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Estimates of Chinook Salmon Abundance in the Kenai River Using Split-Beam Sonar, 2003

by

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November 2005

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

Symbols and Abbreviations

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Weights and measures (metric)

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

Weights and measures (English)

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

Time and temperature

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

Physics and chemistry

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

General

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

Measures (fisheries)

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

Mathematics, statistics

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

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TABLE OF CONTENTS

Page

TABLE OF CONTENTS (Continued)

Page

LIST OF TABLES

Table **Page**

LIST OF FIGURES

LIST OF APPENDICES

ABSTRACT

The passage of Chinook salmon *Oncorhynchus tshawytscha* in the Kenai River in 2003 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. Total upstream Chinook salmon passage from 16 May through 3 August 2003 was an estimated 54,984 (SE = 479) fish, 13,325 (SE = 199) fish during the early run and 41,659 (SE = 435) fish during the late run. The standard errors associated with these estimates reflect only sampling error and not other sources of uncertainty including target detectability, species composition, direction of travel, and target tracking. The early run peak daily passage occurred on 8 June with 50% of the run having passed by 10 June. The late run peak daily passage occurred on 22 July, with 50% of the late run having passed by 17 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*; Mills 1979-1980, 1981*a-b*, 1982-1994; Walker et al. 2003; Jennings et al. 2004). The fishery has been a source of contention because Kenai River Chinook salmon are considered fully allocated 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 through 1998 these runs were managed for spawning escapement goals of 9,000 for early-run and 22,300 for late-run Chinook salmon (McBride et al. 1989). In February 1999, the 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 (Hammarstrom and Hasbrouck 1998, 1999; Bosch and Burwen 1999). The revised escapement goals define a range of escapement levels desired, and are 7,200 to 14,400 Chinook for the early run (5 AAC 56.070 Kenai River Early Run Chinook Management Plan) and 17,800 to 35,700 Chinook for the late run (5 AAC 21.359 Kenai River Late Run Chinook Management Plan). It is anticipated that these escapement goal ranges should provide for a more stable fishing season without compromising either run.

Sonar estimates of inriver run 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 much public scrutiny. Restrictions on the sport fishery were imposed in each year from 1989 through 1992 to ensure spawning escapement goals were met. Since 1993, the 1997, 1998, 2000 and 2002 early runs, and the 1998 late run required a restriction of the sport fishery to meet escapement goals.

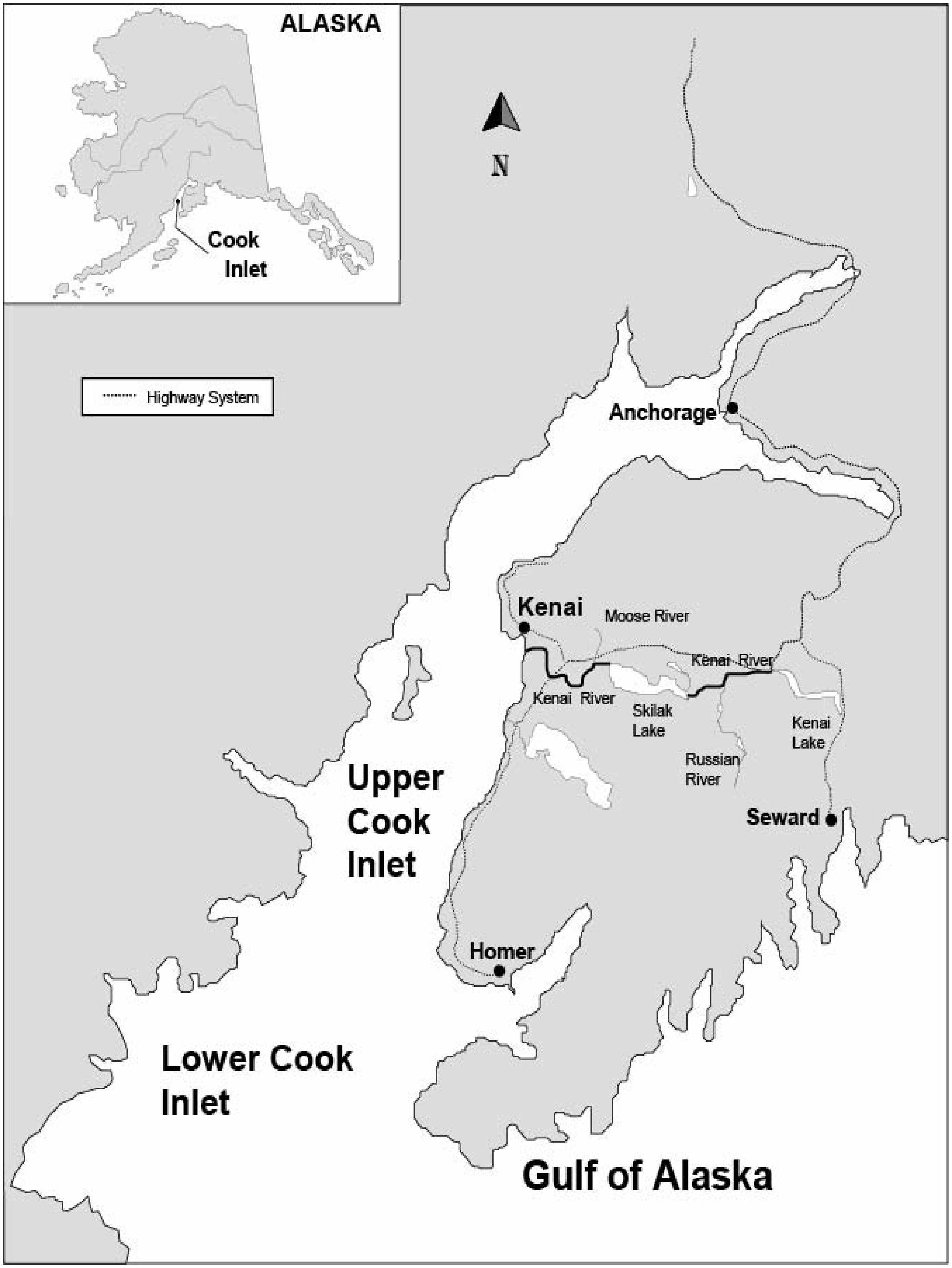

Figure 1.–Cook Inlet showing location of the Kenai River.

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 (Hammarstrom and Larson 1986; Conrad and Larson 1987; Conrad 1988; Carlon and Alexandersdottir 1989; Alexandersdottir and Marsh 1990). These estimates had low precision and appeared to be biased high, particularly during the late run (Bernard and Hansen 1992).

In order to obtain timely and accurate estimates of Chinook salmon passage, the department initiated studies to determine whether an acoustic assessment program could be developed to provide daily estimates of Chinook salmon into 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 1987-2002, 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 have 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 large Chinook salmon. Due to the considerable size difference between Kenai River Chinook salmon and other species of fish present in the river, it was postulated that dual-beam sonar could be used to distinguish the larger 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 were believed to migrate near the bank and to have a smaller target strength than Chinook salmon, which preferred the midchannel section 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 due to the mark-recapture biases mentioned above.

A more advanced acoustic technology known as split-beam sonar was used to test assumptions and design parameters of the dual-beam configuration in 1994 (Burwen et al. 1995). The split-beam system provided advantages over the dual-beam system in its ability to determine the 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, which resulted in an improved (higher) signal-to-noise ratio (SNR). 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). In this comparative study, both systems performed similarly, detecting comparable numbers of fish. The split-beam data confirmed earlier studies showing that fish were strongly oriented to the river bottom. However, experiments conducted with the split-beam system could not confirm the validity of discriminating Chinook salmon from sockeye salmon based on acoustic size. These results supported modeling exercises performed by Eggers (1994) that also questioned the feasibility of discriminating between Chinook and sockeye salmon using target strength. It was hypothesized that discrimination between the two species was primarily accomplished using range thresholds on the acoustic data that exploited the spatial segregation of the species (sockeye salmon migrating nearshore and Chinook salmon migrating midriver; Eggers et al. 1995; Burwen et al. 1995). In 1995, the dual-beam system was replaced with the split-beam system in order to take advantage of the additional information on direction of travel and spatial position of targets.

Two ancillary studies (Burwen et al. 1998) were conducted in 1995 directed at providing more definitive answers to remaining questions regarding: (1) the degree to which sockeye and Chinook salmon are spatially separated at the site at river km 14 (river mile 8.5), and (2) the utility of using target strength and/or other acoustic parameters as discriminatory variables for species separation. Results of these studies confirmed the potential for misclassifying sockeye salmon as Chinook salmon using current methodology. The netting study found that sockeye salmon were present in the middle insonified portion of the river during the study period, 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.

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

As a result of these findings, the inriver drift-netting program, 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 standardized drift zone was defined just downstream from the sonar site and crews fished a standard drift period 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 biased high due to inclusion of sockeye (or other species; Bosch and Burwen 2000, Miller et al. 2002-2003, Miller and Burwen 2002).

Subsequent analysis of 3 years (1998-2000) of standardized CPUE data suggested the netting data were better suited for species apportionment than for abundance estimation (Reimer et al. 2002). In 2001, the inriver netting project continued to produce daily CPUE estimates, but for the first time Chinook abundance was experimentally estimated using a combination of Chinook catch proportions from the netting program and unfiltered passage estimates from the sonar program (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 program for the 2002 season that included using multiple mesh sizes (Reimer 2003, 2004*a*).

In addition to developing an alternative index of Chinook abundance, we continued to pursue improved techniques for separating Chinook and sockeye salmon. An alternative site 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 below areas of major spawning activity. A netting program 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 alternate sonar site also had several disadvantages over the current site including greater boat traffic, less acoustically favorable bottom topography, and increased background noise resulting in difficult fish tracking conditions.

Improved techniques 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, a new experimental imaging sonar (DIDSON) was tested on the Kenai River in 2002 to delineate its range limitations and to determine the feasibility of using it to measure fish size (Burwen et al. *In prep*).

PROJECT OBJECTIVES

Objectives for 2003 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.

METHODS

STUDY AREA

The Kenai River drains an area of 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. Some of these tributaries are the Russian River, Skilak River, Killey River, Moose River, and Funny River.

The Kenai River drainage is located in a transitional zone between a maritime climate and a continental climate (USDA 1992). The geographic position and local topography influence both rainfall and temperature throughout the drainage. Average annual (1971-2000) precipitation for the City of Kenai, located at the mouth of the Kenai River, is 48 cm. Average summer (June, July, and August) temperature for the City of Kenai is 12°C (WRCC 2003).

SITE DESCRIPTION

The 2003 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.

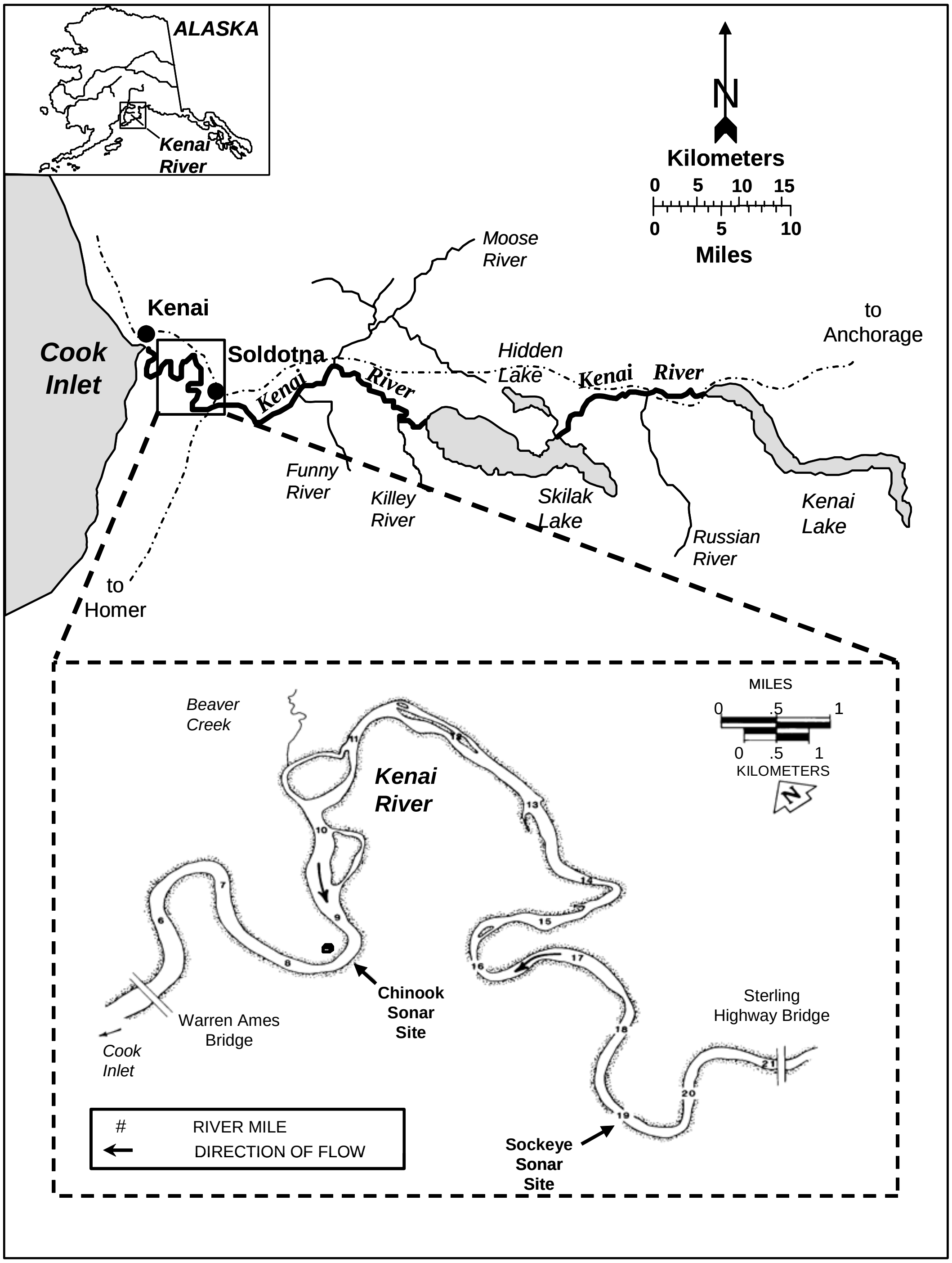

Figure 2.-Kenai River showing location of Chinook salmon sonar site, 2003.

The river bottom in this area has remained stable for the past 18 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 below 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), reducing the incidence of Chinook salmon holding in the sonar beam or returning downstream. Initially, almost all sport fishing occurred some distance upstream of this site. However, fishing activity near the site has increased over the past several years, mostly during the late run.

ACOUSTIC SAMPLING

A Hydroacoustic Technology Inc. (HTI) split-beam sonar system was operated from 16 May through 5 August 2003[1]. Components of the system are listed in Table 1 and further described in HTI manuals (HTI 1996, 1997). A brief explanation of the theory of split-beam sonar and its use in estimating target strength can be found in Appendix A1. A more detailed explanation can be found in (Ehrenberg 1983).

Table 1.–Main components of the split-beam sonar system used in 2003.

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.

[1] Sampling was terminated at 2240 on 5 August. However, by convention, the project has been stopped after 3 consecutive days of passage less than 1% of the total to date. This was achieved on 3 August, so final Chinook passage was estimated through 3 August.

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 led 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).

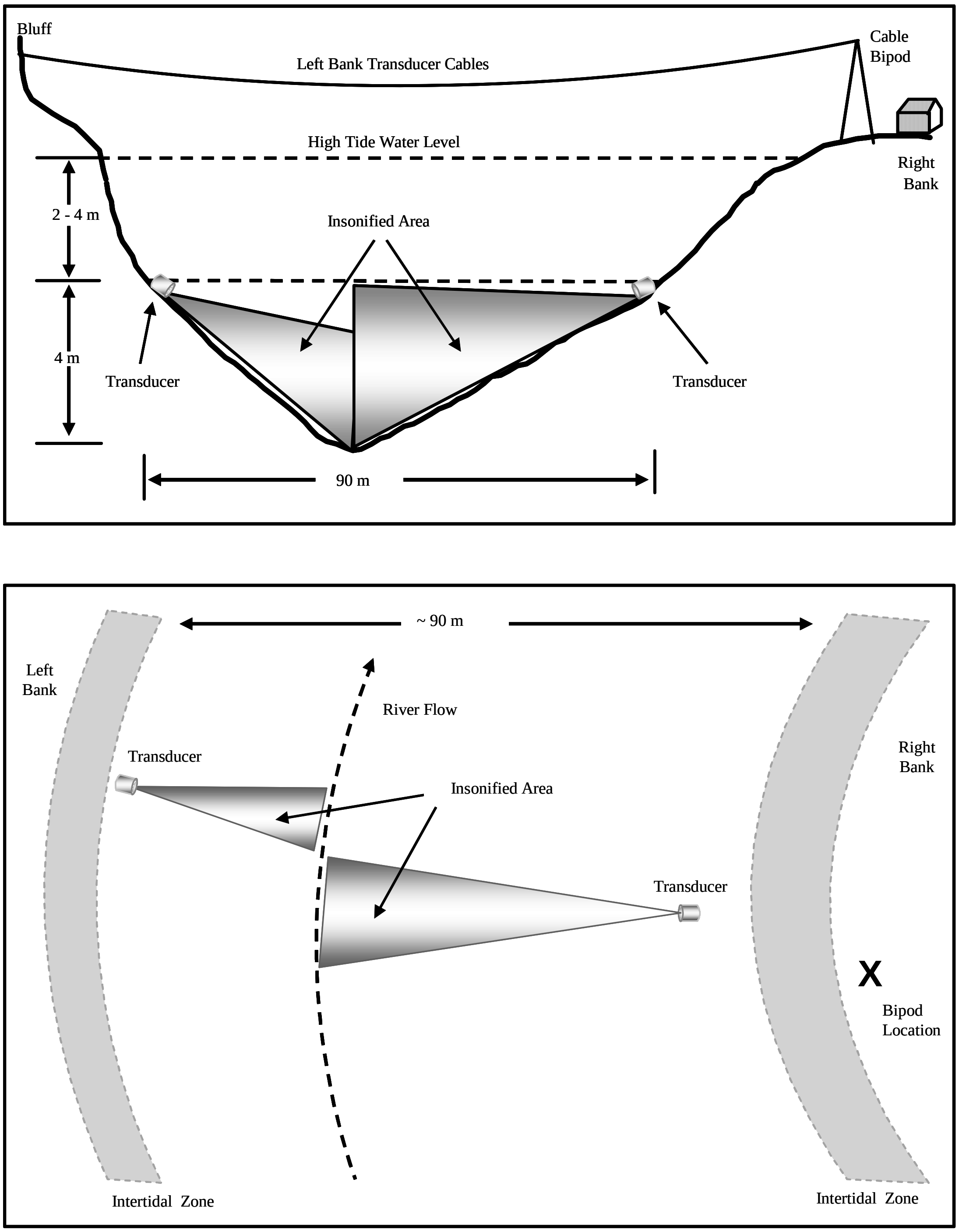

Figure 3.–Cross-sectional (top) and aerial (bottom) views of sonar site showing insonified portions of the Kenai River, 2003.

Steel tripods were used to deploy the transducers offshore. One elliptical, split-beam transducer was mounted 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. During 16 May to 3 August, water level at low tide rose approximately 1.7 m. Rising water level throughout the season and heavy debris accumulation on the gear resulted in occasional relocation of transducer tripods. Total range insonified by both (right and left) sonar beams ranged from a low of approximately 62 m on 17 June to a high of 87 m on 18 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 indicated the aiming angle in the vertical and horizontal planes. In the vertical plane, the transducer was aimed using an oscilloscope and chart recorder to verify that the sonar beam was 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 tripod placement. Transducer tripods 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.

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 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 well the water column above the bottom substrate was insonified by the acoustic beam could be generated (Figure 5).

Each time the transducer was moved throughout the season, 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.

Prior to 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, one 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 was deployed at this new location in 2001, 2002, and again in 2003. Due to the offset deployment of the right and left bank transducers, completeness of beam coverage near the thalweg is now more difficult to assess (Miller et al. 2004).

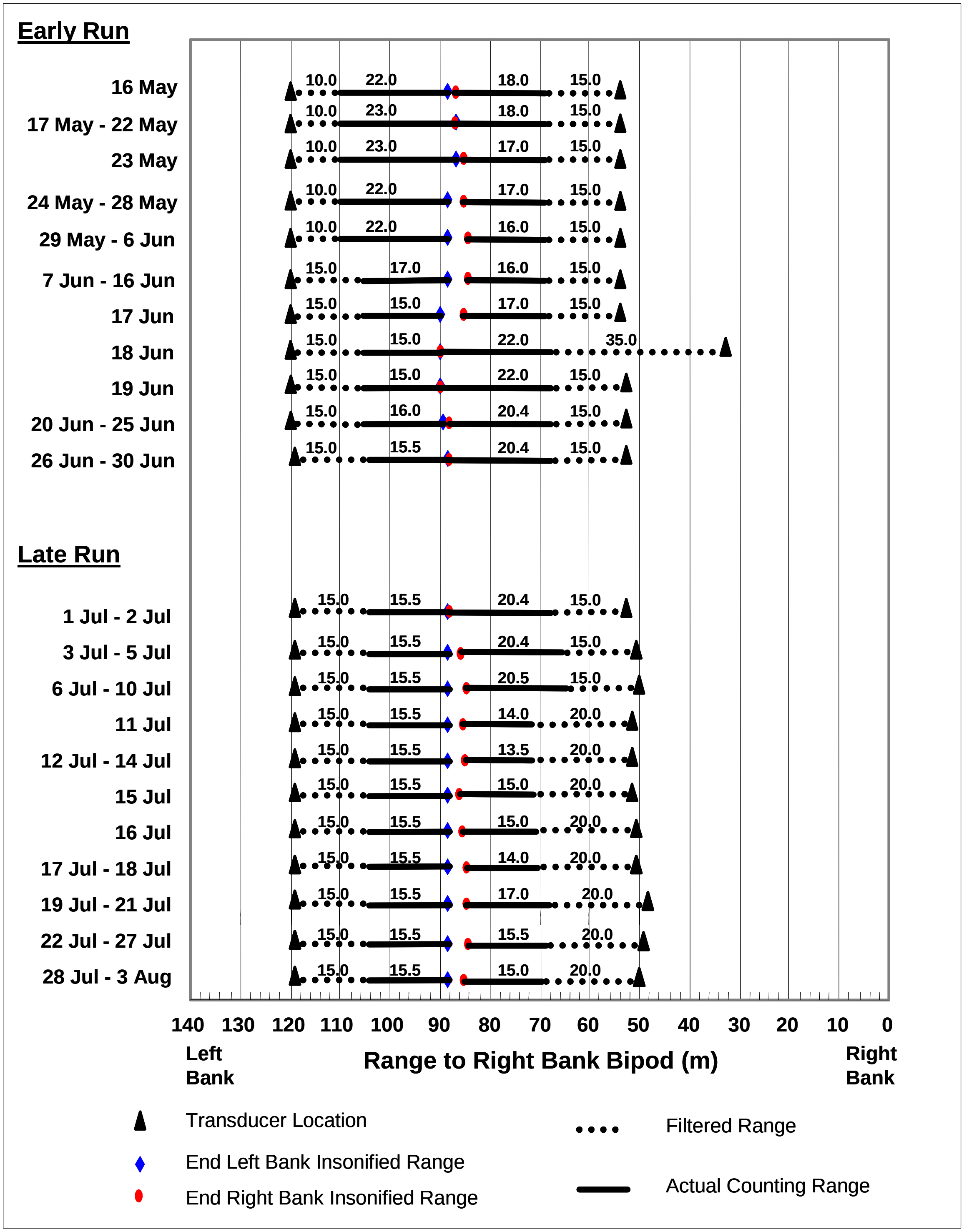

Figure 4.–Daily right- and left-bank transducer locations and counting ranges relative to bipod tower located on the right bank, Kenai River, 2003.

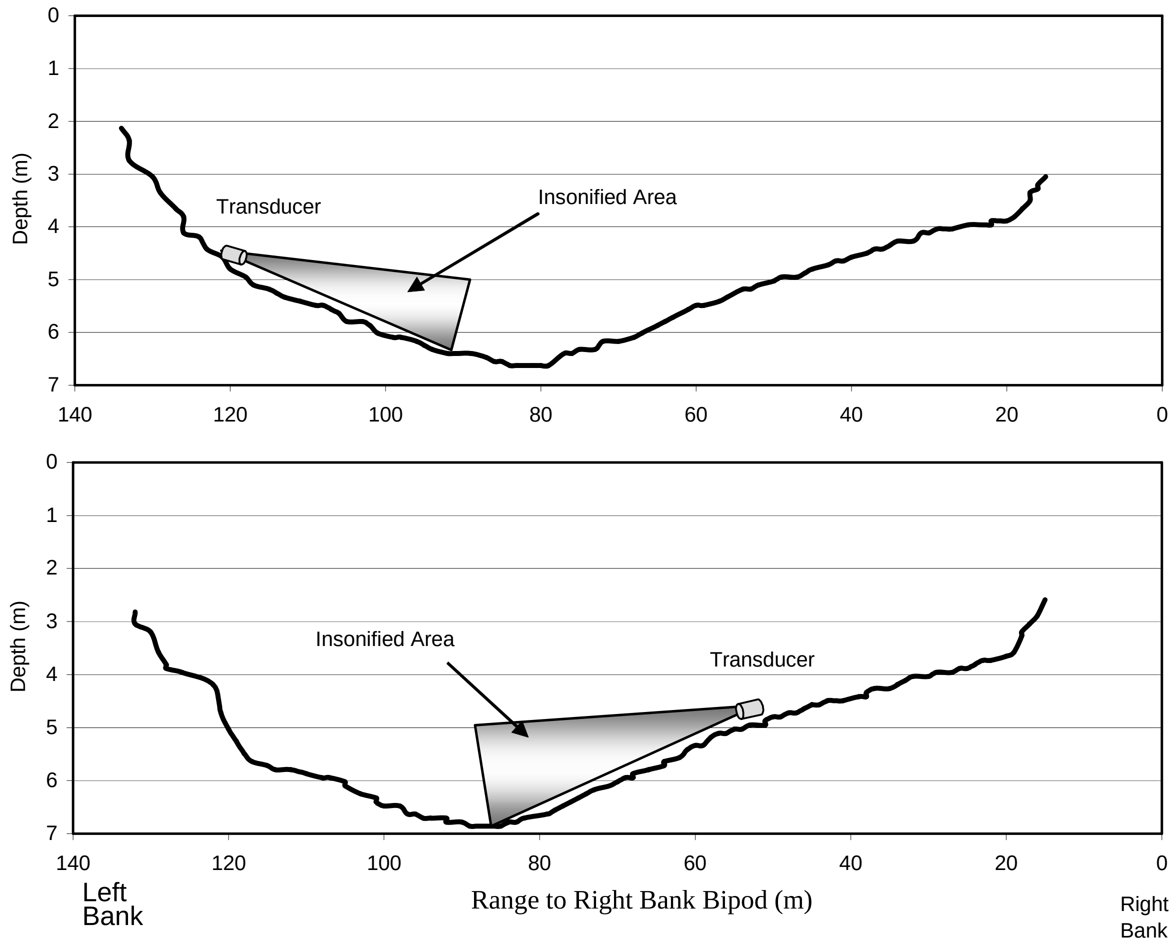

Figure 5.–Left- and right-bank bottom profiles at the Kenai River Chinook sonar site with approximate transducer locations and sonar beam coverage for 16 May, 2003.

System Calibration

HTI performed reciprocity calibrations with a naval standard transducer on 17 December 2002. 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 15 May, 28 July, and 1 August. For each calibration verification, 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 full 1-hour counts and estimates obtained using expanded 20-min counts (Miller et al. 2002).

Echo Sounder Settings

Relevant echo sounder settings are listed in Table 2 with a more complete summary in Appendix B1 and Appendix 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 2003.

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

The 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 to the computer hard drive 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. The angle filters were used to prevent consideration of unreliable data from transducer side lobes.

Table 3.–Echo acceptance criteria for digital echo processing, 2003.

Bank	pulse width[a] (ms) at -6 dB	Vertical angle off-axis (^{o})	Horizontal angle off-axis(^{o})	Threshold mV (dB)	Minimum Range (m)
Right					
16-May to 3-Aug	0.04 to 10.0	-2.5 to 2.5	-5.0 to 5.0	722 (-35 dB)	2.0
Left					
16-May to 3-Aug	0.04 to 10.0	-2.5 to 2.5	-5.0 to 5.0	452 (-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).

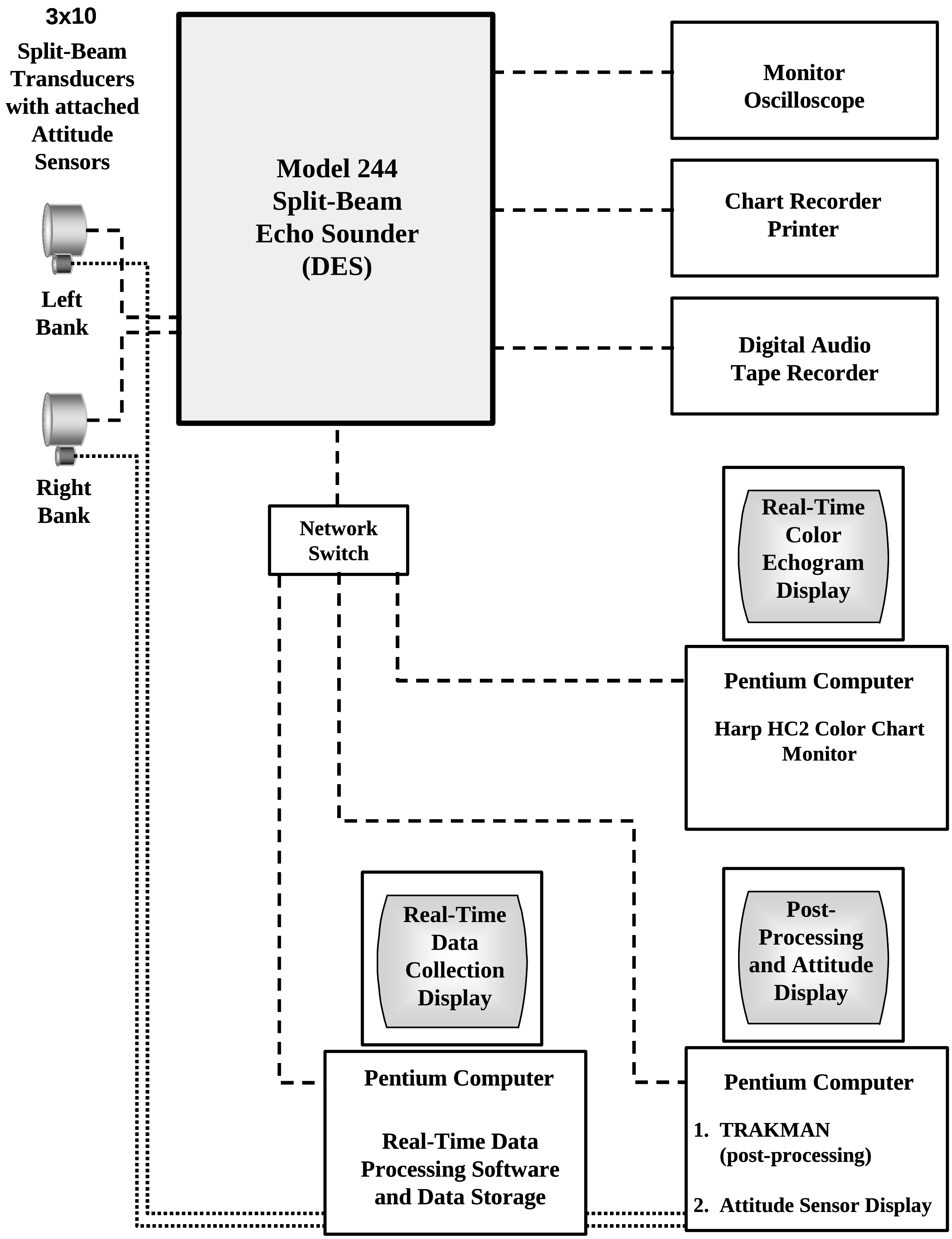

Figure 6.–Schematic diagram of 2003 split-beam sonar system configuration and data flow.

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 causes 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 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 to a computer hard disk in ASCII file format (*.RAW files). This file provided a permanent 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 echo: (1) range 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 Model 244 DES was also output to a dot matrix 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

A diagram illustrating inseason data flow can be found in Appendix C1. Echoes in the *.RAW files were manually grouped (tracked) into fish using HTI proprietary software called TRAKMAN. This program produces an electronic chart recording for all valid echoes collected during a 20-min sample on the computer monitor. 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 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 earlier except that it contained only those echoes combined into

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

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 are reversed.

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 (range from transducer) as the target transited 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 downstream targets were excluded from consideration as valid fish targets during the tracking procedure and the remainder of downstream targets was 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

Fish passage rates have been shown to be related to tide stage (Eggers et al. 1995). Therefore tide stage was determined throughout the season using water level measurements taken at the top of each hour and at 20 minutes past each hour from a staff gauge located at the site. For the purpose of this study, 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 due to the very short duration of high slack tide. 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).

Inseason range (z-axis) distributions for each bank were plotted separately for upstream and downstream fish. Range distributions were calculated using the mean range for each target. Prior to 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 tripod/transducer locations change throughout the season the comparisons were poor descriptors of actual fish range distributions across the river. Beginning in 2000, range estimates by 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):

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

where:

z_a = adjusted range (in meters),

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

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

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

Vertical distributions were plotted by direction of travel (upstream and downstream) and tide stage. Vertical distributions were calculated from the midpoint angle off-axis 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. Inseason target strength distributions were plotted separately for early- and late-run fish and for upstream and downstream fish.

Species Discrimination

Tracked fish were filtered using criteria intended to minimize the number of sockeye salmon counted. Two parameters have been used historically on this project to separate large Chinook salmon from sockeye salmon and other species: target strength (-28 dB threshold) and distance from the transducer (range). The vast majority of sockeye salmon swim near shore, and can be excluded by simply counting offshore targets. Although we now 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 to ensure 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 transducer tripods were moved, or when fish distribution and behavior indicated that species discrimination could be improved by doing so. Early-run range thresholds were 10 m (16 May–6 June) and 15 m (7 June-30 June) on the left bank and 15 m (16 May-17 June and 19 June–30 June) and 35 m (18 June) on the right bank (Figure 4). Late-run range thresholds were 15 m (1 July–3 August) on the left bank and 15 m (1 July–10 July) and 20 m (11 July–3 August) 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. For this reason, hourly samples containing substantial numbers of paired or grouped targets at far range (beyond the range thresholds) were considered unreliable and were excluded from calculation of the Chinook passage estimate (Appendix D1).

Passage Estimates

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

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

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

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

where n_{ik} was the number of hours during which passage was estimated (or imputed) on bank k for day i. When the sonar was functional on bank k during hour j of day i, then hourly Chinook salmon passage was estimated as follows:

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

where:

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

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

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

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

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

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

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

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

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

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

$$\hat{Y} = \sum_i \hat{y}_i \text{ , and,} \quad (9)$$

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

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

c'_{jk} = number of upstream-bound fish greater than 15 m from the right-bank transducer and greater than 10 m from the left-bank transducer, for bank k and hour j.

The "alternative" daily estimate (or net-apportioned estimate) of Chinook salmon abundance was calculated by multiplying the unfiltered sonar passage estimate by the proportion $\hat{q}_i$ of Chinook salmon in drift gillnet catches near the sonar site (Reimer 2004*b*):

$$\hat{y}'_i = \hat{x}_i \hat{q}_i . \quad (11)$$

The variance estimate of the alternative estimate follows Goodman 1960:

$$\hat{var}(\hat{y}'_i) = \hat{x}_i^2\ \hat{var}(\hat{q}_i) + \hat{q}_i^2\ \hat{var}(\hat{x}_i) - \hat{var}(\hat{q}_i)\hat{var}(\hat{x}_i). \quad (12)$$

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 detectability, 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 whatever bias is present will also be consistent.

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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).

RESULTS

System Calibration

During system calibration at the HTI calibration facility, the target strength of a 38.1-mm tungsten carbide standard sphere was measured at -39.0 dB and -39.6 dB with the right- and left-bank transducers, respectively (HTI 2002; 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 –37.1 dB to –38.7 dB on the right bank and from –38.5 dB to –40.1 dB on the left bank (Table 4). Small fluctuations in mean target strength are expected throughout the season as target strength can vary with signal-to-noise ratio, water temperature, depth, conductivity and other factors.

Table 4.–Results of 2003 *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]	17-Dec	-38.99	0.82	1,004	6.2	N/A[b]	N/A[b]
Kenai River	15-May	-38.72	2.60	4,570	13.7	100	120
Kenai River	1-Aug	-37.05	3.23	2,217	17.3	170	180
Left Bank							
HTI[a]	17-Oct	-39.62	0.75	623	6.2	N/A[b]	N/A[b]
Kenai River	15-May	-38.48	1.50	2,147	18.0	80	120
Kenai River	28-Jul	-40.13	2.16	1,418	16.2	90	100

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

[b] Not available or not applicable.

Target Tracking

In 2003, 63,332 targets were manually tracked, 9,069 during the early run and 54,263 during the late run. After filtering for range and target strength criteria and making temporal expansions, the proportion of upstream fish was 95% for the early run and 97% for the late run (Appendix E1 and Appendix E2).

The number of acquired echoes per fish varied by run, bank, and direction of travel. During the early run, upstream fish averaged 72 (SD = 42) and 63 (SD = 41) echoes per fish on the left and right banks, respectively. Downstream fish averaged 69 echoes (SD = 70) on the left bank and 69 echoes (SD = 77) on the right bank. During the late run, upstream fish averaged 83 (SD = 46) echoes on the left bank and 75 (SD = 45) echoes on the right bank. Downstream fish averaged 94 (SD = 78) echoes on the left bank and 95 (SD = 93) echoes per fish on the right bank.

TIDAL AND TEMPORAL DISTRIBUTION

Upstream passage during both the early and late runs occurred mostly during the falling tide (58.8% and 54.9% respectively; Tables 5 and 6, Figure 7). Early-run downstream passage was similar between the rising (42.8%) and falling (39.3%) tides, while late-run downstream passage occurred primarily during the falling tide (46.3%).

Table 5.-Estimates of Chinook salmon passage by tide stage and direction of travel for the 2003 early run (16 May to 30 June).

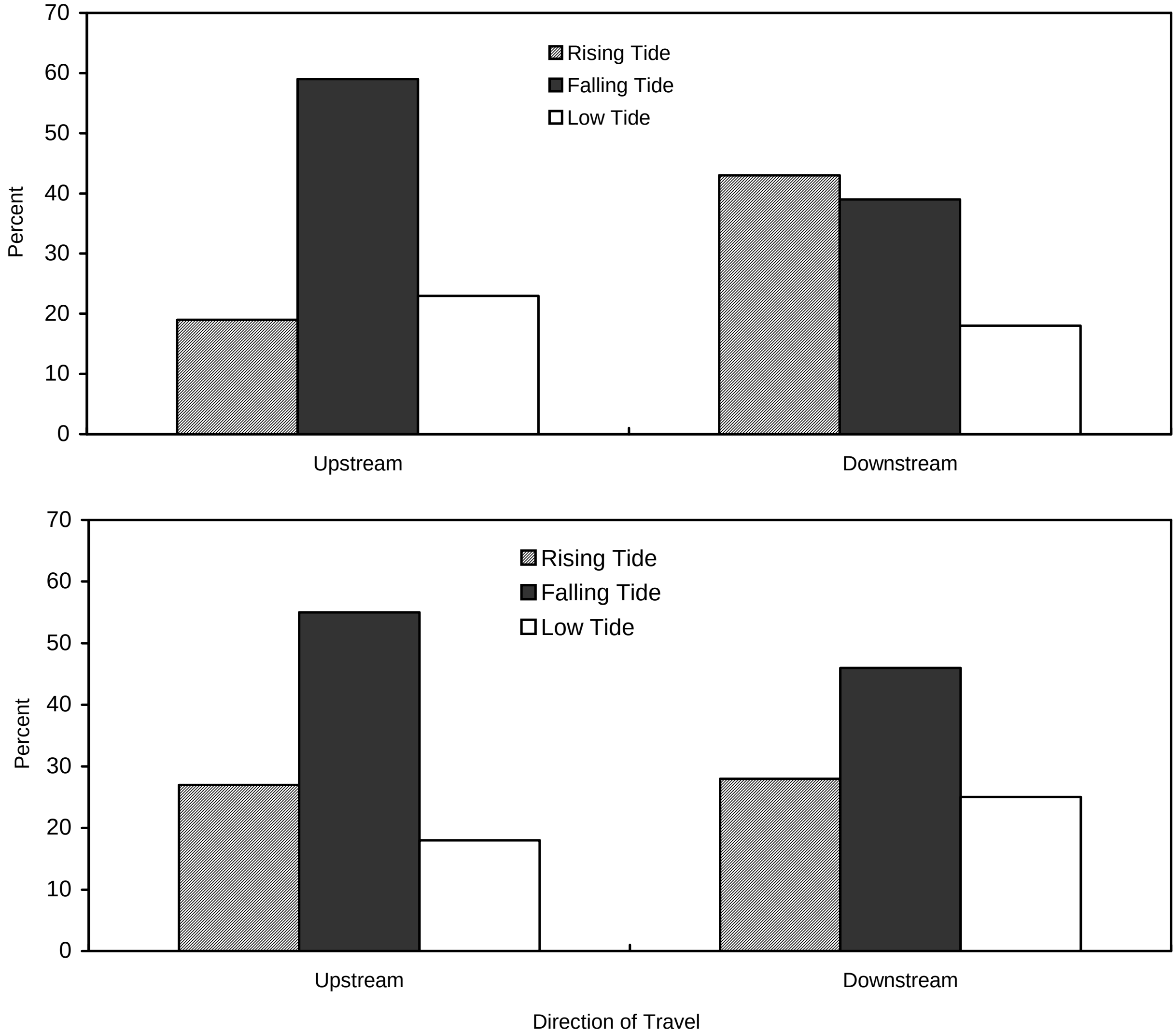
2003 Early Run	Total Number of Fish	Rising	Falling	Low
Upstream	13,325	2,487	7,834	3,004
Row %	100.0%	18.7%	58.8%	22.3%
Column %	95.4%	90.0%	96.8%	96.3%
Downstream	647	277	254	116
Row %	100.0%	42.8%	39.3%	17.9%
Column %	4.6%	10.0%	3.2%	3.7%

Test for Independence: Chi-square = 228.36, df = 2, P < 0.0001.

Table 6.-Estimates of Chinook salmon passage by tide stage and direction of travel for the 2003 late run (1 July to 3 August).

2003 Late Run	Total Number of Fish	Rising	Falling	Low
Upstream	41,659	11,231	22,871	7,557
Row %	100.0%	27.0%	54.9%	18.1%
Column %	96.6%	96.4%	97.1%	95.3%
Downstream	1,259	357	583	319
Row %	100.0%	28.4%	46.3%	25.3%
Column %	3.4%	3.6%	2.9%	4.7%

Test for Independence: Chi-square = 51.55, df = 2, P < 0.0001.



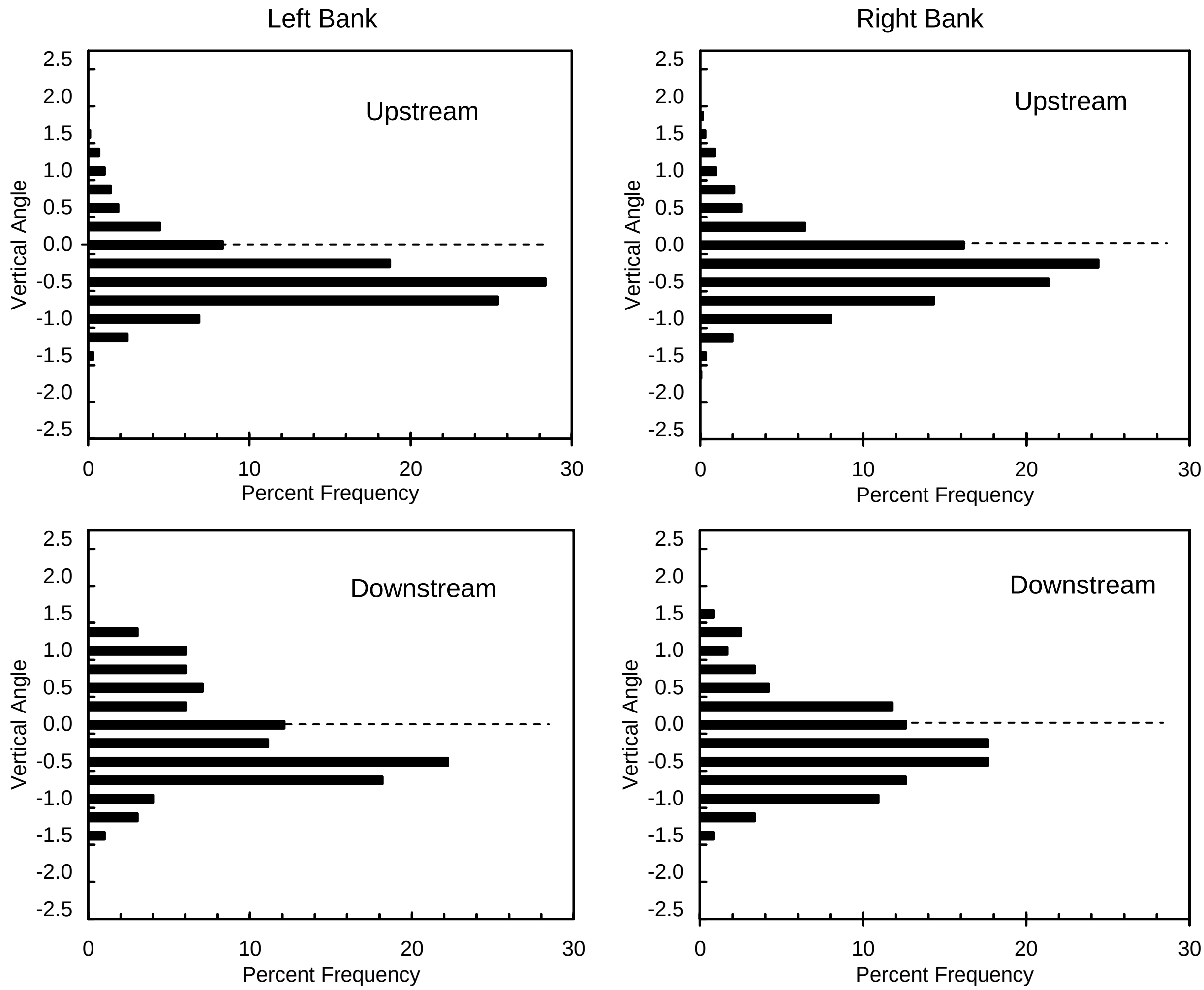
Note: Data have been filtered by range and target strength criteria.

Figure 7.-Distribution of upstream and downstream moving fish by tide stage during the early (top panel) and late (bottom panel) runs, Kenai River, 2003.

SPATIAL DISTRIBUTION

Vertical Distribution

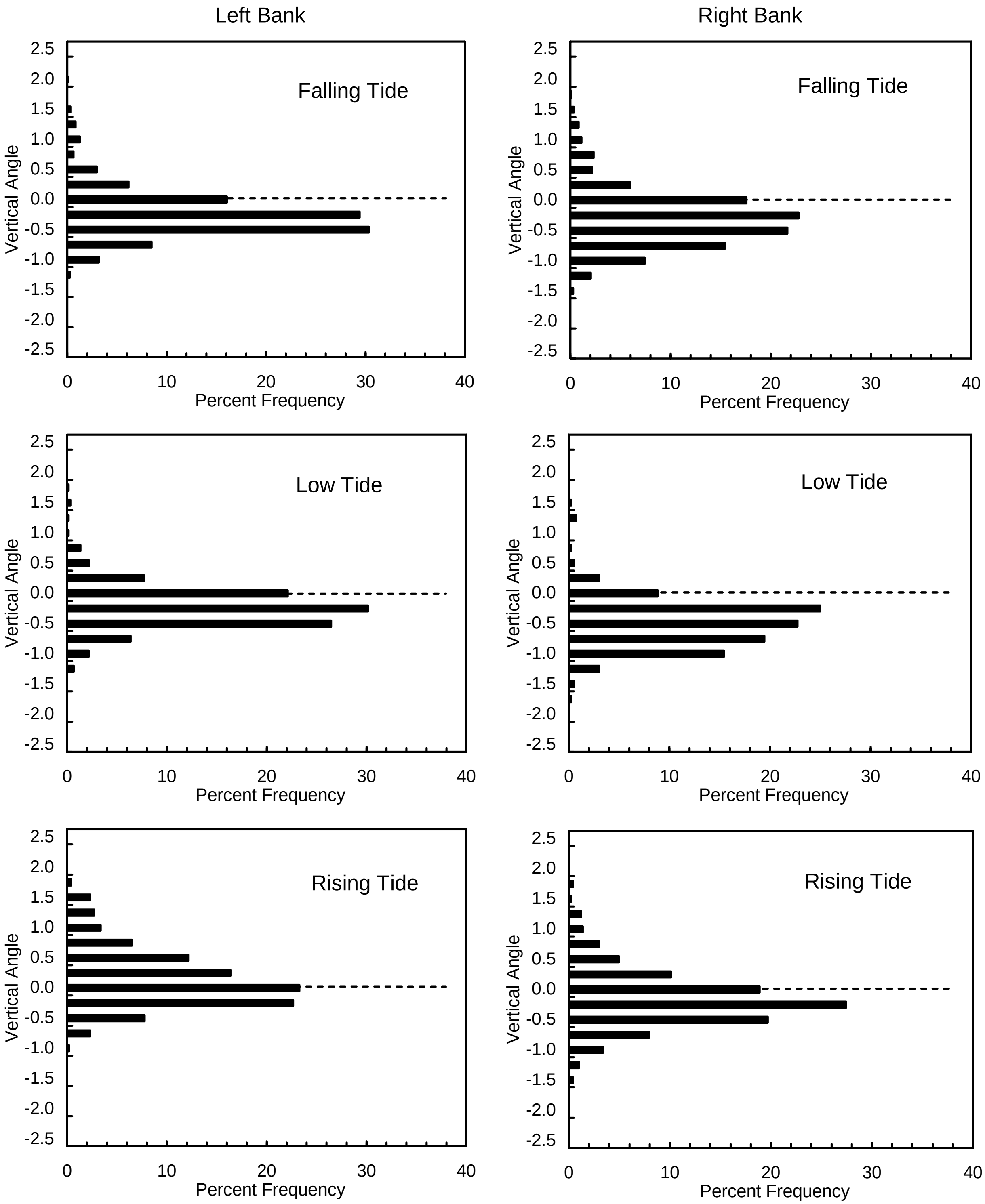
Fish were bottom-oriented during both runs, although vertical distribution did vary somewhat by direction of travel, tide stage, and season (Appendices F1 and F2). During the early run, 90% of the upstream fish (Chinook targets) on the left bank and 87% on the right bank were on or below the acoustic axis (Figure 8). Downstream fish were less bottom-oriented (Appendix F1).



Note: Data have been filtered by range and target strength criteria.

Figure 8.-Vertical distributions of early-run upstream and downstream moving fish on the left and right banks, Kenai River, 2003.

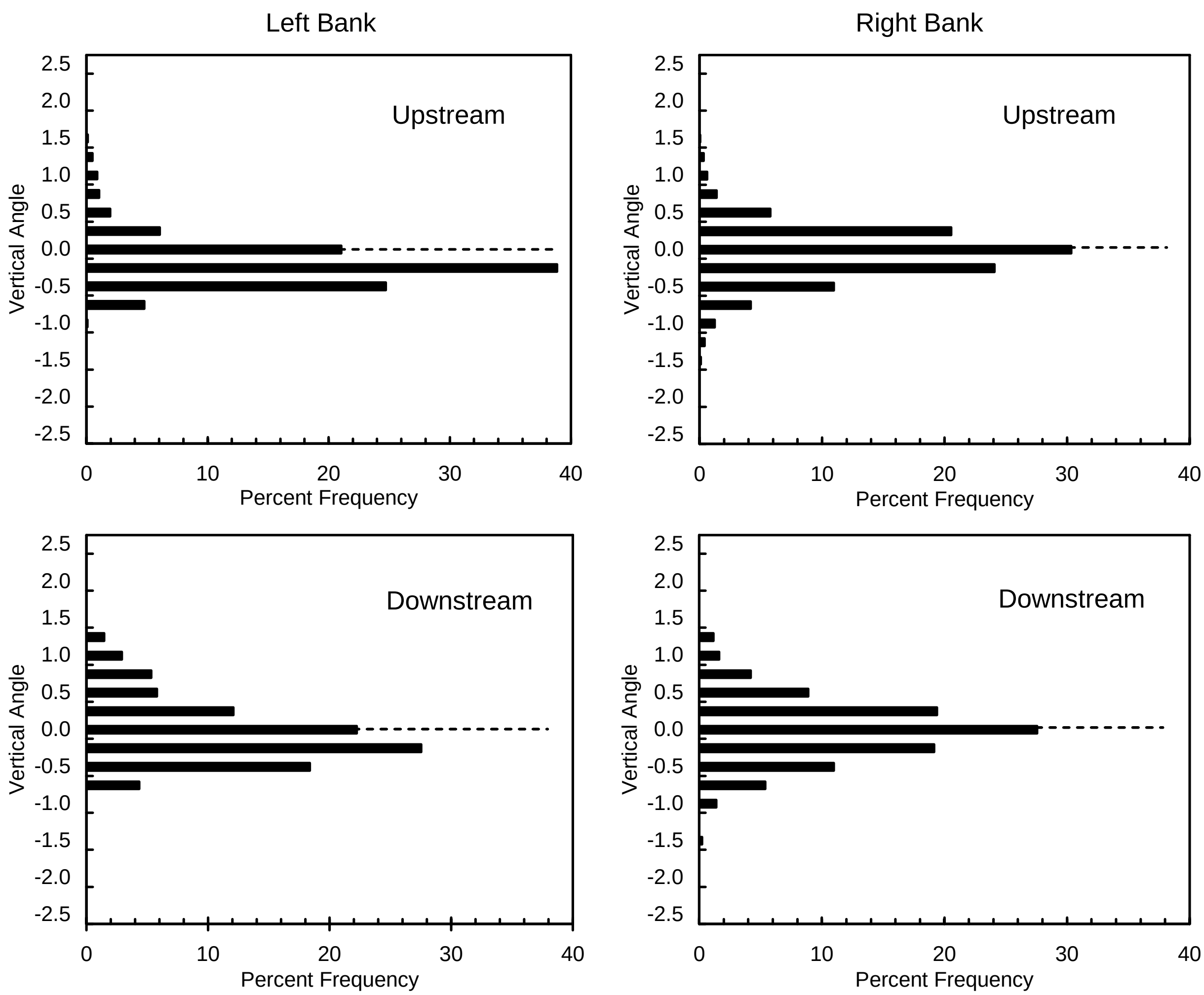
Seventy-two percent of downstream fish on the left bank and 76% on the right bank were below the acoustic axis (Figure 8). Upstream fish (Chinook targets) on the left bank (mean = -0.56°, SD = 0.43, n = 2,645) were on average significantly lower ($t = 3.86$, $P < 0.001$) in the water column than downstream fish (mean = -0.31°, SD = 0.63, n = 99). On the right bank, upstream fish (mean = -0.44°, SD = 0.47, n = 1,975) were not significantly lower in the water column ($t = 0.94$, $P = 0.17$) than downstream fish (mean = -0.38°, SD = 0.58, n = 119). Upstream traveling fish on both banks were bottom oriented during all tide phases, but left bank fish were distributed slightly higher in the water column during the rising tide phase (Figure 9).



Note: Data have been filtered by range and target strength criteria.

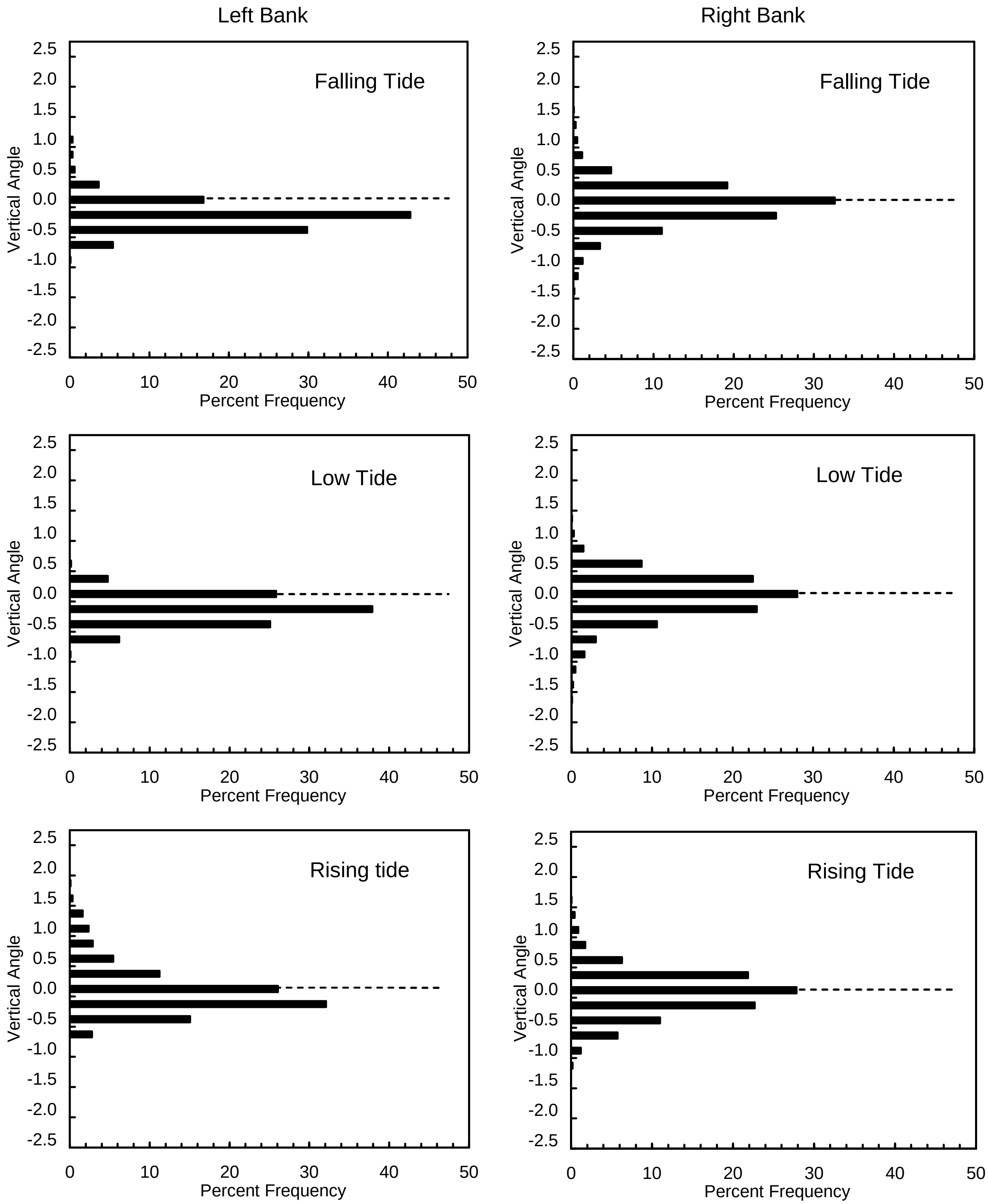
Figure 9.–Vertical distributions of early-run upstream moving fish during falling, low, and rising tide stages on the left and right banks, Kenai River, 2003.

Late-run fish also showed a tendency to travel along the river bottom (Figure 10 and Appendix F2). Ninety percent of upstream fish on the left bank and 71% of upstream fish on the right bank were on or below the acoustic axis. Downstream fish were slightly higher in the water column (Appendix F2). Seventy-three percent of downstream fish on the left bank and 65% on the right bank were on or below the acoustic axis. Upstream fish on the left bank (mean = -0.33°, SD = 0.32, n = 6,967) traveled lower ($t = 5.48$, $P < 0.001$) in the insonified water column than downstream fish (mean = -0.17°, SD = 0.42, n = 207). Similarly, upstream fish on the right bank (mean = -0.19°, SD = 0.35, n = 17,452) traveled lower ($t = 2.84$, $P = 0.002$) in the insonified water column than downstream fish (mean = -0.13°, SD = 0.42, n = 428). Vertical distribution of upstream traveling fish was similar among all three tide stages on the right bank, but was slightly higher during the rising tide stage on the left bank (Figure 11).



Note: Data have been filtered by range and target strength criteria.

Figure 10.–Vertical distributions of late-run upstream and downstream moving fish on the left and right banks, Kenai River, 2003.

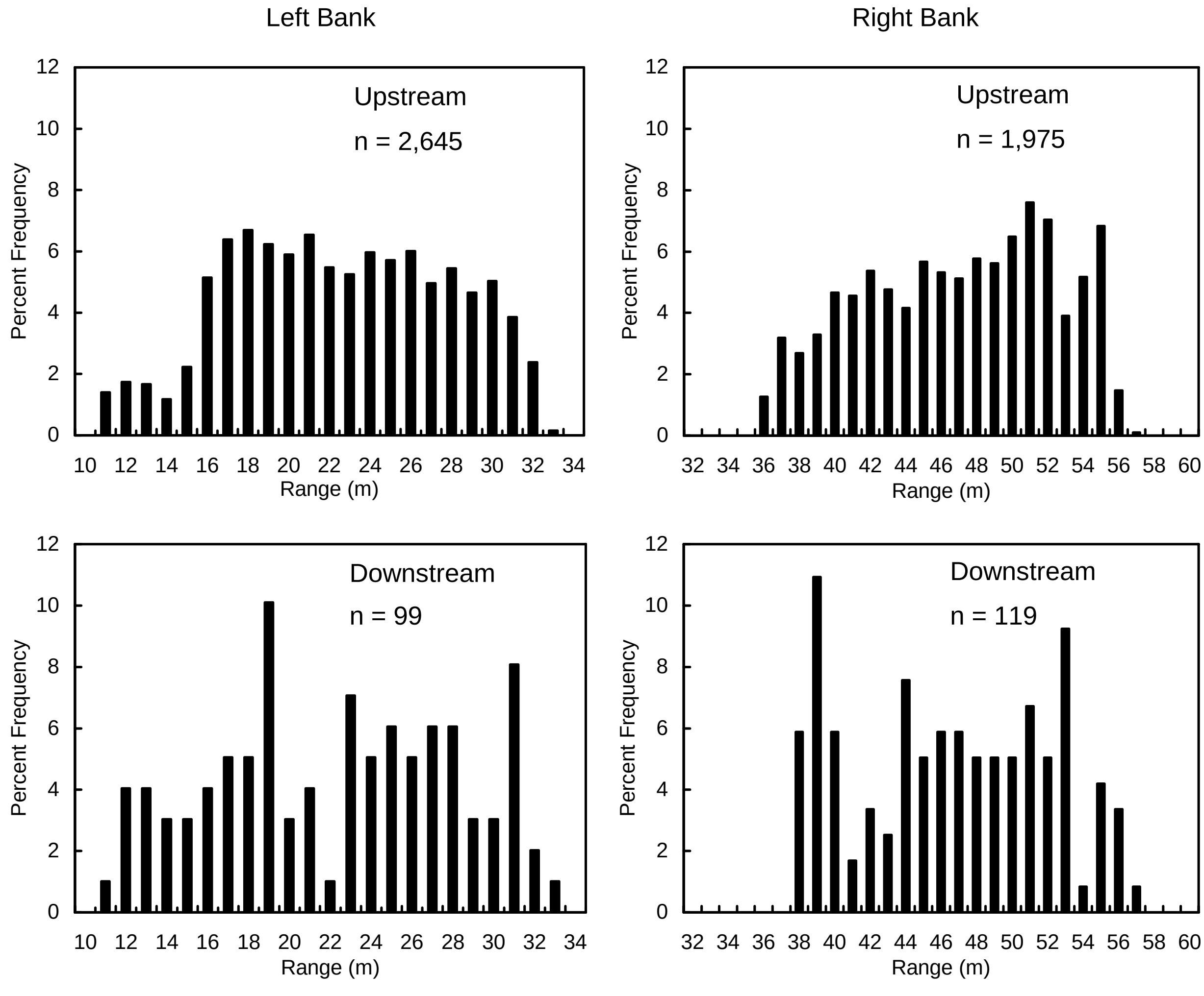


Note: Data have been filtered by range and target strength criteria.

Figure 11.–Vertical distributions of late-run upstream moving fish during falling, low, and rising tide stages on the left and right banks, Kenai River, 2003.

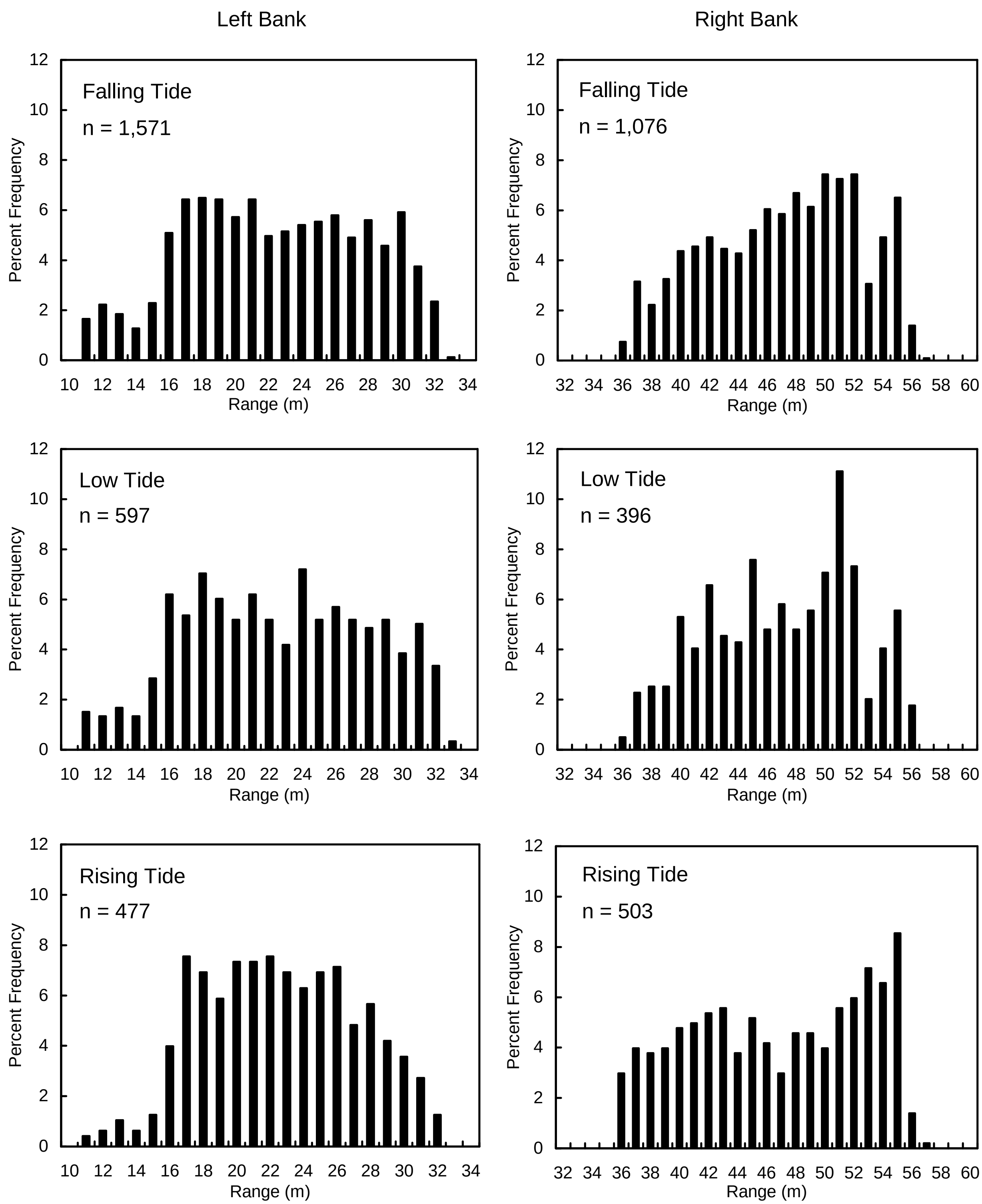
Range Distribution

During the early run, upstream fish were distributed throughout the range on both the left and right bank; peak passage on the left bank occurring at 18 m and peak passage on the right bank occurring at 51 m (Figure 12). There was no statistical difference between the upstream and downstream range distributions on the left bank (Anderson-Darling, P = 0.37), but there was a significant difference on the right bank (Anderson-Darling, P = 0.01; Figure 12). Range distributions were similar among the three tide stages on the left bank, although the rising tide exhibited slightly reduced near (12-14 m) and far (30-32 m) range passage (Figure 13). On the right bank, range distributions differed slightly among the three tide stages, and the rising tide exhibited a slight bimodal distribution (Figure 13).



Note: Data have been filtered by range and target strength criteria.

Figure 12.–Range distributions of early-run upstream and downstream moving fish on the left and right banks, Kenai River, 2003.

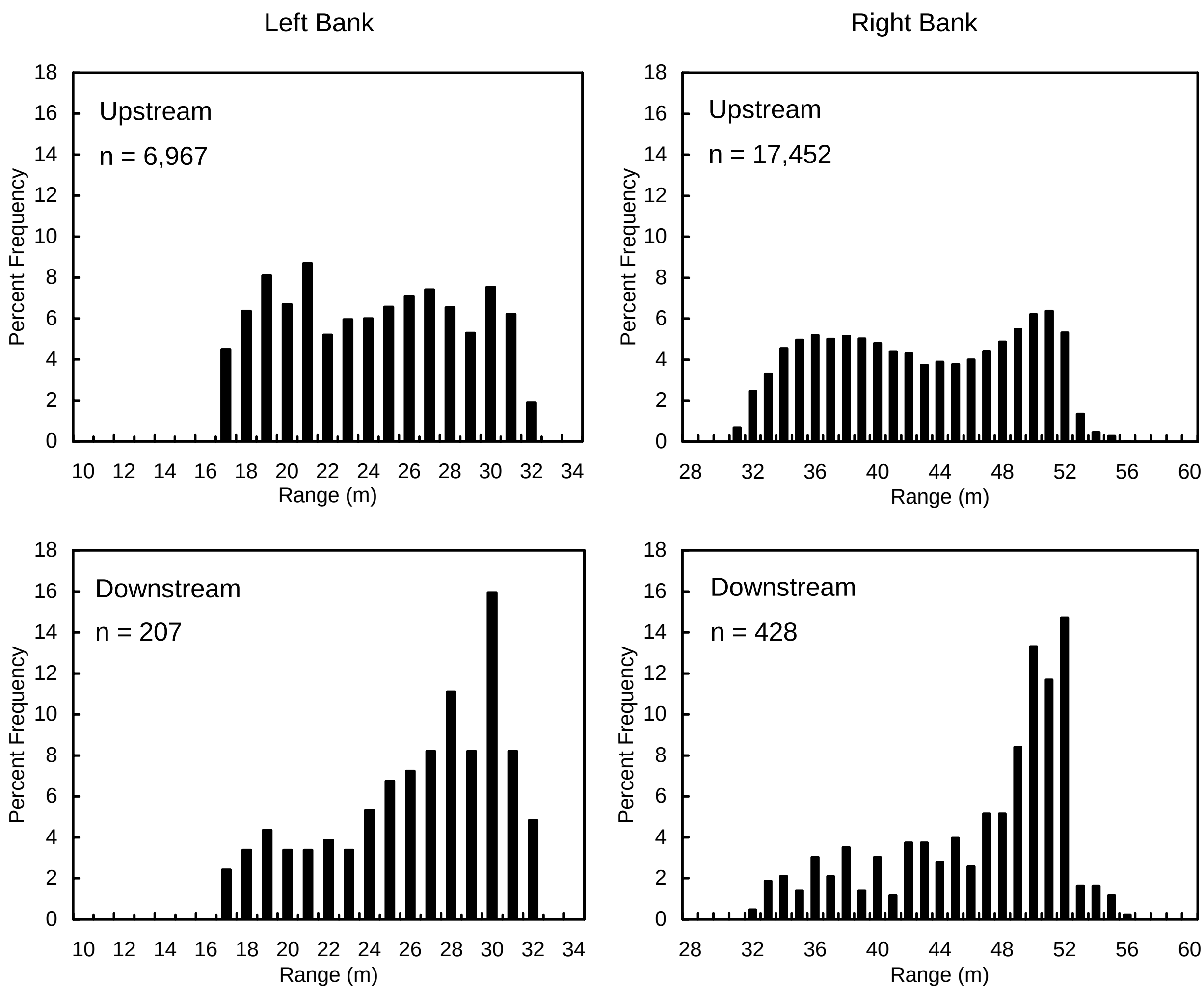


Note: Data have been filtered by range and target strength criteria.

Figure 13.–Range distributions of early-run upstream moving fish during falling, low, and rising tide stages on the left and right banks, Kenai River, 2003.

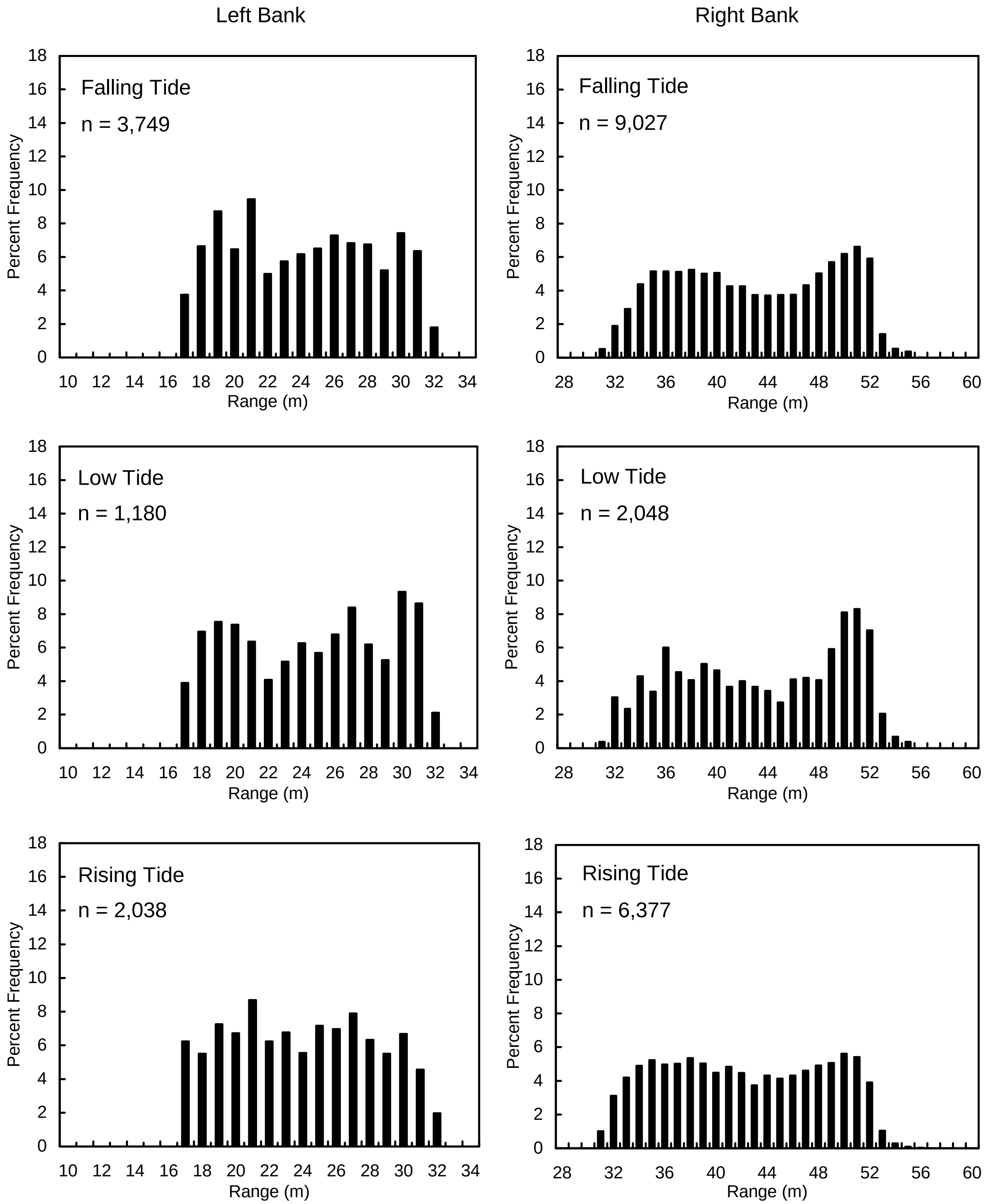
During the late run, upstream fish on the left bank were distributed throughout the range and showed no distinct trend in range distribution; upstream-moving fish on the right bank exhibited a bimodal range distribution with peaks at 36 m and 51 m (Figure 14). Range distributions were significantly different between upstream- and downstream-moving fish on both the left (Anderson-Darling, $P < 0.001$) and right (Anderson-Darling, $P < 0.001$) banks; downstream fish exhibited higher offshore distribution on each bank (Figure 14). Range distributions were similar among the three tide stages on the left and the right bank (Figure 15).

Estimates of upstream fish passage by bank were higher for the left bank during the early run and for the right bank during the late run (Tables 7 and 8). During the early run 58% of upstream passage was estimated to occur on the left bank while 42% occurred on the right bank (Table 7). During the late run 60% of upstream passage was estimated to occur on the right bank and 40% on the left bank (Table 8).



Note: Data have been filtered by range and target strength criteria.

Figure 14.–Range distributions of late-run upstream and downstream moving fish on the left and right banks, Kenai River, 2003.



Note: Data have been filtered by range and target strength criteria.

Figure 15.–Range distributions of late-run upstream moving fish during falling, low, and rising tide stages on the left and right banks, Kenai River, 2003.

Table 7.–Estimates of early-run fish passage by direction of travel, 2003.

	Estimate of Upstream Component		Estimate of Downstream Component		Estimate of Total Fish Passage[a]	
Bank	Number	Percent	Number	Percent	Number	Percent
Right	5,541	42%	336	42%	5,877	42%
Left	7,784	58%	311	58%	8,095	58%
Total	13,325	100%	647	100%	13,972	100%

[a] Total passage (upstream component plus downstream component) is provided to maintain comparability between recent (1998-2003) 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 late-run fish passage by direction of travel, 2003.

	Estimate of Upstream Component		Estimate of Downstream Component		Estimate of Total Fish Passage[a]	
Bank	Number	Percent	Number	Percent	Number	Percent
Right	24,989	60%	761	60%	25,750	60%
Left	16,670	40%	498	40%	17,168	40%
Total	41,659	100%	1,259	100%	42,918	100%

[a] Total passage (upstream component plus downstream component) is provided to maintain comparability between recent (1998-2003) 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.

Target Strength

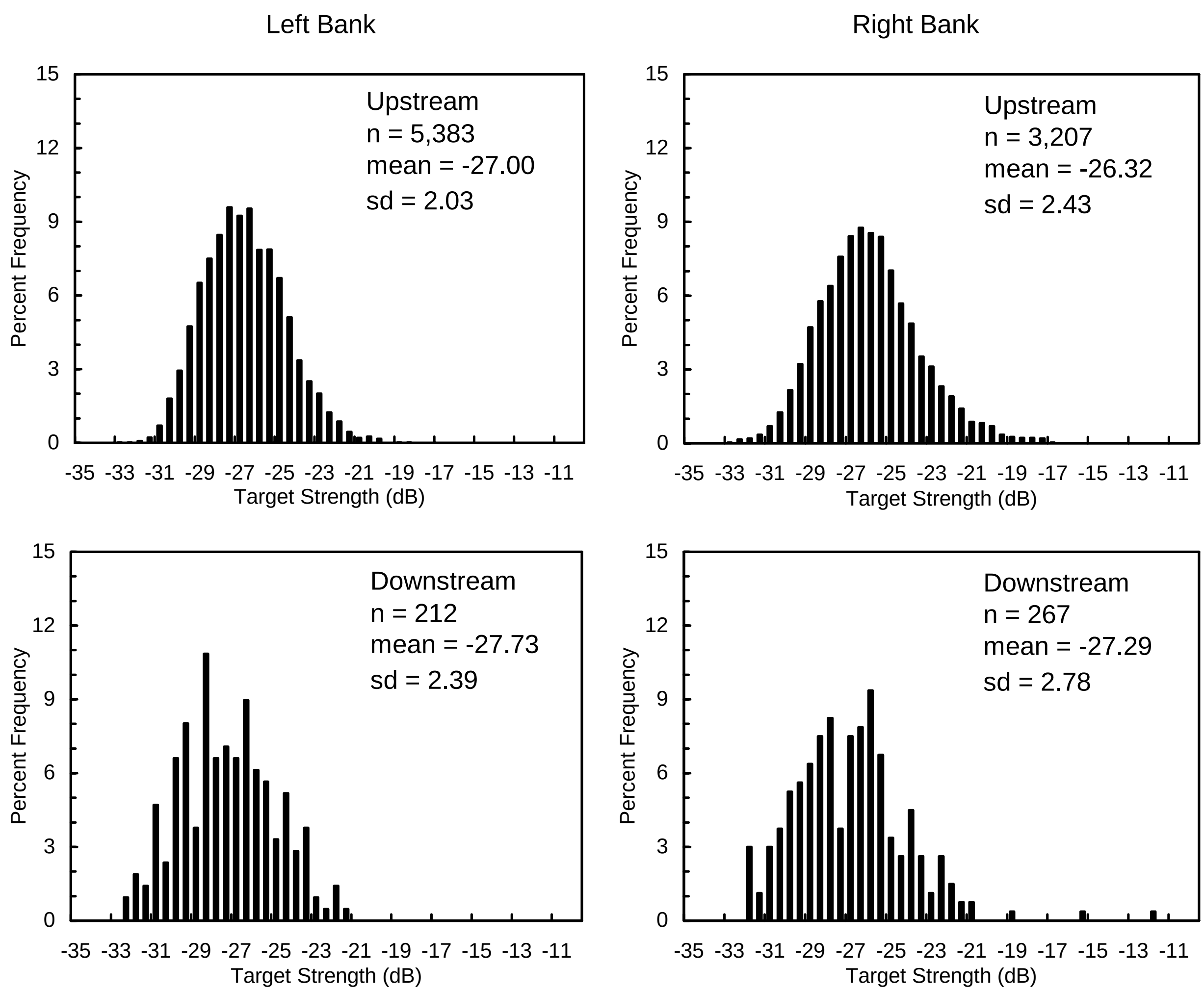
Target strength distributions varied by bank, direction of travel, and run. Table 9 shows target strength statistics for fish that met minimum range and target strength criteria, whereas Figure 16 and Figure 17 show target strength distributions and statistics that include all tracked targets.

Table 9.–Mean target strength (dB) for upstream and downstream targets (Chinook only) by river bank during the early (16 May-30 June) and late (1 July-3 August) runs, 2003.

Location	Upstream Mean Target Strength (dB)	SD	N	Downstream Mean Target Strength (dB)	SD	N
Early Run						
Left Bank	-25.99	1.47	2,645	-25.84	1.53	99
Right Bank	-25.77	1.96	1,975	-25.51	1.92	119
Late Run						
Left Bank	-26.66	1.28	6,967	-26.37	1.42	207
Right Bank	-25.31	1.89	17,452	-25.68	1.85	428

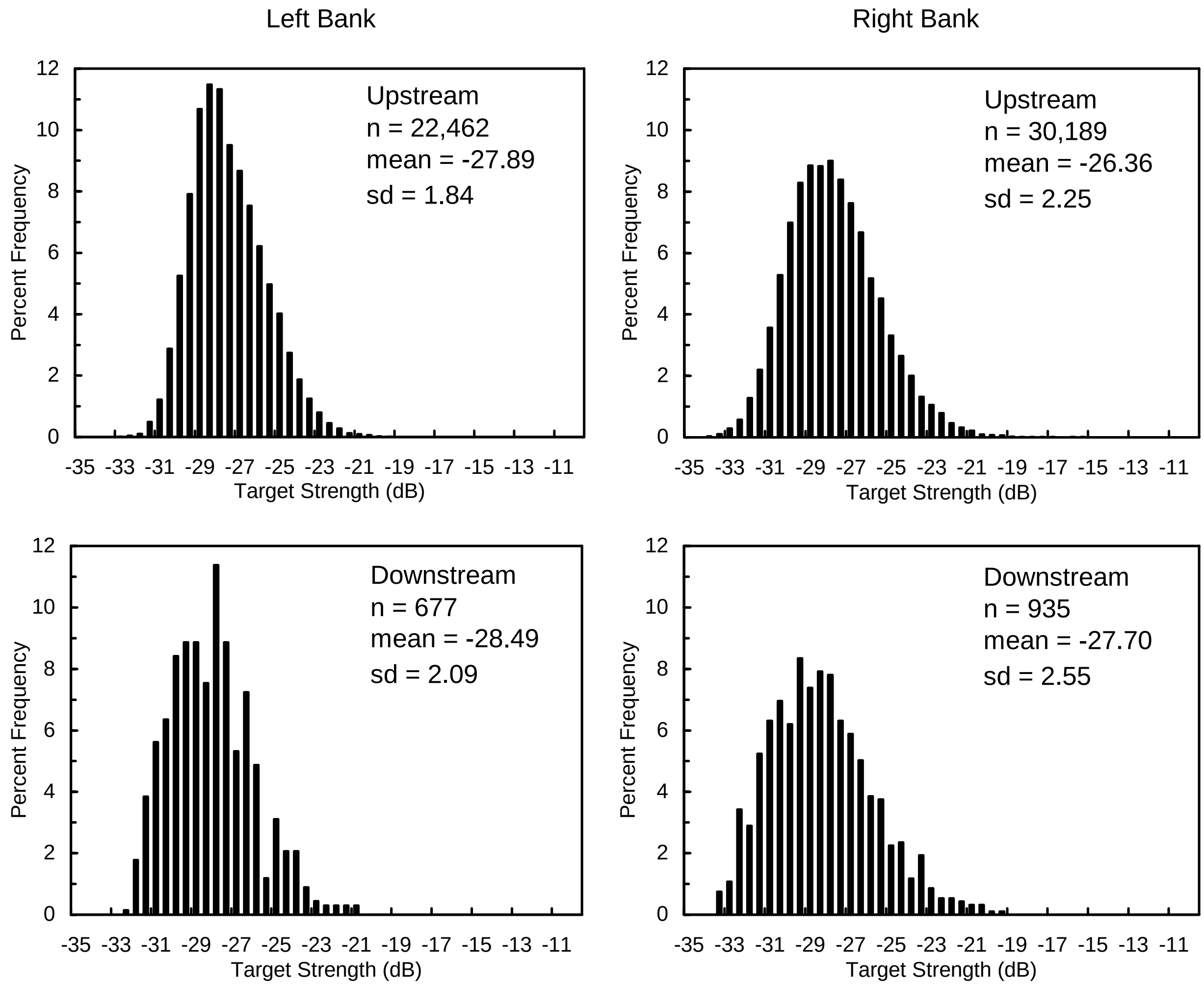
Mean target strength estimates for all upstream targets on the right bank during the early run averaged < 1 dB higher than left bank estimates (Figure 16). During the late run, right bank mean target strength estimates for all upstream targets averaged over 1 dB higher than left bank estimates (Figure 17). Mean target strength of all upstream and downstream targets varied more on the right bank than 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 = 0.30; Table 9). Mean target strength of Chinook salmon was also similar (t = -0.80, P = 0.21) on the right bank among upstream and downstream traveling fish, as was mean target strength variability (F = 0.99, P = 0.39; Table 9).



Note: Data have not been filtered by range and target strength criteria.

Figure 16.–Early-run target strength distributions for all upstream and downstream targets on the left and right banks, Kenai River, 2003.



Note: Data have not been filtered by range and target strength criteria.

Figure 17.–Late-run target strength distributions for all upstream and downstream targets on the left and right banks, Kenai River, 2003.

During the late run on the left bank, mean target strength of Chinook salmon was again similar (t = 0.09, P = 0.46) among upstream and downstream traveling fish, but variability was slightly higher for downstream fish (F = 1.23, P = 0.01, Table 9). On the right bank during the late run, mean target strength was slightly (0.4 dB) higher (t = -3.88, P < 0.01) among upstream traveling fish, but mean target strength variability was similar (F = 0.95, P = 0.27; Table 9). The statistical significance of the difference in mean target strength between upstream and downstream traveling fish was likely an artifact of sample size.

Passage Estimates

Daily estimates of Chinook salmon passage were generated for 16 May-3 August. During the 80-day season, a total of 569 hours of acoustic data were processed from the right bank and 604 hours from the left bank. This represented 30% of the total available sample time on the right bank and 31% on the left bank.

Final upstream Chinook salmon passage from 16 May through 3 August was estimated at 54,984 (SE = 479) fish, composed of 13,325 (SE = 199) early-run fish and 41,659 (SE = 435) late-run fish (Tables 7, 8, 10 and 11). The daily peak of the early run occurred on 8 June; 50% of the run passed by 10 June (Figure 18). When compared with historic mean escapement timing, the 2003 early run was average, but appeared early during the first two weeks of June (Figure 18 and Appendix G1). The daily peak of the late run occurred on 22 July; 50% of the late run passed by 17 July (Figure 19). Migratory timing of the late run was early compared to historic mean escapement timing (Figure 19 and Appendix G2).

DISCUSSION

SPATIAL DISTRIBUTION

Bank Preference

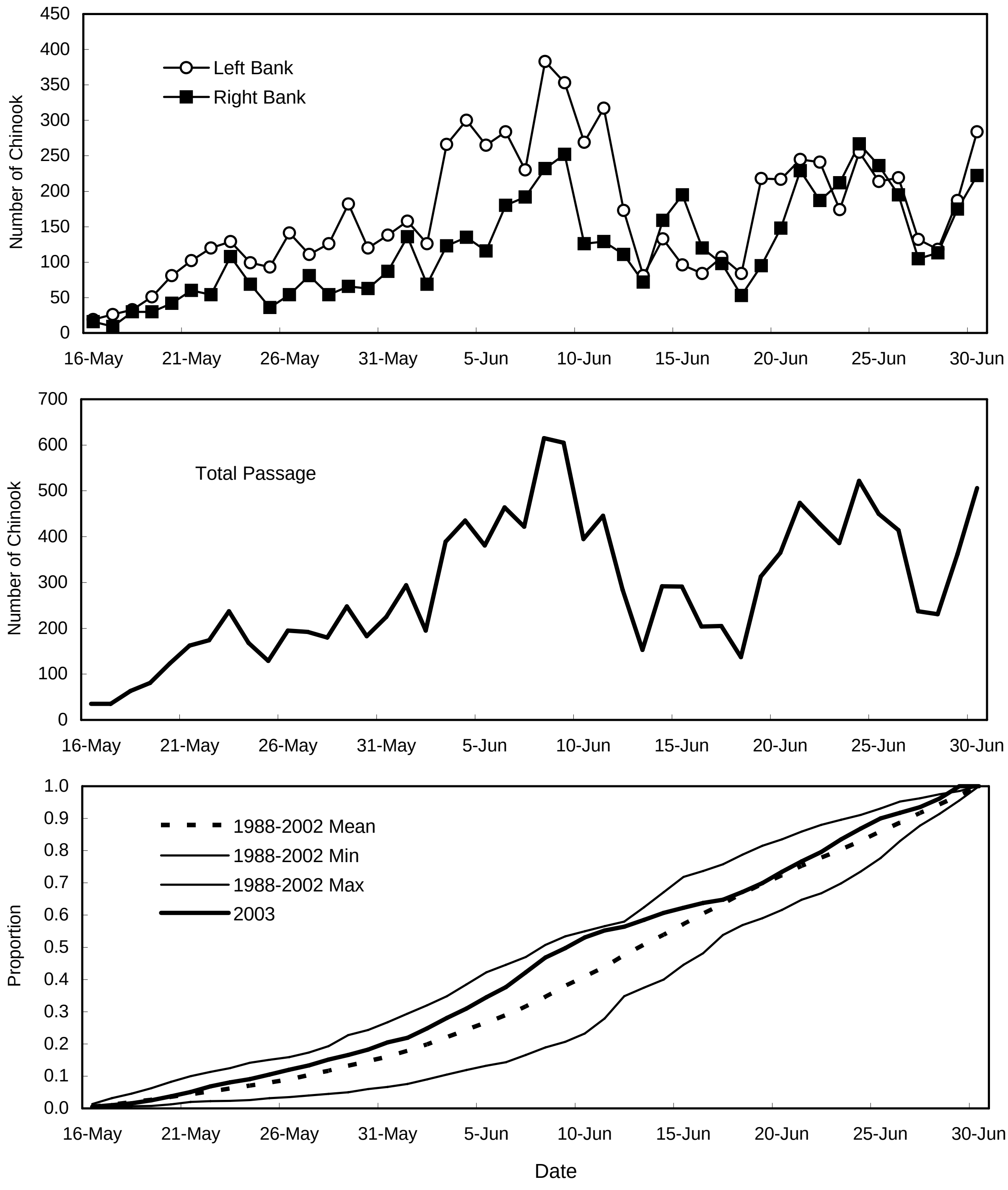
During the early years of the project (prior to 1996), the right bank was heavily favored by migrating fish during both the early and late runs, and the proportion of fish traveling up the right bank increased as the season progressed (Bosch and Burwen 1999; Burwen and Bosch 1998; Burwen and Bosch 1995*a*; Burwen and Bosch 1995*b*, 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 left-bank passage: almost half the early-run upstream passage 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). In 2002 the left bank passage was greater than right bank passage during the early run and almost as large as the right bank passage during the late run (Miller et al. 2004). Again in 2003, the early run passage was greater on the left bank than on the right bank (Table 10). The apparent changes in bank preference do not appear to be related to a changing bottom contour, as the bottom profile at the site has remained relative stable over the past several years. Bosch and Burwen 1999) pointed out that below average discharge rates during the early runs of 1996 and 1997 might have influenced bank preference. Below average discharge rates also occurred in 1999 (Miller et al. 2002). However, discharge rates in 2001-2003 were near or above average during both runs (Miller et al. 2003, Miller et al. 2004, USGS 2003). Thus discharge rates do not appear to fully account for changes in bank preference. Relocation of the left-bank transducer several meters downstream of its historic location during the 2001 season, and the subsequent improved aim, may have contributed to the higher left-bank passage estimate in that the improved aim was able to detect fish that may not have been detected with the old aim. Increased left-bank preferences observed in previous years, however, suggest that the increased left-bank proportions after 2000 may have resulted from factors other than, or in addition to, increased fish detectability.

Table 10.–Estimated daily upstream passage of Chinook salmon, Kenai River sonar, early run, 2003.

Date	Left Bank	Right Bank	Daily Total	Cumulative Total
16-May	19	16	35	35
17-May	26	9	35	70
18-May	33	30	63	133
19-May	51	30	81	214
20-May	81	42	123	337
21-May	102	60	162	499
22-May	120	54	174	673
23-May	129	108	237	910
24-May	99	69	168	1,078
25-May	93	36	129	1,207
26-May	141	54	195	1,402
27-May	111	81	192	1,594
28-May	126	54	180	1,774
29-May	182	66	248	2,022
30-May	120	63	183	2,205
31-May	138	87	225	2,430
1-Jun	158	136	294	2,724
2-Jun	126	69	195	2,919
3-Jun	266	123	389	3,308
4-Jun	300	135	435	3,743
5-Jun	265	116	381	4,124
6-Jun	284	180	464	4,588
7-Jun	230	192	422	5,010
8-Jun	383	232	615	5,625
9-Jun	353	252	605	6,230
10-Jun	269	126	395	6,625
11-Jun	317	129	446	7,071
12-Jun	173	111	284	7,355
13-Jun	81	72	153	7,508
14-Jun	133	159	292	7,800
15-Jun	96	195	291	8,091
16-Jun	84	120	204	8,295
17-Jun	107	98	205	8,500
18-Jun	84	53	137	8,637
19-Jun	218	95	313	8,950
20-Jun	217	148	365	9,315
21-Jun	245	229	474	9,789
22-Jun	241	187	428	10,217
23-Jun	174	212	386	10,603
24-Jun	255	267	522	11,125
25-Jun	214	236	450	11,575
26-Jun	219	195	414	11,989
27-Jun	132	105	237	12,226
28-Jun	118	113	231	12,457
29-Jun	187	175	362	12,819
30-Jun	284	222	506	13,325
Total	7,784	5,541	13,325	

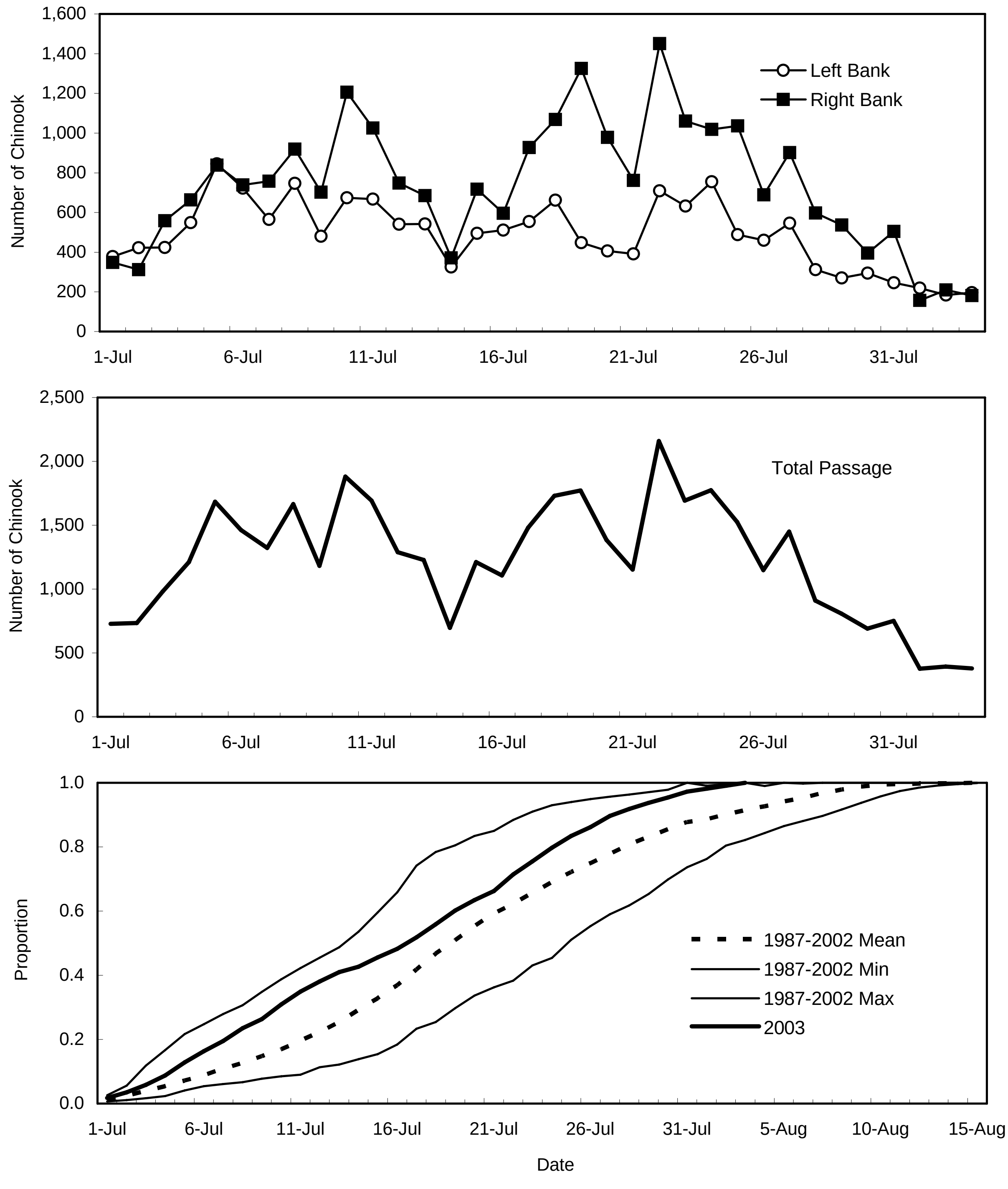
Table 11.–Estimated daily upstream passage of Chinook salmon, Kenai River sonar, late run, 2003.

Date	Left Bank	Right Bank	Daily Total	Cumulative Total
1-Jul	378	349	727	727
2-Jul	423	312	735	1,462
3-Jul	424	558	982	2,444
4-Jul	549	663	1,212	3,656
5-Jul	845	839	1,684	5,340
6-Jul	723	739	1,462	6,802
7-Jul	565	757	1,322	8,124
8-Jul	747	919	1,666	9,790
9-Jul	480	703	1,183	10,973
10-Jul	674	1,206	1,880	12,853
11-Jul	667	1,026	1,693	14,546
12-Jul	541	748	1,289	15,835
13-Jul	542	685	1,227	17,062
14-Jul	325	372	697	17,759
15-Jul	495	717	1,212	18,971
16-Jul	511	596	1,107	20,078
17-Jul	555	927	1,482	21,560
18-Jul	662	1,069	1,731	23,291
19-Jul	448	1,325	1,773	25,064
20-Jul	406	978	1,384	26,448
21-Jul	392	761	1,153	27,601
22-Jul	709	1,450	2,159	29,760
23-Jul	633	1,060	1,693	31,453
24-Jul	755	1,019	1,774	33,227
25-Jul	489	1,036	1,525	34,752
26-Jul	460	689	1,149	35,901
27-Jul	547	902	1,449	37,350
28-Jul	312	597	909	38,259
29-Jul	271	537	808	39,067
30-Jul	295	396	691	39,758
31-Jul	246	505	751	40,509
1-Aug	220	157	377	40,886
2-Aug	184	210	394	41,280
3-Aug	197	182	379	41,659
Total passage	16,670	24,989	41,659	



Note: Mean in bottom panel is based on estimates of total passage for 1988-1997 and upstream passage for 1998-2002.

Figure 18.–Daily sonar estimates of passage by bank (top panel), total passage (center panel), and historical cumulative proportions (bottom panel) for the early run of Chinook salmon returning to the Kenai River, 2003.



Note: Mean in bottom panel is based on estimates of total passage for 1987-1997 and upstream passage for 1998-2002.

Figure 19.–Daily sonar estimates of passage by bank (top panel), total passage (center panel), and historical cumulative proportions (bottom panel) for the late run of Chinook salmon returning to the Kenai River, 2003.

Vertical Distribution

Monitoring the spatial distribution of migrating fish is particularly important at the present 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 that can potentially be used by migrating Chinook salmon. Fish position data suggest that most upstream fish are within the insonified zone. When sockeye are not present in large numbers, most fish are observed migrating in the offshore, bottom section of the river where beam coverage is maximized. Although there were more fish in the upper half of the beam during the rising tide stage on both banks during the 2003 early run (Figure 9), very few fish occupied the upper half of the beam overall (Figure 8). A similar trend occurred on the left bank during the late run (Figures 10, 11). Right-bank vertical fish distribution was quite similar among the three tide stages during the late run (Figure 11). Data collected in previous years showed that fish 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 fish travel close to the river bottom (Figures 8 and 10), our greatest concern is missing fish passing under the sonar beam. No fish were detected below the -2.0° beam angle (Figures 8 and 10). Even with the decreased ability to detect targets on the edge of the beam, we assume there would be larger numbers of targets detected in this region if substantial numbers of fish were traveling below the effective beam, given the large acoustic size of Chinook salmon.

Range Distribution

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

The range distribution of upstream-moving fish on the left bank indicates that fish were dispersed throughout the insonified range during both the early and late runs. The offshore truncation of the left-bank early- and late-run range distribution (Figures 12 and 14) was the result of transducer deployment locations and river bottom contour restricting the left-bank maximum insonified range to 32-33 m. Low passage inside of 16 m during the early run and no passage inside 17 m during the late run (Figures 12 and 14) was the result of using range thresholds to eliminate nearshore sockeye salmon from Chinook salmon counts. The nearshore range distribution was partially influenced by varying range thresholds and by tripod relocations closer to shore as the water level rose.

Passage of upstream fish on the right bank was distributed throughout the range during both runs and exhibited a bimodal distribution during the late run (Figures 12 and 14). The reduced passage and offshore truncation at 56-57 m during the early run and 53-55 m during the late run resulted from varying transducer locations and bottom contour restrictions. The lack of passage inside of 36 m during the early run and 31 m during the late run was the result of using nearshore range thresholds. As with the left bank, right bank nearshore range distributions were influenced by varying range thresholds and varying tripod locations (relative to distance from shore).

In recent years the delineation between nearshore-traveling sockeye and offshore-traveling Chinook seems to have become more obscured (Miller and Burwen 2002). Apparent bursts of high-sockeye passage are often brief and periodic, related to the tide cycle. Consequently, in 2000, we began to selectively exclude individual sample periods when we had evidence that substantial numbers of sockeye were passing the site within the counting range (Miller and Burwen 2002). Hourly samples excluded in 2003 are listed in Appendix D1. We believe this technique reduces the potential for overestimating Chinook salmon passage, at the possible cost of creating bias in the opposite direction. If Chinook passage was relatively high during the excluded samples, our Chinook passage estimates are biased conservatively low by excluding those periods.

TARGET STRENGTH

From 1996 through 2000, the left bank produced higher mean target strength estimates on average than did the right bank (6% higher for early run; 9% higher for later run; Burwen and Bosch 1998; Bosch and Burwen 1999; Bosch and Burwen 2000; 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 on the left bank prevented the sonar beam from being aimed as close to the river bottom on that bank as it was 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 failed to meet the voltage threshold, 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 banks during both the early and late runs (Miller et al. 2003, Miller et al. 2004). The similarity in mean target strength between banks was attributed to the new left-bank transducer location and the improved left-bank aim that resulted in more on-axis targets. Mean target strength estimates were again similar between banks in 2003 (Figures 16 and 17).

Downstream unfiltered targets were slightly smaller (<1 dB on each bank) than upstream unfiltered targets during the early run (Figure 16). The proportion of downstream targets during the early run was similar between the unfiltered and filtered data sets (~5% for each bank; Figure 16 and Table 9). During the late run, downstream unfiltered targets were smaller (<1 dB on the left bank and <2 dB on the right bank) than upstream targets and the proportion of downstream targets was similar (~3%) for filtered and unfiltered data (Table 9, Figure 17). The tendency for downstream traveling targets to have smaller average target strengths than upstream-traveling targets has been documented in prior years (Bosch and Burwen 1999; Bosch and Burwen 2000; Miller and Burwen 2002; Miller et al. 2002; Miller et al. 2003; Miller et al. 2004). Discerning between debris-like traces and a fish traveling downstream can be difficult, and crewmembers are instructed to include downstream targets as valid fish traces when in doubt. Some misclassification of downstream-traveling debris as fish is inevitable. This is the reason that this project and many others choose to ignore downstream targets rather than subtract them from upstream estimates even when direction of travel is known. Typically, the proportion of downstream targets is small, and the potential error that would be introduced by misclassifying debris as downstream traveling fish is of greater concern.

After applying range and target strength filters to both the early and late runs, average target strength of upstream and downstream traveling Chinook salmon on each bank differed by less than 1 dB (Table 9). This suggests that at least in the data set used to generate Chinook salmon estimates, most downstream targets were correctly classified as fish rather than debris.

DIRECTION OF TRAVEL

All tracked targets have been classified by direction of travel since 1995, when split-beam technology was first implemented. Since then, the downstream component of the early run has varied from 2% to 12% and averaged 7%, while the downstream component of the late run has ranged from 3% to 14% and has averaged 6% (Burwen and Bosch 1998; Burwen and Bosch 1996; Bosch and Burwen 1999; Bosch and Burwen 2000; Miller and Burwen 2002; Miller et al. 2002; Miller et al. 2003; Miller et al. 2004). The downstream component of the late run during 7 of the past 8 years has equaled 6% or less with the exception of the 14% anomaly estimated in 1998 (Bosch and Burwen 2000). Downstream passage in 2003 averaged 5% during the early run and 3% during the late run (Tables 5 and 6).

The daily proportion of downstream targets in 2003 was relatively high during the first 10 days of the early run, but was relatively low during the remainder of the early run and throughout the late run (Appendices E1 and E2). The reason for relatively high numbers of downstream targets during the early part of the season is not understood. The most likely explanation is that crewmembers become more adept at discriminating debris from downstream traveling fish as the season progresses.

ACCURACY OF ABUNDANCE ESTIMATES

Past research indicates that sonar estimates of Chinook passage are potentially subject to bias from several sources, including (1) imperfect target detection (fish swimming above, below, or behind the beam; or not meeting the voltage threshold), (2) errors in target tracking (including direction of travel determination), and (3) inaccurate species discrimination. Generally, in the first two cases, the resulting bias would be small, consistent, or negative (resulting in conservative estimates). We are more concerned about species discrimination errors, which can potentially 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 a very imprecise predictor of fish size and species; many sockeye salmon exceed the –28dB 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 over-estimated due to misclassification of mid-river sockeye. In response, we instituted a refinement in our species discrimination algorithm in 2000. Often fish distribution and behavior made it evident when sockeye were abundant in mid-river, and these episodes were often discrete and short-lived. Since 2000, on days when we have suspected that this was occurring, we have censored the data from the associated 1-hour samples, and generated the abundance estimate from those remaining (see Methods). This procedure has reduced the probability of a large positive error in the Chinook abundance estimate, but it has the drawback of being somewhat subjective to implement, and it may increase the probability of negative errors. Inclusion of all available samples hours in 2003, regardless of the presence of offshore sockeye, would have generated a late-run passage estimate of 62,252 (SE = 888). This estimate, however, is likely biased high, and under normal circumstances (i.e. no censoring of samples) would have been lower due to the extension of range thresholds to compensate for the large numbers of sockeye present at far range.

We are currently developing two methods of estimating the species composition of the inriver return, based on (1) catches in the drift gillnets, and (2) echo envelope length ("pulse width") measurements, analyzed with a mixture model. Both methods (described below) offer the advantage of objective species discrimination and, importantly, the means to assess the uncertainty associated with it. Chinook proportions from these two methods are multiplied by "unfiltered" sonar estimates, i.e., those deriving from all upstream fish beyond minimum range thresholds of 15 m on the right bank and 10m on the left bank (see Methods). Although these alternative methods are currently still experimental, we are hopeful that they will eventually lead to more accurate estimates of Chinook salmon passage. At present, we use the alternative estimates to compare with the "standard" estimates, to help gauge their accuracy.

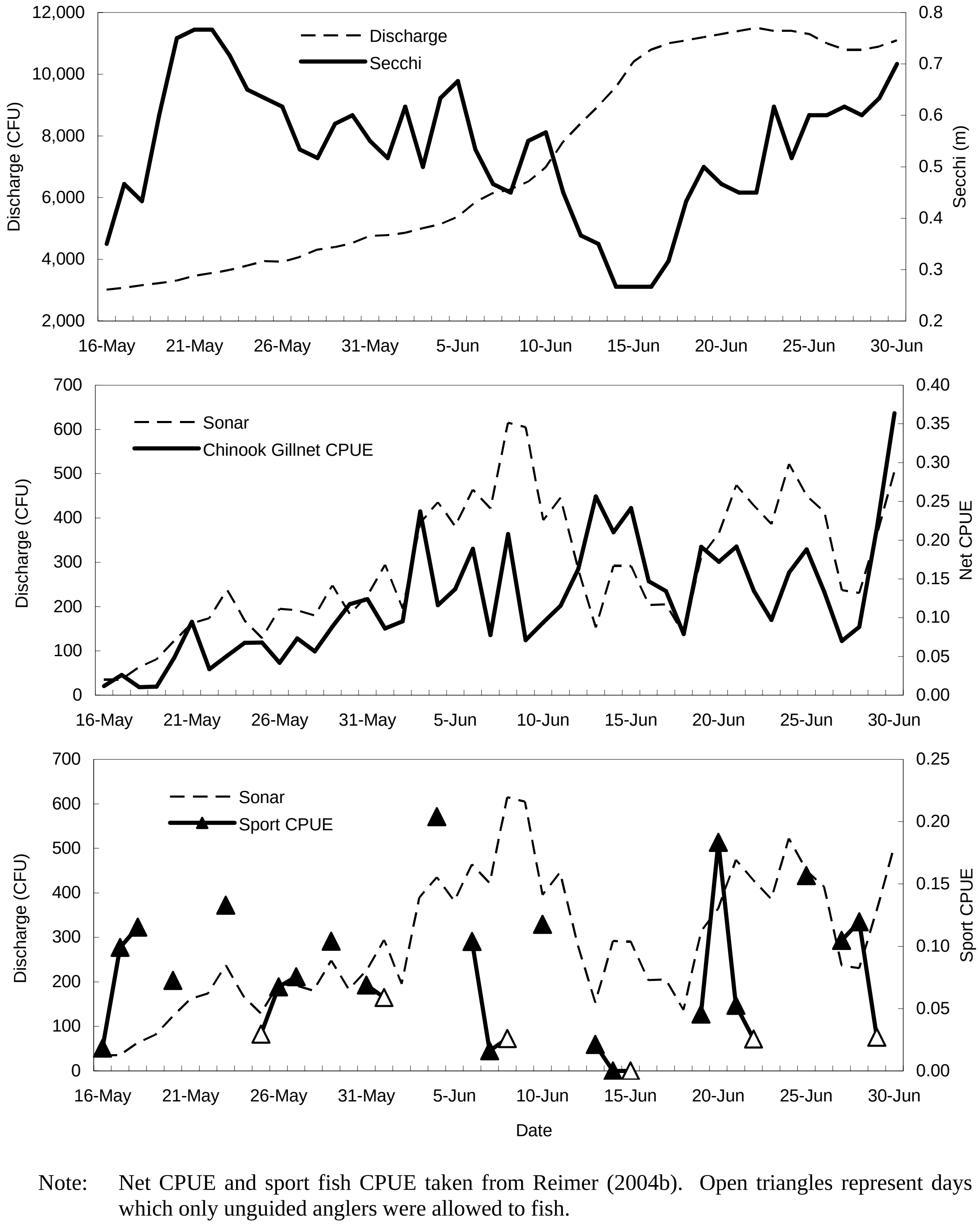
The first alternative method utilizes data from gillnets drifted immediately below the sonar site to estimate the species composition of fish counted by the sonar. Two mesh sizes (5.0 in and 7.5 in stretched) are used. See Reimer (2004*b*) for a full description. For now, we assume that the gillnets are not size-selective.

The second alternative method is based on echo envelope length standard deviation (ELSD), which is a better hydroacoustic index of fish size than target strength (Burwen et al. 2003). We are developing methods that model the frequency distribution of observed ELSD as a mixture of distributions from two or more component species. See Appendix I for a full description. This approach yields robust estimates of species composition even when fish size distributions overlap and change over time. Currently, such estimates 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.

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.

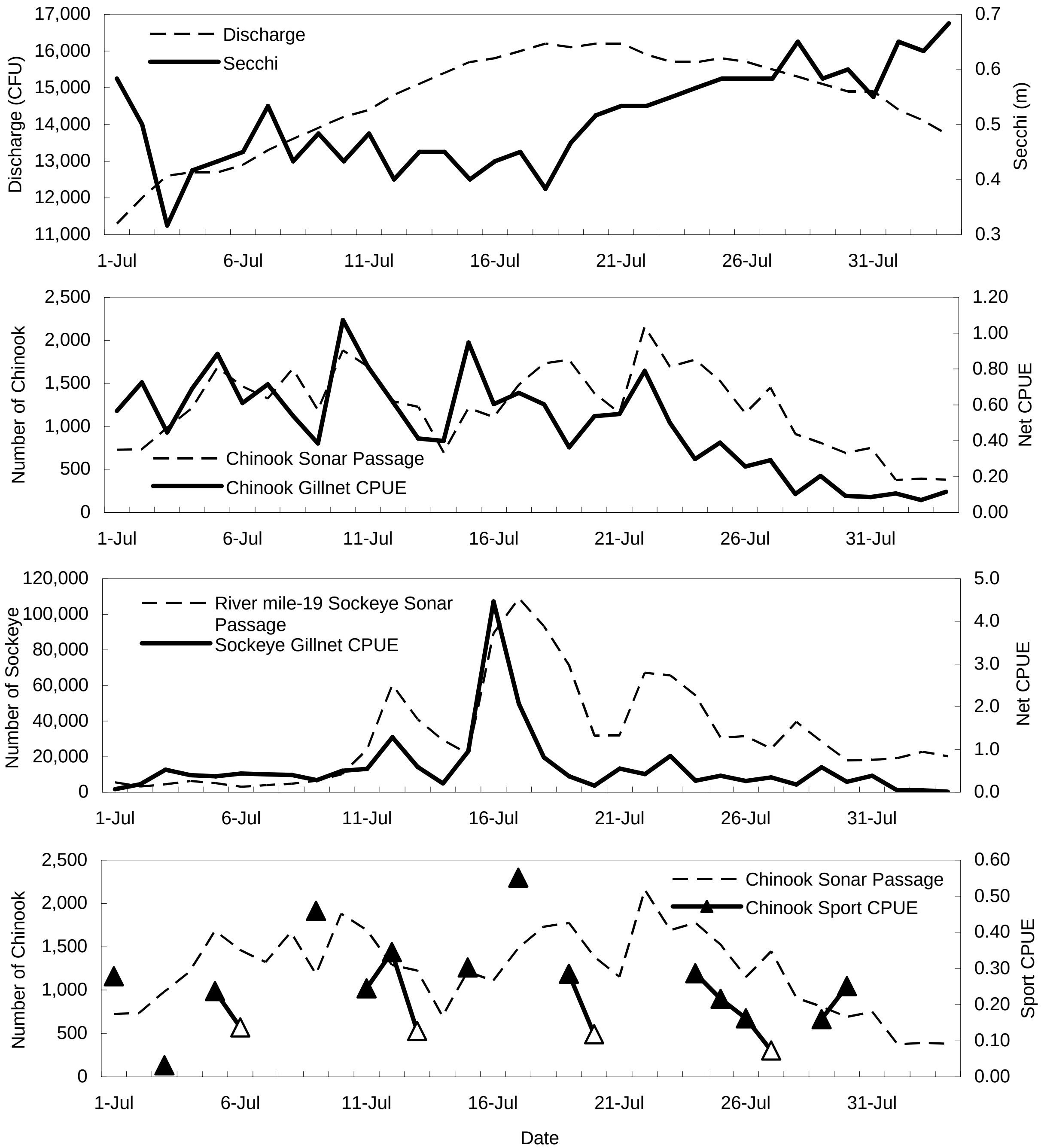
Gillnets have been drifted near the sonar site since the 1980s in order to estimate age composition (Reimer et al. 2002). In 1998, gillnetting methods were standardized in order to produce consistent estimates of CPUE, which we hoped to compare within and between years as an index of Chinook salmon abundance. After analyzing 3 years (1998-2000) of 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 conditions. Several changes to the gillnetting procedures were implemented in 2002: an additional mesh size (5 in) was added, nets were constructed of multi-monofilament (formerly cable-lay braided nylon), the color of the mesh was changed to more closely match that of the river, and drifts were shortened and constrained to more closely match the portion of the channel sampled by the sonar. These changes had the effects of increasing net efficiency, and decreasing the effect of water clarity on net catches (Reimer 2004*a*).

Inriver sport fish CPUE, estimated with an intensive creel survey (Reimer 2004*b*), has historically been considered to be a useful index of Chinook salmon abundance. More recent work (unpublished) indicates that it has little or no predictive value as such an index, even after controlling for the effects of water clarity and discharge. For now, however, we continue to present sport fish CPUE in this report (Figures 20 and 21), for historical consistency.



Note: Net CPUE and sport fish CPUE taken from Reimer (2004b). Open triangles represent days on which only unguided anglers were allowed to fish.

Figure 20.–Daily discharge rates collected at the Soldotna Bridge, Secchi depth 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, 2003.



Note: River mile-19 sockeye sonar estimates taken from Westerman (2003). Net CPUE and sport fish CPUE taken from Reimer (2004b). The Chinook sport fishery closed by regulation on 31 July, so no sport fish CPUE data was available after this date.

Open triangles represent days on which only unguided anglers were allowed to fish.

Figure 21.–Daily discharge rates collected at the Soldotna Bridge, Secchi depth 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-3 August), Kenai River, 2003.

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 through 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 undoubtedly varies, we believe it averages 1 to 2 days. Information from this project identifies periods when sockeye are abundant and when the potential for misclassifying sockeye as Chinook salmon may be high.

Early Run

The 2003 early-run passage estimate of 13,325 Chinook salmon was below average compared with past years, but the inriver recreational fishery was not restricted (Figure 22; Appendix G1). The eulachon *Thaleichthys pacificus* migration, quite large in 2002 (Miller et al. 2004), appeared relatively small in 2003 and did not appear to influence salmon target detectability. A heavy noise band observed on the right bank during the second half of the early run caused some concern, but there were no indications that fish detectability within or beyond the noise band was greatly affected. The intensity and range of the noise band fluctuated with the tide and was most severe during falling and low tide stages. We assume the noise band resulted from plumes of sediment washing downriver during periods of high water current. Daily inseason plots of right-bank target range distribution failed to suggest decreased detectability within or beyond the noise band. If target detectability were affected, the result would be a more conservative early-run Chinook salmon passage estimate.

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 12,657 (SE = 407), which is within 5% of the standard early-run estimate of 13,325 (Figure 22; Appendix H1). On the other hand, the standard estimates generally exceeded the net-apportioned estimates through 12 June, but were lower for the remainder of the early run.

The ELSD mixture model estimated 16,777 (SE = 615) Chinook salmon in the early run, approximately 26% higher than the standard estimate (Appendix I). The standard and mixture model estimates were very close during the first 4 weeks, ending 12 June, but the mixture model estimates were substantially higher thereafter (Figure I4).

Mixture and net-apportioned estimates tracked fairly well, although the net estimates were consistently lower than the mixture estimates until the final week (Figure I4). Ninety-five percent interval estimates overlapped for all weeks except week 4. There was similar agreement during the 2002 early run (Miller et al. 2004). We are encouraged that the two estimates of species composition, which are largely independent of each other, have been fairly well correlated (Figure I5). Both alternative estimates suggest that as the early run progressed, the standard estimates may have become more conservative. All three estimates indicate an average to slightly below average run in 2003.

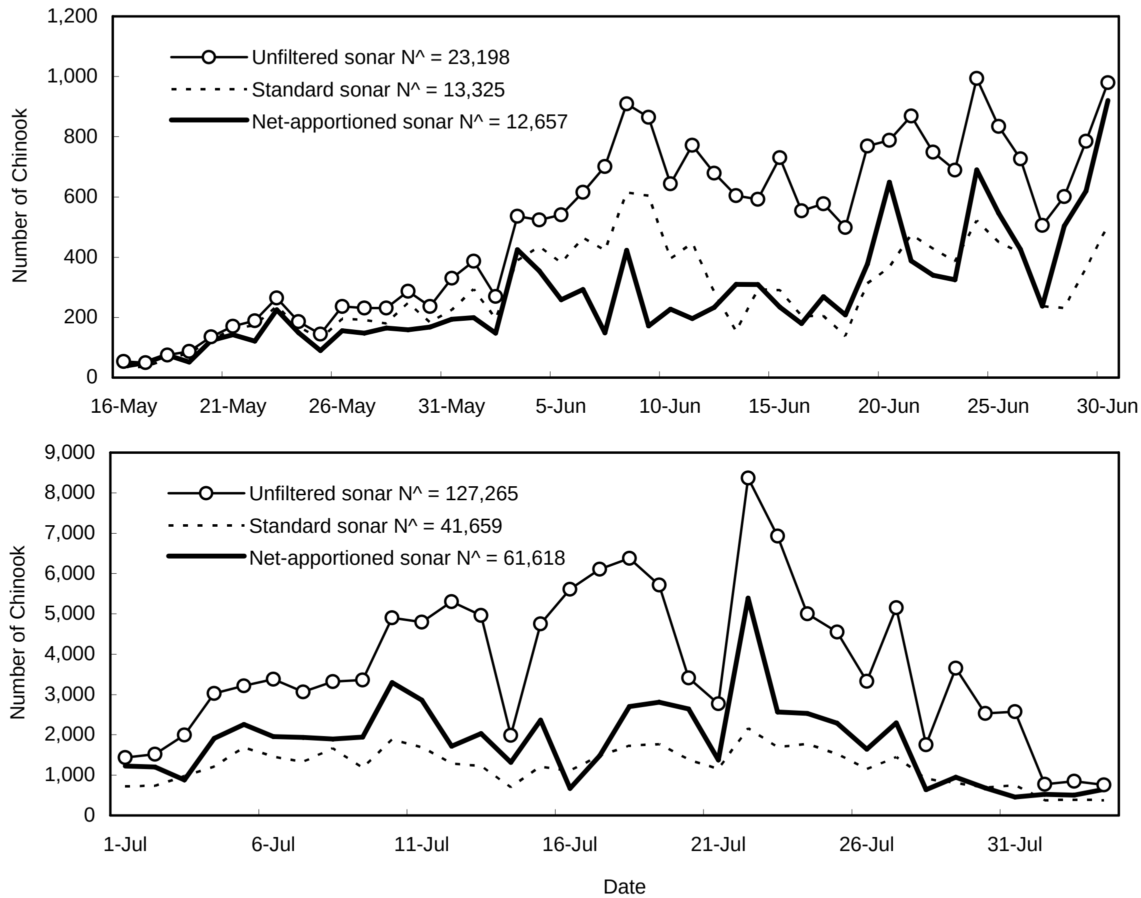


Figure 22.–Estimated early- (top) and late-run (bottom) fish passage based on unfiltered sonar (all species), standard filtered sonar (official Chinook only), and net-apportioned sonar (alternative Chinook only), Kenai River, 2003.

As in past years (Reimer et al. 2002) sonar estimates and gillnet CPUE tracked each other on a short-term basis (Figure 20). Peaks in the two time series generally were aligned, except on 13 June, when a high gillnet CPUE coincided with a low sonar estimate. Also as in past years (Reimer et al. 2002), the relationship between sonar and CPUE appeared to change over time. For instance, CPUE was low relative to the sonar on 4-11 and 20-28 June, but relatively high during the intervening period. Notably, during 11-15 June both discharge and water clarity were changing rapidly (Figure 20).

Late Run

The 2003 late-run passage estimate of 41,659 Chinook salmon was above average, and the inriver recreational fishery was not restricted (Appendix G2). Net-apportioned sonar estimates tracked the standard sonar estimates quite 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 61,618 (SE = 2,005) Chinook salmon was almost 50% higher than the standard sonar estimate. The large proportion of small Chinook salmon caught in the gillnets (Reimer 2004*b*) may have contributed to the apparent conservative late-run standard Chinook sonar estimate. The –28 dB target strength threshold used to filter sockeye salmon from Chinook salmon estimates favors the exclusion of smaller fish. Thus, if the late run were composed of a higher than normal proportion of small Chinook salmon as suggested by the gillnet catches, the target strength filter may have excluded a higher than normal proportion of Chinook salmon from the final estimate, thus resulting in a conservative estimate.

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 coincide with peak sockeye salmon gillnet CPUE. If significant misclassification of sockeye occurred, one would expect it to have taken place on or around 16 July when peak sockeye gillnet CPUE was observed. Peak sonar passage did not occur until 22 July, with smaller peaks occurring on 10 July and 19 July.

Chinook gillnet CPUE tracked fairly well with the daily sonar estimates, except for 19 July when a peak in the sonar estimate corresponded with a low CPUE (Figure 21). The relationship appeared to change in mid-July. CPUE was lower, relative to the sonar, in late July than in early July. In summary, misclassification of sockeye salmon as Chinook salmon was likely minimal in 2003, and comparison of the standard estimate with the alternative net-apportioned estimate suggests that the late-run standard estimate may have been conservative.

OUTLOOK

We continue to pursue several avenues of investigation for improving our estimation of Chinook salmon abundance. We are satisfied that the refinements made to the netting program 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. We are developing estimates of gillnet size-selectivity with which to correct both alternative estimates in 2004. At that point we will also 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. We are currently funding a graduate student at the University of Washington who is concentrating on some of the low level signal processing details of echo envelope measurements. Results from this research may provide information that will allow us to improve or build on the relationship between echo pulse shape and fish size.

Finally, we will continue experiments in 2004 with a new long-range prototype of the DIDSON imaging sonar (DIDSON-LR). Burwen et al. (*in prep*) found that the standard version of the DIDSON (DIDSON-S) tested in 2002 could provide relatively accurate estimates of fish size at short ranges but failed to provide the range coverage necessary for application at the Kenai River Chinook sonar site. Preliminary tests of the DIDSON-LR indicate that it has substantially increased range capabilities (Suzanne Maxwell, ADF&G, Division of Commercial Fish, Soldotna, personal communication) over the DIDSON-S. The DIDSON-LR will be tested at several sites in 2004, however it is questionable whether size-information will be of the quality required for species classification due to the reduced resolution of this system.

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APPENDIX A. TARGET STRENGTH ESTIMATION

Appendix A1.-Using the sonar equation to estimate target strength 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- Tuesday July 1 12:00:09 2003

* 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		-170.4	gn - transducer through system gain at one meter
203	-1		-18	rg - receiver gain used to collect data
204	-1		2.8	narr_ax_bw - vertical nominal beam width
205	-1		10	wide_ax_bw - horizontal axis nominal beam width
206	-1		0	narr_ ax_corr - vertical axis phase correction
207	-1		0	wide_ax_corr - horizontal axis phase correction
208	-1		11.0011	ping_rate - pulses per second
209	-1		0	echogram start range in meters
210	-1		37	echogram stop range in meters
211	-1		722	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.

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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	-15.8636	ux - horizontal electrical to mechanical angle ratio
223	-1	-32.7772	uy - vertical electrical to mechanical angle ratio
224	-1	0	ud_coef_a - a coeff. for up-down beam pattern eq.
225	-1	-0.0068	ud_coef_b - b coeff. for up-down beam pattern eq.
226	-1	-2.4542	ud_coef_c - c coeff. for up-down beam pattern eq.
227	-1	0.1769	ud_coef_d - d coeff. for up-down beam pattern eq.
228	-1	-0.1831	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	-0.0001	lr_coef_b - b coeff. for left-rt beam pattern eq.
231	-1	-0.2079	lr_coef_c - c coeff . for left-rt beam pattern eq.
232	-1	0.0006	lr_coef_d - d coeff. for left-rt beam pattern eq.
233	-1	-0.0002	lr_coef_e - ecoeff. for left-rt beam pattern eq.
234	-1	4	maximum fish velocity in meters per second
235	-1	1	Echo Scope Bottom Location
236	-1	0.4	maxpw - pulse width search window size
238	-1	35.4	bottom - bottom depth in meters
239	-1	0	init_slope - initial slope for tracking in m/ping
240	-1	0.2	exp_cont - exponent for expanding tracking window
241	-1	0.2	max_ch_rng - maximum change in range in m/ping
242	-1	0.04	pw_criteia->min_pw_6-min -6 dB pulse width
243	-1	10	pw_criteria->max_pw_6-max -6 dB pulse width
244	-1	0.04	pw_criteria->min_pw_12 - min -12 dB pulse width
245	-1	10	pw_criteria->max_pw_12 - max -12 dB pulse width
246	-1	0.04	pw_criteria->min_pw_18 - min -18 dB pulse width
247	-1	10	pw_criteria->max_pw_18 - max -18 dB pulse width
249	-1	10	maximum voltage to allow in .RAW file
250	-1	0.2	TX argument #1 - pulse width in milliseconds
251	-1	25	TX argument #2 - transmit power in dB-watts
252	-1	-12	RX argument #1 - receiver gain
253	-1	90.9	REP argument #1 - ping rate in ms per ping
254	-1	10	REP argument #2 - pulsed cal tone separation
255	-1	1	TVG argument #1 - TVG start range in meters
256	-1	100	TVG argument #2 - TVG end range in meters
257	-1	40	TVG argument #3 - TVG function (XX Log Range)
258	-1	-6	TVG argument #4 - TVG gain
259	-1	0	TVG argument #5 - alpha (spreading loss) in dB/Km
260	-1	0.2	minimum absolute distance fish must travel in x plane
261	-1	0.2	minimum absolute distance fish must travel in y plane
262	-1	0.2	minimum absolute distance fish must travel in z plane
263	-1	2	bottom_window - auto tracking bottom window (m)
264	-1	3	bottom_threshold - auto tracking bottom threshold (V)
265	-1	11.2	TVG argument #7 - 20/40 log crossover (meters)
266	-1	0	rotator - which rotator to aim
267	-1	0	aim_pan - transducer aiming angle in pan (x, lf/rt)
268	-1	0	aim_tilt - transducer aiming angle in tilt (y, u/d)
401	0	1	th_layer[0] – bottom of first threshold layer (m)
401	1	5	th_layer[1] – bottom of second threshold layer (m)

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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	722	th_val[0], threshold for 1st layer in millivolts
402	1	722	th_val[1], threshold for 2nd layer in millivolts
402	2	722	th_val[2], threshold for 3rd layer in millivolts
402	3	722	th_val[3], threshold for 4th layer in millivolts
402	4	722	th_val[4], threshold for 5th layer in millivolts
402	5	722	th_val[5], threshold for 6th layer in millivolts
402	6	722	th_val[6], threshold for 7th layer in millivolts
402	7	722	th_val[7], threshold for 8th layer in millivolts
402	8	722	th_val[8], threshold for 9th layer in millivolts
402	9	722	th_val[9], threshold for 10th layer in millivolts
402	10	722	th_val[10], threshold for 11th layer in millivolts
402	11	722	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- Tuesday July 1 12:00:09 2003**

* 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		-171.96	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		452	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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Appendix B2.-Page 2 of 3.

220	-1		5	max_angoff_ h - maximum angle off axis horiz.
221	-1		-24	max_dB_off - maximum angle off in dB
222	-1		-15.7449	ux - horizontal electrical to mechanical angle ratio
223	-1		-54.9056	uy - vertical electrical to mechanical angle ratio
224	-1		0	ud_coef_a - a coeff. for up-down beam pattern eq.
225	-1		0.0014	ud_coef_b - b coeff. for up-down beam pattern eq.
226	-1		-2.9361	ud_coef_c - c coeff. for up-down beam pattern eq.
227	-1	-0.1048		ud_coef_d - d coeff. for up-down beam pattern eq.
228	-1		-0.1185	ud_coef_e - e coeff. for up-down beam pattern eq.
229	-1		0	lr_coef_a - a coeff. for left-rt beam pattern eq.
230	-1		0	lr_coef_b - b coeff. for left-rt beam pattern eq.
231	-1		-0.2161	lr_coef_c - c coeff . for left-rt beam pattern eq.
232	-1		-0.0001	lr_coef_d - d coeff. for left-rt beam pattern eq.
233	-1		-0.0002	lr_coef_e - ecoeff. for left-rt beam pattern eq.
234	-1		4	maximum fish velocity in meters per second
235	-1		1	Echo Scope Bottom Location
236	-1		0.4	maxpw - pulse width search window size
238	-1		30.5	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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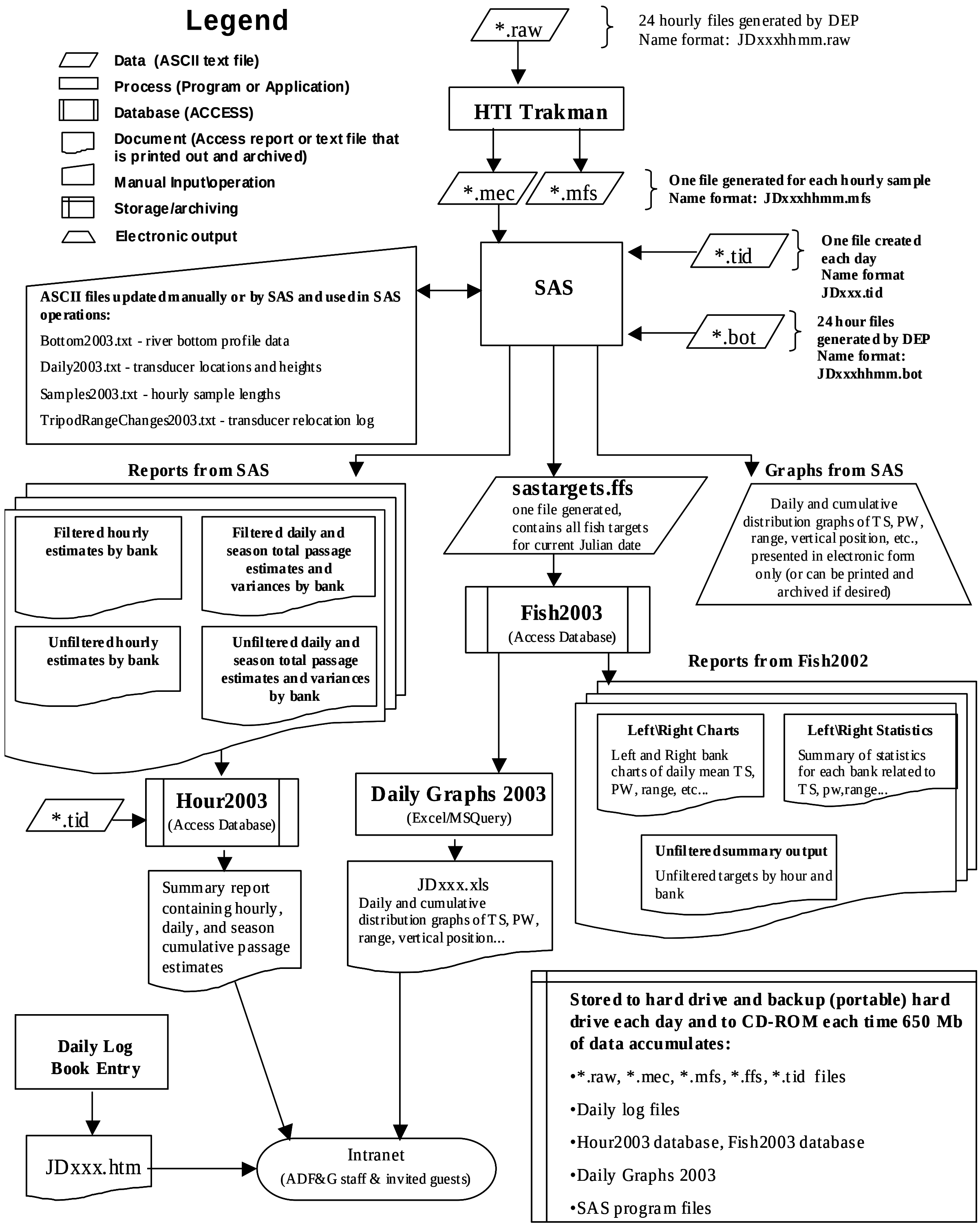
Appendix B2.-Page 3 of 3.

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	452	th_val[0], threshold for 1st layer in millivolts
402	1	452	th_val[1], threshold for 2nd layer in millivolts
402	2	452	th_val[2], threshold for 3rd layer in millivolts
402	3	452	th_val[3], threshold for 4th layer in millivolts
402	4	452	th_val[4], threshold for 5th layer in millivolts
402	5	452	th_val[5], threshold for 6th layer in millivolts
402	6	452	th_val[6], threshold for 7th layer in millivolts
402	7	452	th_val[7], threshold for 8th layer in millivolts
402	8	452	th_val[8], threshold for 9th layer in millivolts
402	9	452	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.-Inseason data flow diagram for the Kenai River Chinook salmon sonar project, 2003.



APPENDIX D. EXCLUDED HOURLY SAMPLES

Appendix D1.-Hourly samples excluded by bank from calculation of early- and late-run Chinook salmon passage estimates, Kenai River, 2003.

Date	Excluded Sample Hours	
	Left Bank	Right Bank
EARLY RUN		
20-Jun	2020-2220	2000-2100
21-Jun	2120-2220	2100-2200
22-Jun	2120	2200-2300
23-Jun		2300
24-Jun	1220-1320	1300-1500
25-Jun	1320	1500
26-Jun	1620	1600
28-Jun	0620, 1820	1600, 1800
29-Jun	0720	1600
30-Jun	1620	1600, 1900
LATE RUN		
1-Jul		1700, 2000, 2200
2-Jul	2020-2120	1700, 2100
4-Jul	1120, 1920	1100-1200, 1900
5-Jul	0720, 2020	0700, 1300, 2000
6-Jul	2020-2120	2100-2200
7-Jul	1020, 1420, 2120	0200, 1400, 2100-2300
8-Jul	1020	1100-1200, 1500-1600, 2200-2300
9-Jul	2220-2320	1200-1300, 1600-1700, 2300
10-Jul	1420, 1720-1920	0500, 1300-1500, 1800-1900
11-Jul	0420, 1420	0000, 0400, 0600-0700, 1400-1500
12-Jul	0920, 1520, 1820-1920	1500, 1800, 2000
13-Jul	0720, 1520, 1820-2020	0800-0900, 1900-2100
14-Jul		0900, 1900, 2200
15-Jul	0720-0920	0700-1000
16-Jul	1020, 1320, 1720	1000-1300, 1500, 1700
17-Jul	1020-1220	1000-1100, 1400-1600, 1800-1900
18-Jul	1220, 2120	0000, 1100-1400, 1900-2100
19-Jul	0720-1020, 2020-2220	0700-1000, 2000-2300
20-Jul	0820-1020, 2120	0100, 0800-1000, 2100
21-Jul	2120-2220	1500-1600, 2100-2300
22-Jul	1220, 1520, 1720-2120,	0900-2300
23-Jul	0720, 1320-1520	0000, 0500, 0700, 1200-2300
24-Jul	0020, 1420-1520	0000-0200, 1400-2000, 2300
25-Jul	0120, 1420-1620	0100, 1500-1700, 1900-2100
26-Jul	1520-1620	1500-2100
27-Jul	0320, 1620, 1920	0100-0200, 0400, 0600-0900, 1500-1800, 1900-2100
29-Jul	0820-1020, 1720-1920	0800-1100, 1600-1900
30-Jul	1720-1820	0900-1200, 1700, 1900-2000, 2200
31-Jul	0820-1020, 1720	0700, 0900-1100, 1700, 2000
1-Aug	2020	2000
2-Aug	1820	1800
3-Aug	1920-2120	2100

APPENDIX E. DAILY PROPORTIONS OF UPSTREAM AND DOWNSTREAM MOVING FISH FOR THE 2003 EARLY AND LATE KENAI RIVER CHINOOK SALMON RUNS

Appendix E1.-Daily proportions of upstream and downstream moving fish for the 2003 Kenai River early Chinook run.

Date	Downstream Count	Upstream Count	Daily Total	% Downstream	% Upstream
16 May	4	35	39	10%	90%
17 May	11	35	46	24%	76%
18 May	9	63	72	13%	88%
19 May	6	81	87	7%	93%
20 May	12	123	135	9%	91%
21 May	36	162	198	18%	82%
22 May	21	174	195	11%	89%
23 May	24	237	261	9%	91%
24 May	9	168	177	5%	95%
25 May	15	129	144	10%	90%
26 May	6	195	201	3%	97%
27 May	12	192	204	6%	94%
28 May	9	180	189	5%	95%
29 May	21	248	269	8%	92%
30 May	18	183	201	9%	91%
31 May	12	225	237	5%	95%
1 June	9	294	303	3%	97%
2 June	12	195	207	6%	94%
3 June	12	389	401	3%	97%
4 June	28	435	463	6%	94%
5 June	13	381	394	3%	97%
6 June	21	464	485	4%	96%
7 June	12	422	434	3%	97%
8 June	15	615	630	2%	98%
9 June	9	605	614	1%	99%
10 June	9	395	404	2%	98%
11 June	21	446	467	4%	96%
12 June	9	284	293	3%	97%
13 June	9	153	162	6%	94%
14 June	24	292	316	8%	92%
15 June	27	291	318	8%	92%
16 June	33	204	237	14%	86%
17 June	6	205	211	3%	97%
18 June	0	137	137	0%	100%
19 June	0	313	313	0%	100%
20 June	14	365	379	4%	96%
21 June	30	474	504	6%	94%
22 June	11	428	439	3%	97%
23 June	6	386	392	2%	98%
24 June	33	522	555	6%	94%
25 June	9	450	459	2%	98%
26 June	6	414	420	1%	99%
27 June	6	237	243	2%	98%
28 June	6	231	237	3%	97%
29 June	24	362	386	6%	94%
30 June	8	506	514	2%	98%
Total	647	13,325	13,972	5%	95%

Appendix E2.-Daily proportions of upstream and downstream moving fish for the 2003 Kenai River late Chinook run.

Date	Downstream Count	Upstream Count	Daily Total	% Downstream	% Upstream
1 July	66	727	793	8%	92%
2 July	36	735	771	5%	95%
3 July	39	982	1,021	4%	96%
4 July	19	1,212	1,231	2%	98%
5 July	51	1,684	1,735	3%	97%
6 July	19	1,462	1,481	1%	99%
7 July	9	1,322	1,331	1%	99%
8 July	58	1,666	1,724	3%	97%
9 July	50	1,183	1,233	4%	96%
10 July	65	1,880	1,945	3%	97%
11 July	83	1,693	1,776	5%	95%
12 July	22	1,289	1,311	2%	98%
13 July	11	1,227	1,238	1%	99%
14 July	25	697	722	3%	97%
15 July	27	1,212	1,239	2%	98%
16 July	32	1,107	1,139	3%	97%
17 July	74	1,482	1,556	5%	95%
18 July	54	1,731	1,785	3%	97%
19 July	33	1,773	1,806	2%	98%
20 July	55	1,384	1,439	4%	96%
21 July	34	1,153	1,187	3%	97%
22 July	64	2,159	2,223	3%	97%
23 July	55	1,693	1,748	3%	97%
24 July	44	1,774	1,818	2%	98%
25 July	53	1,525	1,578	3%	97%
26 July	31	1,149	1,180	3%	97%
27 July	14	1,449	1,463	1%	99%
28 July	37	909	946	4%	96%
29 July	18	808	826	2%	98%
30 July	14	691	705	2%	98%
31 July	7	751	758	1%	99%
1 August	25	377	402	6%	94%
2 August	23	394	417	6%	94%
3 August	12	379	391	3%	97%
Total	1,259	41,659	42,918	3%	97%

APPENDIX F. AVERAGE VERTICAL ANGLE BY TIDE STAGE, RUN, BANK, AND FISH ORIENTATION (UPSTREAM OR DOWNSTREAM) FOR THE 2003 KENAI RIVER CHINOOK SALMON RUNS

Appendix F1.-Average vertical angle by tide stage and orientation for the 2003 Kenai River early Chinook run.

Tide Stage / Fish Orientation	Average Vertical Angle	Standard Deviation	Sample Size
Left Bank			
Falling			
Downstream	-0.63	0.53	24
Upstream	-0.63	0.39	1,571
Tide Stage Total	-0.63	0.40	1,595
Low			
Downstream	-0.43	0.31	13
Upstream	-0.61	0.36	597
Tide Stage Total	-0.60	0.36	610
Rising			
Downstream	-0.16	0.66	62
Upstream	-0.23	0.49	477
Tide Stage Total	-0.22	0.51	539
Left Bank Total	-0.55	0.44	2,744
Right Bank			
Falling			
Downstream	-0.33	0.57	61
Upstream	-0.44	0.47	1,076
Tide Stage Total	-0.43	0.48	1,137
Low			
Downstream	-0.46	0.61	25
Upstream	-0.63	0.41	396
Tide Stage Total	-0.62	0.42	421
Rising			
Downstream	-0.43	0.59	33
Upstream	-0.29	0.47	503
Tide Stage Total	-0.30	0.48	536
Right Bank Total	-0.43	0.48	2,094

Appendix F2.-Average vertical angle by tide stage and orientation for the 2003 Kenai River late Chinook run.

Tide Stage / Fish Orientation	Average Vertical Angle	Standard Deviation	Sample Size
Left Bank			
Falling			
Downstream	-0.17	0.45	86
Upstream	-0.40	0.25	3,749
Tide Stage Total	-0.40	0.25	3,835
Low			
Downstream	-0.25	0.34	57
Upstream	-0.38	0.24	1,180
Tide Stage Total	-0.37	0.25	1,237
Rising			
Downstream	-0.10	0.44	64
Upstream	-0.17	0.40	2,038
Tide Stage Total	-0.17	0.40	2,102
Left Bank Total	-0.33	0.32	7,174
Right Bank			
Falling			
Downstream	-0.12	0.42	211
Upstream	-0.20	0.34	9,027
Tide Stage Total	-0.20	0.34	9,238
Low			
Downstream	-0.24	0.38	83
Upstream	-0.41	0.37	2,048
Tide Stage Total	-0.40	0.37	2,131
Rising			
Downstream	-0.16	0.41	134
Upstream	-0.18	0.37	6,377
Tide Stage Total	-0.18	0.37	6,511
Right Bank Total	-0.19	0.36	17,880

APPENDIX G. HISTORIC PASSAGE BY YEAR AND DATE (1987–2003).

Appendix G1.-Kenai River early-run Chinook salmon sonar passage estimates, 1987-2003.

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

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Appendix G1.–Page 2 of 2.

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

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, 1987-2003.

Date/Year	1987	1988	1989	**1990**	1991	**1992**	1993[a]	1994[a]	1995	1996	1997	**1998**[b]	1999[b]	2000[b]	2001[b]	2002[b]	2003[b]
1 July	507	526	769	578	267	364	619	663	350	341	486	491	453	461	697	563	727
2 July	429	404	489	305	300	297	525	342	398	240	642	597	612	373	766	1,596	735
3 July	405	398	353	486	333	320	404	625	353	303	600	480	486	370	1,075	2,456	982
4 July	628	292	566	436	519	198	468	858	439	393	633	450	396	488	714	1,855	1,212
5 July	596	482	1,106	853	316	225	429	705	667	1,067	657	606	369	787	676	1,949	1,684
6 July	523	654	879	795	242	331	996	975	720	879	627	612	683	778	645	1,205	1,462
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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 August	470	925	351	**393**	897	**921**	776	1,037	474		247	**909**	591	695	455	642	377
2 August	314	781	201	**388**	867	**1,018**	626	1,223	369		291	**1,512**	468	421	459	553	394
3 August	263	989	132	**533**	392	**837**	350	1,078	447		213	**1,006**	642	294	504	752	379

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Appendix G2.-Page 2 of 2.

Date/Year	1987	1988	1989	**1990**	1991	**1992**	1993[a]	1994[a]	1995	1996	1997	**1998[b]**	1999[b]	2000[b]	2001[b]	2002[b]	2003[b]
4 August	835	1,524	142	**717**	331	**862**	467	658	519			**1,131**	444	453	840	995	
5 August	904	1,091	107	**723**	174	**861**	711	536	404			**1,094**	436	489	581	575	
6 August	648	1,333	107	**552**	343	**654**	1,076	1,042	408			**864**	654	504	417	754[c]	
7 August	694	1,186	65	**516**	618	**558**	655	797	279			**843**	678	366	618	676[c]	
8 August	658	1,449		**682**	600	**217**	682		267			**750**	804	417	467	636[c]	
9 August	368	1,132		**679**		**165**	424		272			**570**	328	399	232	456[c]	
10 August	312	755		**678**		**249**	252					**496**	165	397	200	337[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]

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, 2003.

Appendix H1.-Estimated fish passage based on unfiltered sonar (all species), standard filtered sonar (official Chinook only), and net-apportioned sonar (alternative Chinook only), Kenai River sonar, early run, 2003.

	Unfiltered		Filtered (Standard)		Net-Apportioned	
Date	Passage	SE	Passage	SE	Passage	SE
16-May	53	15	35	13	37	14
17-May	49	8	35	7	49	8
18-May	75	16	63	13	75	16
19-May	87	16	81	15	52	23
20-May	135	17	123	17	123	17
21-May	171	19	162	18	142	22
22-May	189	22	174	19	121	32
23-May	264	29	237	27	225	41
24-May	186	23	168	22	149	39
25-May	144	17	129	16	90	30
26-May	236	25	195	24	155	28
27-May	231	22	192	21	147	32
28-May	231	22	180	19	165	31
29-May	287	34	248	30	158	38
30-May	236	29	183	25	167	23
31-May	330	28	225	19	193	36
1-Jun	387	37	294	28	199	35
2-Jun	269	28	195	23	148	28
3-Jun	536	43	389	39	425	70
4-Jun	524	39	435	34	355	64
5-Jun	541	40	381	31	258	49
6-Jun	616	42	464	37	293	42
7-Jun	701	41	422	30	148	50
8-Jun	909	70	615	48	423	98
9-Jun	865	64	605	47	171	36
10-Jun	644	50	395	32	227	57
11-Jun	772	55	446	39	196	61
12-Jun	679	64	284	35	233	71
13-Jun	605	54	153	22	310	61
14-Jun	592	32	292	22	308	35
15-Jun	731	49	291	36	234	46
16-Jun	554	51	204	31	180	51
17-Jun	577	45	205	24	268	63
18-Jun	499	44	137	23	208	76
19-Jun	769	50	313	28	377	102
20-Jun	788	78	365	33	649	88
21-Jun	869	73	474	37	387	125
22-Jun	749	56	428	36	340	53
23-Jun	689	42	386	30	325	65
24-Jun	994	71	522	32	692	65
25-Jun	835	63	450	34	546	101
26-Jun	727	52	414	39	426	75
27-Jun	506	44	237	21	238	39
28-Jun	602	63	231	29	504	87
29-Jun	785	61	362	38	620	117
30-Jun	980	92	506	39	921	93
Total	23,198	314	13,325	199	12,657	407

Appendix H2.-Estimated fish passage based on unfiltered sonar (all species), standard filtered sonar (official Chinook only), and net-apportioned sonar (alternative Chinook only), Kenai River sonar, late run, 2003.

	Unfiltered		Filtered (Standard)		Net-Apportioned	
Date	Passage	SE	Passage	SE	Passage	SE
1-Jul	1,440	99	727	52	1,230	118
2-Jul	1,521	100	735	48	1,206	80
3-Jul	1,994	82	982	63	882	151
4-Jul	3,025	167	1,212	50	1,913	272
5-Jul	3,217	201	1,684	94	2,258	328
6-Jul	3,384	269	1,462	99	1,957	288
7-Jul	3,067	263	1,322	97	1,932	350
8-Jul	3,325	188	1,666	89	1,898	311
9-Jul	3,361	245	1,183	49	1,940	279
10-Jul	4,905	262	1,880	86	3,298	343
11-Jul	4,796	387	1,693	81	2,863	409
12-Jul	5,304	554	1,289	69	1,714	604
13-Jul	4,964	412	1,227	95	2,037	450
14-Jul	1,987	147	697	52	1,315	230
15-Jul	4,752	394	1,212	84	2,364	691
16-Jul	5,612	516	1,107	62	669	168
17-Jul	6,110	536	1,482	94	1,487	334
18-Jul	6,378	354	1,731	105	2,704	265
19-Jul	5,714	413	1,773	115	2,811	351
20-Jul	3,413	202	1,384	72	2,645	164
21-Jul	2,770	191	1,153	58	1,377	293
22-Jul	8,370	366	2,159	102	5,388	554
23-Jul	6,928	360	1,693	68	2,567	598
24-Jul	5,002	304	1,774	70	2,531	327
25-Jul	4,551	289	1,525	85	2,288	309
26-Jul	3,329	223	1,149	65	1,641	444
27-Jul	5,148	353	1,449	74	2,295	574
28-Jul	1,758	119	909	68	638	139
29-Jul	3,649	337	808	73	946	285
30-Jul	2,534	214	691	41	687	159
31-Jul	2,574	248	751	69	462	193
1-Aug	772	63	377	35	530	84
2-Aug	850	51	394	34	501	138
3-Aug	761	49	379	29	644	75
Total	127,265	1,731	41,659	435	61,618	2,005

APPENDIX I. ECHO LENGTH MIXTURE MODEL ESTIMATES OF SPECIES COMPOSITION AND CHINOOK ABUNDANCE, EARLY RUN 2003

Appendix I1.-Echo length mixture model estimates of species composition and Chinook abundance, early run, 2003.

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.

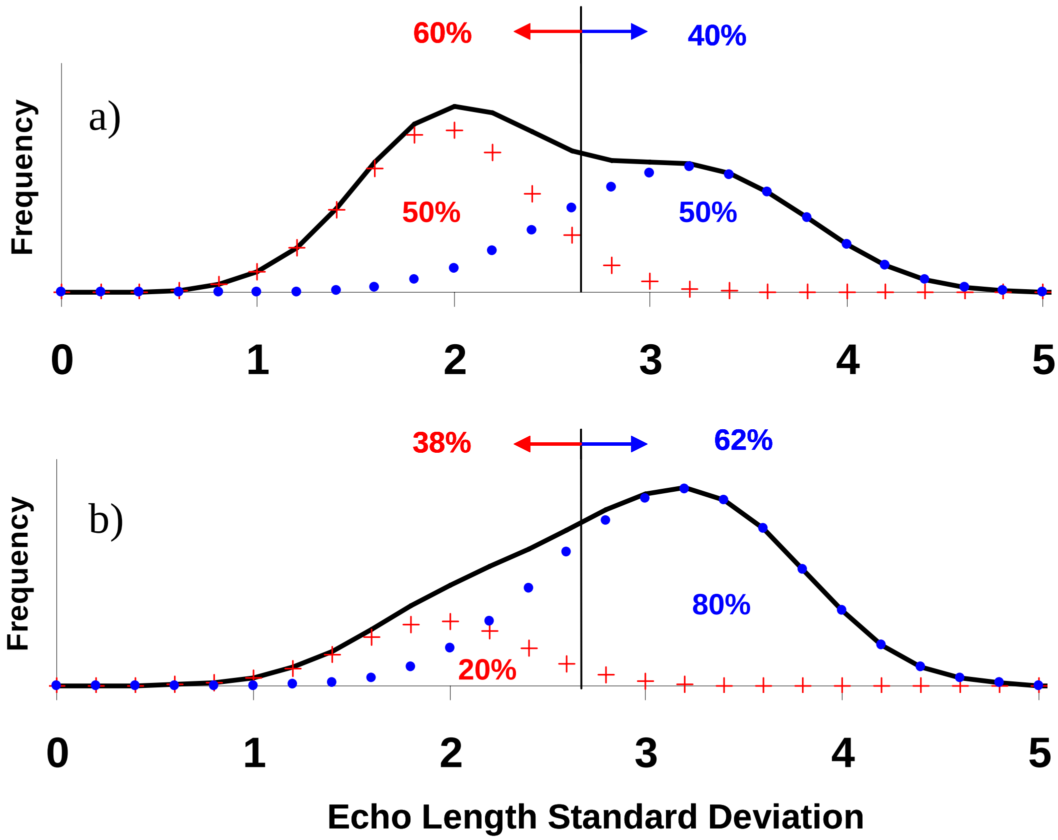

Figure I1. Threshold-based discrimination is subject to bias when discriminating variables are imprecise. Solid lines are simulated frequency distributions of echo length standard deviation arising from component distributions due to sockeye salmon (plus symbols) and Chinook salmon (solid symbols). a)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

Consequently we have developed other methods, based on mixture models, which extract information about species composition from the frequency distribution of echo length measurements. Because the mixture model approach incorporates information about fish size distributions, and because it explicitly models the expected variability in hydroacoustic measurements, it is not subject to the above pitfalls. There is no bias against extreme proportions, and the estimates are germane to the entire population of Chinook salmon, not just those Chinook larger than sockeye. Finally, as long as length and hydroacoustic measurements are paired in time, mixture model estimates of species proportions are unbiased in the presence of temporal changes in fish size distribution.

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

Methods

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

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

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 2003 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),

$$f(y) = \pi_S f_S(y) + \pi_C f_C(y) \qquad \text{(I2)}$$

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.

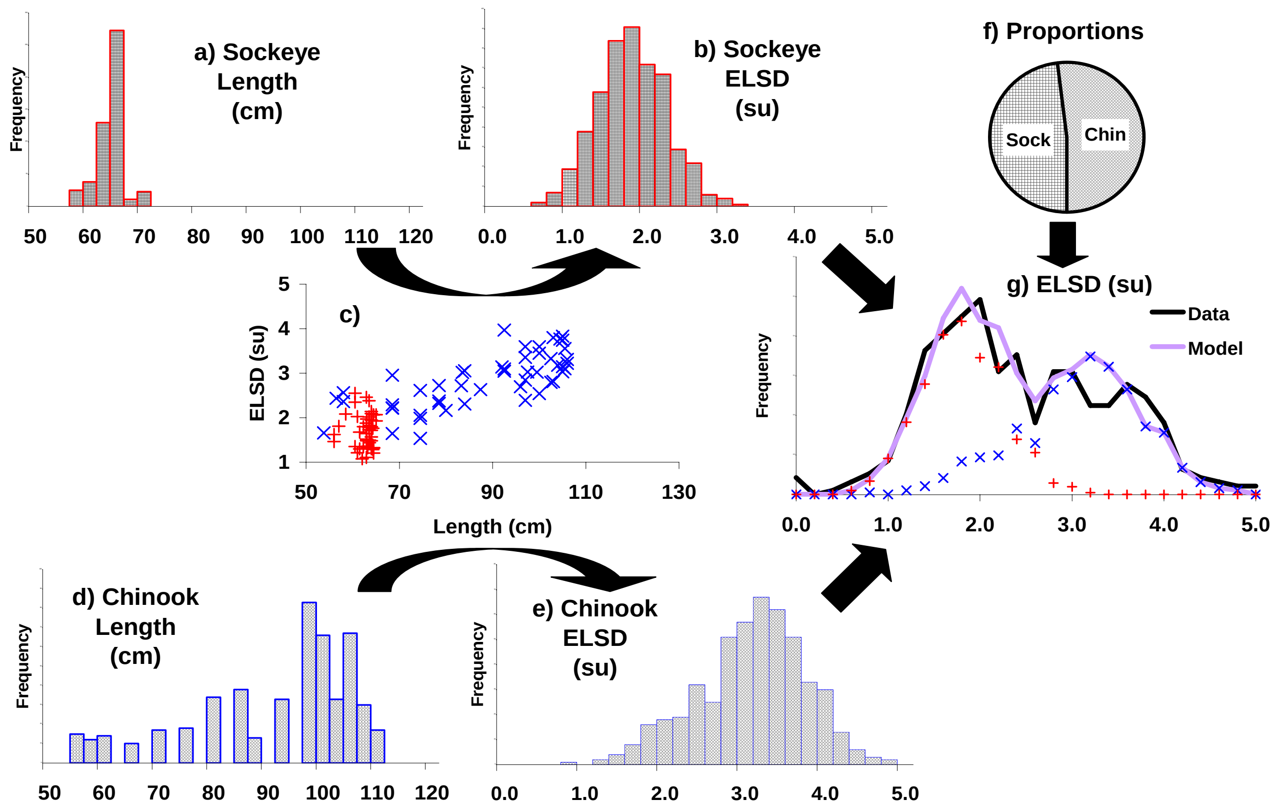

Figure I2. Flow chart of mixture model described in the text. The frequency distribution of echo length standard deviation (ELSD, panel g) is modeled as a weighted mixture of species-specific ELSD distributions (b and e), which in turn are the products of species-specific size distributions (a and d) 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.

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

$$y_i = \beta_0 + \beta_1 x_i + \gamma z_i + \varepsilon_i \qquad \text{(I3)}$$

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 2004b) 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.

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

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

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

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

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

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 16,777 (SE=615) for the early run, somewhat higher than the official estimate of 13,325 (SE=199) and the net apportioned estimate of 12,657 (SE=406). Modelled ELSD frequency distributions fit the weekly data reasonably well (Figure I3). Mixture model estimates also tracked official estimates and net-apportioned estimates fairly well (Figures I4 and 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 marginal posterior distributions of parameters estimated from a Bayesian mixture model analysis of 7 weeks of Kenai River sonar and netting data, 2003.

	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: 50 fish netted, 59 hydroacoustic targets					
β_0	2.89	0.13	2.65	2.88	3.15
β_1	0.0334	0.0030	0.0275	0.0334	0.0392
γ	-0.30	0.12	-0.54	-0.30	-0.05
σ	0.472	0.028	0.420	0.471	0.531
π_C	0.862	0.067	0.706	0.871	0.967
Week 2 Posteriors: 113 fish netted, 157 hydroacoustic targets					
β_0	2.94	0.10	2.74	2.94	3.14
β_1	0.0329	0.0029	0.0273	0.0330	0.0384
γ	-0.37	0.12	-0.61	-0.37	-0.13
σ	0.467	0.027	0.417	0.466	0.524
π_C	0.868	0.047	0.764	0.872	0.948
Week 3 Posteriors: 189 fish netted, 430 hydroacoustic targets					
β_0	2.86	0.11	2.66	2.86	3.07
β_1	0.0338	0.0030	0.0279	0.0339	0.0395
γ	-0.33	0.12	-0.57	-0.33	-0.08
σ	0.468	0.023	0.424	0.467	0.517
π_C	0.806	0.059	0.692	0.805	0.926
Week 4 Posteriors: 284 fish netted, 762 hydroacoustic targets					
β_0	2.89	0.12	2.66	2.89	3.13
β_1	0.0369	0.0033	0.0303	0.0369	0.0433
γ	-0.37	0.15	-0.64	-0.38	-0.07
σ	0.516	0.024	0.471	0.515	0.564
π_C	0.648	0.064	0.531	0.647	0.773
Week 5 Posteriors: 223 fish netted, 1188 hydroacoustic targets					
β_0	2.89	0.10	2.70	2.89	3.09
β_1	0.0344	0.0031	0.0281	0.0345	0.0402
γ	-0.30	0.14	-0.56	-0.30	-0.02
σ	0.505	0.020	0.466	0.505	0.546
π_C	0.592	0.048	0.505	0.590	0.692
Week 6 Posteriors: 192 fish netted, 1428 hydroacoustic targets					
β_0	2.85	0.12	2.66	2.83	3.13
β_1	0.0386	0.0033	0.0313	0.0390	0.0441
γ	-0.22	0.17	-0.58	-0.21	0.09
σ	0.512	0.020	0.474	0.512	0.551
π_C	0.785	0.067	0.657	0.785	0.911
Week 7 Posteriors: 93 fish netted, 739 hydroacoustic targets					
β_0	2.91	0.12	2.68	2.92	3.14
β_1	0.0338	0.0028	0.0285	0.0337	0.0393
γ	-0.38	0.14	-0.63	-0.38	-0.09
σ	0.510	0.032	0.460	0.509	0.566
π_C	0.724	0.075	0.596	0.718	0.884

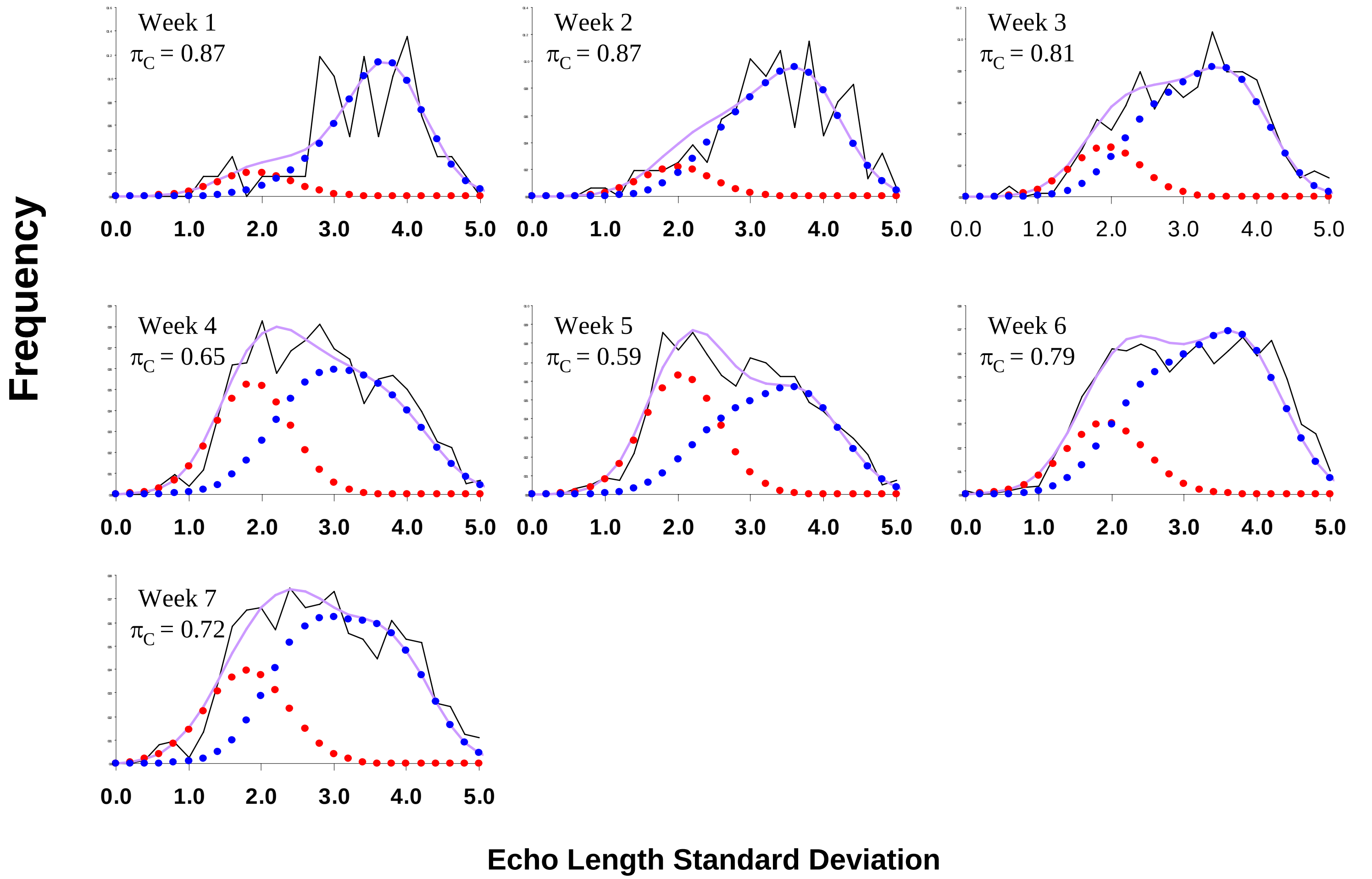

Figure I3. Observed (black) and fitted (gray) frequency distributions of echo length standard deviation (ELSD) from the 2003 early run, by week. Dotted lines are the component distributions from sockeye (left) and Chinook salmon (right). Estimated proportion of Chinook salmon pC is listed in the header of each panel.

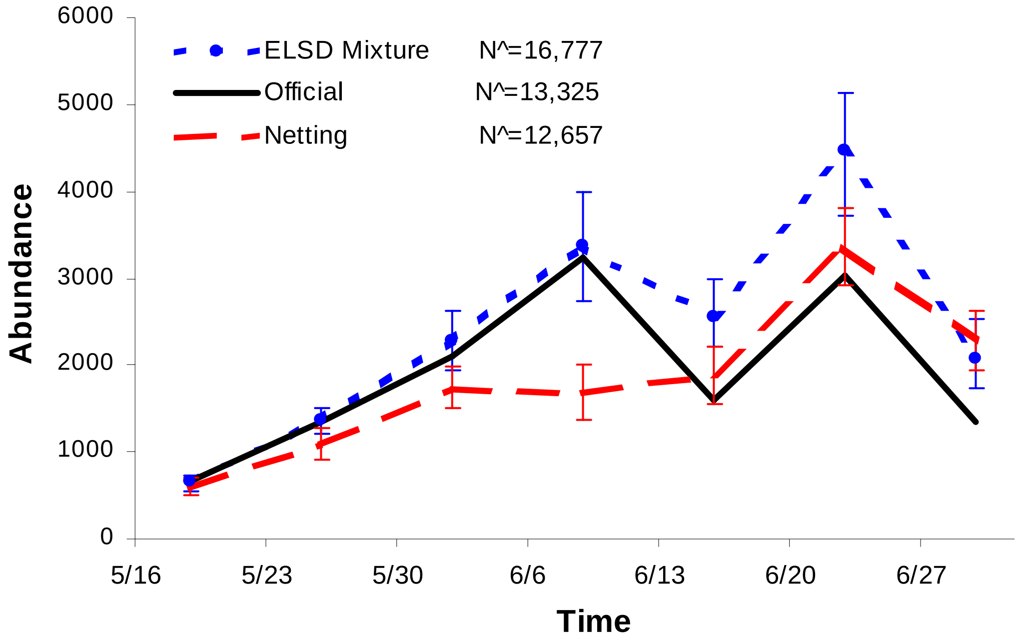

Figure I4. Weekly Chinook salmon abundance estimates for the 2003 Kenai River early run. Solid line = official estimates; dashed line = netting-apportioned estimates; dotted line = ELSD mixture model estimates. Error bars represent lower and upper 95% intervals.

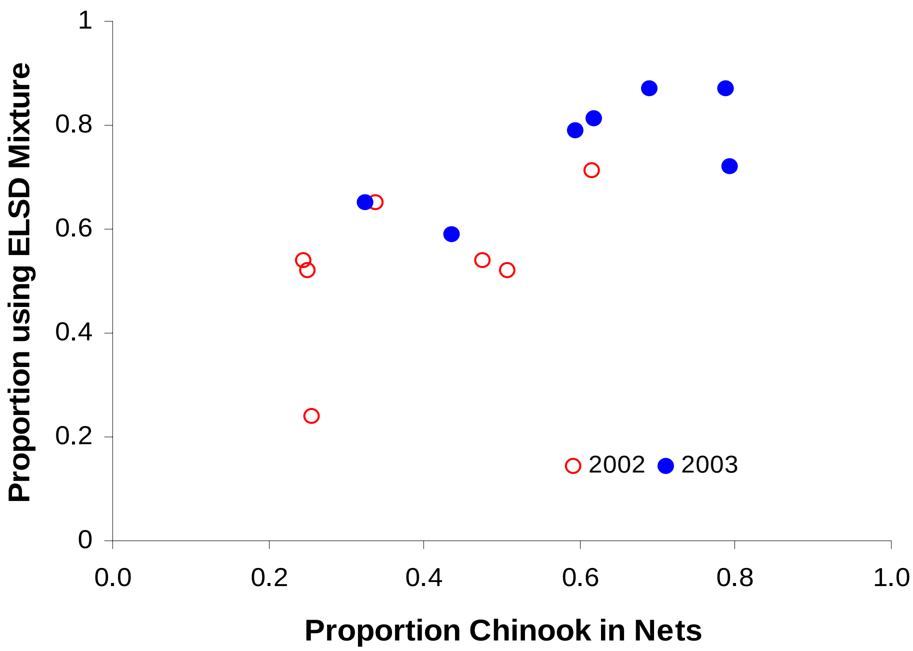

Figure I5. ELSD mixture model estimates vs net-apportioned weekly estimates of the proportion of Chinook salmon among fish passing the Kenai River sonar, early run 2002 (open symbols) and 2003 (solid).