,289	1,208	2,557
13 July	747	2,251	910	1,175	308	605	3,572	1,072	570	1,128	5,373	262	401	2,327	1,148	1,288	1,227	2,567	1,643
14 July	761	2,370	2,284	1,481	572	689	3,425	1,332	714	4,437	2,031	368	969	2,709	1,448	1,034	697	2,577	1,203
15 July	913	2,405	1,111	1,149	542	745	2,353	2,221	750	3,222	4,042	1,118	636	2,808	1,338	450	1,212	1,943	1,427
16 July	1,466	1,259	1,344	1,011	1,029	703	2,421	3,802	1,962	3,494	3,420	1,416	927	2,264	1,201	1,253	1,107	2,718	1,811
17 July	1,353	1,520	963	2,395	2,052	570	2,098	4,692	1,128	2,253	4,584	1,424	3,558	1,915	2,415	1,481	1,482	2,262	1,710
18 July	841	2,180	1,382	2,113	3,114	853	1,472	2,157	3,942	2,820	2,334	1,638	2,784	2,154	2,065	1,001	1,731	2,008	1,142
19 July	2,071	1,724	425	1,363	1,999	1,128	714	3,504	4,692	2,236	1,146	1,146	1,869	1,919	1,568	915	1,773	1,753	1,786
20 July	3,709	2,670	820	1,499	1,422	1,144	1,383	2,328	4,779	2,609	1,578	741	3,471	1,155	994	964	1,384	1,566	1,091
21 July	3,737	3,170	916	787	1,030	799	959	1,695	3,132	3,435	894	1,608	3,354	933	786	970	1,153	1,757	847
22 July	1,835	1,302	583	573	1,050	619	1,140	1,386	3,465	2,250	1,840	1,411	1,998	702	497	845	2,159	1,401	752
23 July	1,700	1,502	756	642	2,632	1,449	1,146	1,050	2,421	3,050	1,441	808	1,875	760	526	1,637	1,693	1,812	712
24 July	2,998	1,386	783	1,106	2,204	**711**	1,376	1,320	831	3,634	1,080	933	1,748	1,868	529	1,175	1,774	2,044	662
25 July	1,915	999	495	810	1,306	**1,713**	2,253	1,444	840	3,240	532	542	1,937	1,761	676	974	1,525	1,107	782
26 July	1,968	924	432	671	1,216	**1,296**	1,421	1,432	1,683	2,319	519	723	1,098	1,034	667	930	1,149	941	1,050
27 July	1,523	960	618	755	1,195	**1,561**	1,945	1,289	1,806	1,782	438	807	3,066	992	775	591	1,449	2,277	985
28 July	2,101	1,398	538	**603**	1,901	**1,957**	1,906	2,226	789	861	333	**954**	1,358	999	1,070	707	909	1,540	814
29 July	1,923	1,400	441	**546**	1,146	**1,533**	1,400	1,333	558	474	401	**1,255**	1,185	1,029	928	406	808	1,724	989
30 July	2,595	1,158	391	**382**	791	**1,198**	1,680	1,769	510	621	450	**1,556**	969	577	508	571	691	1,523	1,059
31 July	2,372	910	383	**316**	974	**951**	873	1,808	480	1,548	420	**1,344**	1,308	549	883	540	751	1,480	819
1 August	470	925	351	**393**	897	**921**	776	1,037	474		247	**909**	591	695	455	642	377	1,078	689
2 August	314	781	201	**388**	867	**1,018**	626	1,223	369		291	**1,512**	468	421	459	553	394	688	682
3 August	263	989	132	**533**	392	**837**	350	1,078	447		213	**1,006**	642	294	504	752	379	722	660

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Appendix G2.-Page 2 of 2.

Date/Year	1987	1988	1989	**1990**	1991	**1992**	1993[a]	1994[a]	1995	1996	1997	**1998[b]**	1999[b]	2000[b]	2001[b]	2002[b]	2003[b]	2004[b]	2005[b]
4 August	835	1,524	142	**717**	331	**862**	467	658	519			**1,131**	444	453	840	995		754	587
5 August	904	1,091	107	**723**	174	**861**	711	536	404			**1,094**	436	489	581	575		940	464
6 August	648	1,333	107	**552**	343	**654**	1,076	1,042	408			**864**	654	504	417	754[c]		1,009[c]	776[c]
7 August	694	1,186	65	**516**	618	**558**	655	797	279			**843**	678	366	618	676[c]		905[c]	696[c]
8 August	658	1,449		**682**	600	**217**	682		267			**750**	804	417	467	636[c]		854[c]	657[c]
9 August	368	1,132		**679**		**165**	424		272			**570**	328	399	232	456[c]		611[c]	470[c]
10 August	312	755		**678**		**249**	252					**496**	165	397	200	337[c]		451[c]	347[c]
11 August		698		**547**															
12 August				**362**															
13 August				**221**															
14 August				**139**															
15 August				**150**															
Total	48,123	52,008	29,035[d]	**33,474**	34,614	**30,314**	51,991	53,474[e]	44,336[f]	53,934[g]	54,881[h]	**34,878**	48,069	44,517	33,916	41,807	41,659[i]	56,205	43,240

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

[b] Only upstream moving fish are reported.

[c] Sampling was terminated on 5 August because of budget constraints. Values for 6-10 August were inferred from previous years.

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

[e] Sampling was terminated on 7 August because pink salmon were spawning in the insonified area.

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

[g] Sampling was terminated on 31 July because pink salmon were spawning in the insonified area.

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

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

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

APPENDIX H. ECHO-LENGTH STANDARD DEVIATION MIXTURE MODEL ESTIMATES OF SPECIES COMPOSITION AND CHINOOK SALMON ABUNDANCE, EARLY RUN, KENAI RIVER, 2005.

Appendix H1.-Echo-length standard deviation mixture model estimates of species composition and Chinook salmon abundance, early run, Kenai River, 2005.

We currently use a target strength threshold to help separate Chinook from sockeye salmon in the Kenai River. Target strength is a measure of the intensity ("loudness") of an echo returning from a fish. Several years ago, we discovered that echo-length (duration) measurements can be superior to target strength as predictors of fish size and species in side-looking riverine sonar applications (Burwen and Fleischman 1998; Burwen et al. 2003). Unfortunately, because the relationship between echo length and fish size is not perfect, and because Kenai River sockeye and Chinook salmon overlap in size, even echo-length measurements cannot ascertain the species of individual fish.

In this situation a threshold-based approach (assigning individuals to one species or another depending on whether or not a measurement exceeds a threshold) has several important drawbacks. When distributions overlap, threshold-based discrimination is subject to bias that worsens for species proportions near 0 and 1 (Figure H1). Furthermore, results are sensitive to fish size distributions. For instance, in the example illustrated in Figure H1, the number of Chinook salmon misclassified as sockeye (number with ELSD < 2.7) depends largely on the relative abundance of small Chinook, which can change over time. In fact, use of such a threshold by itself does not discriminate Chinook from sockeye, but rather large Chinook from sockeye and small Chinook.

Consequently, we have developed other methods, based on mixture models, which extract information about species composition from the frequency distribution of echo-length measurements. Because the mixture model approach incorporates information about fish size distributions, and because it explicitly models the expected variability in hydroacoustic measurements, it is not subject to the above pitfalls. There is no bias against extreme proportions, and the estimates are germane to the entire population of Chinook salmon, not just those Chinook larger than sockeye. Finally, as long as length and hydroacoustic measurements are paired in time, mixture model estimates of species proportions are unbiased in the presence of temporal changes in fish size distribution. An abbreviated description of the approach is presented here, along with results from the 2004 early run. See Fleischman and Burwen (2003) for more details.

Methods

We used echo-length standard deviation (ELSD) as the hydroacoustic correlate of fish size:

$$ELSD = \sqrt{\sum_{j=1}^{m} \left(w_j - \overline{w}\right)^2 \Big/ m-1}\,, \qquad \text{(H1)}$$

where m was the number of echoes and w_j was 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 > 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 < 6 dB above threshold, w_j was not defined.

Recent work (unpublished) indicates that targets located far from the acoustic axis may suffer a slight negative bias in ELSD. Therefore, only those fish less than 3 dB off-axis were used in the analyses. These fish comprised 61% of all fish in the 2004 early run dataset.

The probability density function (pdf) of hydroacoustic variable *y* (= ELSD) was modeled as a weighted mixture of two component distributions arising from sockeye and Chinook salmon (Figure H2),

$$f(y) = \pi_S f_S(y) + \pi_C f_C(y), \tag{H2}$$

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

Individual observations of *y* were modeled as normal random variates whose mean was a linear function of fish length *x*:

$$y_i = \beta_0 + \beta_1 x_i + \gamma z_i + \varepsilon_i \tag{H3}$$

where β_0 was the intercept; β_1 the slope; γ was the mean difference in *y* between sockeye and Chinook after controlling for length; z_i equaled 1 if fish *i* was a sockeye salmon, or 0 if Chinook; and ε_i was 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 H2). The species proportions π_S and π_C were the parameters of interest.

Length measurements were obtained from fish captured by gillnets (Eskelin 2007) immediately downstream of the sonar site. Length data were paired with hydroacoustic data from the same time periods. In this analysis, we assume no gillnet size selectivity.

Sockeye and Chinook salmon return from the sea to spawn at several discrete ages. We modeled the species-specific length distributions as three-component normal age mixtures.

$$f_S(x) = \theta_{S1} f_{S1}(x) + \theta_{S2} f_{S2}(x) + \theta_{S3} f_{S3}(x) \tag{H4}$$

$$f_C(x) = \theta_{C1} f_{C1}(x) + \theta_{C2} f_{C2}(x) + \theta_{C3} f_{C3}(x) \tag{H5}$$

where θ_{Ca} and θ_{Sa} were the proportions of Chinook and sockeye salmon in age component *a*,

$$f_{Sa}(x) \sim N(\mu_{Sa},,\tau^2_{Sa}), \text{ and} \tag{H6}$$

$$f_{Ca}(x) \sim N(\mu_{Ca},,\tau^2_{Ca}). \tag{H7}$$

The overall design was a mixture of (transformed) mixtures. That is, the observed hydroacoustic data were modeled as a two-component mixture of *y*, each component of which was transformed from a three-component normal mixture of *x*.

We employed Bayesian statistical methods because they provide realistic estimates of uncertainty and the ability to incorporate auxiliary information. We implemented the Bayesian mixture model in WinBUGS (<u>B</u>ayes <u>U</u>sing <u>G</u>ibbs <u>S</u>ampler; Gilks et al. 1994). Bayesian methods require that prior probability distributions be formulated for all unknowns in the model. Species proportions π_S and π_C were assigned an uninformative dirichlet(1,1) prior. Likewise, age proportions $\{\theta_{Sa}\}$ and $\{\theta_{Ca}\}$ were assigned dirichlet(1,1,1) priors. Informative normal priors, based on historical data, were used for the length-at-age means μ and standard deviations τ.

Informative priors were also used for regression parameters β_0, β_1, γ, and σ^2. Linear statistical models of tethered fish data reported by Burwen et al. (2003) provided estimates of the regression parameters with which to construct those prior distributions (Table H1).

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. Some parameters exhibited slow mixing and large positive autocorrelations. Therefore, relatively long burn-ins of 10,000 or more samples were used and samples thereafter, were thinned up to 10 to 1. 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 our model, this distribution has many dimensions and cannot be presented in its entirety. Generally, what is of interest are the marginal (one-dimensional) probability distributions of the parameters. These probability distributions can be graphed, and one can extract whichever statistics are needed, such as the mean, standard deviation, and/or various percentiles like 2.5, 5, 25, 50 (the median), 75, 95, 97.5. For values that can be interpreted as point estimates, we have chosen the posterior median. The interpretation of this value is as follows: there is an even (50/50) chance that the true value of the parameter lies above or below the posterior median. The posterior standard deviation (SD) is analogous to the standard error of an estimate from a classical (non-Bayesian) statistical analysis.

Sample size limitations necessitated pooling the data by week. Week one was 16-22 May, week six was 20-26 June, and week seven (incomplete, because the early run ended 30 June) was 27-30 June. Posterior medians of the Chinook proportion parameter π_C were multiplied by unfiltered sonar estimates $\hat{x}_i$ to obtain estimates of absolute Chinook abundance y'' for week w.

$$\hat{y}''_w = \hat{\pi}_{Cw} \sum_{i \in w} \hat{x}_i \qquad \text{(H8)}$$

Results

Weekly statistics from the marginal posterior distributions of model parameters are summarized in Table H1. Posterior distributions of regression parameters shifted only slightly among weeks. Mixture model estimates totaled 15,078 (SE = 577) for the early run, lower than the official estimate of 20,450 (SE = 295) and higher than the net-apportioned estimate of 12,413 (SE = 732). Modeled ELSD frequency distributions fit the weekly ELSD data reasonably well (Figure H3). Weekly mixture model estimates were between official estimates and net-apportioned estimates in most weeks (Figure H4). Weekly estimates by the two alternative methods have shown good agreement during 2002-2005 (Figure H5). Further comparisons of alternative early-run abundance estimates can be found in this report (see Results).

Table H1.-Summary statistics of prior and posterior distributions of parameters estimated from a Bayesian mixture model analysis of 7 weeks of Kenai River sonar and gillnetting data, 2005.

	Mean	Std Dev	2.5%	Median	97.5%
Priors for regression parameters based on tethered fish experiments					
β_0	2.87	0.27	2.47	2.87	3.28
β_1	0.032	0.003	0.026	0.032	0.038
γ	-0.33	0.11	-0.55	-0.33	-0.10
σ	0.43	0.026	0.39	0.43	0.49
Week 1 Posteriors: 23 fish netted, 42 hydroacoustic targets					
β_0	3.01	0.16	2.74	3.00	3.34
β_1	0.036	0.003	0.030	0.036	0.042
γ	-0.26	0.13	-0.52	-0.26	-0.02
σ	0.49	0.03	0.44	0.49	0.56
π_C	0.78	0.09	0.59	0.79	0.92
Week 2 Posteriors: 70 fish netted, 182 hydroacoustic targets					
β_0	2.86	0.10	2.67	2.86	3.05
β_1	0.036	0.003	0.030	0.036	0.042
γ	-0.30	0.13	-0.55	-0.30	-0.04
σ	0.51	0.03	0.46	0.51	0.56
π_C	0.40	0.05	0.31	0.40	0.50
Week 3 Posteriors: 139 fish netted, 1043 hydroacoustic targets					
β_0	2.90	0.09	2.73	2.90	3.08
β_1	0.041	0.003	0.035	0.041	0.047
γ	-0.36	0.13	-0.58	-0.32	-0.08
σ	0.52	0.02	0.49	0.52	0.56
π_C	0.39	0.02	0.35	0.39	0.44
Week 4 Posteriors: 383 fish netted, 4933 hydroacoustic targets					
β_0	2.82	0.08	2.67	2.81	2.97
β_1	0.055	0.002	0.050	0.055	0.059
γ	-0.05	0.10	-0.26	-0.05	0.15
σ	0.52	0.01	0.50	0.52	0.55
π_C	0.29	0.02	0.26	0.29	0.33
Week 5 Posteriors: 225 fish netted, 2541 hydroacoustic targets					
β_0	2.90	0.11	2.70	2.90	3.11
β_1	0.043	0.003	0.037	0.043	0.050
γ	-0.24	0.15	-0.52	-0.24	0.04
σ	0.56	0.02	0.53	0.56	0.59
π_C	0.32	0.03	0.26	0.32	0.39

-continued-

Table H1.-Page 2 of 2.

Week 6 Posteriors: 307 fish netted, 2878 hydroacoustic targets					
β_0	2.98	0.11	2.77	2.98	3.20
β_1	0.044	0.003	0.037	0.044	0.049
γ	-0.22	0.15	-0.53	-0.22	0.07
σ	0.55	0.02	0.52	0.55	0.58
π_C	0.25	0.03	0.20	0.25	0.32
Week 7 Posteriors: 146 fish netted, 2699 hydroacoustic targets					
β_0	3.04	0.12	2.80	3.04	3.29
β_1	0.045	0.004	0.038	0.045	0.050
γ	-0.13	0.18	-0.49	-0.13	0.22
σ	0.67	0.02	0.64	0.67	0.70
π_C	0.26	0.02	0.22	0.26	0.31

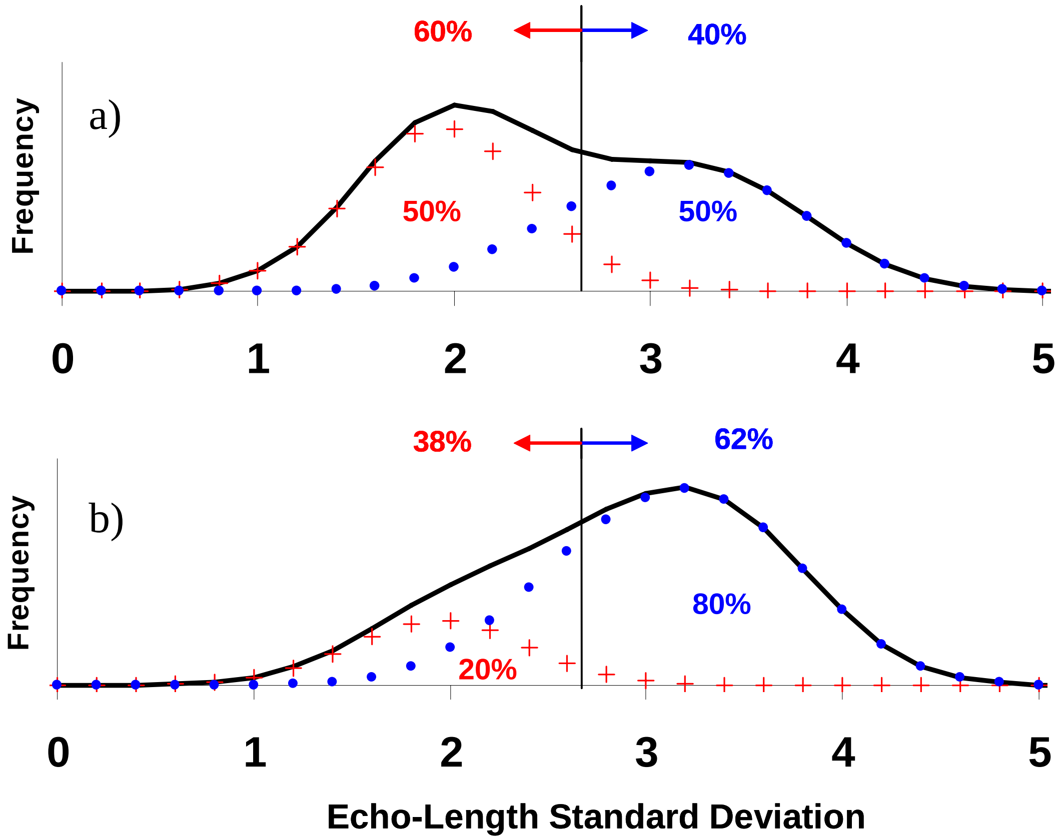

Figure H1.–Threshold-based discrimination is subject to bias when discriminating variables are imprecise. Solid lines are simulated frequency distributions of echo-length standard deviation arising from component distributions due to sockeye salmon (plus symbols) and Chinook salmon (solid symbols). (a) If the true species composition is 50% sockeye / 50% Chinook salmon, and a threshold criterion of 2.7 is used, estimated species composition will be 60% / 40%. (b) If the true species composition is 20% / 80%, estimated species composition will be 38% / 62%.

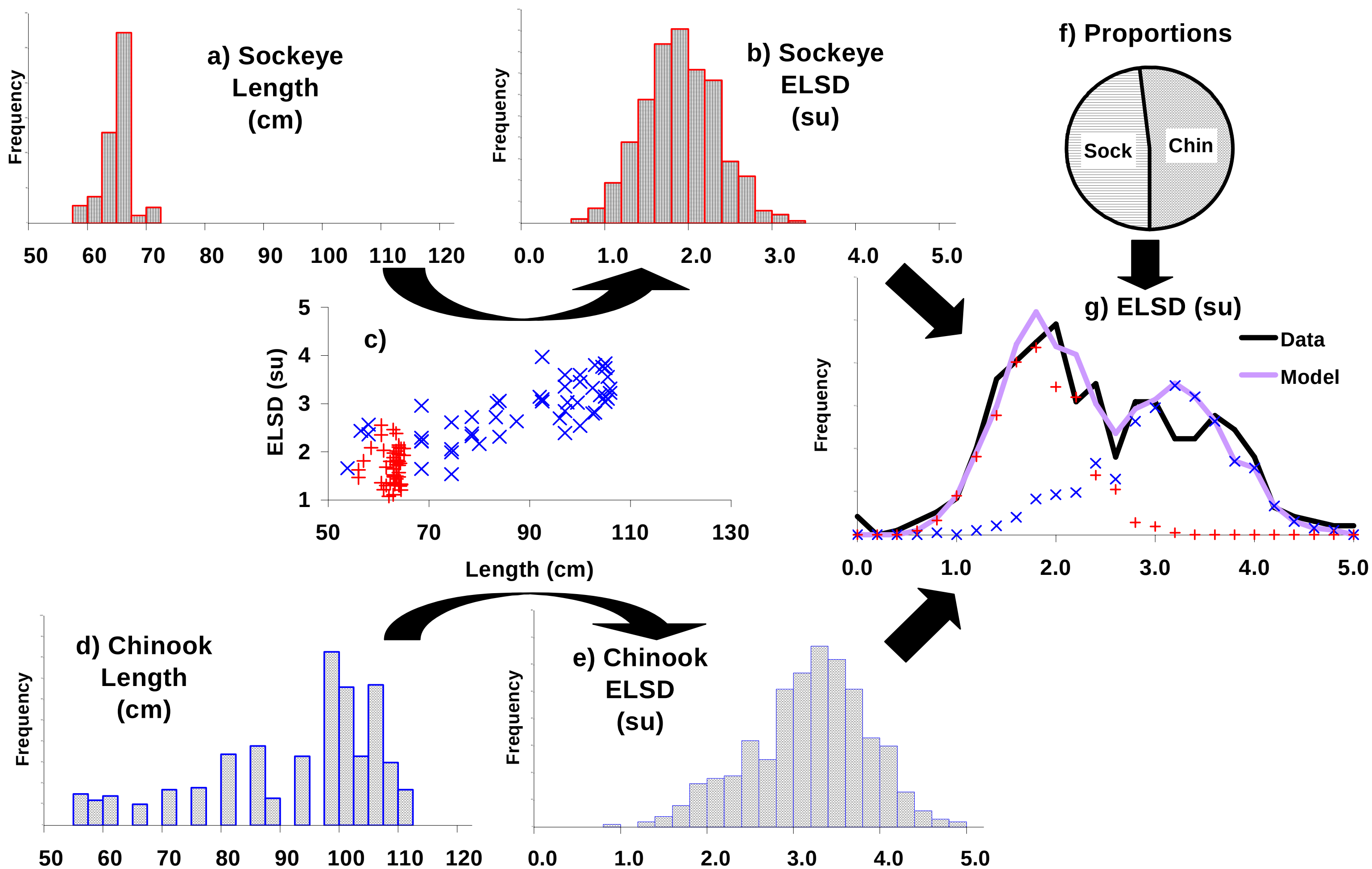

Figure H2.–Flow chart of mixture model. The frequency distribution of echo-length standard deviation (ELSD, panel g) is modeled as a weighted mixture of species-specific ELSD distributions (panels b and e), which in turn are the products of species-specific size distributions (panels a and d) and the relationship between ELSD and fish length (panel c). The weights (species proportions, panel f) are the parameters of interest. Plus symbol = sockeye, x = Chinook. Units for ELSD are 48 kHz digital sampling units.

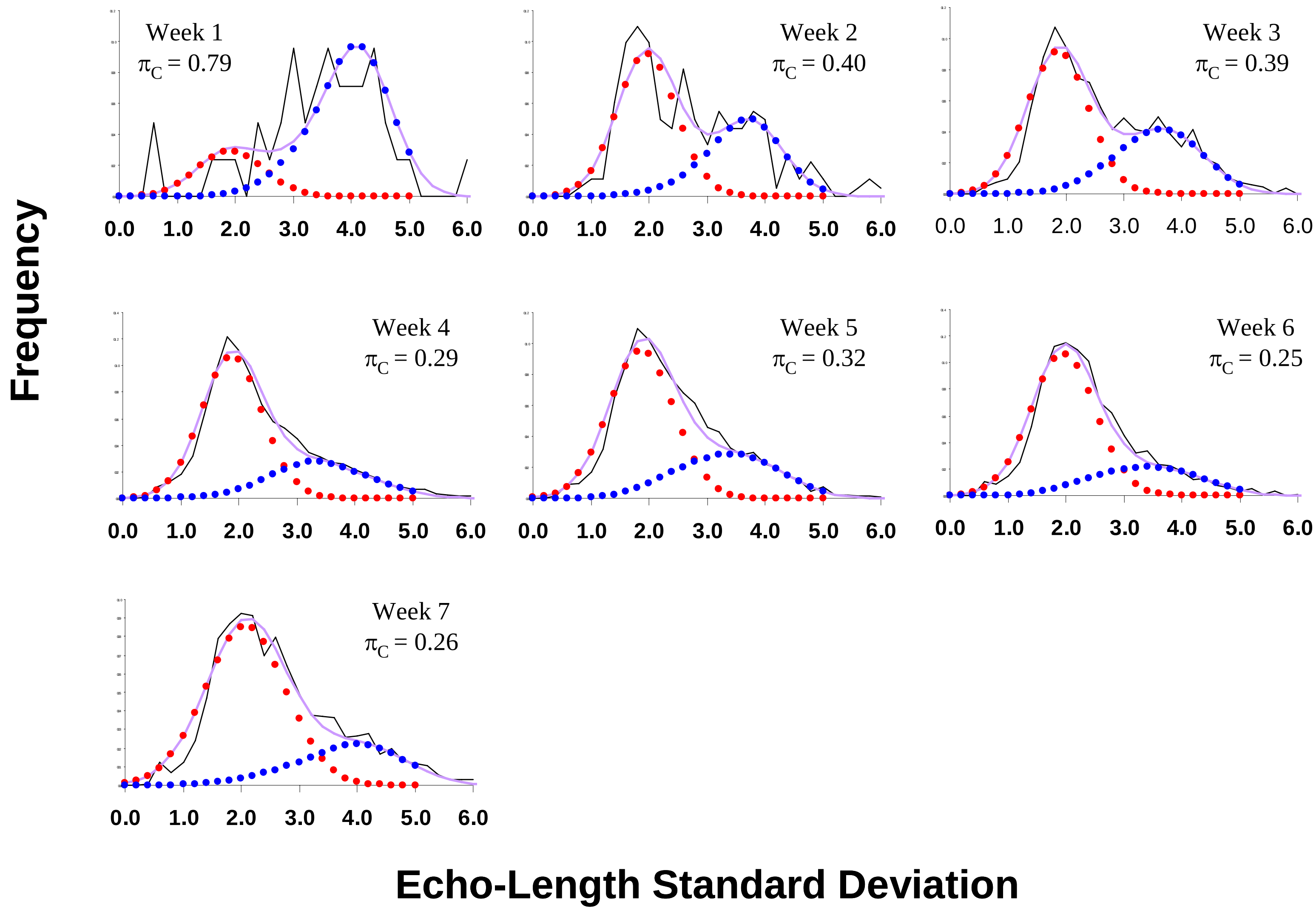

Figure H3.–Observed (black) and fitted (gray) frequency distributions of echo-length standard deviation (ELSD) from the 2005 early run by week. Dotted-lines are the component distributions from sockeye (left) and Chinook salmon (right). The posterior median of the proportion of Chinook salmon πC is listed in the header of each panel.

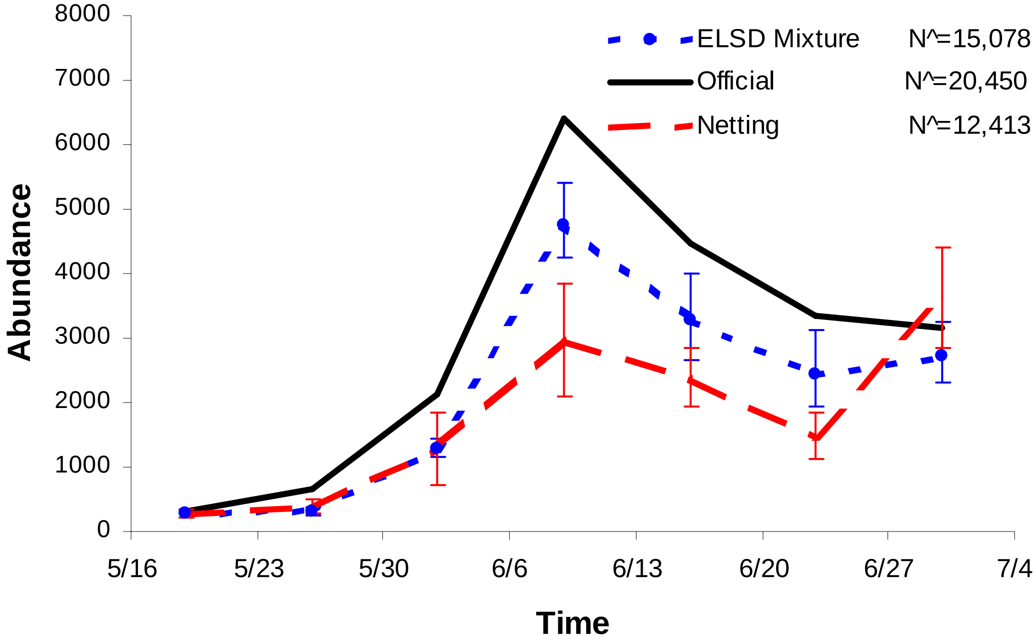

Figure H4.–Weekly Chinook salmon abundance estimates for the 2005 Kenai River early run. Solid-line = official estimates; dashed-line = net-apportioned estimates; dotted-line = ELSD mixture model estimates. Error bars represent 95% CI for netting and mixture estimates.

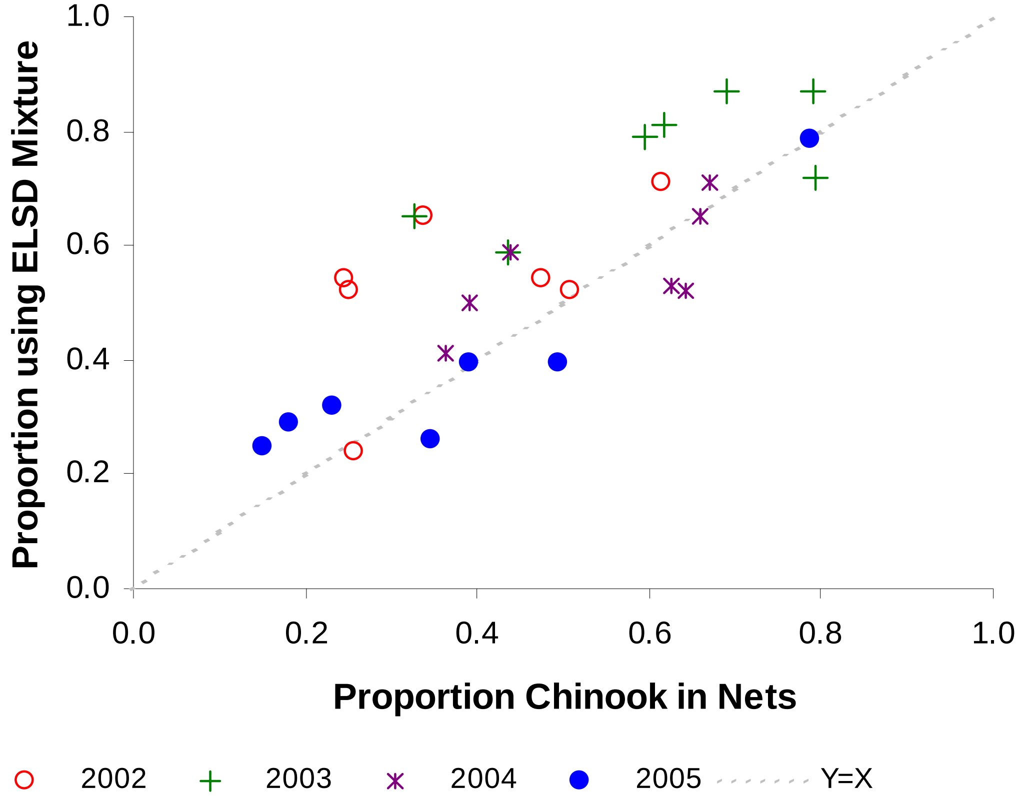

Figure H5.–Weekly ELSD mixture model estimates vs. net-apportioned estimates of the proportion of fish passing the Kenai River sonar site that are Chinook salmon, early run, 2002-2005.

APPENDIX I. FILTERED (CONVENTIONAL), UNFILTERED, AND NET-APPORTIONED CHINOOK SALMON PASSAGE ESTIMATES, KENAI RIVER SONAR, EARLY AND LATE RUNS, 2005

Appendix I1.–Estimated fish passage based on unfiltered sonar (all species), standard filtered sonar (Chinook salmon only), and net-apportioned sonar (alternative Chinook salmon only), Kenai River, early run, 2005.

Date	Unfiltered		Filtered (Standard)		Net-Apportioned	
	Passage	SE	Passage	SE	Passage	SE
16-May	54	9	54	10	54	9
17-May	60	10	51	9	60	10
18-May	30	9	27	9	21	10
19-May	24	6	21	6	5	5
20-May	75	10	66	8	65	11
21-May	115	14	108	14	77	24
22-May	87	14	78	11	75	16
23-May	115	24	96	23	78	24
24-May	93	20	76	17	37	13
25-May	102	18	93	18	23	7
26-May	98	18	75	17	10	5
27-May	121	19	97	16	52	28
28-May	174	21	140	18	114	18
29-May	245	25	203	20	75	37
30-May	267	21	195	19	104	20
31-May	340	29	244	27	202	35
1-Jun	523	32	342	28	166	24
2-Jun	575	41	335	26	171	49
3-Jun	476	42	255	32	127	46
4-Jun	862	55	551	45	430	187
5-Jun	1,196	92	671	67	553	204
6-Jun	1,710	123	908	68	471	174
7-Jun	2,130	268	784	53	280	103
8-Jun	2,591	187	1,063	68	370	80
9-Jun	3,023	229	969	77	399	142
10-Jun	2,642	204	861	78	381	119
11-Jun	3,244	249	1,135	64	523	321
12-Jun	2,766	196	939	65	556	127
13-Jun	1,208	66	587	46	291	103
14-Jun	1,290	93	712	68	296	64
15-Jun	1,126	108	548	57	450	97
16-Jun	1,390	98	594	32	345	105
17-Jun	1,068	80	443	35	261	104
18-Jun	1,449	118	636	54	186	49
19-Jun	1,541	104	597	49	267	79
20-Jun	1,769	100	661	50	161	96
21-Jun	1,208	77	394	39	157	59
22-Jun	1,214	79	440	40	111	39
23-Jun	1,096	67	344	23	124	23
24-Jun	1,082	72	344	30	94	42
25-Jun	1,888	126	557	45	565	99
26-Jun	1,531	109	479	43	276	81
27-Jun	1,093	69	380	37	732	142
28-Jun	1,607	127	459	47	358	138
29-Jun	2,110	172	687	58	1,160	124
30-Jun	4,205	306	1,151	77	1,099	324
Total	51,29	779	20,450	295	12,413	732

Appendix I2.–Estimated fish passage based on unfiltered sonar (all species), standard filtered sonar (Chinook salmon only), and net-apportioned sonar (alternative Chinook salmon only), Kenai River, late run, 2005.

Date	Unfiltered		Filtered (Standard)		Net-Apportioned	
	Passage	SE	Passage	SE	Passage	SE
1-Jul	4,321	331	1,283	71	1,185	350
2-Jul	3,847	284	1,109	68	2,011	164
3-Jul	4,680	488	1,204	77	1,758	343
4-Jul	2,168	158	778	53	1,614	221
5-Jul	6,494	921	1,454	87	3,520	1,037
6-Jul	4,245	355	1,020	66	2,393	312
7-Jul	3,495	247	863	64	1,960	353
8-Jul	5,249	731	882	53	2,763	549
9-Jul	7,880	813	1,687	73	4,257	1,440
10-Jul	7,962	705	1,616	91	4,379	455
11-Jul	5,003	471	1,475	99	4,545	439
12-Jul	11,713	1,439	2,557	145	6,398	1,259
13-Jul	8,303	725	1,643	92	4,383	1,443
14-Jul	4,144	433	1,203	73	2,606	332
15-Jul	6,950	458	1,427	84	2,878	453
16-Jul	9,304	760	1,811	122	4,351	869
17-Jul	6,529	455	1,710	87	4,460	1,009
18-Jul	4,566	500	1,142	72	2,501	573
19-Jul	6,588	554	1,786	94	3,318	612
20-Jul	4,058	280	1,091	80	1,988	265
21-Jul	2,503	212	847	70	1,379	564
22-Jul	2,377	187	752	53	1,900	391
23-Jul	2,045	144	712	59	904	154
24-Jul	2,138	163	662	84	1,260	138
25-Jul	1,406	115	782	50	1,114	92
26-Jul	2,898	246	1,050	58	2,031	362
27-Jul	2,587	220	985	57	1,850	219
28-Jul	1,757	130	814	57	1,284	173
29-Jul	2,851	162	989	71	1,313	192
30-Jul	3,009	189	1,059	64	1,781	259
31-Jul	1,802	111	819	50	1,097	171
1-Aug	1,225	94	689	45	1,115	112
2-Aug	1,849	159	682	49	1,669	146
3-Aug	1,685	221	660	48	1,421	307
4-Aug	1,444	157	587	42	1,373	163
5-Aug	1,082	84	464	41	832	107
Total	150,157	2,876	40,294	445	85,595	3,456