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Estimates of Chinook Salmon Abundance in the Kenai River Using Split-Beam Sonar, 2004

by

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November 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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ABSTRACT

Chinook salmon *Oncorhynchus tshawytscha* abundance in the Kenai River in 2004 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 2004, the sonar project operated 16 May through 5 August. The total estimated upstream Chinook salmon passage in 2004 was 67,873 (SE = 641) fish: 15,498 (SE = 261) fish during the early run and 52,375 (SE = 585) fish during the late run. Total late-run passage estimate extrapolated through 10 August was 56,205 (SE = 1,784) 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 10 June, with 50% of the run having passed by 14 June. The late-run peak daily passage occurred on 16 July, with 50% of the late run having passed by 18 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, 2001 a-d; Jennings et al. 2004, 2006a; 2006b; 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. From 1989 to 1998 these runs were managed for spawning escapement goals of 9,000 early-run and 22,300 late-run Chinook salmon (McBride et al. 1989). In February 1999, the Alaska Board of Fisheries 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; Burwen et al. 1998; Hammarstrom and Hasbrouck 1998, 1999). The revised escapement goals define a range of escapement levels desired: 7,200 to 14,400 for early-run Chinook salmon (as defined by 5 AAC 56.070, Kenai River and Kasilof River Early-Run King Salmon Conservation Management Plan) and 17,800 to 35,700 for late-run Chinook salmon (5 AAC 21.359, Kenai River Late-Run King Salmon Management Plan). By providing flexible management it is anticipated that these escapement goal ranges 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 in each year from 1989 to 1992 to ensure spawning escapement goals were met. Since 1993, the 1997, 1998, 2000 and

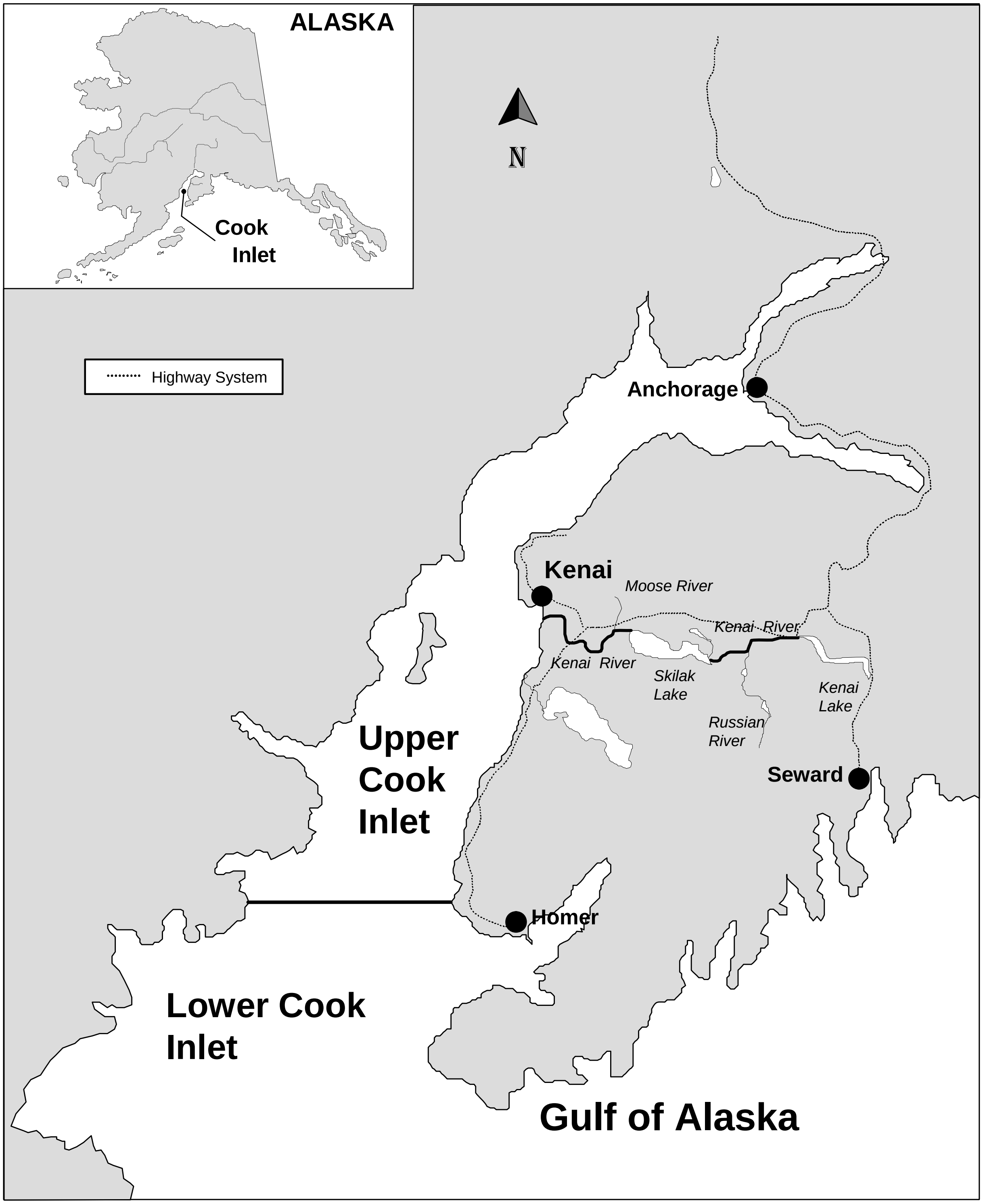


Figure 1.-Cook Inlet showing location of the Kenai River.

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 2003, sockeye salmon escapement estimates generated by the river mile-19 sockeye sonar project ranged from 625,000 to 1,600,000 (Westerman and Willette 2003) 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 species of fish 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 smaller target strengths than Chinook salmon, which primarily migrate near the midchannel area 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 mark-recapture estimates for the years 1987 through 1990 (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; MacLennan and Simmons 1992). 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 in general 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 more 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 netting 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 due to inclusion of sockeye (or other species; Bosch and Burwen 2000, Miller et al. 2002, Miller and Burwen 2002, Miller et al. 2003, 2004, 2005).

Analysis of the 1998-2000 standardized CPUE data suggested that gillnetting data were better suited for determining species apportionment than for estimating abundance (Reimer et al. 2002). In 2001, Chinook salmon abundance was estimated for the first time using a combination of Chinook catch proportions from the netting 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 netting project beginning in 2002 that included using multiple mesh sizes (5.0” and 7.5” stretched; Reimer 2003, Reimer 2004a). 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 from 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. Netting data indicated that there were fewer sockeye salmon in the offshore area at the alternative site than there were at the current site. However, there were still relatively large numbers of sockeye salmon present in the offshore area of the alternative site during peak migration periods as well as high numbers of Chinook salmon present in the nearshore area. The alternative sonar site also had 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 with 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 2004 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, measured 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 2004 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 spawning habitat of Chinook salmon.

The river bottom in this area has remained stable for the past 19 years despite a 140-year flood 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 signal-to-noise 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 spawning sites of Chinook salmon, yet far enough from the mouth that most of the fish counted are probably committed to the Kenai River (Alexandersdottir and Marsh 1990). Historically, 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 to 5 August 2004. 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 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 1.1 m. Rising water level throughout the season and heavy debris accumulation on the gear resulted in occasional relocation of transducer tripods. Total insonified range by both (right and left) sonar beams ranged from a low of approximately 62 m on 17-18 July to a high of 86 m on 29 June (Figure 4).

Vertical and horizontal aiming of each transducer was remotely controlled by a dual-axis electronic pan and tilt system. A digital readout showed the aiming angle in the vertical and horizontal planes. In the vertical plane, the transducer was aimed using an oscilloscope and chart recorder to verify that the sonar beam was grazing 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 in such a manner as to maximize counting range in an attempt to fully insonify the cross section of the river between the right- and left-bank transducers.

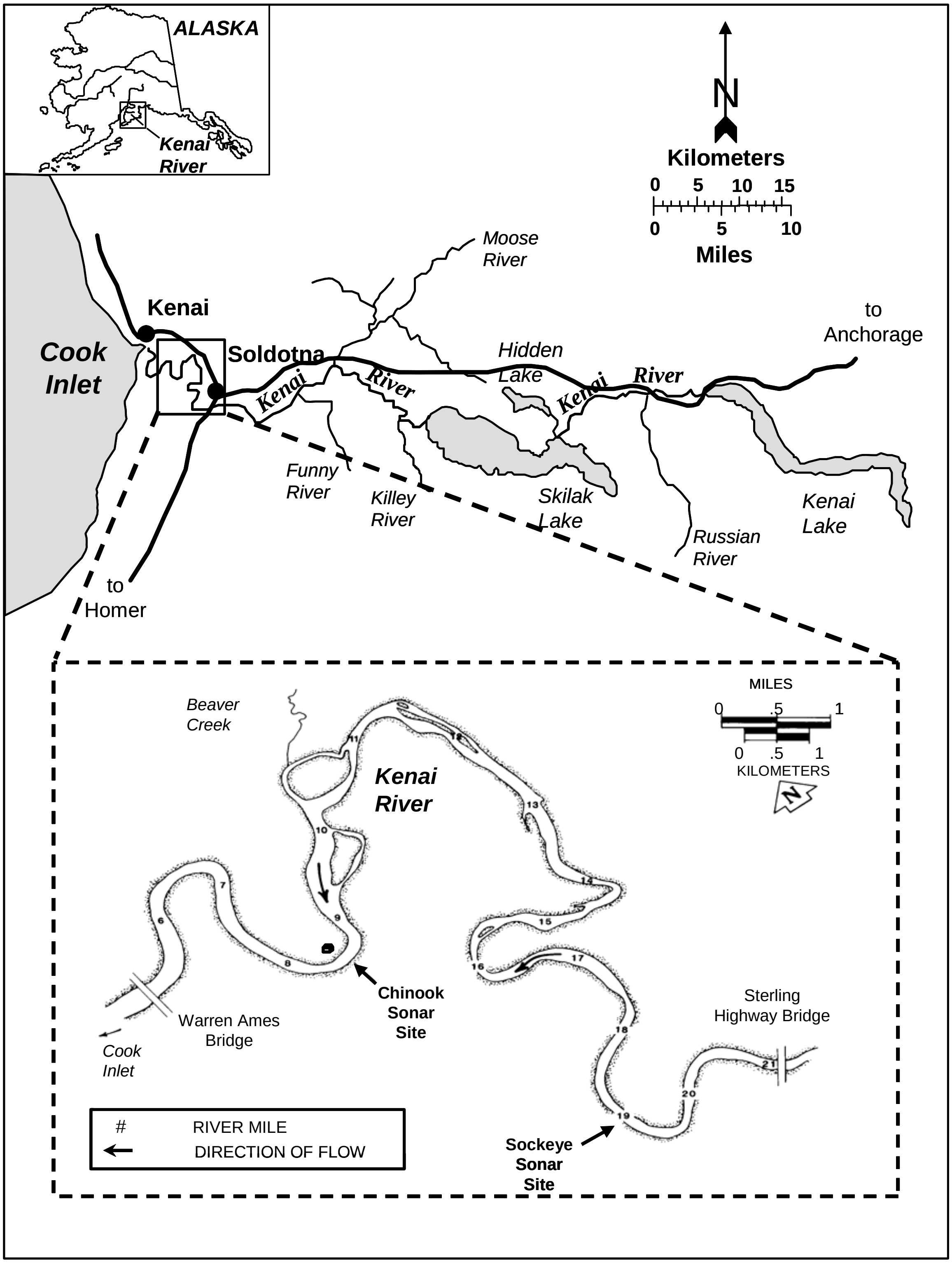


Figure 2.-Kenai River showing location of sonar sites, 2004.

Table 1.-Main components of the split-beam sonar system used in 2004.

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 range (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 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).

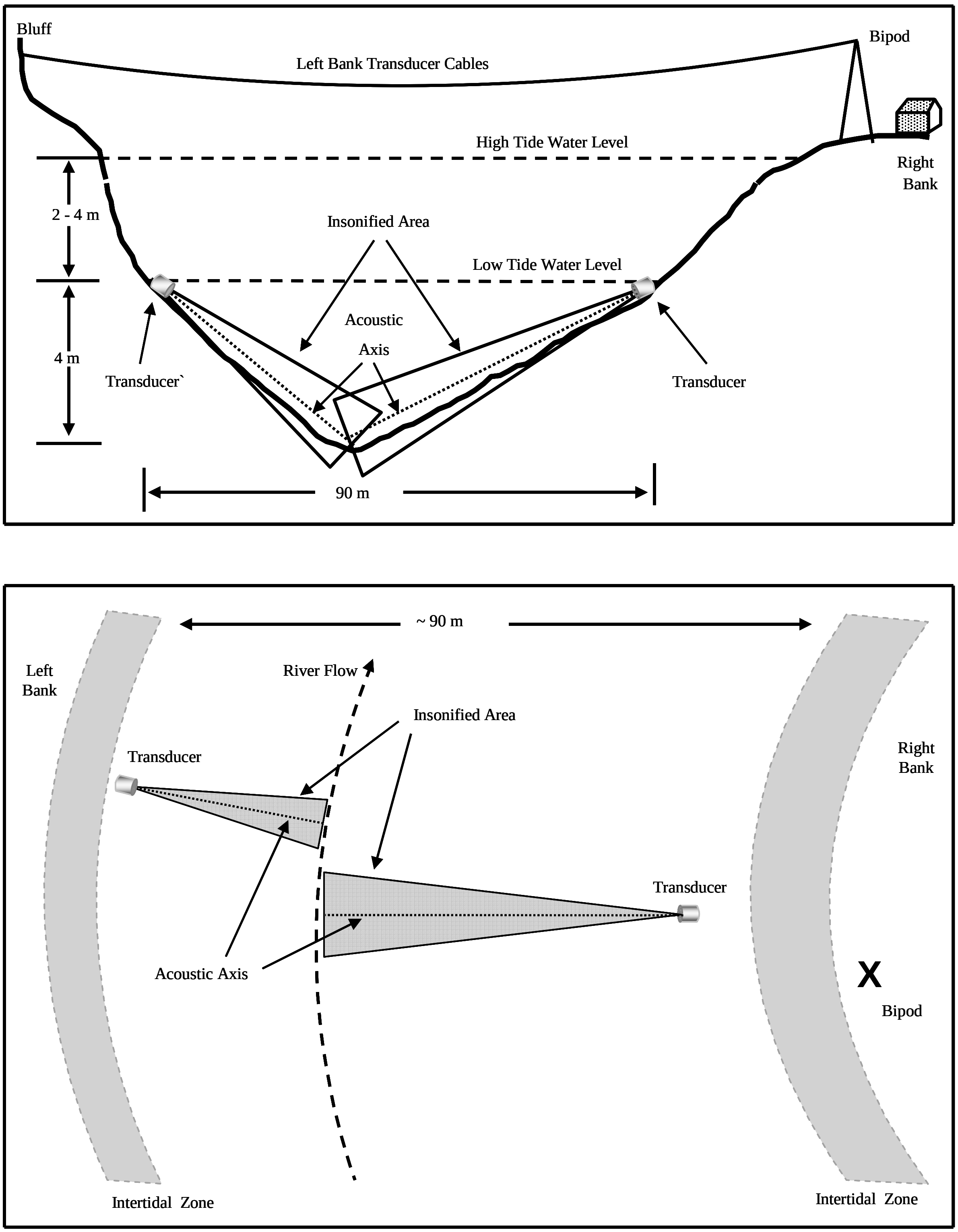
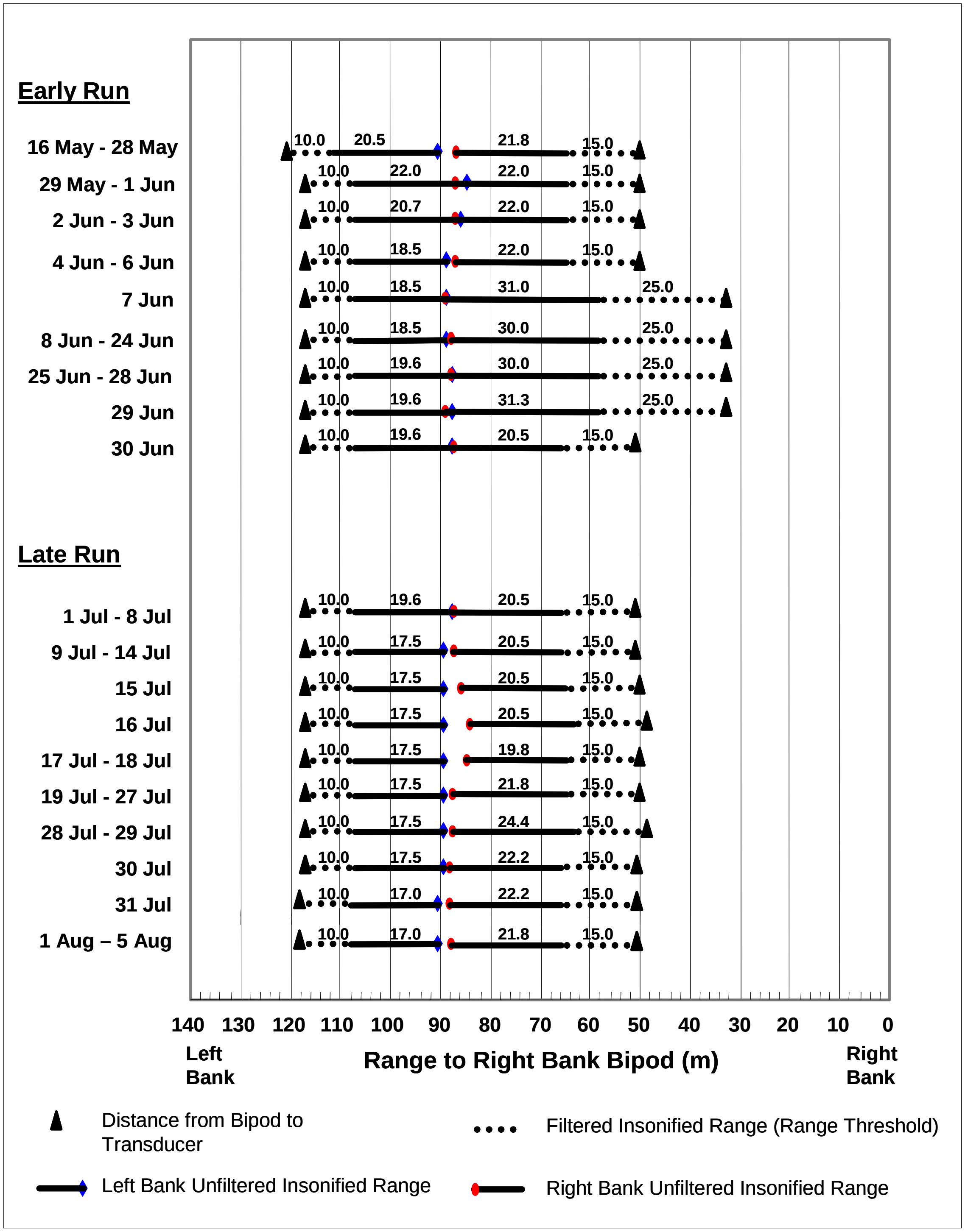


Figure 3.-Cross-sectional (top) and aerial (bottom) diagrams of sonar site illustrating insonified portions of the Kenai River, 2004.



Note: Distance from bipod to thalweg is approximately 88 m.

Figure 4.-Daily right and left bank transducer placement and insonified ranges relative to bipod tower located on the right bank, Kenai River, 2004.

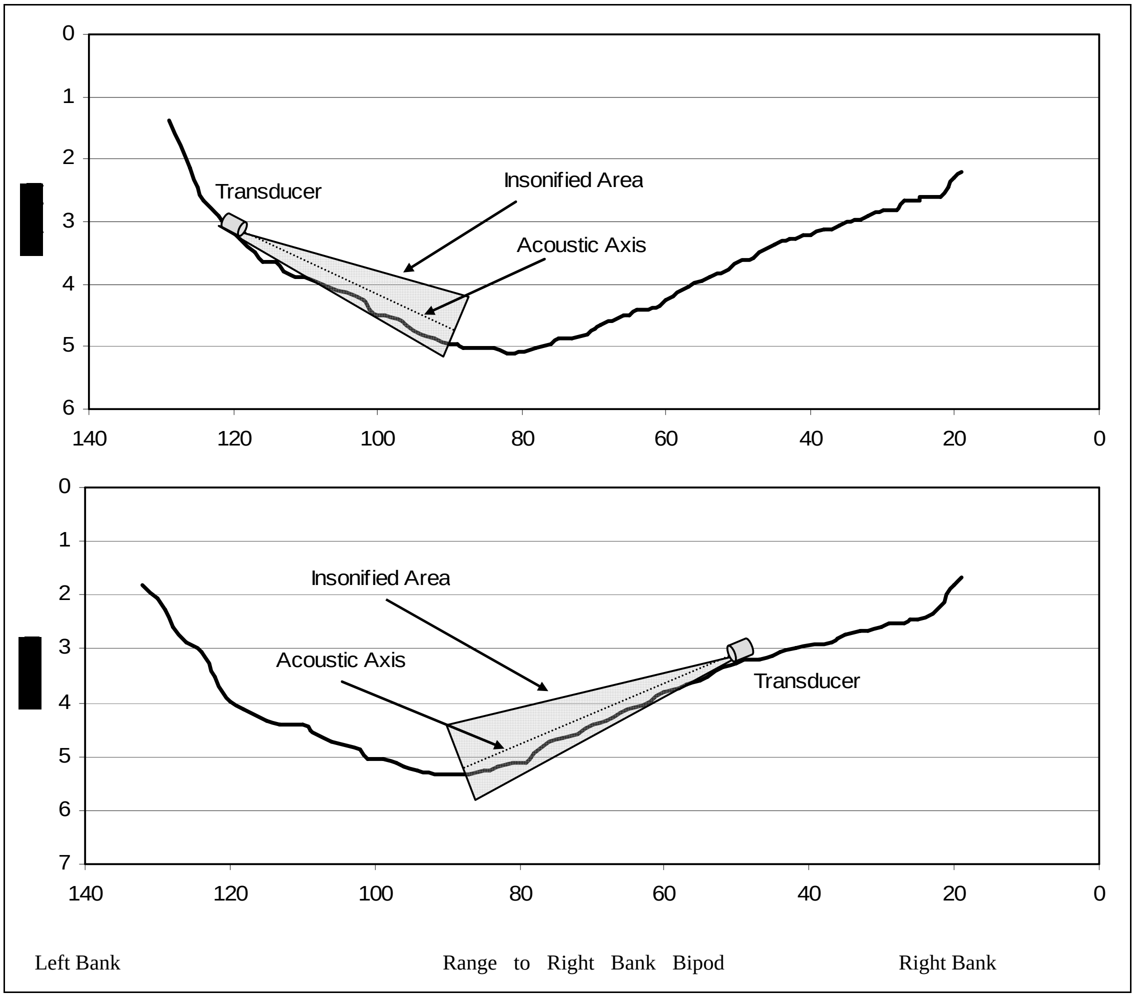


Figure 5.-Bottom profiles by bank for the Kenai River Chinook sonar site with approximate transducer placement and sonar beam coverage for 16 May 2004.

System Calibration

HTI performed reciprocity calibrations with a naval standard transducer on 3 December 2003. Calibration results 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 13 May, 9 July, 12 July, and 3 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 hourly estimates of Chinook salmon passage obtained using 1-hour counts and estimates obtained by extrapolating 20-min counts (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 2004.

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 (MacLennan and Simmonds 1992), as were echoes which 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 wake, the river bottom, and the water surface. Collection of data from unwanted noise creates data management problems and also makes it difficult to distinguish echoes originating from valid fish targets. The amount 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 amount of background noise fluctuates periodically, with lowest noise levels

Table 3.-Echo acceptance criteria for digital echo processing, 2004.

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 to 5-Aug	0.04 to 10.0	-2.5 to 2.0	-5.0 to 5.0	713 (-35 dB)	2.0
Left					
16-May to 5-Aug	0.04 to 10.0	-2.5 to 2.0	-5.0 to 5.0	451 (-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).

during high tide and the highest levels during falling and low tides. Voltage thresholds corresponding to a -35 dB target on-axis were selected for each bank as the lowest threshold that would exclude background noise at low tide when noise was at a maximum.

For each echo passing initial filtering criteria, the DES wrote information in ASCII file format (*.RAW files). This file provided a record of all raw echo data, which could then be used by other post-processing software. A uniquely-named file was produced for each sample hour and 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 subthreshold 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 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

[1] Product names used in this report are included for scientific completeness but do not constitute a product endorsement.

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 (meters) 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 above 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 structure, boat wake 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 (see section below on species discrimination).

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 comparisons provided information on distribution of fish targets from the face of the transducer, but because transducer locations changed throughout the season the comparisons were poor

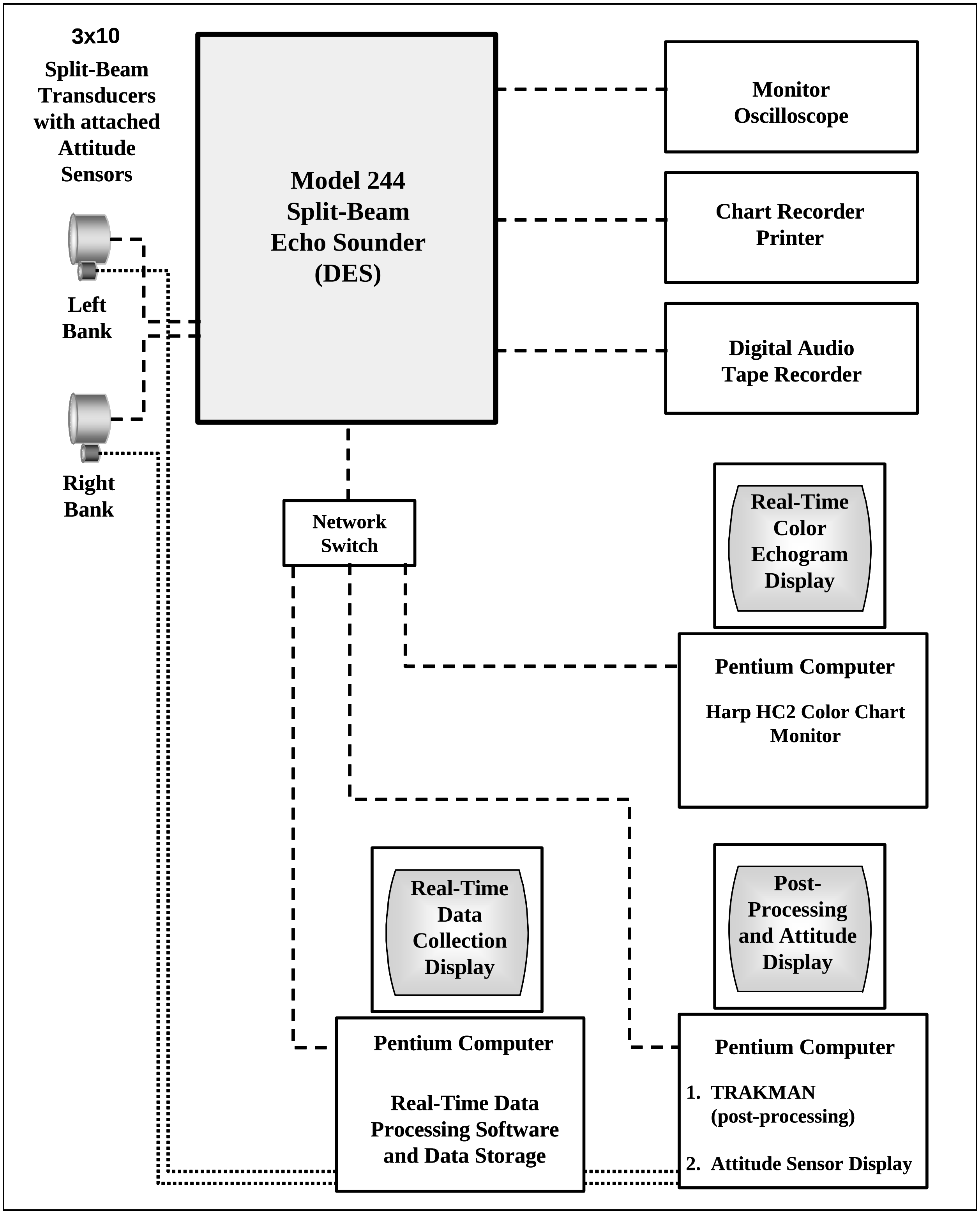


Figure 6.-Diagram of 2004 split-beam sonar system configuration and data flow.

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):

$$z_a = z_m + |z_t - z_n|, \qquad (1)$$

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:

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

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 distinguish 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 swims near shore, and can be excluded by simply counting 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 (see Discussion).

Range thresholds differed by bank and over time. Range thresholds were changed when transducers were moved or when fish distribution and behavior indicated that species discrimination could be improved. Early-run range thresholds were 10 m (16 May–30 June) on the left bank and 15 m (16 May-6 June and 30 June) and 25 m (7 June–29 June) on the right bank (Figure 4). Late-run (1 July–5 August) range thresholds were 10 m on the left bank and 15 m on the right bank (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:

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

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

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

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:

$$\hat{y}_{ijk} = \frac{60}{t_{ijk}}c_{ijk} , \tag{5}$$

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 passage on the non-functional bank k from passage on the functional bank k' with a ratio estimator:

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

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:

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

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:

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

where *f* was the sampling fraction (approximately 0.33), and ϕ_{ijk} 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:

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

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

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:

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

where:

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

Unfiltered[2] 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 (Reimer *In prep*.):

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

The variance estimate of the alternative estimate follows Goodman 1960:

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

Note that variance of sonar estimates presented 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, target strength of the 38.1-mm tungsten carbide standard sphere was measured at -39.7 dB with the right-bank transducer and -39.1 dB with the left-bank transducer (HTI 2003; Table 4). The theoretical value for the sphere is -39.5 dB (MacLennan and Simmonds 1992). During subsequent *in situ* calibration checks using the same sphere, mean target strength varied from –37.5 dB to –38.9 dB on the right bank and from –37.4 dB to –40.0 dB on the left bank (Table 4). Small fluctuations in mean target strength are expected throughout the season during *in situ* calibration checks as target strength can vary with signal-to-noise ratio, water temperature, depth, conductivity and other factors.

TARGET TRACKING

In 2004, 70,584 targets were manually tracked, 13,414 during the early run and 57,170 during the late run. After filtering for range and target strength criteria and making temporal

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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).

expansions, the proportion of upstream moving fish was 95% for the early run and 96% for the late run (Appendices E1 and E2). The daily proportion of upstream moving Chinook salmon in 2004 ranged from 80% to 100% during the early run and 91% to 99% during the late run.

Echo counts per fish (filtered for range and target strength criteria) varied by run, bank, and direction of travel. Upstream moving Chinook averaged 77 (SD = 61) echoes per fish on the left bank during the early run and 95 (SD = 60) echoes on the right bank. Downstream moving Chinook averaged 81 (SD = 76) echoes on the left bank and 110 (SD = 105) echoes on the right bank. During the late run, upstream moving Chinook averaged 94 (SD = 63) echoes on the left bank and 72 (SD = 48) echoes on the right bank. Downstream moving Chinook averaged 130 (SD = 115) echoes on the left bank and 109 (SD = 97) echoes per fish on the right bank.

Table 4.-Results of 2004 *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]	3-Dec-03	-39.7	0.66	1,018	6.2	N/A[b]	N/A[b]
Kenai River	13-May-04	-37.5	2.21	2,234	18.5	220	225
Kenai River	9-Jul-04	-38.7	2.20	1,687	14.0	140	220
Kenai River	12-Jul-04	-38.9	1.71	1,423	13.8	130	150
Kenai River	3-Aug-04	-38.5	2.56	1,774	11.9	100	150
Left Bank							
HTI[a]	3-Dec-03	-39.1	0.81	1,164	6.2	N/A[b]	N/A[b]
Kenai River	13-May-04	-37.4	3.35	1,606	17.9	95	100
Kenai River	9-Jul-04	-39.7	0.59	2,114	8.5	70	75
Kenai River	12-Jul-04	-39.6	0.56	1,516	8.9	70	75
Kenai River	3-Aug-04	-40.0	2.10	1,810	22.3	70	75

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

[b] Not available or not applicable.

TIDAL AND TEMPORAL DISTRIBUTION

Upstream Chinook passage during both the early and late runs occurred mostly during the falling tide (50.2% and 52.9%, respectively; Tables 5 and 6, Figure 7). Early-run downstream passage was similar between the rising (37.8%) and falling (41.1%) tides, while late-run downstream passage occurred primarily during the falling tide (56.1%).

SPATIAL DISTRIBUTION

Vertical Distribution

Chinook salmon were bottom-oriented during both runs, although vertical distribution did vary somewhat by direction of travel, tide stage, and season (Appendices F1 and F2). During the

Table 5.-Estimates of Chinook salmon passage by tide stage and direction of travel for the 2004 early run (16 May to 30 June).

2004 Early Run	Total Number of Fish	Rising	Falling	Low
Upstream	15,498	5,727	7,782	1,988
Row %	100.0%	37.0%	50.2%	12.8%
Column %	95.0%	96.9%	95.9%	92.0%
Downstream	816	308	336	172
Row %	100.0%	37.8%	41.1%	21.1%
Column %	5.0%	5.1%	4.1%	8.0%

Test for Independence: Chi-square = 53.07, df = 2, P < 0.0001

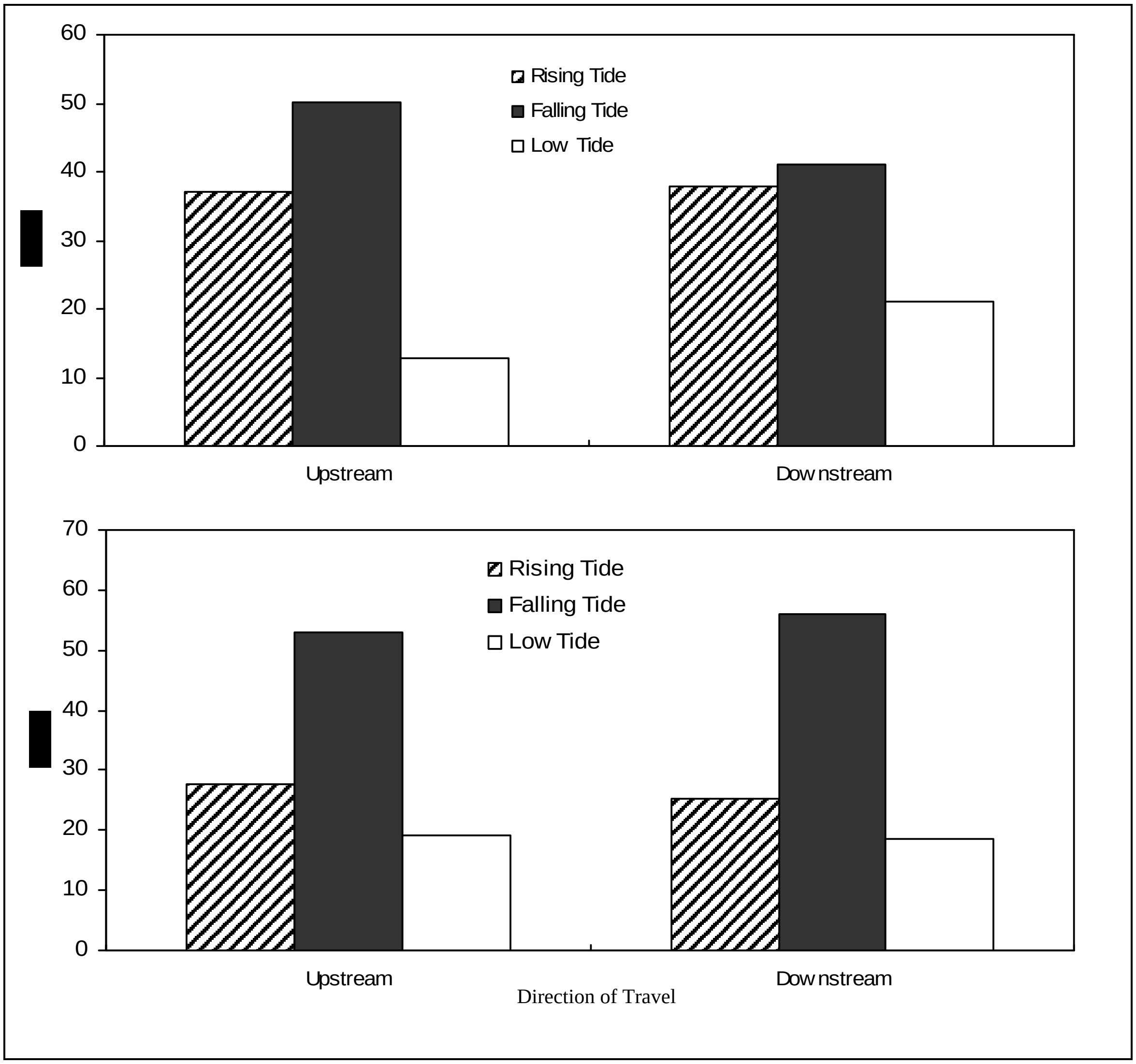
Table 6.-Estimates of Chinook salmon passage by tide stage and direction of travel for the 2004 late run (1 July to 5 August).

2004 Late Run	Total Number of Fish	Rising	Falling	Low
Upstream	52,375	14,585	27,730	10,060
Row %	100.0%	27.8%	52.9%	19.2%
Column %	96.1%	96.4%	95.8%	96.2%
Downstream	2,148	541	1,205	402
Row %	100.0%	25.2%	56.1%	18.7%
Column %	3.9%	3.6%	4.2%	3.8%

Test for Independence: Chi-square = 9.35, df = 2, P = 0.009

early run, 87% of the upstream moving Chinook salmon on the left bank and 85% on the right bank were on or below the acoustic axis (Figure 8). Downstream moving Chinook salmon were less bottom-oriented (Appendix F1). Seventy-one percent of downstream moving fish on the left bank and 79% on the right bank were below the acoustic axis (Figure 8). Upstream moving fish on the left bank (mean = -0.44°, SD = 0.48, n = 2,018) were on average lower (t = 3.55, P < 0.001) in the water column than downstream moving fish (mean = -0.25°, SD = 0.52, n = 79). Similarly, upstream moving fish on the right bank (mean = -0.29°, SD = 0.36, n = 3,625) were lower in the water column (t = 3.27, P < 0.001) than downstream fish (mean = -0.20°, SD = 0.43, n = 229). Upstream traveling fish on both banks were bottom-oriented during all tide phases, but were distributed slightly higher in the water column during rising tides (Figure 9).

Late-run Chinook salmon also showed a tendency to travel along the river bottom (Figure 10 and Appendix F2). Eighty-seven percent of upstream moving fish on the left bank and 88% of upstream moving fish on the right bank were on or below the acoustic axis. Downstream



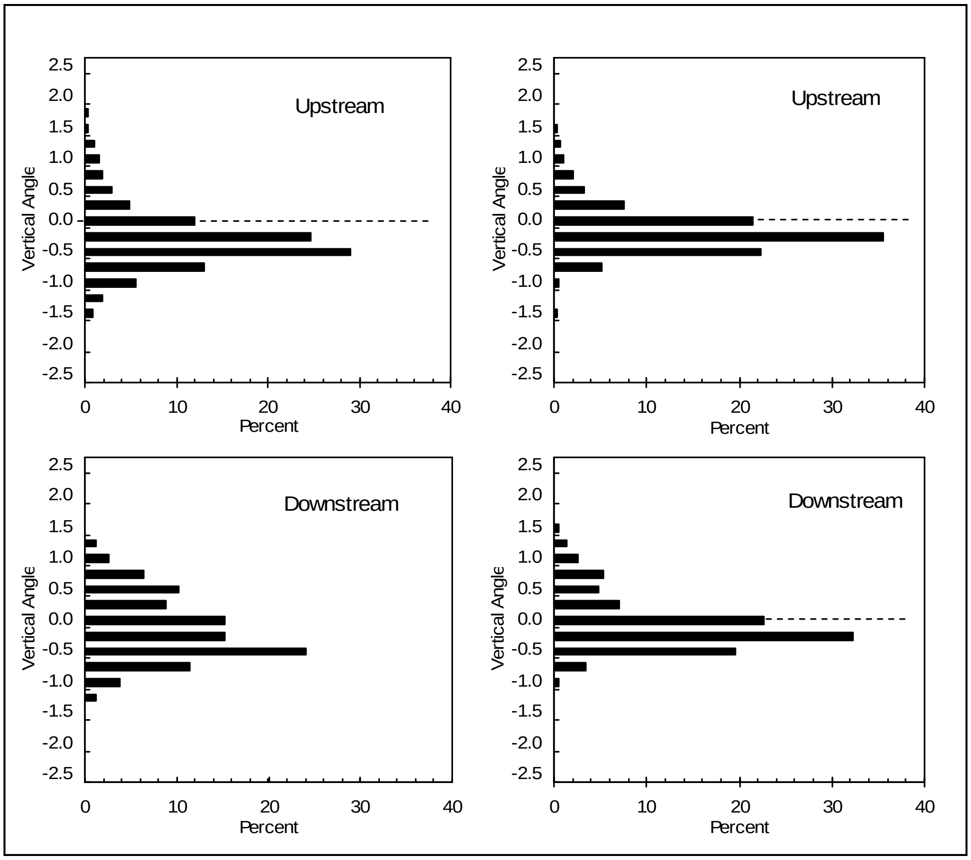
Note: Data have been filtered by range (distance from transducer) and target strength criteria.

Figure 7.-Percent of upstream and downstream moving Chinook salmon by tide stage during the early (top) and late (bottom) runs, Kenai River, 2004.

traveling fish were slightly higher in the water column (Appendix F2). Eighty-three percent of downstream moving fish on the left bank and 84% on the right bank were on or below the acoustic axis. Upstream moving fish on the left bank (mean = -0.40°, SD = 0.39, n = 8,723) traveled lower (t = 2.18, P = 0.015) in the water column than downstream fish (mean = -0.36°, SD = 0.40, n = 362). Similarly, upstream moving fish on the right bank (mean = -0.32°, SD = 0.33, n = 18,204) traveled lower (t = 4.67, P < 0.001) in the water column than downstream fish (mean = -0.25°, SD = 0.36, n = 711). Vertical distribution of upstream traveling fish was slightly higher during rising tides on both the left and right bank (Figure 11).

Range Distribution

During the early run, upstream traveling Chinook were distributed throughout the insonified range on both the left and right bank (Figure 12). Fish range distributions were relatively similar among the three tide stages on the left bank (Figure 13). On the right bank, the bimodal range distribution during the falling and low tides was more pronounced than during the rising tide (Figure 13).

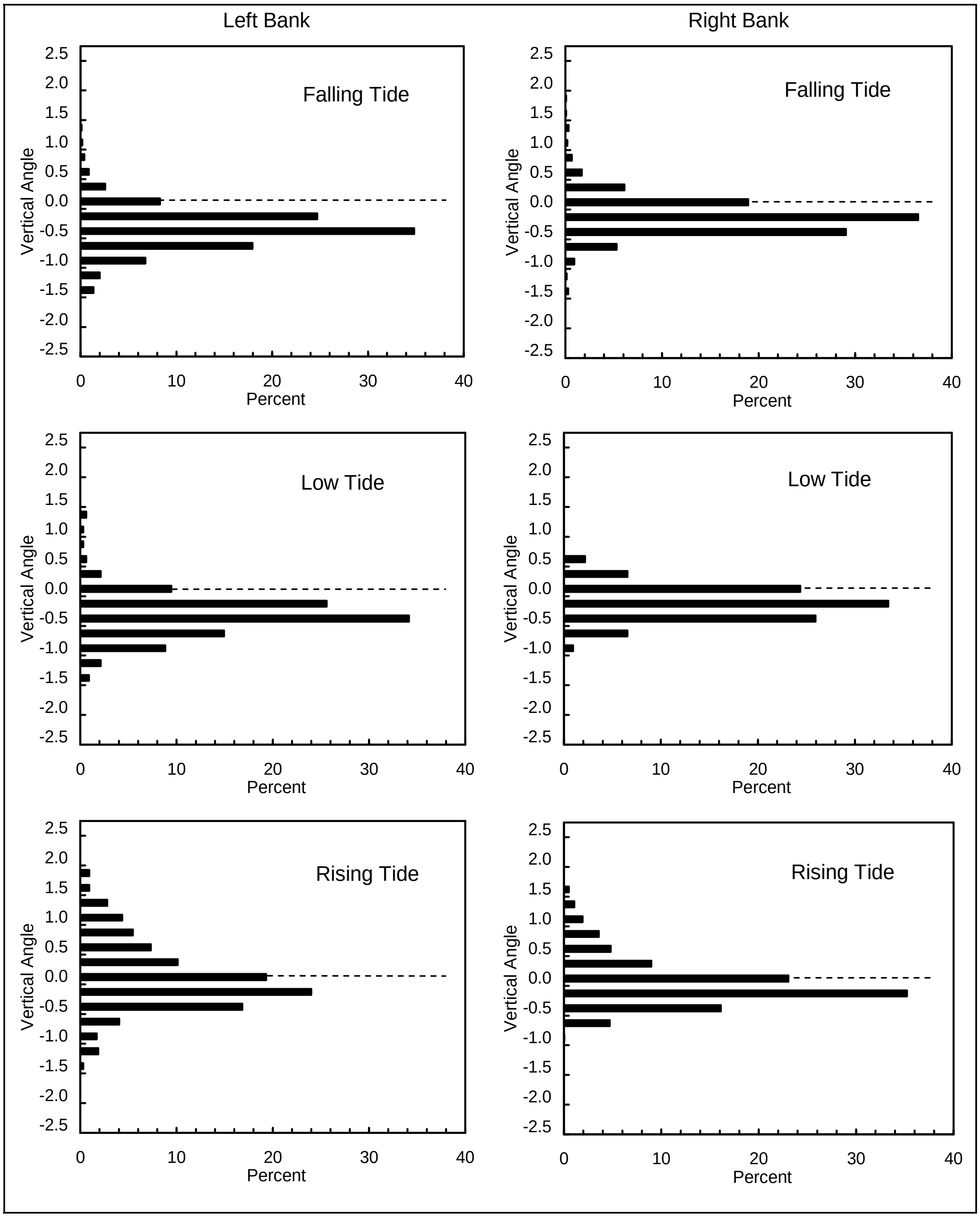


Note: Data have been filtered by range (distance from transducer) and target strength criteria. Acoustic axis = 0.0.

Figure 8.-Vertical distributions above and below the acoustic axis of early-run upstream and downstream moving Chinook salmon by bank, Kenai River, 2004.

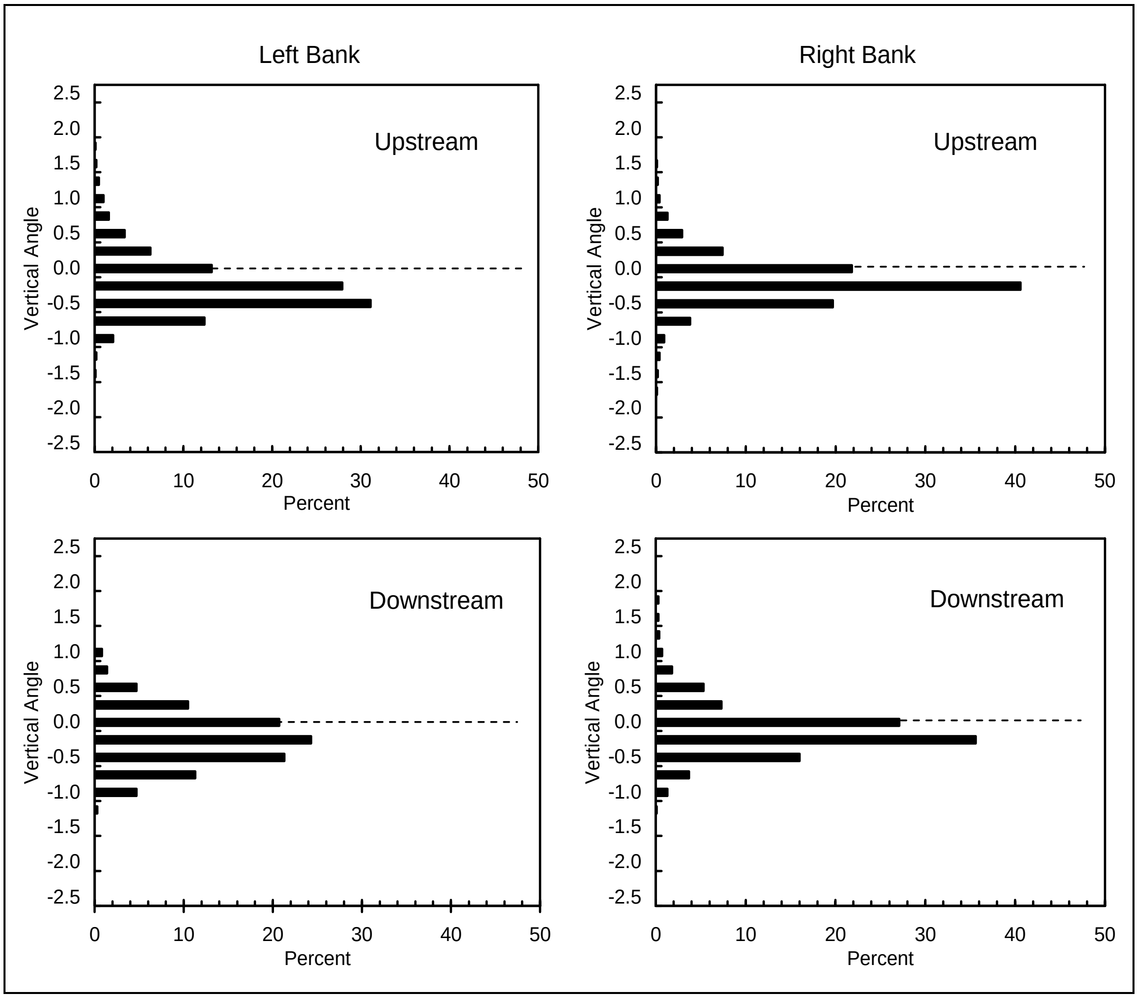
During the late run, upstream traveling Chinook were again distributed throughout the insonified range on both banks, while downstream traveling fish were distributed primarily offshore (Figure 14). Bimodal range distributions of upstream moving fish were observed on both banks during the falling and low tide stages (Figure 15). Peak passage during these tide stages on the right bank occurred near the beginning and end of the insonified range. During the rising tide, upstream fish distribution was more evenly distributed (Figure 15).

Estimates of upstream Chinook salmon passage by bank were higher for the right bank during both the early and late run (Tables 7 and 8). During the early run 62% of upstream passage was estimated to occur on the right bank while 38% occurred on the left bank (Table 7). During the late run 63% of upstream passage was estimated to occur on the right bank and 37% on the left bank (Table 8).



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

Figure 9.-Vertical distributions above and below the acoustic axis of early-run upstream moving Chinook salmon by tide stage and bank, Kenai River, 2004.



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

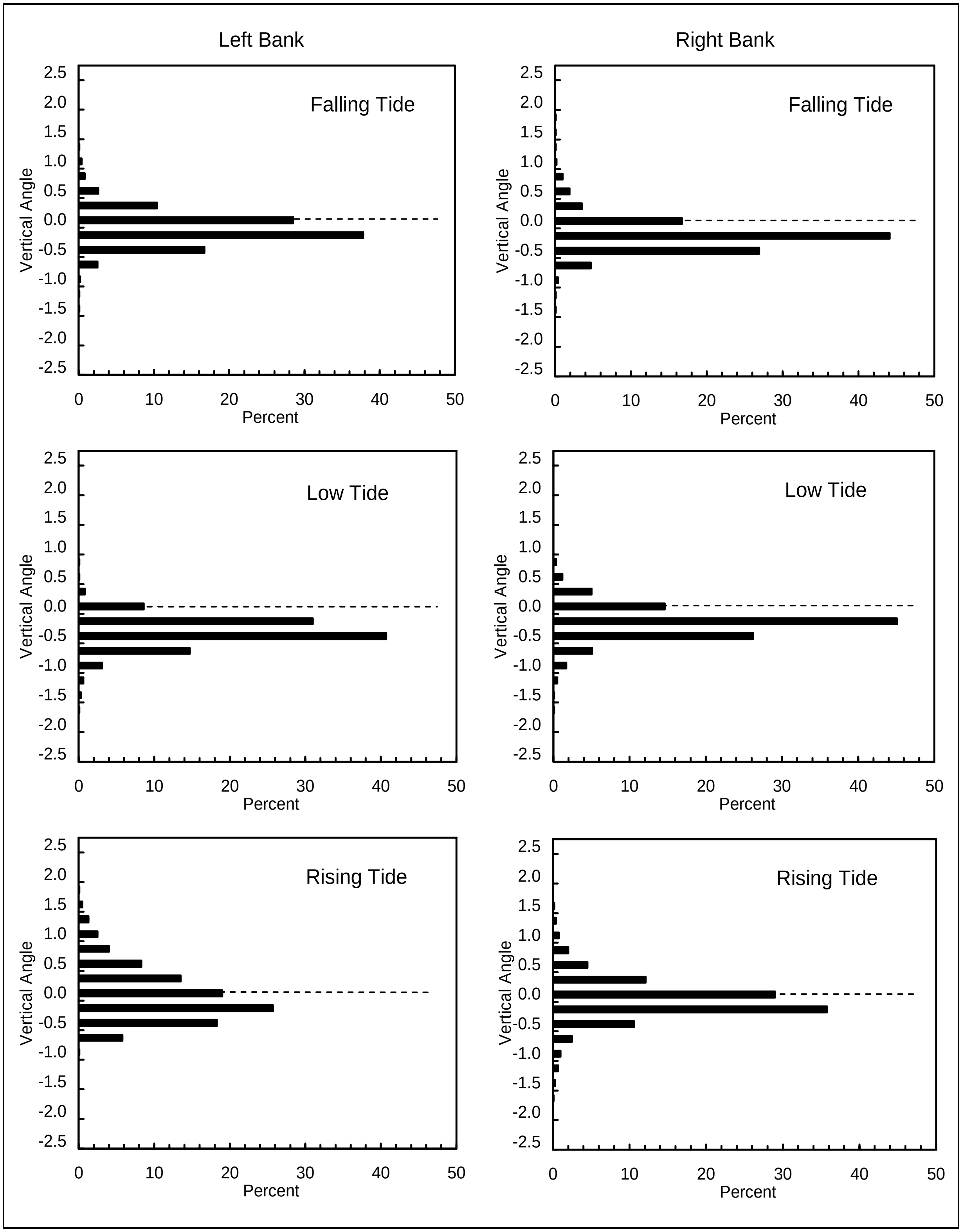
Figure 10.-Vertical distributions above and below the acoustic axis of late-run upstream and downstream moving Chinook salmon by bank, Kenai River, 2004.

TARGET STRENGTH

Target strength distributions varied by bank, direction of travel, and run. Table 9 shows target strength statistics for fish that met minimum range and target strength criteria, whereas Figure 16 and Figure 17 show target strength distributions and statistics that include all tracked targets.

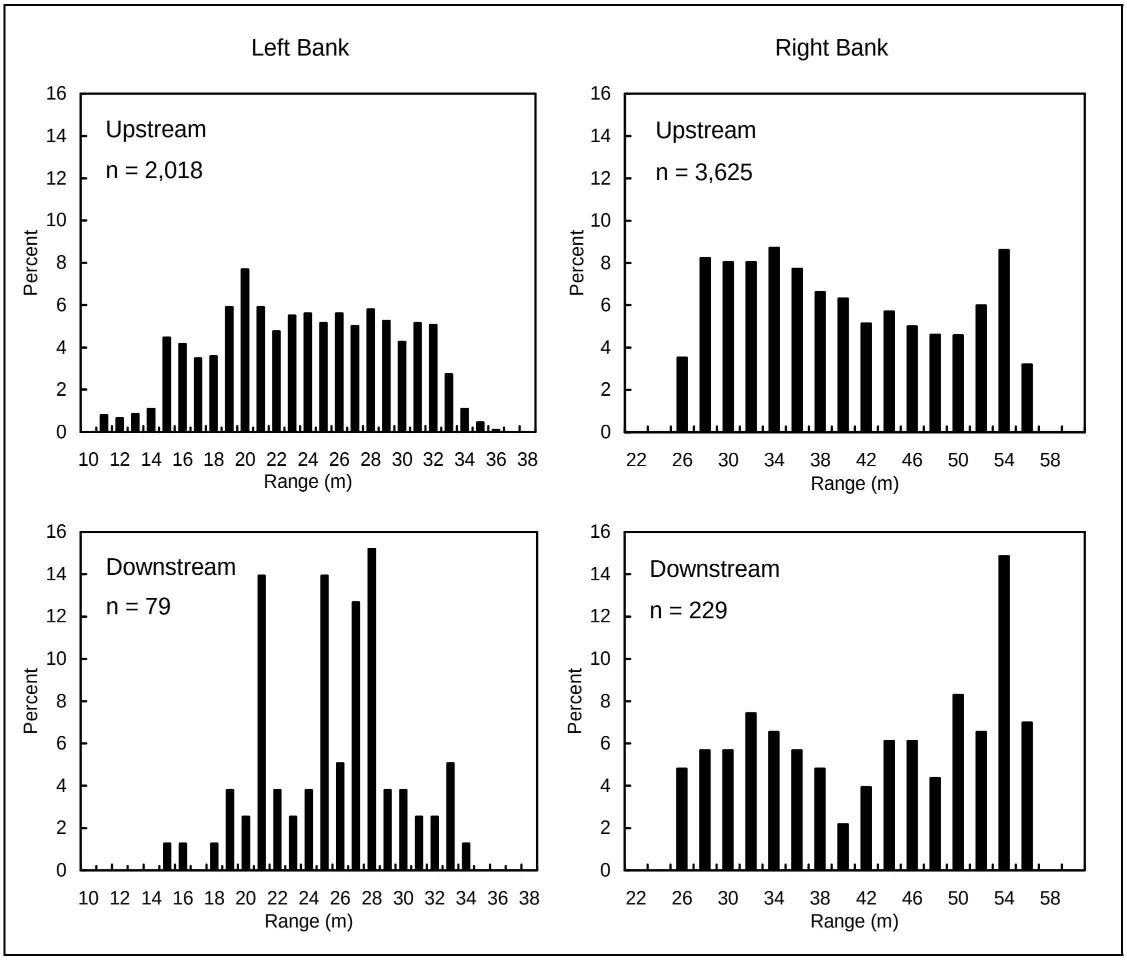
Mean target strength estimates for all upstream moving targets on the right bank during both the early and late run were 1 dB higher on average than left bank estimates (Figures 16 and 17). Mean target strength of all upstream and downstream moving targets varied more on the right bank than on the left bank.

During the early run on the left bank, mean target strength of Chinook salmon was similar (t = -1.01, P = 0.16) among upstream and downstream traveling fish, as was mean target strength variability (F = 1.07, P = 0.31, Table 9). On the right bank, mean target strength of upstream



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

Figure 11.-Vertical distributions above and below the acoustic axis of late-run upstream moving Chinook salmon by tide stage and bank, Kenai River, 2004.



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

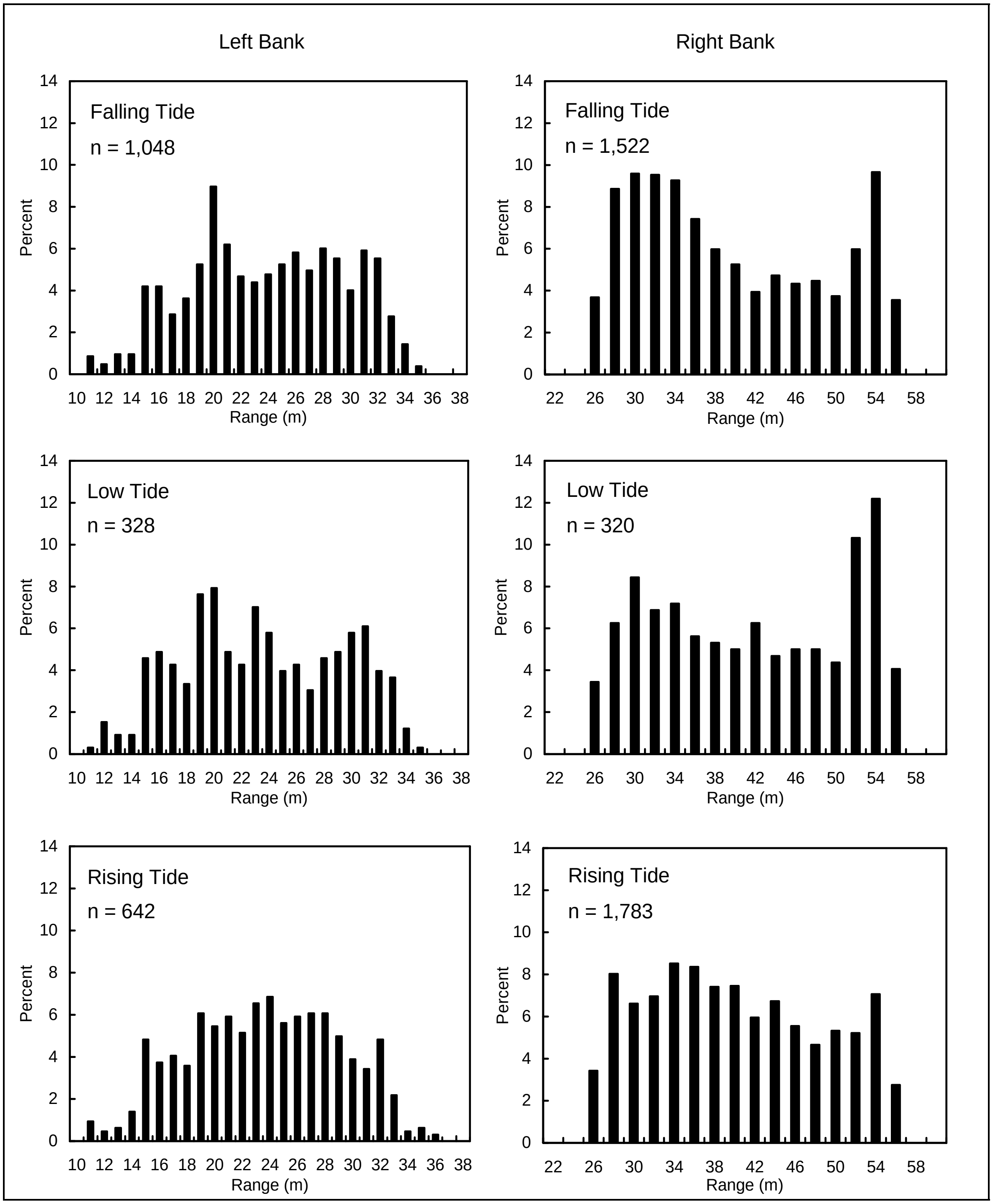
Figure 12.-Standardized distance from transducer of early-run upstream and downstream moving Chinook salmon by bank, Kenai River, 2004.

traveling Chinook was slightly higher (t = -4.96, P < 0.01), and variability was greater (F = 0.78, P < 0.01) than that of downstream traveling Chinook (Table 9). The statistical significance of the difference in mean target strength between upstream and downstream traveling fish was likely an artifact of disparity in sample size than an actual difference in mean target strength.

During the late run on the left bank, mean target strength of Chinook salmon was again similar (t = 1.40, P = 0.08) among upstream and downstream traveling fish, but variability was higher for downstream fish (F = 1.21, P < 0.01, Table 9). On the right bank during the late run, mean target strength was similar (t = -1.49, P = 0.07) among upstream traveling fish, as was mean target strength variability (F = 0.93, P = 0.10, Table 9).

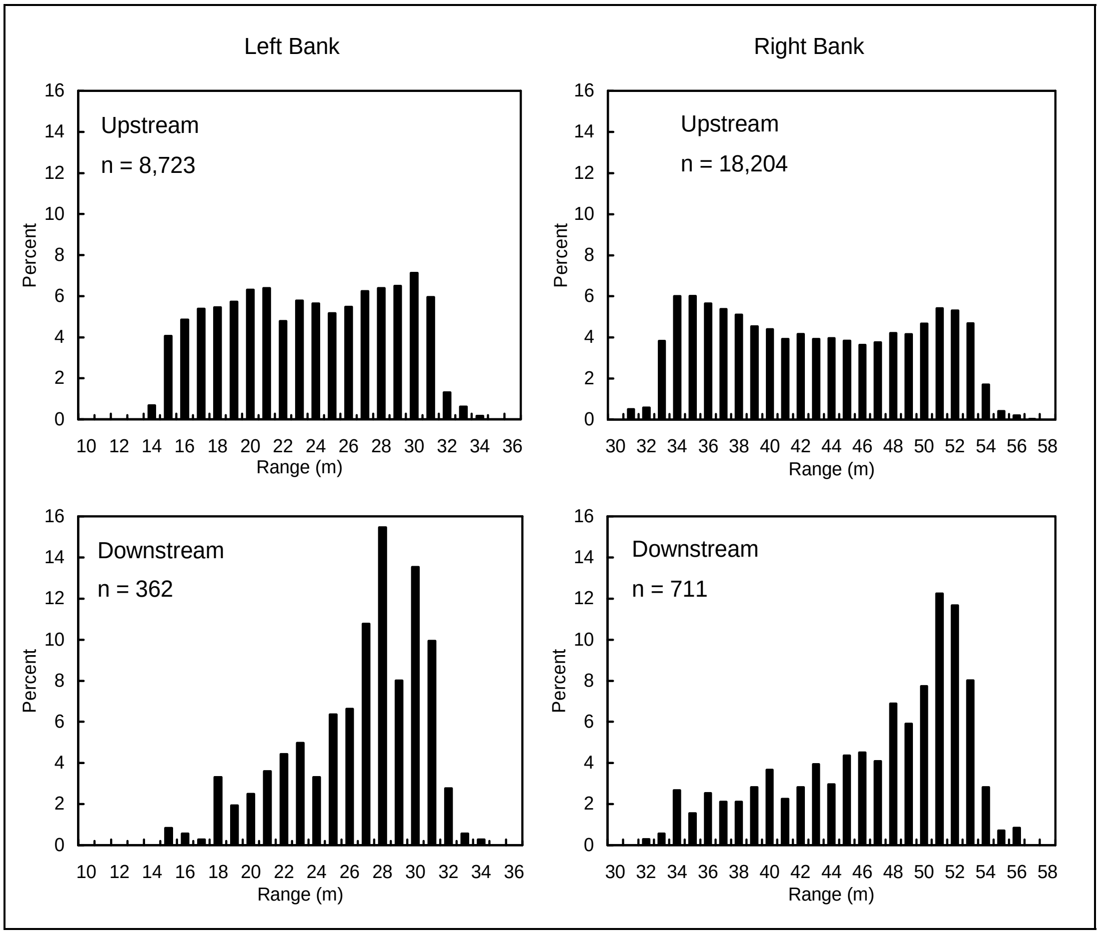
Passage Estimates

Daily estimates of Chinook salmon passage were generated for 16 May through 5 August. A total of 546 hours of acoustic data were processed from the right bank and 617 hours from the left bank during the 82-day season. This represented 28% of available sample time (on average in a 24-hour period) for the right bank and 31% for the left bank.



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

Figure 13.-Standardized distance from transducer of early-run upstream moving Chinook salmon by tide stage and bank, Kenai River, 2004.



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

Figure 14.-Standardized distance from transducer of late-run upstream and downstream moving Chinook salmon by bank, Kenai River, 2004.

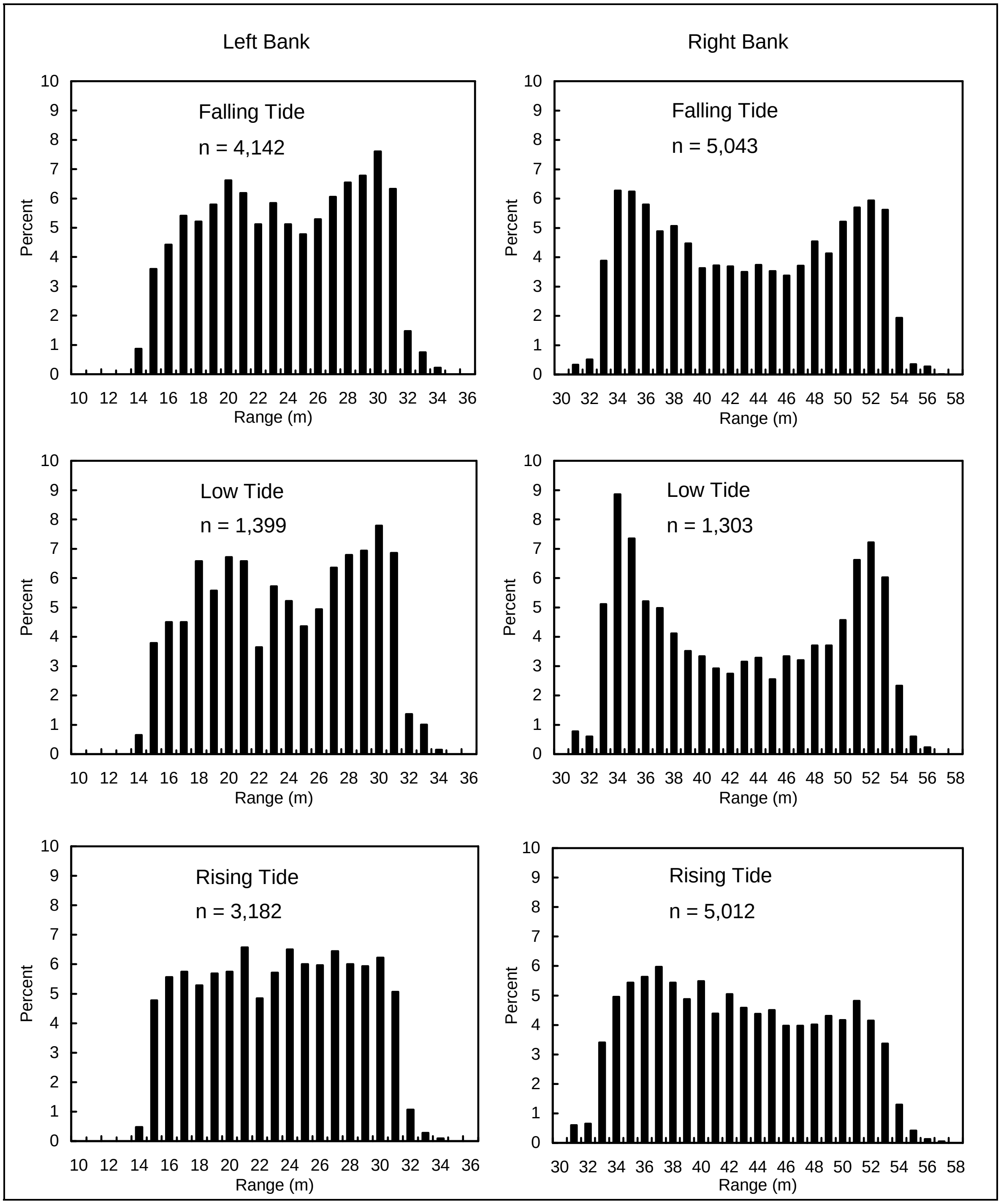
Final upstream Chinook salmon passage from 16 May to 5 August was estimated at 67,873 (SE = 641) fish, composed of 15,498 (SE = 261) early-run fish and 52,375 (SE = 585) late-run fish (Tables 7, 8, 10, and 11). Late-run passage extrapolated through 10 August was estimated at 56,205 (SE = 1,784) fish. The daily peak of the early run occurred on 10 June; 50% of the run passed by 14 June (Figure 18). When compared with historic mean escapement timing, the 2004 early run was late (Figure 18 and Appendix G1). The daily peak of the late run occurred on 16 July; 50% of the late run passed by 18 July (Figure 19). Migratory timing of the late run was average compared to historic mean escapement timing (Figure 19 and Appendix G2).

DISCUSSION

SPATIAL DISTRIBUTION

Bank Distribution

During the early years of the project (before 1996), the right bank was heavily used by migrating Chinook salmon during both the early and late runs, and the proportion of fish traveling up the right bank increased as the season progressed (Bosch and Burwen 1999; Burwen and Bosch 1998; 1995a; 1995b, 1996; Eggers et al. 1995; Miller and Burwen 2002). Since 1995 this trend has not been as obvious or as consistent. The 1996 and 1997 early runs experienced heavy



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

Figure 15.-Standardized distance from transducer of late-run upstream moving Chinook salmon by tide stage and bank, Kenai River, 2004.

Table 7.-Estimates of Chinook salmon passage by river bank and direction of travel for the 2004 early run (16 May to 30 June).

	Estimate of Upstream Component		Estimate of Downstream Component		Estimate of Total Fish Passage[a]	
Bank	Number	Percent	Number	Percent	Number	Percent
Right	9,582	62%	585	72%	10,167	62%
Left	5,916	38%	231	28%	6,147	38%
Total	15,498	100%	816	100%	16,314	100%

[a] Total passage (upstream component plus downstream component) is provided to maintain comparability between recent (1998-2004) 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 8.-Estimates of Chinook salmon passage by river bank and direction of travel for the 2004 late run (1 July to 5 August).

	Estimate of Upstream Component		Estimate of Downstream Component		Estimate of Total Fish Passage[a]	
Bank	Number	Percent	Number	Percent	Number	Percent
Right	32,857	63%	1,360	63%	34,217	63%
Left	19,518	37%	789	37%	20,307	37%
Total	52,375	100%	2,149	100%	54,524	100%

[a] Total passage (upstream component plus downstream component) is provided to maintain comparability between recent (1998-2004) 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.

left-bank passage: almost half the upstream passage in the early run occurred on the left bank during both years (Bosch and Burwen 1999; Burwen and Bosch 1998). The 1999 and 2001 early and late runs both experienced a higher proportion of passage on the left bank than on the right bank (Miller and Burwen 2002; Miller et al. 2003). The left bank also had a higher proportion of passage during the early runs in 2002 and 2003 (Miller et al. 2004, 2005). In 2004, the majority of Chinook salmon passage during both runs occurred on the right bank (Tables 7 and 8). The differences in bank distribution do not appear to be related to changes in bottom contour, as the bottom profile at the site has remained relatively stable over the past several years. Bosch and Burwen 1999 pointed out that below average stream flows during the early runs of 1996 and 1997 might have influenced bank distribution. Below average stream flows also occurred in 1999 (Miller et al. 2002). However, flows from 2001 to 2003 were near or above average during both runs (Miller et al. 2003, 2004, 2005; USGS 2004). Thus, stream flows do not appear to fully account for changes in bank distribution.

Table 9.-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, 2004

Location	Upstream Mean Target Strength (dB)	SD	N	Downstream Mean Target Strength (dB)	SD	N
Early Run						
Left Bank	-26.31	1.38	2,018	-26.15	1.43	79
Right Bank	-25.59	1.79	3,616	-26.13	1.58	227
Late Run						
Left Bank	-26.41	1.25	8,723	-26.30	1.38	362
Right Bank	-25.72	1.74	18,204	-25.82	1.68	711

Vertical Distribution

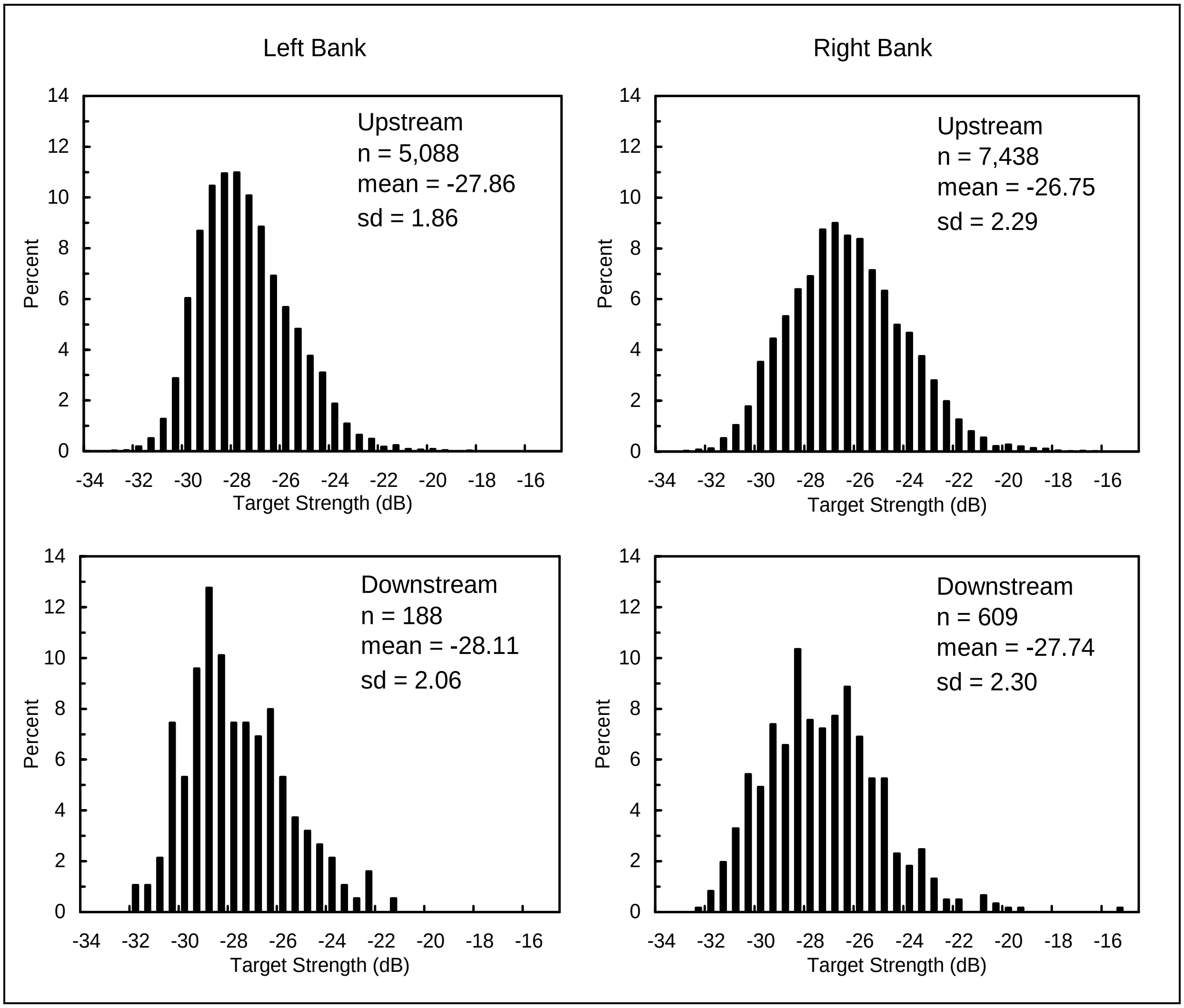
Monitoring the spatial distribution of migrating fish is particularly important at the present sonar site, where tide-induced changes in water level have been shown to affect fish distribution. A primary concern is that fish may swim over the beam during rising and falling tide stages. Because the site experiences extreme semidiurnal tidal fluctuations that average 4 m, and are as high as 7 m (Figure 3), it is not possible to insonify the entire cross-sectional area of the river. However, fish position data suggest that most upstream moving fish are within the insonified zone. When sockeye are not present in large numbers, most Chinook salmon are observed migrating offshore in the bottom portion of the river where beam coverage is maximized. Although more fish were in the upper half of the beam during rising tides on both banks during the 2004 early run (Figure 9), relatively few fish occupied the upper half of the beam overall (Figure 8). Similar trends occurred during the late run (Figures 10 and 11). Previous data show that fish in general have maintained a strong bottom orientation during all three tide stages during both the early and late runs (Burwen et al. 1995; Eggers et al. 1995).

Because the vast majority of Chinook salmon travel close to the river bottom (Figures 8 and 10), our greatest concern is missing fish passing under the sonar beam. However, no fish were detected below beam angles of -2.0° (Figures 8 and 10). Even with the reduced ability to detect targets on the edge of the "effective" beam, we assume there would be more targets detected if substantial numbers of fish were traveling in this area.

Range Distribution

Because transducer locations varied throughout the season due to changing water levels (Figure 4), fish range distributions by bank and run were standardized based on the closest nearshore transducer. Hence, fish range distributions for a given bank reflect distance from the closest nearshore transducer location for that bank.

The range distribution of upstream traveling Chinook salmon on the left and right banks indicates that fish were dispersed throughout the insonified range during both the early and late run (Figures 12 and 14). The truncated distribution of fish targets on the left bank (from 15 to 31 m for the early run, and from 15 to 32 m for the late run) is an artifact of target filtering and



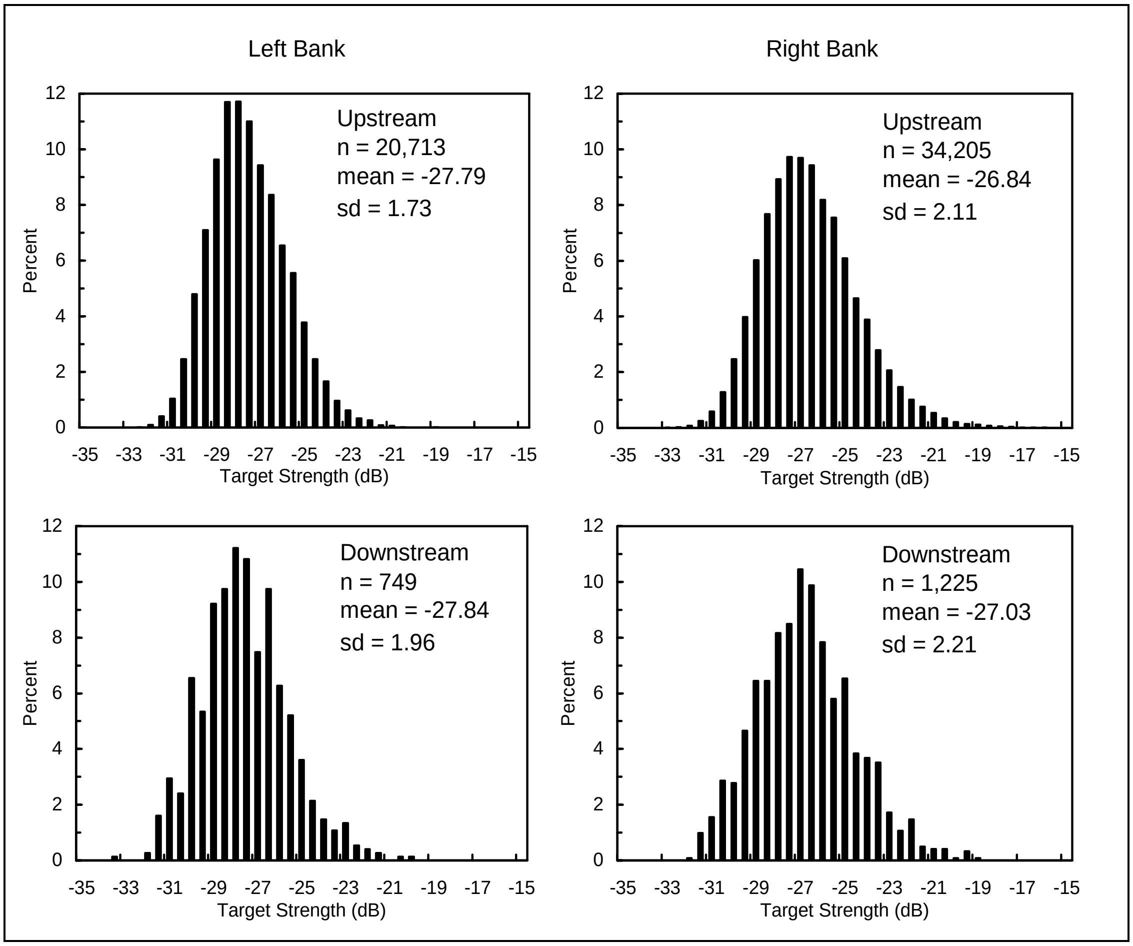
Note: Data have not been filtered by range (distance from transducer) and target strength criteria.

Figure 16.-Early-run target strength (acoustic size) for all upstream and downstream moving targets by bank, Kenai River, 2004.

transducer relocations. The truncated distribution of fish targets on the right bank (from 26 to 53 m for the early run, and from 31 to 54 m for the late run) is also an artifact of target filtering and transducer relocations.

TARGET STRENGTH

From 1996 to 2000, mean target strength estimates on the left bank were higher on average than the right bank (6% higher for early run; 9% higher for later run; Bosch and Burwen 1999; 2000; Burwen and Bosch 1998; Miller and Burwen 2002; Miller et al. 2002). The higher mean target strength observed on the left bank was attributed to threshold-induced bias rather than actual differences in fish size. It was concluded that the acoustically reflective gravel substrate prevented the sonar beam from being aimed as close to the river bottom on the left bank as it was



Note: Data have 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, 2004.

on the right. Because left-bank fish were, on average, farther from the acoustic axis than right-bank fish, a greater proportion of small echoes from left-bank fish were filtered out, thus biasing target strength estimates upward. In addition, the higher background noise experienced on the left bank resulted in higher variability in positional estimates, which also resulted in a positive target strength bias (Fleischman and Burwen 2000).

In 2001 and 2002, mean target strength estimates were very similar between the left and right bank during both the early and late run (Miller et al. 2003, 2004). The similarity in mean target strength between banks was attributed to the relocation of the left-bank transducer in 2001 and the improved left-bank aim that provided more on-axis targets. Since 2002, mean target strength estimates during both runs have been slightly higher on the right bank than on the left bank (Miller et al. 2005; Figures 16 and 17).

ACCURACY OF ABUNDANCE ESTIMATES

Past 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

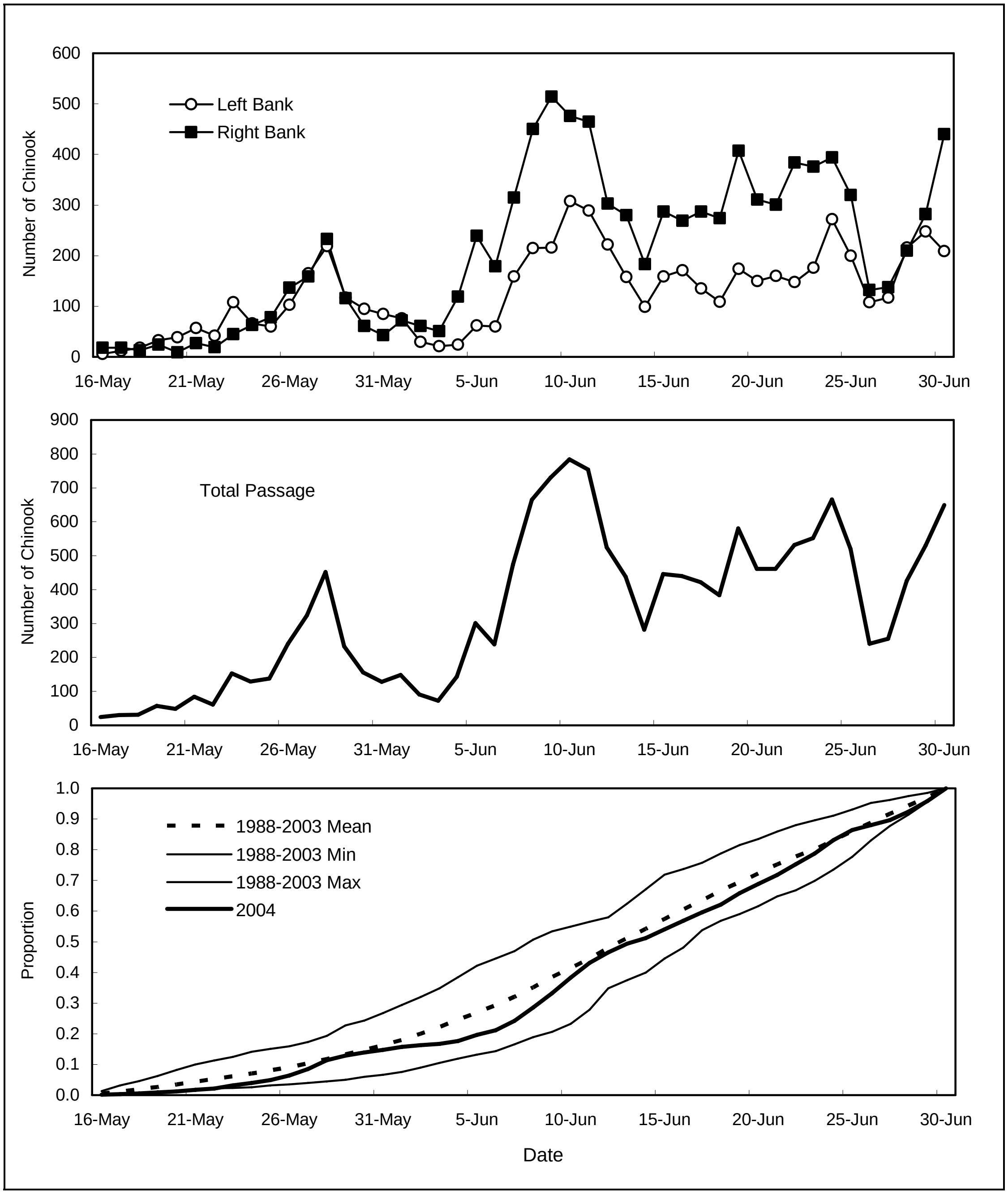
Table 10.-Estimated daily upstream passage of Chinook salmon, Kenai River sonar, early run, 2004.

Date	Left Bank	Right Bank	Daily Total	Cumulative Total
16-May	6	18	24	24
17-May	12	18	30	54
18-May	18	13	31	85
19-May	33	24	57	142
20-May	39	9	48	190
21-May	57	27	84	274
22-May	42	19	61	335
23-May	108	45	153	488
24-May	66	63	129	617
25-May	60	78	138	755
26-May	103	137	240	995
27-May	165	159	324	1,319
28-May	219	233	452	1,771
29-May	117	116	233	2,004
30-May	95	61	156	2,160
31-May	85	43	128	2,288
1-Jun	76	72	148	2,436
2-Jun	30	61	91	2,527
3-Jun	21	51	72	2,599
4-Jun	24	119	143	2,742
5-Jun	62	239	301	3,043
6-Jun	60	179	239	3,282
7-Jun	159	315	474	3,756
8-Jun	215	450	665	4,421
9-Jun	216	514	730	5,151
10-Jun	308	476	784	5,935
11-Jun	289	465	754	6,689
12-Jun	222	303	525	7,214
13-Jun	158	280	438	7,652
14-Jun	99	183	282	7,934
15-Jun	159	287	446	8,380
16-Jun	171	269	440	8,820
17-Jun	135	287	422	9,242
18-Jun	109	274	383	9,625
19-Jun	174	407	581	10,206
20-Jun	150	311	461	10,667
21-Jun	160	301	461	11,128
22-Jun	148	384	532	11,660
23-Jun	176	376	552	12,212
24-Jun	272	394	666	12,878
25-Jun	200	320	520	13,398
26-Jun	108	132	240	13,638
27-Jun	117	138	255	13,893
28-Jun	216	210	426	14,319
29-Jun	248	282	530	14,849
30-Jun	209	440	649	15,498
Total	5,916	9,582	15,498	

Table 11.-Estimated daily upstream passage of Chinook salmon, Kenai River sonar, late run, 2004.

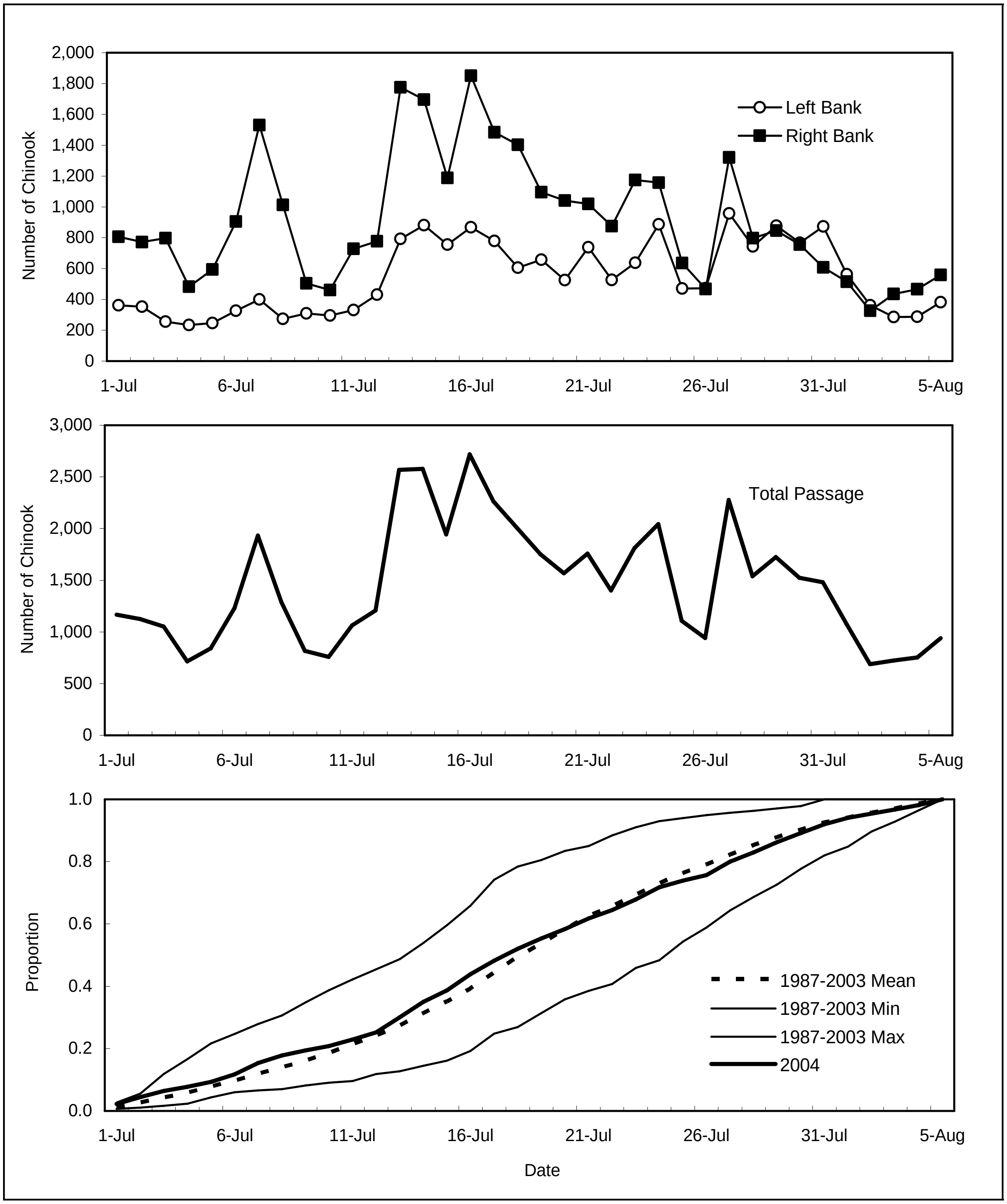
Date	Left Bank	Right Bank	Daily Total	Cumulative Total
1-Jul	362	805	1,167	1,167
2-Jul	353	772	1,125	2,292
3-Jul	255	798	1,053	3,345
4-Jul	233	482	715	4,060
5-Jul	248	594	842	4,902
6-Jul	326	905	1,231	6,133
7-Jul	401	1,531	1,932	8,065
8-Jul	275	1,012	1,287	9,352
9-Jul	310	505	815	10,167
10-Jul	296	461	757	10,924
11-Jul	332	729	1,061	11,985
12-Jul	431	777	1,208	13,193
13-Jul	793	1,774	2,567	15,760
14-Jul	882	1,695	2,577	18,337
15-Jul	755	1,188	1,943	20,280
16-Jul	868	1,850	2,718	22,998
17-Jul	779	1,483	2,262	25,260
18-Jul	605	1,403	2,008	27,268
19-Jul	658	1,095	1,753	29,021
20-Jul	525	1,041	1,566	30,587
21-Jul	738	1,019	1,757	32,344
22-Jul	527	874	1,401	33,745
23-Jul	638	1,174	1,812	35,557
24-Jul	886	1,158	2,044	37,601
25-Jul	471	636	1,107	38,708
26-Jul	473	468	941	39,649
27-Jul	957	1,320	2,277	41,926
28-Jul	743	797	1,540	43,466
29-Jul	878	846	1,724	45,190
30-Jul	767	756	1,523	46,713
31-Jul	873	607	1,480	48,193
1-Aug	563	515	1,078	49,271
2-Aug	362	326	688	49,959
3-Aug	286	436	722	50,681
4-Aug	288	466	754	51,435
5-Aug	381	559	940	52,375
6-Aug	-	-	1,009 [a]	53,384
7-Aug	-	-	905 [a]	54,289
8-Aug	-	-	854 [a]	55,142
9-Aug	-	-	611 [a]	55,754
10-Aug	-	-	451 [a]	56,205
Total	-	-	56,205	

[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 1998-2003.

Figure 18.-Daily sonar passage estimates by bank (top), total passage (center), and historical cumulative proportions (bottom) for the early run of Chinook salmon returning to the Kenai River, 2004.



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 1998-2003.

Figure 19.-Daily sonar passage estimates by bank (top), total passage (center), and historical cumulative proportions (bottom) for the late run of Chinook salmon returning to the Kenai River, 2004.

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 the first two sources would generally be small, consistent, or negative (resulting in conservative estimates). We are more concerned about species discrimination errors, which can cause large biases (in either direction).

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). And although only a small fraction of sockeye salmon swim outside of our range thresholds, they can comprise more than 50% of fish in mid-channel (Burwen et al. 1998). Under these circumstances range thresholds are ineffective, and Chinook abundance can be overestimated. In response, we refined our species discrimination algorithm in 2000. Fish distribution and behavior made it evident when sockeye were abundant in mid-river; episodes of abundant sockeye in mid-river were often discrete and short-lived. Since 2000, when we suspected that this occurred, we have censored the data from the associated 1-hour samples, and generated the abundance estimate from the remaining hourly samples (see Methods). This procedure has reduced the probability of grossly overestimating Chinook abundance, but it has the drawback of being somewhat subjective to implement, and it may increase the probability of underestimating abundance. Inclusion of all available hourly samples in 2004, regardless of the presence of offshore sockeye, would have generated a late-run Chinook passage estimate through 5 August of 81,359 (SE = 1,520). However, this estimate is likely biased high, and under normal circumstances (i.e., no censoring of samples) would have been lower because of the extension of range thresholds to compensate for the large numbers of sockeye present in mid-river.

We are developing 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 Reimer *In prep*) 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 I) 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" method to help gauge their accuracy.

Historically, we have also compared sonar estimates of Chinook abundance with several other indices of Chinook and sockeye abundance to aid in evaluating the sonar's accuracy. 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.

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, which we hoped to compare within and between years as an index of Chinook salmon abundance. After analyzing the 1998-2000 standardized data, we concluded that gillnet CPUE is, at best, 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") 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 2004a).

Inriver sport fish CPUE, estimated with an intensive creel survey (Reimer *In prep*), 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 consistency.

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 2003). Although travel time between the river mile-8.6 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

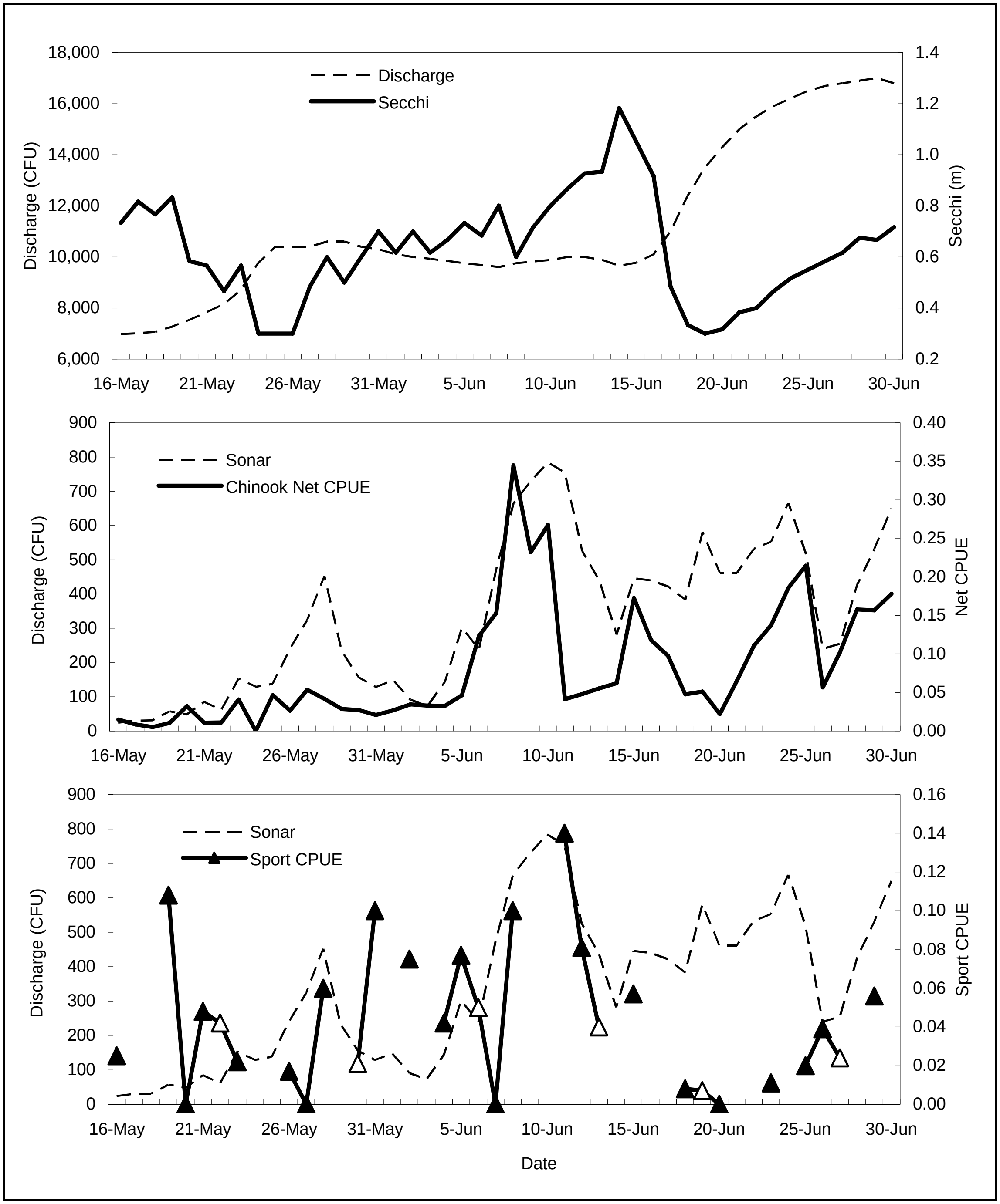
The 2004 early-run standard sonar passage estimate of 15,498 Chinook salmon was average to above average (Appendix G1). A large eulachon *Thaleichthys pacificus* migration in late May and early June resulted in sound shadowing effects that forced us to exclude the most severely affected hourly samples from calculation of the early-run daily passage estimate. Approximately 4% of the early run sample hours were dropped because of the sound shadowing effects. It is possible late-May and early-June passage estimates were biased low as a result of these actions.

Net-apportioned estimates, which are the product of unfiltered sonar estimates and the proportion of Chinook salmon in the gillnet catches (Equation 12), tracked standard sonar estimates fairly well and totaled 17,998 (SE = 710), which was 16% higher than the standard early-run estimate of 15,498 (Figure 22; Appendix H1). The standard estimates generally exceeded the net-apportioned estimates through 6 June, but were lower throughout much of the remaining early run.

The ELSD mixture model estimated 17,264 (SE = 707) Chinook salmon in the early run, approximately 11% higher than the standard sonar estimate (Appendix I). The standard sonar and mixture model estimates were close during the first 6 weeks of the early run, with standard sonar estimates falling within the 95% mixture model confidence intervals for 5 of the 6 weeks. During the seventh and final week, however, the mixture model estimate was substantially higher than the standard sonar estimate (Figure I1.4).

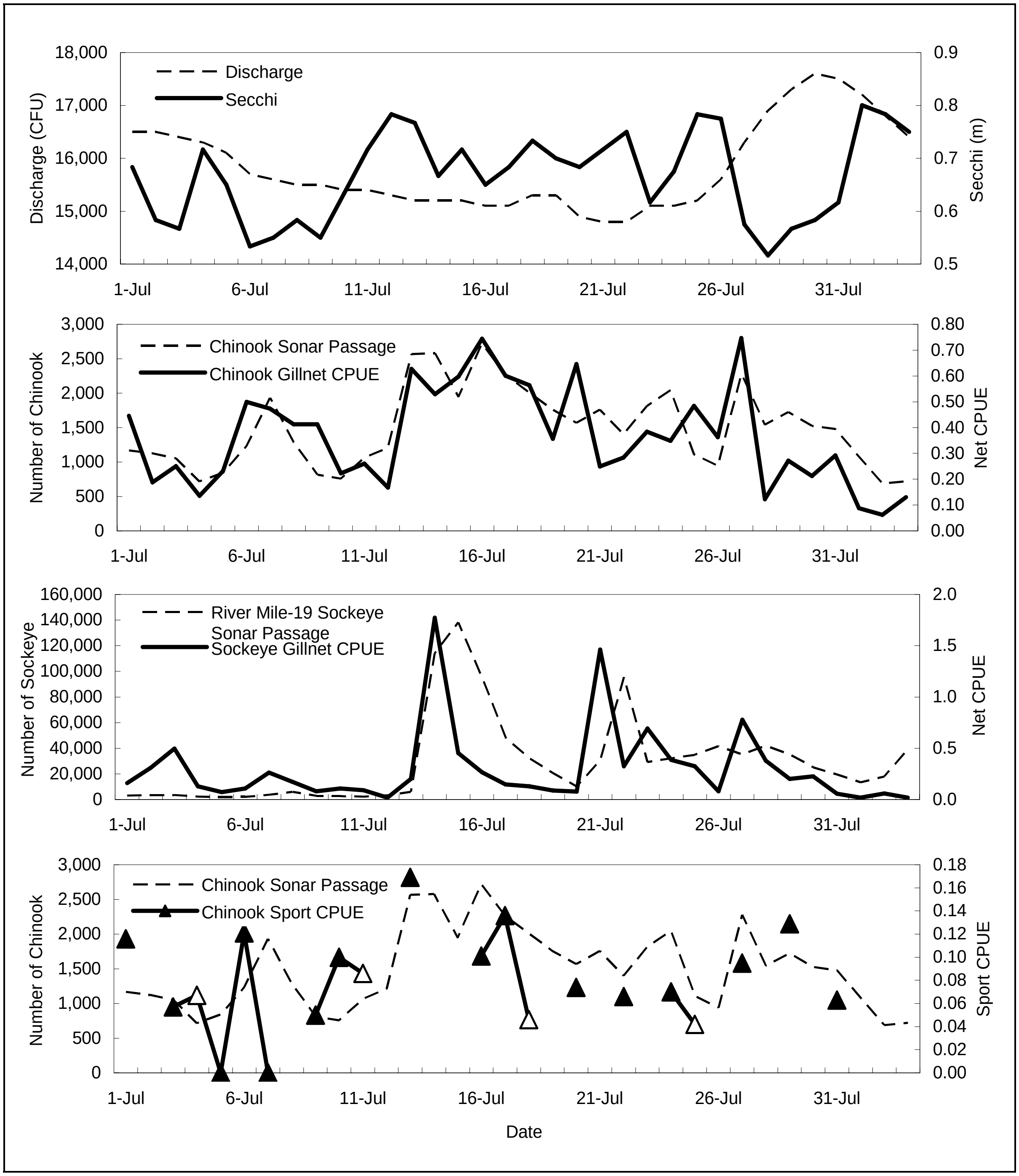
Mixture and net-apportioned abundance estimates tracked fairly well (Figure I1.4). Ninety-five percent confidence interval estimates overlapped for all weeks. Similar observations were made during the 2002 and 2003 early runs (Miller et al. 2004, 2005). We are encouraged that the two estimates, which are largely independent of each other, are correlated (Figure I1.5). In 2004, both tracked well with the standard sonar estimate. All three estimates indicate an average to slightly above average run in 2004.

As in past years (Reimer et al. 2002) sonar estimates and gillnet CPUE tracked each other short-term, but the relationship changed over time (Figure 20). Peaks in estimated sonar passage



Note: Net CPUE and sport fish CPUE taken from Reimer (*In prep*). 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 sonar passage estimates, inriver gillnet CPUE, and Chinook sport fish CPUE, early run (16 May-30 June), Kenai River, 2004.



Note: River mile-19 sockeye sonar estimates taken from Westerman and Willette (2006). Net CPUE and sport fish CPUE taken from Reimer (*In prep*). The Chinook sport fishery closed by regulation on 31 July, so no sport fish CPUE data were 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 sonar passage estimates, inriver gillnet CPUE, river mile-19 sockeye sonar passage estimates, and Chinook sport fish CPUE, late run (1 July-5 August), Kenai River, 2004.

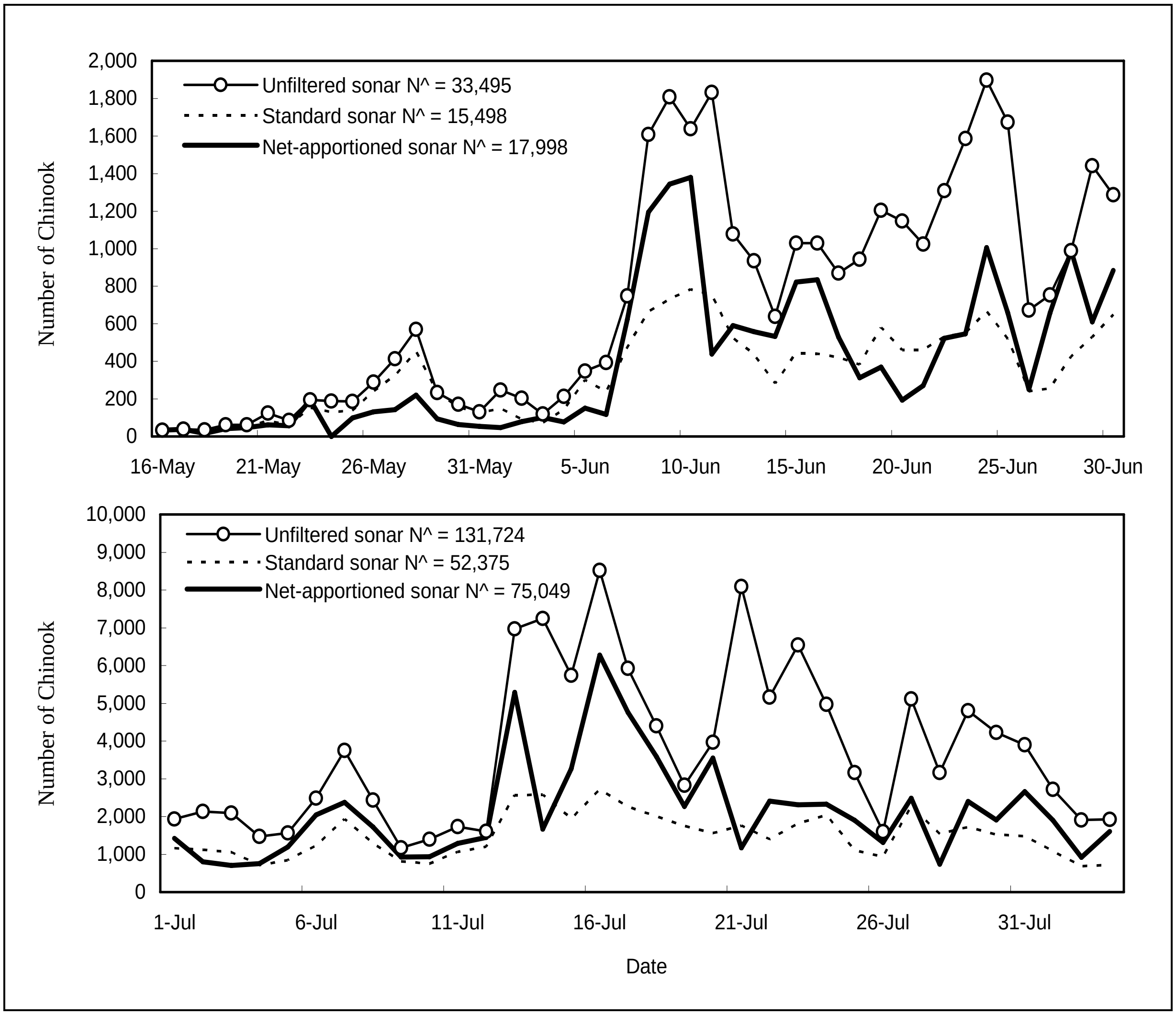


Figure 22.-Estimated early- (top) and late-run (bottom) fish passage based on unfiltered sonar (all species), standard filtered sonar (Chinook only), and net-apportioned sonar (alternative estimate, Chinook only), Kenai River, 2004.

and gillnet CPUE generally were aligned, but the relative magnitude of the changes in the two estimates varied through time. For instance, CPUE was particularly low relative to the sonar estimate on 26-30 May, 9-14 June, and 17-24 June (Figure 20). Gillnet CPUE on 17-24 June may have been influenced by the rapid fluctuations in discharge and water clarity observed. A similar disparity occurred during this time between sonar estimates and Chinook sport fish CPUE (Figure 20).

Late Run

The 2004 late-run standard sonar passage estimate through 5 August of 52,375 Chinook salmon was above average (Appendix G2). Net-apportioned sonar estimates tracked the standard sonar estimates well, but were consistently higher than the standard sonar estimates throughout much of the late run (Figure 22; Appendix H2). The cumulative net-apportioned estimate of 75,049 (SE = 2,679) Chinook salmon was 43% higher than the standard sonar estimate. A similar percentage was observed during the 2003 late run (Miller et al. 2005). The higher net-apportioned estimate in 2003 was partially attributed to the higher than average proportion of small Chinook salmon caught in gillnets that year. The proportion of small Chinook salmon caught in gillnets during the 2004 late run (Reimer *In prep*) was less than half the proportion caught during the 2003 late run (Reimer 2004b).

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 Chinook sonar passage, however, did not always coincide with peak sockeye salmon gillnet CPUE. On days when it did coincide, the magnitude of the increase in estimated Chinook passage was small relative to the increase in sockeye gillnet CPUE. In fact, several estimated peaks of Chinook salmon passage occurred on days with relatively low sockeye salmon gillnet CPUE (Figure 21). If significant misclassification of sockeye occurred, we would expect it to have occurred on days of peak sockeye salmon gillnet CPUE.

Throughout most of the late run, Chinook gillnet CPUE tracked fairly well with the daily sonar estimates (Figure 21). Some exceptions occurred on days when increases in gillnet CPUE corresponded with decreases in daily sonar estimates (and vise versa), but the magnitude of the increases or decreases were relatively small.

In summary, misclassification of sockeye salmon as Chinook salmon was likely minimal in 2004, and comparison of the standard estimate with the alternative net-apportioned estimate suggests that the late-run standard estimate may have been conservatively low (i.e., underestimated Chinook abundance).

OUTLOOK

We continue to pursue several avenues of investigation for improving our estimates of Chinook salmon abundance. Refinements made to the gillnetting project in 2002 have resulted in improved net-apportioned estimates, and we plan to continue to use them experimentally as an objective alternative index of Chinook abundance. Likewise, ELSD mixture model estimates have proven useful during the early run when sockeye salmon density is low. We are developing estimates of gillnet size-selectivity to correct both alternative estimates in 2004 and to further investigate the feasibility of implementing mixture model estimates for the late run.

It is possible that current echo length measurements can be improved to provide more precise estimates of fish size. An Alaska Sea Grant has been awarded to fund a graduate student at the University of Washington starting in September 2006. This student will focus on developing methods to improve the relationship between echo pulse shape and fish size.

Finally, we will continue experiments in 2005 using DIDSON imaging sonar to produce camera-quality images of fish up to 15 m and determine reasonably accurate measurements of fish size. In 2005, a DIDSON imaging system will be run simultaneously with an independent split-beam sonar system. The goal of this research is to synchronize split-beam and DIDSON data on free-swimming Chinook and sockeye salmon. If a sufficient sample size for each species is obtained, then species classification techniques can be tested on free-swimming fish of known size and species for the first time.

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

Dual-beam sonar (Ehrenberg 1983) uses 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 ($B(\theta,\phi)$). 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).

* Start Processing at Port 1 -FILE_PARAMETERS- Thursday July 1 12:00:09 2004

* Data processing parameters used in collecting this file for Port 1

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		220.57	sl - transducer source level
202	-1		-170.51	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		38	echogram stop range in meters
211	-1		713	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-

220	-1	5	max_angoff_ h - maximum angle off axis horiz.
221	-1	-24	max_dB_off - maximum angle off in dB
222	-1	-15.9377	ux - horizontal electrical to mechanical angle ratio
223	-1	-31.4935	uy - vertical electrical to mechanical angle ratio
224	-1	0	ud_coef_a - a coeff. for up-down beam pattern eq.
225	-1	-0.0019	ud_coef_b - b coeff. for up-down beam pattern eq.
226	-1	-2.5744	ud_coef_c - c coeff. for up-down beam pattern eq.
227	-1	0.0563	ud_coef_d - d coeff. for up-down beam pattern eq.
228	-1	-0.1206	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	-0.0007	lr_coef_b - b coeff. for left-rt beam pattern eq.
231	-1	-0.211	lr_coef_c - c coeff . for left-rt beam pattern eq.
232	-1	0.001	lr_coef_d - d coeff. for left-rt beam pattern eq.
233	-1	-0.0002	lr_coef_e - ecoeff. for left-rt beam pattern eq.
234	-1	4	maximum fish velocity in meters per second
235	-1	1	Echo Scope Bottom Location
236	-1	0.4	maxpw - pulse width search window size
238	-1	35.5	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)
401	0	1	th_layer[0] – bottom of first threshold layer (m)
401	1	5	th_layer[1] – bottom of second threshold layer (m)

-continued-

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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	713	th_val[0], threshold for 1st layer in millivolts
402	1	713	th_val[1], threshold for 2nd layer in millivolts
402	2	713	th_val[2], threshold for 3rd layer in millivolts
402	3	713	th_val[3], threshold for 4th layer in millivolts
402	4	713	th_val[4], threshold for 5th layer in millivolts
402	5	713	th_val[5], threshold for 6th layer in millivolts
402	6	713	th_val[6], threshold for 7th layer in millivolts
402	7	713	th_val[7], threshold for 8th layer in millivolts
402	8	713	th_val[8], threshold for 9th layer in millivolts
402	9	713	th_val[9], threshold for 10th layer in millivolts
402	10	713	th_val[10], threshold for 11th layer in millivolts
402	11	713	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_External	Trigger option
608	-1	LeftToRight	River flow direction

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

*** Start Processing at Port 2 -FILE_PARAMETERS- Thursday July 1 12:20:09 2004**

* Data processing parameters used in collecting this file for Port 2

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	11	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	11	N_int_layers-number of integration strata
123	-1	11	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	218.07	sl - transducer source level
202	-1	-171.98	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	32	echogram stop range in meters
211	-1	451	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.

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220	-1	5	max_angoff_ h - maximum angle off axis horiz.
221	-1	-24	max_dB_off - maximum angle off in dB
222	-1	-15.7307	ux - horizontal electrical to mechanical angle ratio
223	-1	-54.9961	uy - vertical electrical to mechanical angle ratio
224	-1	0	ud_coef_a - a coeff. for up-down beam pattern eq.
225	-1	0.0434	ud_coef_b - b coeff. for up-down beam pattern eq.
226	-1	-2.3036	ud_coef_c - c coeff. for up-down beam pattern eq.
227	-1	-0.238	ud_coef_d - d coeff. for up-down beam pattern eq.
228	-1	-0.2092	ud_coef_e - e coeff. for up-down beam pattern eq.
229	-1	0	lr_coef_a - a coeff. for left-rt beam pattern eq.
230	-1	-0.0003	lr_coef_b - b coeff. for left-rt beam pattern eq.
231	-1	-0.2138	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	29.6	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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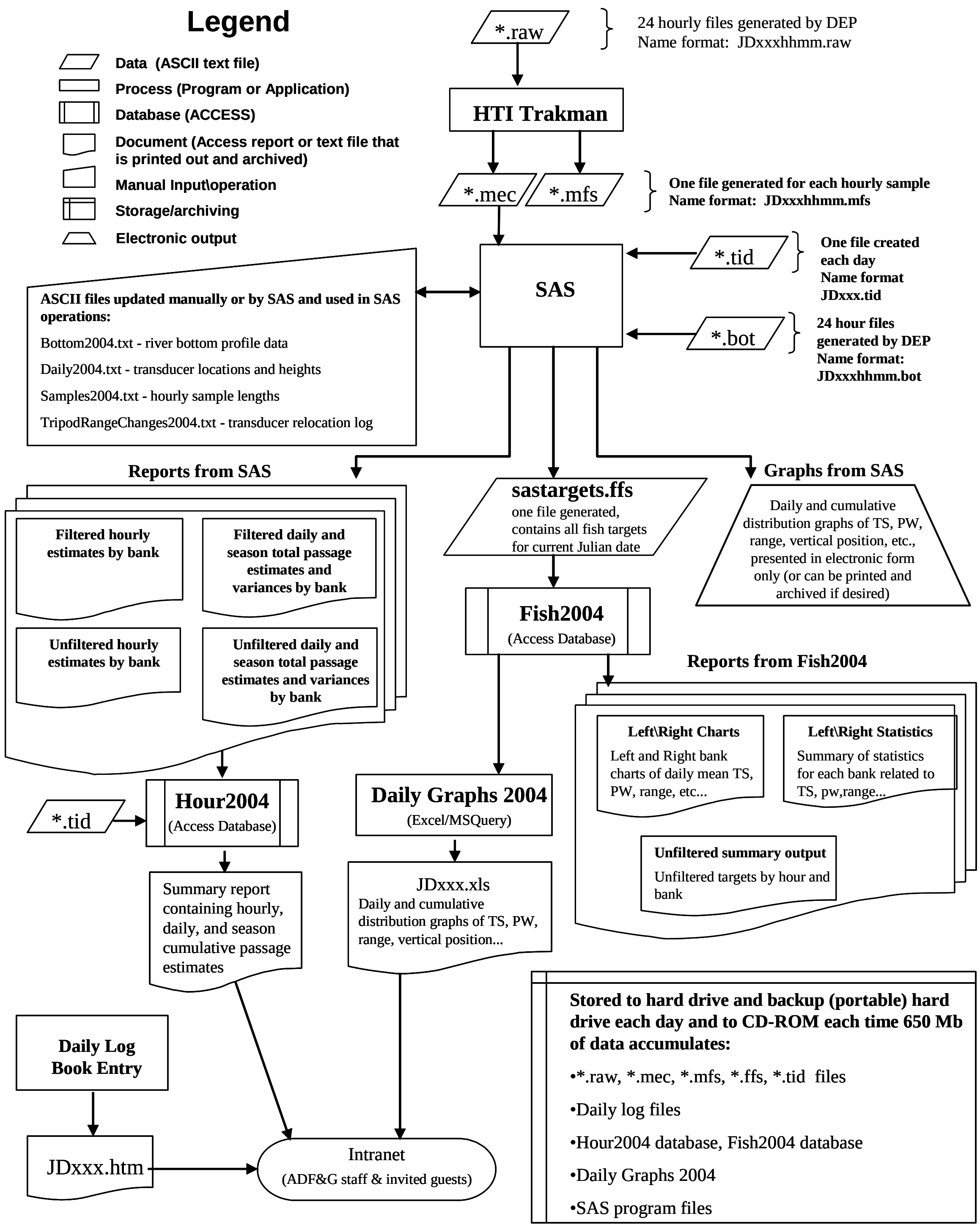
Appendix B2.-Page 3 of 3.

401	0	1	th_layer[0], bottom of 1st threshold layer
401	1	6	th_layer[1], bottom of 2nd threshold layer
401	2	11	th_layer[2], bottom of 3rd threshold layer
401	3	16	th_layer[3], bottom of 4th threshold layer
401	4	21	th_layer[4], bottom of 5th threshold layer
401	5	26	th_layer[5], bottom of 6th threshold layer
401	6	31	th_layer[6], bottom of 7th threshold layer
401	7	36	th_layer[7], bottom of 8th threshold layer
401	8	41	th_layer[8], bottom of 9th threshold layer
401	9	46	th_layer[9], bottom of 10th threshold layer
401	10	51	th_layer[10], bottom of 11th threshold layer
402	0	451	th_val[0], threshold for 1st layer in millivolts
402	1	451	th_val[1], threshold for 2nd layer in millivolts
402	2	451	th_val[2], threshold for 3rd layer in millivolts
402	3	451	th_val[3], threshold for 4th layer in millivolts
402	4	451	th_val[4], threshold for 5th layer in millivolts
402	5	451	th_val[5], threshold for 6th layer in millivolts
402	6	451	th_val[6], threshold for 7th layer in millivolts
402	7	451	th_val[7], threshold for 8th layer in millivolts
402	8	451	th_val[8], threshold for 9th layer in millivolts
402	9	451	th_val[9], threshold for 10th layer in millivolts
402	10	9999	th_val[10], threshold for 11th 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	9999	Integration threshold value for layer 11 (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_External	Trigger option
608	-1	LeftToRight	River flow direction

APPENDIX C. DATA FLOW



Appendix C1.-Data flow diagram for the Kenai River Chinook salmon sonar project, 2004.

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, 2004.

Date	Excluded Sample Hours	
	Left Bank	Right Bank
EARLY RUN		
17-May	-	1700, 1900
18-May	-	2000-2200
19-May	-	0000
25-May	2120	-
26-May	1020-1120	1000-1100
29-May	0020	0000, 1400
30-May	0120, 1420	0100, 1400, 2100
31-May	1420	0100-0200, 0500-1000, 1300-1500, 1700-2100
1-Jun	-	0100, 0300, 0700-0900, 1400, 1900-2100
2-Jun	-	0800-1200, 1500, 2100-2300
3-Jun	-	0000, 0200, 1000-1200, 1600, 2200
4-Jun	0320, 1720, 1920	0300, 0900-1100, 1700-1900
5-Jun	0420, 1820	0400, 1100, 1600, 1800-1900
6-Jun	-	1100
8-Jun	-	0700
9-Jun	-	0900-1000, 2100
10-Jun	-	1000, 2200
11-Jun	1220, 2320	1100, 2300
12-Jun	-	1200
13-Jun	-	0000, 1300
14-Jun	-	0000, 1800
15-Jun	-	0100, 1500, 1800
16-Jun	-	0100, 1500
22-Jun	-	0600
23-Jun	-	2000
24-Jun	2120	2100
25-Jun	0920-1020	0900-1000
30-Jun	-	1500
LATE RUN		
1-Jul	1520-1620	1500-1600, 1800
2-Jul	-	0800-1000, 2100
3-Jul	-	1000-1100
4-Jul	-	1000-1200, 1700
5-Jul	1020, 2120	1000, 2100
6-Jul	-	0800-1200, 2300
7-Jul	-	0100, 0800, 1300, 1900, 2000
8-Jul	-	0800-0900, 1300-1400
9-Jul	-	2100
11-Jul	2320	2300
13-Jul	1420-1620, 1820	1100-1600, 1800
14-Jul	0020, 0120, 0820, 1420-1520, 1720	0700-1000, 1400-1500, 1700
15-Jul	0220, 0820, 1520-1720	0700-0800, 1500-1700
16-Jul	0220, 1520-1920	0200, 0700-0800, 1300-1400, 1600-2000
17-Jul	0820, 1720-1820	0300-0400, 0800-0900, 1600-1900, 2100-2300

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Appendix D1.-Page 2 of 2.

Date	Excluded Sample Hours	
	Left Bank	Right Bank
18-Jul	0920-1020, 1720-2020	0500, 0900-1100, 1700-2200
19-Jul	1820	1800
20-Jul	1820-1920, 2120-2320	0500, 1000-1200, 1800-1900, 2200-2300
21-Jul	0820, 1020-1320, 1820, 2020	0500-1500, 1800-1900
22-Jul	0620-0920, 1320, 1920-2120	0700-1300, 1900-2100
23-Jul	0720-0820, 1420, 1920-2120	0700-0900, 1100-1400, 1900-2100
24-Jul	0820-1120, 2020-2120	0800-1100, 1400, 1600, 2000-2100
25-Jul	1020-1120, 2120-2320	1000-1200, 2100-2300
26-Jul	2220-2320	2200-2300
27-Jul	0920, 1220-1320	0900-1500, 1700-1800, 2300
28-Jul	-	0600-0700, 1400-1500, 1700
29-Jul	0120-0220, 1420-1520, 1820	0000-0200, 1400-1600, 1800
30-Jul	0220, 0820, 1520-1620	0200-0400, 0700-0800, 1500-1700
31-Jul	0320, 1520-1920	1600-1900
1-Aug	620, 820, 1620, 1820	0600-0900, 1600, 1800-2000
2-Aug	1720, 2120-2320	0800, 1700, 2100-2300
3-Aug	0420, 1720, 2120	1000, 1700, 2100-2300
4-Aug	0520, 1120, 2220-2320	0500-0600, 1000-1400, 1800, 2100, 2300
5-Aug	0620-0820, 1120, 1820-1920, 2120-2220	0600-0900, 1100, 1800-1900, 2200

APPENDIX E. DAILY PROPORTION OF UPSTREAM AND DOWNSTREAM MOVING FISH FOR THE CHINOOK EARLY AND LATE RUNS, KENAI RIVER, 2004

Appendix E1.-Daily proportion of upstream and downstream moving fish for the Chinook early run, Kenai River, 2004.

Date	Downstream Count	Upstream Count	Daily Total	% Downstream	% Upstream
16 May	6	24	30	20%	80%
17 May	0	30	30	0%	100%
18 May	3	31	34	9%	91%
19 May	3	57	60	5%	95%
20 May	0	48	48	0%	100%
21 May	3	84	87	3%	97%
22 May	6	61	67	9%	91%
23 May	9	153	162	6%	94%
24 May	3	129	132	2%	98%
25 May	9	138	147	6%	94%
26 May	6	240	246	2%	98%
27 May	3	324	327	1%	99%
28 May	6	452	458	1%	99%
29 May	6	233	239	3%	97%
30 May	4	156	160	3%	98%
31 May	6	128	134	4%	96%
1 June	6	148	154	4%	96%
2 June	3	91	94	3%	97%
3 June	3	72	75	4%	96%
4 June	6	143	149	4%	96%
5 June	16	301	317	5%	95%
6 June	12	239	251	5%	95%
7 June	30	474	504	6%	94%
8 June	30	665	695	4%	96%
9 June	43	730	773	6%	94%
10 June	76	784	860	9%	91%
11 June	46	754	800	6%	94%
12 June	52	525	577	9%	91%
13 June	31	438	469	7%	93%
14 June	51	282	333	15%	85%
15 June	85	446	531	16%	84%
16 June	48	440	488	10%	90%
17 June	45	422	467	10%	90%
18 June	18	383	401	4%	96%
19 June	12	581	593	2%	98%
20 June	9	461	470	2%	98%
21 June	12	461	473	3%	97%
22 June	11	532	543	2%	98%
23 June	5	552	557	1%	99%
24 June	10	666	676	1%	99%
25 June	8	520	528	2%	98%
26 June	6	240	246	2%	98%
27 June	6	255	261	2%	98%
28 June	15	426	441	3%	97%
29 June	21	530	551	4%	96%
30 June	27	649	676	4%	96%
Total	816	15,498	16,314	5%	95%

Appendix E2.-Daily proportion of upstream and downstream moving fish for the Chinook late run, Kenai River. 2004.

Date	Downstream Count	Upstream Count	Daily Total	% Downstream	% Upstream
1 July	37	1,167	1,204	3%	97%
2 July	53	1,125	1,178	4%	96%
3 July	38	1,053	1,091	3%	97%
4 July	8	715	723	1%	99%
5 July	28	842	870	3%	97%
6 July	26	1,231	1,257	2%	98%
7 July	28	1,932	1,960	1%	99%
8 July	26	1,287	1,313	2%	98%
9 July	29	815	844	3%	97%
10 July	18	757	775	2%	98%
11 July	30	1,061	1,091	3%	97%
12 July	42	1,208	1,250	3%	97%
13 July	122	2,567	2,689	5%	95%
14 July	124	2,577	2,701	5%	95%
15 July	65	1,943	2,008	3%	97%
16 July	134	2,718	2,852	5%	95%
17 July	123	2,262	2,385	5%	95%
18 July	129	2,008	2,137	6%	94%
19 July	151	1,753	1,904	8%	92%
20 July	115	1,566	1,681	7%	93%
21 July	40	1,757	1,797	2%	98%
22 July	24	1,401	1,425	2%	98%
23 July	26	1,812	1,838	1%	99%
24 July	47	2,044	2,091	2%	98%
25 July	39	1,107	1,146	3%	97%
26 July	63	941	1,004	6%	94%
27 July	111	2,277	2,388	5%	95%
28 July	71	1,540	1,611	4%	96%
29 July	51	1,724	1,775	3%	97%
30 July	37	1,523	1,560	2%	98%
31 July	47	1,480	1,527	3%	97%
1 August	37	1,078	1,115	3%	97%
2 August	55	688	743	7%	93%
3 August	69	722	791	9%	91%
4 August	52	754	806	6%	94%
5 August	53	940	993	5%	95%
Total	2,148	52,375	54,523	4%	96%

APPENDIX F. AVERAGE VERTICAL ANGLE BY TIDE STAGE, RUN, BANK, AND FISH ORIENTATION (UPSTREAM OR DOWNSTREAM) FOR THE CHINOOK EARLY AND LATE RUNS, KENAI RIVER, 2004

Appendix F1.-Average vertical angle by tide stage and orientation for the Chinook early run, Kenai River, 2004.

Tide Stage / Fish Orientation	Average Vertical Angle	Standard Deviation	Sample Size
	Left Bank		
Falling			
Downstream	-0.44	0.37	22
Upstream	-0.59	0.34	1,048
Tide Stage Total	-0.59	0.35	1,070
Low			
Downstream	-0.32	0.58	23
Upstream	-0.57	0.37	328
Tide Stage Total	-0.56	0.39	351
Rising			
Downstream	-0.08	0.53	34
Upstream	-0.14	0.57	642
Tide Stage Total	-0.13	0.56	676
Left Bank Total	-0.44	0.48	2,097
	Right Bank		
Falling			
Downstream	-0.17	0.46	100
Upstream	-0.37	0.30	1,522
Tide Stage Total	-0.36	0.32	1,622
Low			
Downstream	-0.29	0.33	38
Upstream	-0.36	0.28	320
Tide Stage Total	-0.36	0.28	358
Rising			
Downstream	-0.19	0.42	91
Upstream	-0.21	0.40	1,783
Tide Stage Total	-0.21	0.40	1,874
Right Bank Total	-0.29	0.37	3,854

Appendix F2.-Average vertical angle by tide stage and orientation for the Chinook late run, Kenai River, 2004.

Tide Stage / Fish Orientation	Average Vertical Angle	Standard Deviation	Sample Size
	Left Bank		
Falling			
Downstream	-0.38	0.39	196
Upstream	-0.52	0.28	4,142
Tide Stage Total	-0.52	0.29	4,338
Low			
Downstream	-0.40	0.34	76
Upstream	-0.55	0.25	1,399
Tide Stage Total	-0.55	0.26	1,475
Rising			
Downstream	-0.27	0.47	90
Upstream	-0.18	0.46	3,182
Tide Stage Total	-0.18	0.46	3,272
Left Bank Total	-0.40	0.39	9,085
	Right Bank		
Falling			
Downstream	-0.26	0.38	404
Upstream	-0.38	0.29	8,062
Tide Stage Total	-0.38	0.29	8,466
Low			
Downstream	-0.27	0.39	97
Upstream	-0.41	0.27	2,190
Tide Stage Total	-0.41	0.28	2,287
Rising			
Downstream	-0.24	0.32	210
Upstream	-0.23	0.36	7,952
Tide Stage Total	-0.23	0.36	8,162
Right Bank Total	-0.32	0.33	18,915

APPENDIX G. HISTORIC PASSAGE BY YEAR AND DATE (1987–2004)

Appendix G1.-Kenai River early-run Chinook salmon sonar passage estimates, 1987-2004.

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

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

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

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

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

[c] Only upstream moving fish reported.

Appendix G2.-Kenai River late-run Chinook salmon sonar passage estimates, 1987-2004.

Date	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]
1 July	507	526	769	578	267	364	619	663	350	341	486	491	453	461	697	563	727	1,167
2 July	429	404	489	305	300	297	525	342	398	240	642	597	612	373	766	1,596	735	1,125
3 July	405	398	353	486	333	320	404	625	353	303	600	480	486	370	1,075	2,456	982	1,053
4 July	628	292	566	436	519	198	468	858	439	393	633	450	396	488	714	1,855	1,212	715
5 July	596	482	1,106	853	316	225	429	705	667	1,067	657	606	369	787	676	1,949	1,684	842
6 July	523	654	879	795	242	331	996	975	720	879	627	612	683	778	645	1,205	1,462	1,231
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
1 August	470	925	351	**393**	897	**921**	776	1,037	474		247	**909**	591	695	455	642	377	1,078
2 August	314	781	201	**388**	867	**1,018**	626	1,223	369		291	**1,512**	468	421	459	553	394	688
3 August	263	989	132	**533**	392	**837**	350	1,078	447		213	**1,006**	642	294	504	752	379	722

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Date	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]
4 August	835	1,524	142	**717**	331	**862**	467	658	519			**1,131**	444	453	840	995		754
5 August	904	1,091	107	**723**	174	**861**	711	536	404			**1,094**	436	489	581	575		940
6 August	648	1,333	107	**552**	343	**654**	1,076	1,042	408			**864**	654	504	417	754[c]		1,009[c]
7 August	694	1,186	65	**516**	618	**558**	655	797	279			**843**	678	366	618	676[c]		905[c]
8 August	658	1,449		**682**	600	**217**	682		267			**750**	804	417	467	636[c]		854[c]
9 August	368	1,132		**679**		**165**	424		272			**570**	328	399	232	456[c]		611[c]
10 August	312	755		**678**		**249**	252					**496**	165	397	200	337[c]		451[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

Note: Bold and outlined numbers represent dates when the Chinook fishery was restricted due to low inriver return.

[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 current table are correct and were originally reported by Burwen and Bosch 1995a; 1995b).

[b] Only upstream moving fish reported.

[c] Sampling was terminated on 5 August due to 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 due to pink salmon 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 due to pink salmon 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.

APPENDIX H. FILTERED (CONVENTIONAL), UNFILTERED, AND NET-APPORTIONED CHINOOK PASSAGE ESTIMATES, KENAI RIVER SONAR, EARLY AND LATE RUNS, 2004.

Appendix H1.-Estimated fish passage based on unfiltered sonar (all species), standard filtered sonar (Chinook only), and net-apportioned sonar (alternative estimate, Chinook only), Kenai River, early run, 2004.

Date	Unfiltered		Filtered (Standard)		Net-Apportioned	
	Passage	SE	Passage	SE	Passage	SE
16-May	33	8	24	8	33	8
17-May	39	7	30	7	39	7
18-May	36	9	31	9	17	14
19-May	63	12	57	10	41	21
20-May	63	8	48	8	47	12
21-May	124	17	84	15	63	27
22-May	85	13	61	12	57	31
23-May	195	21	153	20	195	21
24-May	189	22	129	14	0	0
25-May	186	20	138	19	99	34
26-May	290	28	240	24	132	27
27-May	414	31	324	29	142	48
28-May	570	43	452	34	221	77
29-May	234	28	233	24	94	23
30-May	172	28	156	23	64	20
31-May	132	20	128	16	55	35
1-Jun	247	33	148	25	47	20
2-Jun	204	54	91	50	79	33
3-Jun	120	17	72	14	101	26
4-Jun	213	40	143	32	78	46
5-Jun	349	39	301	43	151	49
6-Jun	393	39	239	32	117	28
7-Jun	748	84	474	51	623	95
8-Jun	1,608	168	665	61	1,195	164
9-Jun	1,808	241	730	61	1,343	300
10-Jun	1,638	207	784	52	1,379	231
11-Jun	1,831	164	754	63	439	137
12-Jun	1,078	104	525	41	591	268
13-Jun	935	141	438	42	559	110
14-Jun	640	64	282	36	533	95
15-Jun	1,030	135	446	40	822	117
16-Jun	1,030	86	440	31	835	90
17-Jun	869	73	422	50	530	165
18-Jun	943	46	383	27	314	64
19-Jun	1,204	74	581	40	370	114
20-Jun	1,148	70	461	45	194	95
21-Jun	1,024	58	461	33	272	88
22-Jun	1,308	103	532	56	524	73
23-Jun	1,587	142	552	39	546	100
24-Jun	1,897	166	666	62	1,007	110
25-Jun	1,674	115	520	46	659	202
26-Jun	673	50	240	25	251	44
27-Jun	754	81	255	40	658	85
28-Jun	989	84	426	53	989	84
29-Jun	1,442	107	530	58	610	115
30-Jun	1,286	111	649	66	885	94
Total	33,495	611	15,498	261	17,998	710

Appendix H2.-Estimated fish passage based on unfiltered sonar (all species), standard filtered sonar (Chinook only), and net-apportioned sonar (alternative estimate, Chinook only), Kenai River, late run, 2004.

Date	Unfiltered		Filtered (Standard)		Net-Apportioned	
	Passage	SE	Passage	SE	Passage	SE
1-Jul	1,932	114	1,167	77	1,421	236
2-Jul	2,131	121	1,125	78	806	147
3-Jul	2,096	130	1,053	109	702	205
4-Jul	1,476	104	715	49	757	126
5-Jul	1,565	108	842	76	1,194	94
6-Jul	2,483	112	1,231	75	2,043	115
7-Jul	3,749	234	1,932	93	2,376	285
8-Jul	2,438	152	1,287	94	1,721	178
9-Jul	1,169	109	815	51	933	119
10-Jul	1,394	64	757	44	941	79
11-Jul	1,735	99	1,061	67	1,287	116
12-Jul	1,603	85	1,208	72	1,447	125
13-Jul	6,967	640	2,567	154	5,285	517
14-Jul	7,246	568	2,577	145	1,665	1,653
15-Jul	5,738	698	1,943	134	3,260	705
16-Jul	8,518	991	2,718	147	6,280	851
17-Jul	5,921	487	2,262	170	4,758	632
18-Jul	4,402	269	2,008	149	3,587	354
19-Jul	2,828	201	1,753	110	2,269	360
20-Jul	3,966	308	1,566	95	3,546	298
21-Jul	8,089	857	1,757	153	1,172	226
22-Jul	5,163	426	1,401	71	2,409	239
23-Jul	6,547	646	1,812	100	2,308	324
24-Jul	4,972	365	2,044	84	2,325	311
25-Jul	3,163	242	1,107	95	1,896	335
26-Jul	1,602	109	941	47	1,312	131
27-Jul	5,115	225	2,277	111	2,488	616
28-Jul	3,166	165	1,540	80	734	243
29-Jul	4,806	411	1,724	91	2,400	386
30-Jul	4,225	339	1,523	83	1,906	428
31-Jul	3,900	396	1,480	83	2,658	538
1-Aug	2,722	183	1,078	75	1,901	181
2-Aug	1,910	124	688	50	923	422
3-Aug	1,922	173	722	49	1,604	206
4-Aug	2,330	216	754	49	1,524	301
5-Aug	2,735	167	940	76	1,212	224
Total	131,724	2,246	52,375	585	75,049	2,679

APPENDIX I. ECHO LENGTH STANDARD DEVIATION MIXTURE MODEL ESTIMATES OF SPECIES COMPOSITION AND CHINOOK ABUNDANCE, EARLY RUN 2004.

Appendix I1.-Echo length standard deviation mixture model estimates of species composition and Chinook abundance, early run, Kenai River, 2004.

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 measurements of the length (duration) of echoes 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 I1). Furthermore, results are sensitive to fish size distributions. For instance, in the example illustrated in Figure I1, 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.

Echo length standard deviation (ELSD) is used as the hydroacoustic correlate of fish size in the mixture models. Estimates based on the mixture model approach currently have two limitations. First, measurements of ELSD may be inflated when fish migrate at high densities, so thus far we have produced mixture model estimates only for the early run, when fish density remains low. Second, the mixture model requires empirical estimates of sockeye and Chinook length distributions from the gillnet catches. Limited gillnet sample sizes make it necessary to pool the data to produce weekly, rather than daily, estimates of species composition.

An abbreviated description of the mixture model approach is presented here, along with results from the 2004 early run. See Fleischman and Burwen (2003) for more details.

METHODS

ELSD is calculated as,

$$ELSD = \sqrt{\sum_{j=1}^{m} \left(w_j - \overline{w}\right)^2 \Big/ m-1}\,, \qquad \text{(I1)}$$

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 analyses reported here. 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 I2),

$$f(y) = \pi_S f_S(y) + \pi_C f_C(y), \tag{I2}$$

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:

$$y_i = \beta_0 + \beta_1 x_i + \gamma z_i + \varepsilon_i, \tag{I3}$$

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 I2). The species proportions π_S and π_C were the parameters of interest.

Length measurements were obtained from fish captured by gillnets (Reimer *In prep*) 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.

$$f_S(x) = \theta_{S1}\, f_{S1}(x) + \theta_{S2}\, f_{S2}(x) + \theta_{S3}\, f_{S3}(x), \tag{I4}$$

$$f_C(x) = \theta_{C1}\, f_{C1}(x) + \theta_{C2}\, f_{C2}(x) + \theta_{C3}\, f_{C3}(x), \tag{I5}$$

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

$$f_{Sa}(x) \sim N(\mu_{Sa},, \tau^2_{Sa}), \text{ and} \tag{I6}$$

$$f_{Ca}(x) \sim N(\mu_{Ca},, \tau^2_{Ca}). \tag{I7}$$

The overall design was therefore 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 (Bayes Using Gibbs Sampler; 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 I1).

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. Samples were thinned up to 10 to 1 thereafter, and at least 10,000 samples per chain were retained.

The end product of a Bayesian analysis is the joint posterior probability distribution of all unknowns in the model. For 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've 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, since 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.

$$\hat{y}''_w = \hat{\pi}_{Cw} \sum_{i \in w} \hat{x}_i \ . \qquad \text{(I8)}$$

RESULTS

Weekly statistics from the marginal posterior distributions of model parameters are summarized in Table I1. Posterior distributions of regression parameters shifted only slightly among weeks. Mixture model estimates totaled 17,264 (SE = 707) for the early run, slightly higher than the official estimate of 15,498 (SE = 261) and slightly lower than the net apportioned estimate of 17,998 (SE = 710). Modeled ELSD frequency distributions fit the weekly ELSD data reasonably well (Figure I3). Weekly mixture model estimates were between official estimates and net-apportioned estimates in most weeks (Figure I4). Weekly estimates by the two alternative methods have shown good agreement during 2002-2004 (Figure I5). Further comparisons of alternative early-run abundance estimates can be found in the main body of this report.

Table I1.-Summary statistics of prior and posterior distributions of parameters estimated from a Bayesian mixture model analysis of 7 weeks of Kenai River sonar and netting data, 2004.

	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	0.0322	0.0028	0.0266	0.0322	0.0377
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: 16 fish netted, 85 hydroacoustic targets					
β_0	3.01	0.11	2.80	3.01	3.22
β_1	0.0341	0.0028	0.0286	0.0341	0.0396
γ	-0.32	0.12	-0.56	-0.32	-0.09
σ	0.45	0.03	0.40	0.45	0.50
π_C	0.71	0.06	0.60	0.71	0.82
Week 2 Posteriors: 46 fish netted, 468 hydroacoustic targets					
β_0	2.97	0.10	2.78	2.97	3.18
β_1	0.0331	0.0028	0.0275	0.0331	0.0385
γ	-0.27	0.12	-0.50	-0.27	-0.04
σ	0.47	0.02	0.42	0.47	0.52
π_C	0.59	0.07	0.46	0.59	0.75
Week 3 Posteriors: 54 fish netted, 342 hydroacoustic targets					
β_0	2.77	0.10	2.57	2.78	2.97
β_1	0.0343	0.0030	0.0284	0.0343	0.0400
γ	-0.30	0.12	-0.54	-0.30	-0.07
σ	0.48	0.03	0.44	0.48	0.54
π_C	0.51	0.06	0.40	0.50	0.63
Week 4 Posteriors: 166 fish netted, 2,264 hydroacoustic targets					
β_0	2.81	0.08	2.66	2.81	2.96
β_1	0.0343	0.0027	0.0290	0.0343	0.0395
γ	-0.24	0.11	-0.45	-0.24	-0.03
σ	0.48	0.02	0.45	0.48	0.51
π_C	0.53	0.03	0.47	0.53	0.59
Week 5 Posteriors: 101 fish netted, 1,592 hydroacoustic targets					
β_0	2.80	0.09	2.63	2.80	2.97
β_1	0.0335	0.0028	0.0279	0.0335	0.0388
γ	-0.33	0.12	-0.56	-0.33	-0.10
σ	0.47	0.02	0.43	0.47	0.51
π_C	0.52	0.03	0.46	0.52	0.59
Week 6 Posteriors: 141 fish netted, 2,514 hydroacoustic targets					
β_0	2.87	0.10	2.69	2.87	3.08
β_1	0.0323	0.0030	0.0262	0.0324	0.0380
γ	-0.23	0.14	-0.50	-0.22	0.04
σ	0.56	0.02	0.53	0.56	0.60
π_C	0.41	0.04	0.33	0.41	0.51
Week 7 Posteriors: 96 fish netted, 1,521 hydroacoustic targets					
β_0	2.88	0.12	2.66	2.88	3.10
β_1	0.0333	0.0030	0.0275	0.0334	0.0391
γ	-0.31	0.13	-0.56	-0.32	-0.06
σ	0.52	0.02	0.48	0.52	0.57
π_C	0.66	0.08	0.52	0.65	0.84

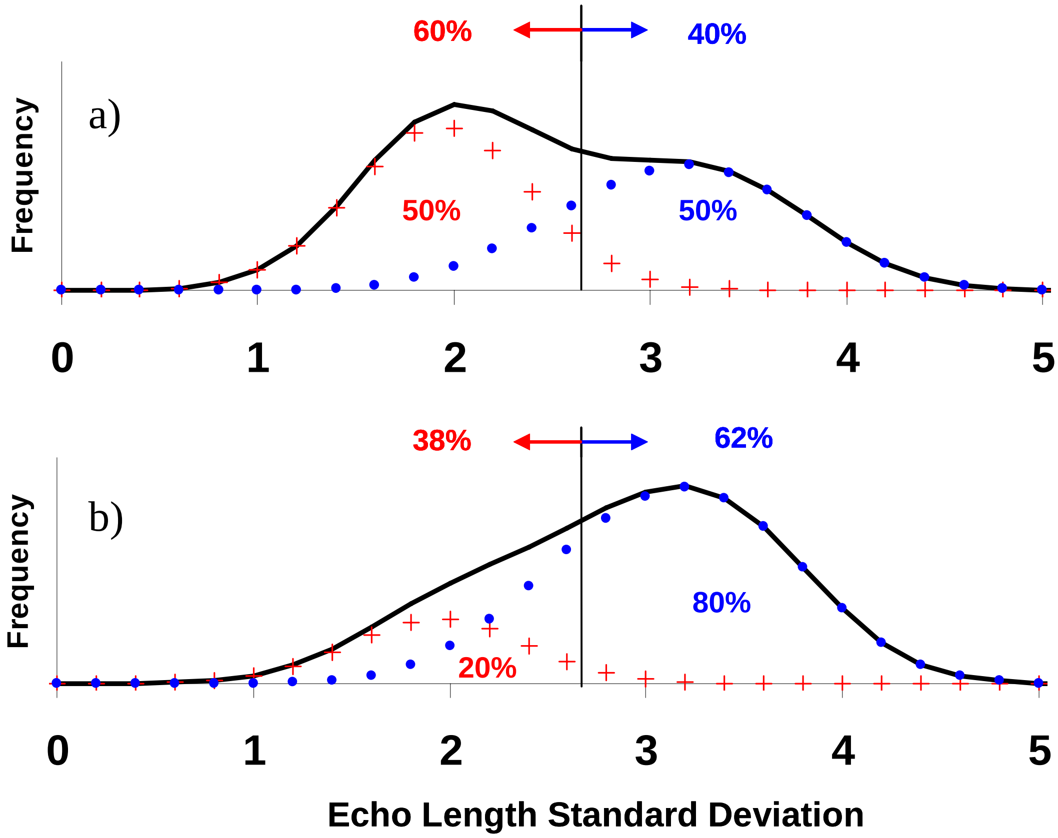

Figure I1.-Threshold-based discrimination is subject to bias when discriminating variables are imprecise. Solid lines are simulated frequency distributions of echo length standard deviation arising from component distributions due to sockeye salmon (plus symbols) and Chinook salmon (solid symbols). (a) If the true species composition is 50% sockeye/50% Chinook, 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%.

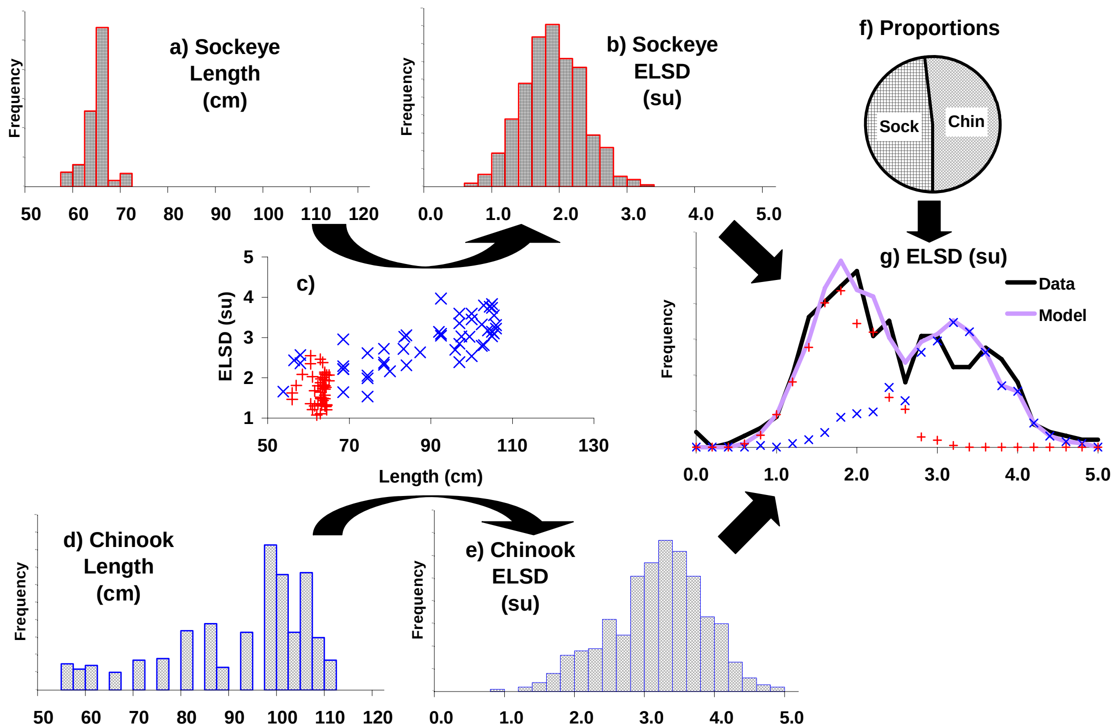

Figure I2.-Flow chart of mixture model described in the text. The frequency distribution of echo length standard deviation (ELSD, panel g) is modeled as a weighted mixture of species-specific ELSD distributions (b and e), which in turn are the products of species-specific size distributions (a and d) and the relationship between ELSD and fish length (c). The weights (species proportions, panel f) are the parameters of interest. Plus symbol = sockeye, x = Chinook. Checkered pattern = sockeye, cross-hatched = Chinook. Units for ELSD are 48 kHz digital sampling units.

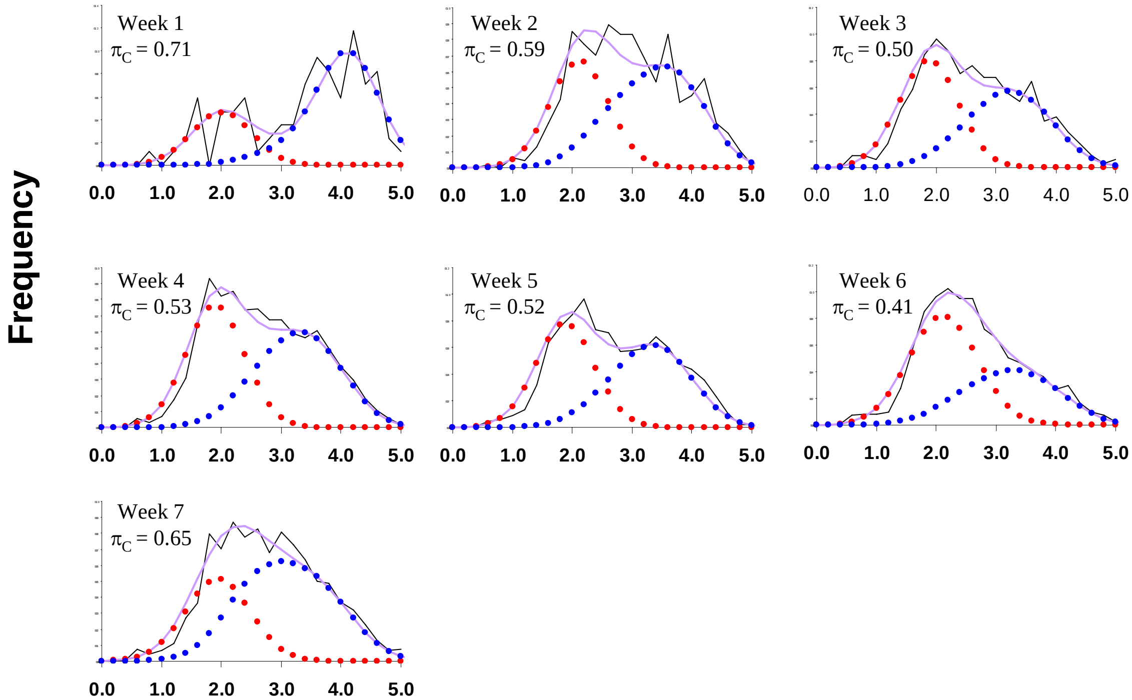

Figure I3.-Observed (black) and fitted (gray) frequency distributions of echo length standard deviation (ELSD) from the 2004 early run, by week. Dotted lines are the component distributions from sockeye (left) and Chinook salmon (right). The posterior median of the proportion of Chinook salmon pC is listed in the header of each panel.

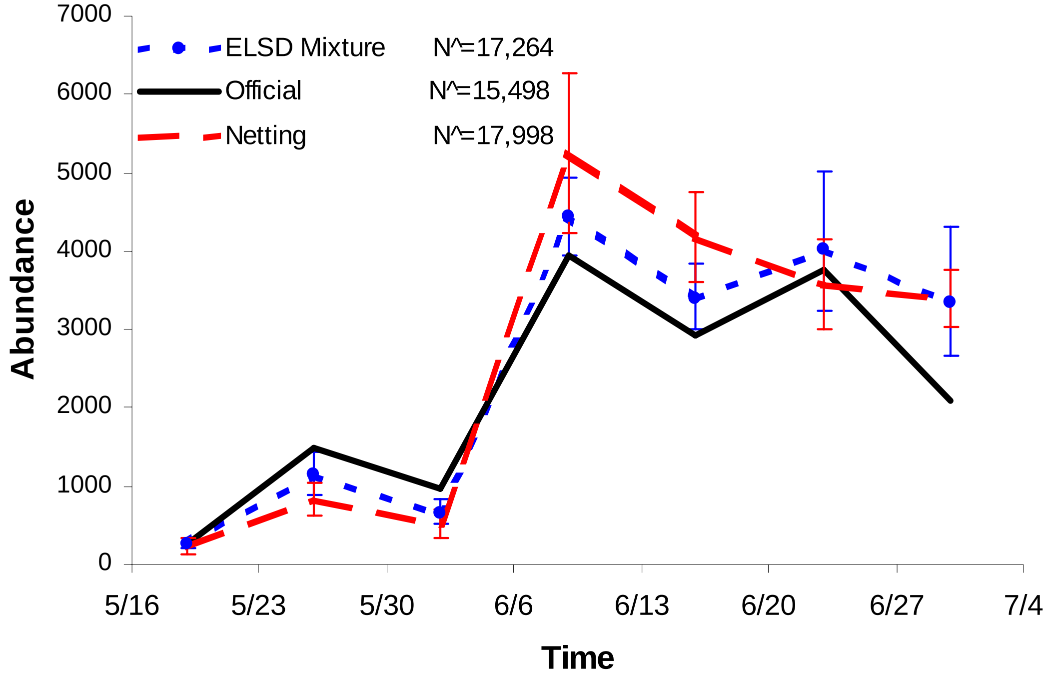

Figure I4.-Weekly Chinook salmon abundance estimates for the 2004 Kenai River early run. Solid line = official estimates; dashed line = netting-apportioned estimates; dotted line = ELSD mixture model estimates. Error bars represent 95% intervals for netting and mixture estimates.

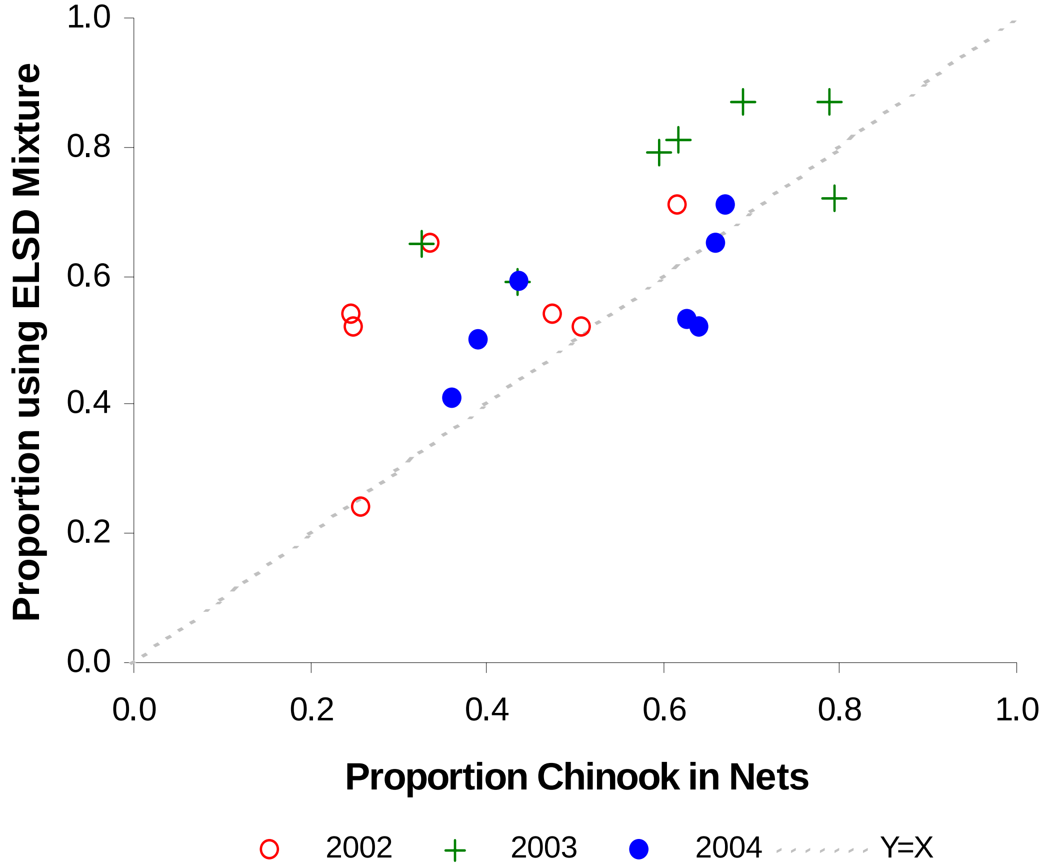

Figure I5.-ELSD mixture model estimates vs. net-apportioned weekly estimates of the proportion of Chinook salmon among fish passing the Kenai River sonar, early run 2002 (open symbols), 2003 (plus signs), and 2004 (solid symbols).