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Estimates of Chinook Salmon Passage in the Kenai River Using Split-Beam Sonar, 2006

by

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June 2010

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
mid eye to fork	MEF
mid eye to tail fork	METF
standard length	SL
total length	TL

Mathematics, statistics

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

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ABSTRACT

Chinook salmon *Oncorhynchus tshawytscha* passage in the Kenai River in 2006 was estimated using split-beam sonar technology. Early (16 May-30 June) and late (1 July-10 August) runs of Kenai River Chinook salmon have been monitored acoustically since 1987. A 200 kHz split-beam sonar system has been used since 1995 to estimate numbers of adult Chinook salmon migrating into the Kenai River. From 1987 to 1994, a 420 kHz dual-beam sonar system was used to generate similar estimates. In 2006, the sonar project operated from 16 May through 8 August. The total estimated upstream passage of Chinook salmon in 2006 was 60,318 (SE = 657): 23,326 (SE = 394) during the early run and 36,992 (SE = 526) during the late run. Total late-run passage estimate extrapolated through the end of the run on 10 August was 37,743 (SE = 719). The standard errors associated with these estimates reflect only sampling error and not other sources of uncertainty including target detection, species composition, direction of travel, and target tracking. The early-run peak daily passage occurred on 17 June with 50% of the run having passed by 16 June. The late-run peak daily passage occurred on 16 July, with 50% of the late run having passed by 21 July.

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

INTRODUCTION

Chinook salmon *Oncorhynchus tshawytscha* returning to the Kenai River (Figure 1) support one of the largest and most intensively managed recreational fisheries in Alaska (Nelson et al. 1999). Kenai River Chinook salmon are among the largest in the world and have sustained in excess of 100,000 angler-days of fishing effort annually (Howe et al. 1995-1996, 2001a-d; Jennings et al. 2004, 2006a-b, 2007; Mills 1979-1980, 1981a-b, 1982-1994; Walker et al. 2003). The Kenai River Chinook salmon fishery has been a source of contention because of competition for a fully allocated resource among sport, commercial, subsistence, and personal use fisheries.

Chinook salmon returning to the Kenai River are managed as two distinct runs (Burger et al. 1985), early (16 May-30 June) and late (1 July-10 August). Early-run Chinook salmon are harvested primarily by sport anglers; and late-run Chinook salmon by commercial, sport, subsistence, and personal use fisheries. These fisheries may be restricted if the projected run size falls below escapement goals adopted by the Alaska Board of Fisheries (BOF). From 1989 to 1998 these runs were managed for spawning escapement goals of 9,000 for early-run and 22,300 for late-run Chinook salmon (McBride et al. 1989). In February 1999, BOF adopted revised escapement goals based on Chinook salmon passage estimated by sonar and our understanding of biases associated with the sonar (Bosch and Burwen 1999; Hammarstrom and Hasbrouck 1998, 1999). The revised escapement goals defined a range of escapement levels: 7,200 to 14,400 for early-run Chinook salmon and 17,800 to 35,700 for late-run Chinook salmon. In January 2005, based on additional brood year information, BOF lowered the early-run escapement goal range to 5,000-9,000 Chinook salmon. Escapement goal ranges (as defined by 5 AAC 56.070, Kenai River and Kasilof River Early-Run King Salmon Conservation Management Plan and 5 AAC 21.359, Kenai River Late-Run King Salmon Management Plan) are expected to provide a stable fishing season without compromising either run.

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

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

The Alaska Department of Fish and Game initiated studies in 1984 to determine whether an acoustic assessment program could provide timely and accurate daily estimates of Chinook salmon passage in the Kenai River (Eggers et al. 1995). Acoustic assessment of Chinook salmon in the Kenai River is complicated by the presence of more abundant sockeye salmon *O. nerka*, which migrate concurrently with Chinook salmon, particularly during the late run. From 1987 to 2004, sockeye salmon passage estimates generated by the river mile-19 sockeye sonar project ranged from 625,000 to 1,600,000 (Westerman and Willette 2007) while late-run Chinook salmon passage estimates generated by the Chinook sonar project at river mile 8.5 ranged from 29,000 to 55,000. Dual-beam sonar was initially chosen for the Chinook sonar project because of its ability to estimate acoustic size (target strength), which was to serve as the discriminatory variable to systematically identify and count only Chinook salmon. Because of the considerable size difference between Chinook salmon and other fish species in the Kenai River, it was postulated that dual-beam sonar could be used to distinguish Chinook salmon from smaller fish (primarily sockeye) and estimate their numbers returning to the river.

Early Kenai River sonar and gillnetting studies indicated that Chinook salmon could be distinguished from sockeye salmon based on target strength and spatial separation (Eggers et al. 1995). Sockeye salmon in the Kenai River migrate primarily near the bank and were believed to have smaller target strengths than Chinook salmon, which primarily migrate near mid channel. A target strength threshold was established to censor "counts" based on acoustic size. A range or distance 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 early- and late-run Chinook salmon returning to the Kenai River.

Daily and total acoustic estimates of early- and late-run Chinook salmon passage have been generated since 1987. Estimates of total passage made with dual beam sonar were consistently lower than the 1987-1990 mark-recapture estimates (Eggers et al. 1995). The inconsistencies between sonar and mark-recapture estimates were 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 than the dual-beam system, providing a higher (improved) signal-to-noise ratio (SNR; Simmonds and MacLennan 2005). It also interfaced with improved fish-tracking software, which reduced the interference from boat wake, and improved fish-tracking capabilities (Burwen and Bosch 1996). The split-beam system was deployed side-by-side with the dual-beam system and run concurrently for much of the 1994 season (Burwen et al. 1995). Both systems detected comparable numbers of fish. The split-beam data confirmed earlier studies showing that most fish targets 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 target strength. Modeling exercises performed by Eggers (1994) also questioned the feasibility of discriminating between Chinook and sockeye salmon using target strength. It was hypothesized that discrimination between the two species was primarily accomplished using range thresholds on the acoustic data that exploited the spatial segregation of the species (sockeye salmon migrating near shore and Chinook salmon migrating mid-river; Burwen et al. 1995; Eggers et al. 1995). In 1995, the dual-beam system was replaced with the split-beam system to take advantage of the additional information on direction of travel and spatial position of targets.

Ancillary drift gillnetting and sonar studies (Burwen et al. 1998) conducted in 1995 were directed at providing answers to questions regarding: (1) the degree to which sockeye and Chinook salmon are spatially separated at the river mile-8.5 Chinook sonar site; and (2) the utility of using target strength and other acoustic parameters for species separation. These studies confirmed the potential for misclassifying sockeye salmon as Chinook salmon. The drift gillnetting study found that sockeye salmon were present in the middle insonified portion of the river. In the concurrent sonar experiment using live fish tethered in front of the split-beam sonar, most sockeye salmon had mean target strengths exceeding the target strength threshold.

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

The inriver drift gillnetting program, originally designed to collect age, sex, and length samples (Marsh 2000), was modified in 1998 to produce standardized estimates of Chinook catch per unit effort (CPUE) for use as an index of Chinook salmon passage (Reimer et al. 2002). A drift zone was established just downstream from the sonar site and crews fished relative to the tide cycles. In addition, the schedule was intensified so that CPUE estimates could be generated daily. During subsequent years, inriver gillnet CPUE was used as a comparison with sonar passage estimates to detect periods when Chinook passage estimates were potentially high because of inclusion of sockeye or other species (Bosch and Burwen 2000, Miller et al. 2002, 2003-2005, 2007a-b; Miller and Burwen 2002).

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

In addition to developing an alternative index of Chinook abundance, we continued to pursue improved techniques for discriminating between Chinook and sockeye salmon. An investigation in 1999 (Burwen et al. 2000) attempted to identify alternative sites above tidal influence with stronger bank-orientation of sockeye salmon, where range thresholds would be more effective. The investigation concentrated on a site located at river mile 13.2 that was upstream of tidal influence, but downstream of major spawning areas. Gillnetting data indicated that there were fewer sockeye salmon in the offshore area at the alternative site than at the current site. However, there were still relatively large numbers of sockeye salmon present in the offshore area of the alternative site during peak migration periods as well as high numbers of Chinook salmon present in the nearshore area. The alternate sonar site also had several disadvantages over the current site including more boat traffic, less acoustically favorable bottom topography, and higher background noise resulting in difficult fish tracking conditions.

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

PROJECT OBJECTIVES

The primary goal of this project is to generate daily and total early- and late-run passage estimates of Chinook salmon using split-beam sonar. Specific objectives are:

1. To estimate daily and total passage of early-run Chinook salmon in the Kenai River such that the upper and lower bounds of the 95% confidence interval are within 5% of the seasonal point estimate.
2. To estimate daily and total passage of late-run Chinook salmon in the Kenai River such that the upper and lower bounds of the 95% confidence interval are within 5% of the seasonal point estimate.

METHODS

STUDY AREA

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

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

SITE DESCRIPTION

The 2006 sonar site was located 14 km (8.5 miles) from the mouth of the Kenai River (Figure 2). This site has been used since 1985 and was selected for its acoustic characteristics and its location downstream of the sport fishery and known Chinook salmon spawning habitat.

The river bottom in this area has remained stable for the past 21 years (Bosch and Burwen 1999). The slope from both banks is gradual and uniform, which allows a large proportion of the water column to be insonified without acoustic shadowing effects. On the right bank, the bottom is composed primarily of mud, providing an acoustically absorptive surface. This absorptive property improves the SNR when the beam is aimed along the river bottom. The left-bank bottom gradient is steeper and consists of more acoustically reflective small rounded cobble and gravel.

The sonar site is located downstream of the lowest suspected Chinook salmon spawning sites, yet far enough from the mouth that most of the fish counted are probably committed to the Kenai River (Alexandersdottir and Marsh 1990). Most sport fishing activity occurs upstream of the sonar site[1].

ACOUSTIC SAMPLING

A Hydroacoustic Technology Inc. (HTI) split-beam sonar system was operated from 16 May to 8[2] August 2006. Components of the system are listed in Table 1 and further described in HTI manuals (HTI 1996, 1997). A brief explanation of the theory of split-beam sonar and its use in estimating target strength can be found in Appendix A1. A more detailed explanation can be found in Ehrenberg (1983).

Sonar System Configuration

Sonar sampling on both banks was controlled by electronics housed in a tent located on the right (north) bank of the river. Communication cables were connected to the sonar equipment on both banks. Cables leading to the left-bank equipment were suspended above the river at a height that would not impede boat traffic (Figure 3). Steel tripods were used to deploy the transducers offshore. One elliptical, split-beam transducer was mounted horizontally (side-looking) on each tripod. At the start of the season the transducer tripods were placed on each bank in a position close to shore but still submerged at low tide. During sampling from 16 May to 8 August, water levels at low tide increased approximately 1.8 m. Rising water levels throughout the season and heavy debris accumulation resulted in occasional relocation of the transducer tripods. Total range insonified during the season by both (right and left bank) sonar beams ranged from approximately 58.5 m to 61.3 m (Figure 4).

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1 In 2005, approximately 98% of the early-run Chinook salmon sport fishing effort and 86% of the late-run effort occurred upstream of the Chinook salmon sonar site.

2 Sampling was terminated prior to 10 August because of numerous fish holding in the sonar beam making it difficult to accurately track fish targets. Chinook passage was estimated through 8 August and extrapolated to the end of the late run on 10 August.

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

River Bottom Profile and Sonar 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 collected with a Lowrance X-16 were paired with range measurements taken from a Bushnell Laser Ranger (±1 m accuracy) aimed at a fixed target on shore. When bottom profile information is combined with information from the attitude sensor, a detailed visualization of how the water column above the bottom substrate is insonified by the acoustic beam can be generated (Figure 5). Each time the transducer was moved, new measurements of the transducer height above the bottom substrate and its position relative to a fixed shore location were updated in an EXCEL worksheet so that beam coverage at the new location could be evaluated.

Before 2001 the right- and left-bank transducers were deployed directly across the river from each other, and complete beam coverage for the entire middle portion of the river was accomplished by extending the counting range for both banks to the thalweg. Under these conditions, we could be relatively certain that the entire middle portion of the river was insonified. In 2001, river bottom profiles indicated improved beam coverage (in the vertical plane) could be attained on the left bank by moving the transducer approximately 35 m downstream of its original location (Miller et al. 2003). The left-bank transducer has been deployed at this new location since 2001. Because of the offset deployment of the right- and left- bank transducers (Figure 3), it is difficult to determine if there is complete beam coverage to the thalweg (Miller et al. 2004).

Sonar System Calibration

HTI performed reciprocity calibrations preseason with a naval standard transducer to ensure consistent target strength parameters for among year sonar comparisons. Calibrations were verified at the facility with a standard 38.1-mm tungsten carbide sphere (Foote and MacLennan 1984) and verified at the sonar site using the same sphere on 11 May, 2 June, 10 July, and 31 July. For each standard sphere measurement, we recorded the maximum background noise level and voltage threshold in addition to the data collected automatically by the onboard signal-processing software.

Sampling Procedure

A systematic sample design (Cochran 1977) was used to estimate fish passage 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 estimate daily fish passage. The equipment was automated to sample the right bank for 20 min starting at the top of each hour followed by a

20-min left-bank sample. The system was inactive for the third 20-min period unless ancillary sonar studies were being conduct. This routine was followed 24 hours per day and 7 days per week unless a transducer on one or both banks was inoperable. A test of this sample design in 1999 found no significant difference between estimates of Chinook salmon passage obtained using 1-hour counts and estimates obtained by extrapolating 20-min counts to 1 hour (Miller et al. 2002).

Because fish passage rates are related to tides (Eggers et al. 1995), tide stage was recorded at the top of each hour and at 20 min past each hour to coincide with the start of each 20-min sample. Tide stage was recorded from a staff gauge at the sonar site using water level measured to the nearest 0.25 ft and converted to meters.

Data Collection Parameters

An HTI Model 244 digital echo sounder (DES) was used for data collection. Key data collection parameters (echo sounder settings) are listed in Table 2 with complete summaries by bank in Appendices B1 and B2. Most echo sounder settings were identical for each bank and remained consistent throughout the 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 targets and SNR.

Data Acquisition

The digital echo sounder performed the initial filtering of returned echoes based on user-selected criteria (Table 3, Appendices B1 and B2) that are input via software stored on an external data processing computer (Table 1, Figure 6). The DES recorded the start time, date, and number of pings (acoustic pulse) processed for each sample.

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

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

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

The sum channel voltage from the DES was also output to a printer, to a Nicolet 310[1] digital storage oscilloscope, and to a Harp HC2 color chart monitor. Output to the printer was filtered only by a voltage threshold, which was set equal to the DES threshold. Real-time echograms were produced for each sample. The echograms were used for data backup and transducer aiming, and to aid in manual target tracking. Voltage output to the oscilloscope and color monitor was not filtered. Monitoring the unfiltered color echogram ensured that sub-threshold targets were not being unintentionally filtered. Advanced features on the digital oscilloscope aided in performing field calibrations with a standard target and in monitoring the background noise level relative to the voltage threshold level.

FISH TRACKING AND ECHO COUNTING

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

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

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

DATA ANALYSES

Tidal and Temporal Distribution

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

Spatial Distribution

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

Fish range (z-axis) distributions (distance from shore) for each bank were plotted separately for upstream and downstream moving targets. Fish range distributions were calculated using the mean distance from transducer for each target. Before 2000, range distribution comparisons were made using z_m, the distance from the face of the transducer to the target location (Miller et al. 2002). These comparisons provided information on distribution of fish targets from the face of the transducer. However, the comparisons were poor descriptors of actual fish range distributions across the river because tripod/transducer locations change throughout the season. Beginning in 2000, estimates of distance from bank were standardized to the nearest shore transducer deployment for that bank based on distances to a fixed point (cable bipod) on the right bank (Figures 3 and 4):

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

where:

z_a = adjusted range (in meters),

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

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

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

Vertical distributions were plotted by direction of travel (up- and downstream) and tide stage. Vertical distributions were calculated from the midpoint angle off-axis[3] in the vertical plane as follows:

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

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

where:

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

y_s = starting vertical coordinate (in meters), and

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

Target Strength Distribution

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

Species Discrimination

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

Range thresholds differed by bank and over time. Range thresholds were changed when transducer tripods were moved, or when fish distribution and behavior indicated that species discrimination could be improved. The left-bank range threshold was 10 m from 16 May to 11 June and 15 m from 12 June to 8 August. The right-bank range threshold was 15 m for the entire season (Figure 4).

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

Passage Estimates

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

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

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

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

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

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

where:

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

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

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

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

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

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

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

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

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

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

$$\hat{Y} = \sum_{i} \hat{y}_i , \tag{9}$$

and

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

Late-run passage through 10 August ($\hat{Y}_e$) was estimated by dividing by the mean proportion of passage ($\overline{p}$) through 8 August for the 10 years (1987, 1988, 1990, 1992, 1993, 1995, and 1998-2001) when the sonar project operated through at least 9 August:

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

where:

$$\overline{p} = \frac{\sum_{g} p_g}{10}, \tag{12}$$

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

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

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

where:

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

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

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

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

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

[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).

The variance estimate of the alternative estimate follows Goodman (1960):

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

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

Downstream Chinook salmon passage[4] for day *i* was estimated as:

$$\hat{w}_i = \hat{y}_i \frac{\sum_j \sum_k d_{ijk}}{\sum_j \sum_k c_{ijk}}, \quad (18)$$

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

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 -39.5 dB for the right-bank transducer and −39.3 dB for the left-bank transducer (HTI 2005; Table 4). The theoretical value for the sphere is −39.5 dB (MacLennan and Simmonds 1992). During subsequent *in situ* calibration checks, mean target strength varied from −37.8 to −39.7 dB on the right bank and from −37.6 dB to −39.4 dB on the left bank (Table 4). Small fluctuations in mean target strength are expected throughout the season during *in situ* calibration checks as target strength can vary with SNR, water temperature, depth, conductivity, and other factors.

TARGET TRACKING

In 2006, 56,779 targets were manually tracked; 16,572 during the early run and 41,107 during the late run. The percentage of fish classified as Chinook[5] salmon that were moving upstream was 98% for the early run and 90% for the late run (Appendices E1 and E2). Daily upstream percentages varied from 67% to 100% during the early run and from 65% to 98% during the late run.

The number of echoes tracked per fish (filtered for range and target strength criteria) varied by run, bank, and direction of travel. Upstream moving fish averaged 68 echoes (SD = 35) per fish on the left bank during the early run and 69 echoes (SD = 40) on the right bank. Downstream moving fish averaged 60 echoes (SD = 46) on the left bank and 59 echoes (SD = 57) on the right bank. During the late run, upstream moving fish averaged 108 echoes (SD = 72) on the left bank

4 Downstream passage is reported for historical comparisons only.
5 Based on range and target strength criteria.

and 89 echoes (SD = 64) on the right bank. Downstream moving fish averaged 116 echoes (SD = 94) on the left bank and 101 echoes (SD = 96) per fish on the right bank.

TIDAL DISTRIBUTION

Upstream Chinook salmon passage during both the early run (65.4%) and late run (56.0%) occurred mostly during the falling tide (Tables 5 and 6, Figure 7). Downstream passage also occurred primarily during the falling tide for both the early (54.1%) and late (53.7%) runs.

SPATIAL DISTRIBUTION

Distribution by Bank

Chinook salmon passage during the early run was greater on the left bank than on the right bank (Table 7). Passage during the late run was greater on the right bank (Table 8).

Distribution by Range[6]

During the early run, upstream-moving Chinook salmon on the left bank were distributed throughout the insonified range, whereas downstream-moving fish were concentrated further away from the riverbank near the end of the insonified range (Figure 8). During the early run on the right bank, both upstream- and downstream-moving Chinook salmon exhibited peaks in passage near the end of the insonified range (Figure 8).

During the late run, upstream- and downstream-moving Chinook salmon on the left bank exhibited similar range distributions with peak passage at 24-25 m from the transducer (Figure 9). Right bank upstream- and downstream-moving Chinook salmon exhibited peaks near the end of the insonified range (31-32 m) with downstream-moving fish exhibiting a more pronounced peak (Figure 9).

The effect of tide stage on Chinook salmon range distribution (distance from shore) was minimal during both the early and late runs (Figures 10 and 11). On the left bank, range distribution was uniform for all tide stages. On the right bank, Chinook salmon were further from shore during falling and low tides than during rising tides (Figures 10 and 11).

Distribution by Vertical Position

Although Chinook salmon were generally bottom-oriented during both the early and late runs, vertical distribution did vary by direction of travel, tide stage, and run (Appendices F1 and F2). During the early run, 82% of the upstream moving Chinook salmon on the left bank and 62% on the right bank were on or below the acoustic axis (Figure 12). Sixty-eight percent of downstream moving Chinook salmon on the left bank and 52% on the right bank were below the acoustic axis (Figure 12). There was no difference (t = 0.68, P = 0.25) between the vertical position of upstream moving fish (mean = −0.22°, SD = 0.38, n = 4,773) and downstream moving fish (mean = −0.17°, SD = 0.56, n = 59) on the left bank. Similarly, on the right bank, no difference was found (t = 1.26, P = 0.10) between the vertical distribution of upstream moving fish (mean = −0.13°, SD = 0.39, n = 4,368) and downstream moving fish (mean = −0.08°, SD = 0.58, n = 155). On both banks, upstream moving fish were distributed slightly higher in the water column during rising tides (Figure 13).

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

Average Chinook salmon vertical position in the water column appeared higher during the late run (Figure 14 and Appendix F2). Only 36% of upstream moving Chinook salmon on the left bank and 43% on the right bank were on or below the acoustic axis. Similarly, 28% of downstream moving fish on the left bank and 43% on the right bank were on or below the acoustic axis. Upstream moving fish on the left bank (mean = 0.15°, SD = 0.35, n = 5,472) traveled lower (t = 3.58, P < 0.001) in the water column than downstream moving fish (mean = 0.21°, SD = 0.37, n = 646). There was no difference (t = 0.37, P = 0.35) between the vertical position of upstream moving fish (mean = 0.05°, SD = 0.37, n = 9,610) and downstream moving fish (mean = 0.06°, SD = 0.41, n = 928) on the right bank. Vertical distribution of upstream moving fish was slightly higher during the rising tide on both banks (Figure 15).

TARGET STRENGTH

Target strength distributions varied by bank, direction of travel, and run. Mean target strength estimates for all upstream moving targets during the early run were similar between the left and right bank (Figure 16). During the late run, right-bank mean target strength estimates for all upstream moving targets averaged approximately 1 dB higher than left-bank estimates (Figure 17). Mean target strength of all upstream and downstream moving targets varied more on the right bank than on the left bank. Figure 16 and Figure 17 show target strength and range distribution for all tracked targets.

During the early run on the left bank, mean target strength of Chinook salmon was higher (t = −2.00, P = 0.02) among upstream traveling fish than among downstream traveling fish. Mean target strength variability was similar (F = 0.94, P = 0.39; Table 9). On the right bank, mean target strength of Chinook salmon traveling upstream was higher (t = −3.27, P < 0.001) and its variability lower (F = 1.27, P = 0.02) than downstream traveling Chinook (Table 9).

During the late run on the left bank, mean target strength of Chinook salmon was slightly higher (t = 1.76, P = 0.04) among downstream traveling fish than among upstream traveling fish, as was mean target strength variability (F = 1.13, P = 0.02; Table 9). On the right bank during the late run, mean target strength of Chinook salmon was higher (t = −9.22, P < 0.001) among upstream traveling fish, as was mean target strength variability (F = 0.71, P < 0.001; Table 9).

CHINOOK SALMON PASSAGE

Daily estimates of Chinook salmon passage were generated for 16 May through 8 August. A total of 627 hours of acoustic data were processed from the right bank and 648 hours from the left bank during the 85-day season. This represented 31% of the total available sample time (on average in a 24-hour period) for the right bank and 32% for the left bank.

Estimated upstream[7] Chinook salmon passage from 16 May to 8 August 2006 was 60,318 (SE = 657), including 23,326 (SE = 394) early-run fish and 36,992 (SE = 526) late-run fish (Tables 7, 8, 10, and 11). Estimated late-run passage through the end of the run on 10 August was 37,743 (SE = 719) fish. Peak daily passage during the early run occurred on 17 June; 50% of the run passed by 16 June (Figure 18). The early run was late compared with historic mean escapement timing (Figure 18 and Appendix G1). Peak daily passage during the late run occurred on 16 July; 50% of the late run passed by 21 July (Figure 19). Timing of the late run was late compared to historic mean escapement timing (Figure 19 and Appendix G2).

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

DISCUSSION

ACCURACY OF PASSAGE ESTIMATES

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

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

In response to these shortcomings, we refined our species discrimination algorithm in 2000. Fish distribution and behavior made it evident when sockeye salmon were abundant mid-river; episodes of abundant sockeye mid-river were often discrete and short-lived. Since 2000, we have censored the data from the extrapolated 1-hour samples when sockeye were abundant mid-river and generated the Chinook passage estimate from the remaining hourly samples. This procedure has reduced the probability of grossly overestimating Chinook passage, but is somewhat subjective to implement and may increase the probability of underestimating passage. Inclusion of all available hourly samples in 2006, regardless of the presence of mid-river sockeye, would have generated an early-run Chinook passage estimate of 26,892 (SE = 494) and a late-run Chinook passage estimate through 8 August of 45,344 (SE = 766). These estimates are approximately 15% and 23% higher than the corresponding censored estimates of 23,326 and 36,992, respectively. However, uncensored estimates may overestimate Chinook salmon passage, because minimum range thresholds before 2000 were extended more frequently than they are presently.

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

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

Gillnets have been drifted near the sonar site since the 1980s to estimate age composition (Reimer et al. 2002). In 1998, gillnetting methods were standardized to produce consistent estimates of CPUE to compare within and between years as an index of Chinook salmon passage. After analyzing 1998-2000 standardized data, we concluded that gillnet CPUE is an inconsistent index of passage, because it is highly variable and is affected by river discharge and water clarity. Several changes to the gillnetting procedures were implemented in 2002: an additional mesh size (5 in) was added, nets were constructed of multi-monofilament (formerly cable-lay braided nylon), the color of the mesh was changed to more closely match that of the river, and drifts were shortened and constrained to more closely match the portion of the channel sampled by the sonar. These changes increased netting efficiency, and decreased the effect of water clarity on gillnet catches (Reimer 2004).

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

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

Early Run

The 2006 early-run standard sonar passage estimate of 23,326 Chinook salmon was above average and was the third highest early-run passage estimate recorded since sonar operations began in 1987 (Appendix G1). However, we suspect that the estimate may be somewhat high.

Sonar passage estimates and gillnet CPUE tracked each other short-term as in past years (Reimer et al. 2002), but the relationship appeared to change throughout the early run (Figure 20). For instance, Chinook salmon CPUE was low relative to the sonar from 17-24 June, but was relatively high after 26 June. River discharge and water clarity did not explain these variations (Figure 20).

Daily Chinook salmon net-apportioned estimates (product of unfiltered sonar estimates and the proportion of Chinook salmon in the gillnet catches; Equation 12) were substantially lower than the standard passage estimates throughout most of the early run (Figure 22). The early-run net-apportioned estimate is 7,456 (SE = 505) Chinook salmon, which is 68% less than the early-run standard sonar estimate of 23,326 (Appendix I1). The early-run ELSD mixture model estimate of 15,738 (SE = 604) Chinook salmon is also substantially (33%) lower than the standard estimate (Appendix H).

Mixture model estimates were lower than standard estimates from 16 May through 21 June, at which time the mixture model estimates began to exceed the standard estimates. As in previous years, the ELSD mixture and net-apportioned estimators were consistent with each other (Figure H3); in both cases passage rates generally increased throughout the early run (Figure H5). Unlike previous years, the net-apportioned and ELSD mixture model estimates diverged widely from the standard sonar estimates during the early run. For instance, a temporary upswing in the standard estimates around 1 June was not evident in the gillnetting estimates (Figure H5). Also, a major peak in standard estimates in mid-June was not reflected in either the gillnetting or the ELSD mixture model estimates (Figure H5).

Based on gillnet CPUE estimates, sockeye salmon were present at the sonar site throughout June, with the highest sockeye salmon CPUE estimates observed in mid-June (Figure 23).

The above comparisons suggest that the standard sonar estimator may have misclassified sockeye salmon as Chinook during much of mid-June, probably resulting in an overestimate of Chinook salmon passage for the early run.

Late Run

The 2006 late-run passage estimate of 36,992 Chinook salmon through 8 August was below average (Appendix G2).

Sockeye salmon gillnet CPUE and river mile-19 sockeye salmon sonar estimates (Figure 21) both indicate the presence of sockeye salmon at the Chinook salmon sonar site during the late run, but differ on when the majority of sockeye salmon were present. Gillnet CPUE data suggests that peaks in daily sockeye salmon passage occurred at the Chinook salmon sonar site during the first half of July, while the river mile-19 estimates showed relatively low sockeye salmon passage until the last 2 weeks of July and into August.

Net-apportioned sonar estimates tracked the standard sonar estimates closely during the late run, and in contrast to the early run, were consistently higher than the standard estimates (Figure 22; Appendix I2). The cumulative net-apportioned estimate of 52,753 (SE = 1,596) Chinook salmon in 2006 was 43% higher than the standard sonar estimate.

This was the fourth consecutive year that the net-apportioned estimate was substantially higher than the standard estimate. In 2003, the net-apportioned estimate was 48% higher; in 2004, it was 43% higher; and in 2005 it was 112% higher (Miller et al. 2005, 2007a-b). We cannot explain why the net-apportioned estimates are lower than the standard and ELSD mixture model estimates in the early run, yet higher than the standard estimates in the late run. For this reason we are reluctant to base conclusions about the absolute size of either run on the net-apportioned estimates alone.

OUTLOOK

Since the late 1990s, it is evident that species discrimination based on target strength is the weak link in our ability to accurately estimate Chinook salmon passage in the Kenai River. As in 2005, the net-apportioned and ELSD mixture model estimates were lower than the standard sonar estimate for the early run, and higher than the standard sonar estimate for the late run.

Although counterintuitive, this suggests that the potential for misclassifying sockeye salmon as Chinook salmon using the standard sonar estimate may sometimes be greatest in the early run.

The ELSD mixture model estimates, which are often intermediate between the standard sonar and net-apportioned estimates, are arguably the most reasonable. We produced ELSD mixture model estimates only for the early run because, with high densities of fish during the late run, ELSD measurements may be biased high due to interference from nearby fish (closely spaced fish can result in corrupted ELSD measurements). We continue to investigate ways to quantify or circumvent this bias, using experimental paired split-beam and DIDSON data collected in 2005 (Burwen et al. 2007a). Currently, we produce daily ELSD mixture model estimates for the late run, but they are experimental and for comparative purposes only.

Finally, progress continues in evaluating the potential for using DIDSON imaging sonar technology for counting Chinook salmon in the Kenai River. The standard DIDSON has improved detection capabilities over split-beam sonar and provides sufficient image resolution out to 12 m that is potentially useful for discriminating larger Chinook salmon from smaller salmon species (Burwen et al. 2007a; Maxwell and Goves 2004). However, high resolution images that provide accurate length measurements at ranges to at least 30 m would be necessary to estimate Chinook salmon abundance in the Kenai River. A newly developed large-lens attachment that effectively doubles the resolution of the current DIDSON lens system will be available in 2007. Studies are planned in 2007 to determine if sufficiently accurate and precise estimates of fish length can be obtained at distances to 30 m using this new prototype lens attachment on a DIDSON long-range system.

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TABLES

Table 1.-Main components of the split-beam sonar system used in 2006.

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^{o}x10.2^{o} Right Bank: nominal beam widths: 2.8^{o}x10.0^{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.

Table 2.-HTI model 244 digital echo sounder settings used in 2006.

Echo Sounder Parameters	Value
Transmit Power	25 dB
System Gain (G_r)	-18 dB
TVG	$40\log_{10}R$
Transmitted Pulse Width	0.20 msec
Ping Rate Right Bank	11 pings/sec
Ping Rate Left Bank	16 pings/sec

Table 3.-Echo acceptance criteria for digital echo processing, 2006.

Bank	Pulse width[a] (ms) at -6 dB	Vertical angle off-axis (°)	Horizontal angle off-axis(°)	Threshold mV (dB)	Minimum range (m)
Right					
16 May-5 Aug	0.04 to 10.0	-2.5 to 2.0	-5.0 to 5.0	734 (-35 dB)	2.0
Left					
16 May-5 Aug	0.04 to 10.0	-2.5 to 2.0	-5.0 to 5.0	424 (-35 dB)	2.0

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

Table 4.-Results of 2006 *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]	22-Nov-05	-39.5	0.52	997	6.1	N/A[b]	N/A[b]
Kenai River	11-May-06	-37.8	1.18	1,494	12.1	100	150
Kenai River	2-Jun-06	-38.0	2.48	1,611	14.2	200	250
Kenai River	10-Jul-06	-39.3	0.86	1,995	9.2	100	120
Kenai River	31-Jul-06	-39.7	0.84	717	11.0	150	160
Left Bank							
HTI[a]	22-Nov-05	-39.3	0.57	997	6.1	N/A[b]	N/A[b]
Kenai River	11-May-06	-37.6	1.82	811	11.9	75	120
Kenai River	2-Jun-06	-39.3	1.66	3,818	16.4	75	100
Kenai River	10-Jul-06	-39.4	0.65	2,561	9.0	25	45
Kenai River	31-Jul-06	-39.3	2.81	938	20.1	70	75

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

b Not available or not applicable.

Table 5.-Chinook salmon passage estimates by tide stage and direction of travel for the 2006 early run (16 May-30 June).

2006 Early run	Total number of fish	Rising	Falling	Low
Upstream	23,326	3,149	15,253	4,924
Row %	100.0%	13.5%	65.4%	21.1%
Column %	97.7%	95.9%	98.1%	97.6%
Downstream	554	136	300	119
Row %	100.0%	24.5%	54.1%	21.4%
Column %	2.3%	4.1%	1.9%	2.4%

Test for Independence: chi-square = 58.17, df = 2, $P < 0.0001$

Table 6.-Chinook salmon passage estimates by tide stage and direction of travel for the 2006 late run (1 July-8 August).

2006 Late run	Total number of fish	Rising	Falling	Low
Upstream	36,992	10,036	20,704	6,252
Row %	100.0%	27.1%	56.0%	16.9%
Column %	90.3%	91.1%	90.6%	87.8%
Downstream	3,989	982	2,142	865
Row %	100.0%	24.6%	53.7%	21.7%
Column %	9.7%	8.9%	9.4%	12.2%

Test for Independence: chi-square = 59.37, df = 2, $P < 0.0001$

Table 7.-Chinook salmon passage estimates by river bank and direction of travel for the 2006 early run (16 May-30 June).

	Estimate of upstream component		Estimate of downstream component		Estimate of total fish passage[a]	
Bank	Number	Percent	Number	Percent	Number	Percent
Right	9,863	42%	380	69%	10,243	43%
Left	13,463	58%	174	31%	13,637	57%
Total	23,326	100%	554	100%	23,880	100%

[a] Total passage (upstream component plus downstream component) is provided to maintain comparability between recent (1998-2006) 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.-Chinook salmon passage estimates by river bank and direction of travel for the 2006 late run (1 July-8 August).

	Estimate of upstream component		Estimate of downstream component		Estimate of total fish passage[a]	
Bank	Number	Percent	Number	Percent	Number	Percent
Right	22,315	60%	2,270	57%	24,585	60%
Left	14,677	40%	1,719	43%	16,396	40%
Total	36,992	100%	3,989	100%	40,981	100%

[a] Total passage (upstream component plus downstream component) is provided to maintain comparability between recent (1998-2006) fish passage estimates derived from split-beam sonar and composed of only upstream targets, and past estimates generated by split-beam (1995-1997) and dual-beam (1987-1994) sonar and composed of both upstream and downstream targets.

Table 9.-Mean target strength (dB) for upstream and downstream moving targets (Chinook salmon only) by riverbank during the early (16 May-30 June) and late (1 July-8 August) runs, 2006.

Location	Upstream mean target strength (dB)	SD	*N*	Downstream mean target strength (dB)	SD	*N*
Early Run						
Left Bank	-25.92	1.30	4,773	-26.26	1.26	59
Right Bank	-25.27	1.79	4,368	-25.81	2.01	155
Late Run						
Left Bank	-26.01	1.47	5,472	-25.90	1.57	646
Right Bank	-25.36	1.93	9,610	-25.88	1.63	928

Table 10.-Daily upstream Chinook salmon passage estimates, Kenai River sonar, early run, 2006.

Date	Left Bank	Right Bank	Daily Total	Cumulative Total
16-May	25	15	40	40
17-May	15	15	30	70
18-May	22	17	39	109
19-May	36	30	66	175
20-May	33	24	57	232
21-May	33	15	48	280
22-May	39	33	72	352
23-May	33	18	51	403
24-May	45	24	69	472
25-May	69	27	96	568
26-May	66	15	81	649
27-May	96	56	152	801
28-May	78	57	135	936
29-May	155	87	242	1,178
30-May	254	147	401	1,579
31-May	304	165	469	2,048
1-Jun	511	309	820	2,868
2-Jun	397	305	702	3,570
3-Jun	247	87	334	3,904
4-Jun	235	91	326	4,230
5-Jun	179	52	231	4,461
6-Jun	201	96	297	4,758
7-Jun	214	129	343	5,101
8-Jun	246	111	357	5,458
9-Jun	371	124	495	5,953
10-Jun	493	191	684	6,637
11-Jun	553	279	832	7,469
12-Jun	362	365	727	8,196
13-Jun	416	419	835	9,031
14-Jun	308	380	688	9,719
15-Jun	530	666	1,196	10,915
16-Jun	592	507	1,099	12,014
17-Jun	892	838	1,730	13,744
18-Jun	684	483	1,167	14,911
19-Jun	547	354	901	15,812
20-Jun	531	515	1,046	16,858
21-Jun	325	287	612	17,470
22-Jun	451	346	797	18,267
23-Jun	441	216	657	18,924
24-Jun	480	283	763	19,687
25-Jun	390	172	562	20,249
26-Jun	232	137	369	20,618
27-Jun	279	274	553	21,171
28-Jun	298	280	578	21,749
29-Jun	434	439	873	22,622
30-Jun	321	383	704	23,326
Total	13,463	9,863	23,326	

Table 11.-Daily upstream Chinook salmon passage estimates, Kenai River sonar, late run, 2006.

Date	Left Bank	Right Bank	Daily Total	Cumulative Total
1-Jul	253	327	580	580
2-Jul	157	186	343	923
3-Jul	111	158	269	1,192
4-Jul	419	425	844	2,036
5-Jul	489	464	953	2,989
6-Jul	366	352	718	3,707
7-Jul	321	507	828	4,535
8-Jul	419	850	1,269	5,804
9-Jul	300	514	814	6,618
10-Jul	179	267	446	7,064
11-Jul	106	204	310	7,374
12-Jul	142	289	431	7,805
13-Jul	150	226	376	8,181
14-Jul	224	420	644	8,825
15-Jul	499	1,426	1,925	10,750
16-Jul	594	1,672	2,266	13,016
17-Jul	439	677	1,116	14,132
18-Jul	394	813	1,207	15,339
19-Jul	416	891	1,307	16,646
20-Jul	555	1,020	1,575	18,221
21-Jul	416	843	1,259	19,480
22-Jul	441	576	1,017	20,497
23-Jul	500	433	933	21,430
24-Jul	297	342	639	22,069
25-Jul	312	646	958	23,027
26-Jul	346	528	874	23,901
27-Jul	422	651	1,073	24,974
28-Jul	484	807	1,291	26,265
29-Jul	571	1,031	1,602	27,867
30-Jul	513	712	1,225	29,092
31-Jul	290	472	762	29,854
1-Aug	344	325	669	30,523
2-Aug	288	317	605	31,128
3-Aug	291	285	576	31,704
4-Aug	420	349	769	32,473
5-Aug	749	883	1,632	34,105
6-Aug	487	425	912	35,017
7-Aug	445	435	880	35,897
8-Aug	528	567	1,095	36,992
9-Aug	-	-	444[a]	37,436
10-Aug	-	-	307[a]	37,743
Total	-	-	37,743	

[a] Counting operations were terminated on 8 August due to numerous fish holding in the beam and hampering our ability to accurately track targets. Daily passage for 9-10 August was estimated using total passage through 8 August and the mean proportion of passage from 9-10 August for years 1987, 1988, 1990, 1992, 1993, 1995, and 1998-2001.

FIGURES

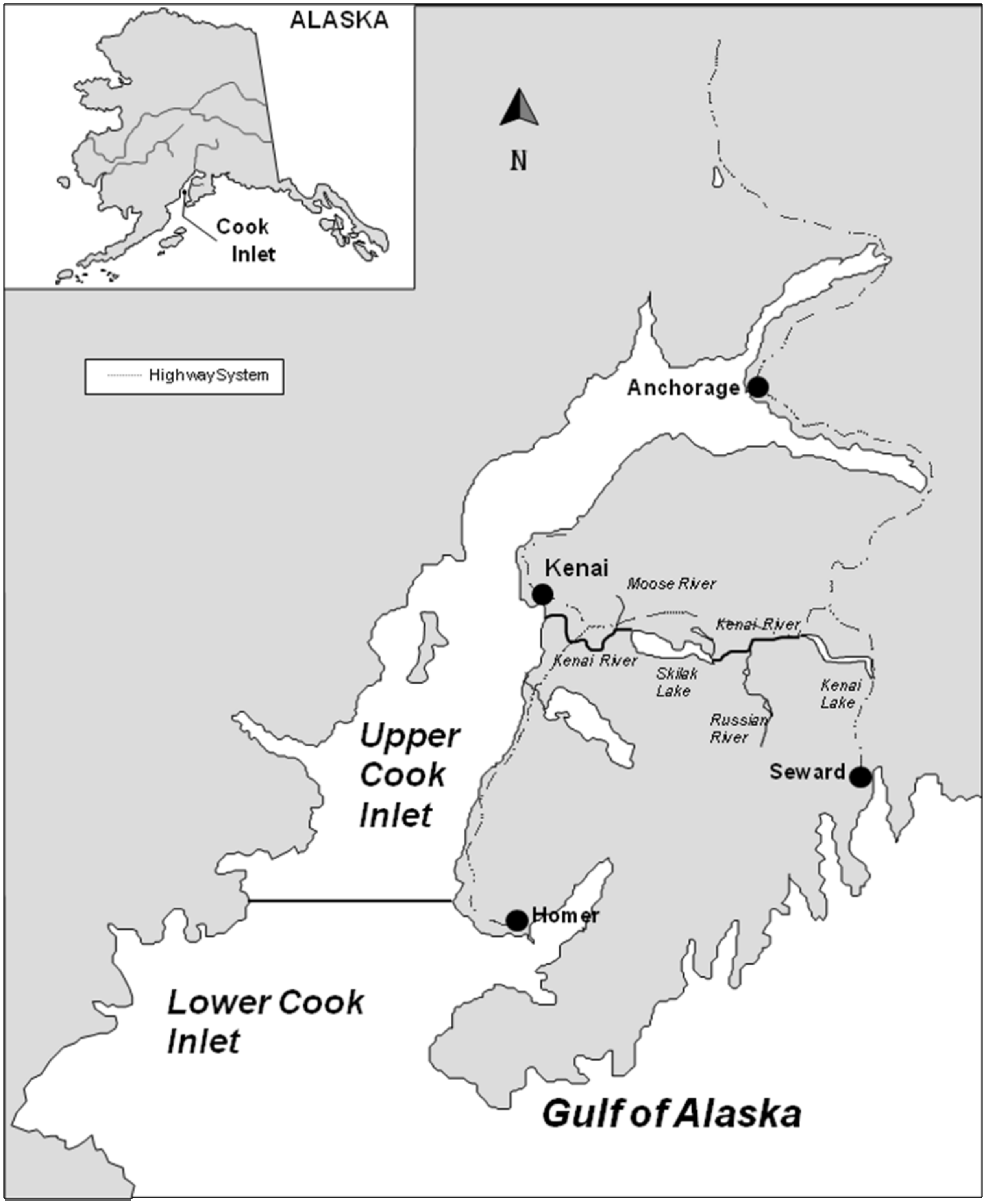


Figure 1.-Cook Inlet showing location of Kenai River.

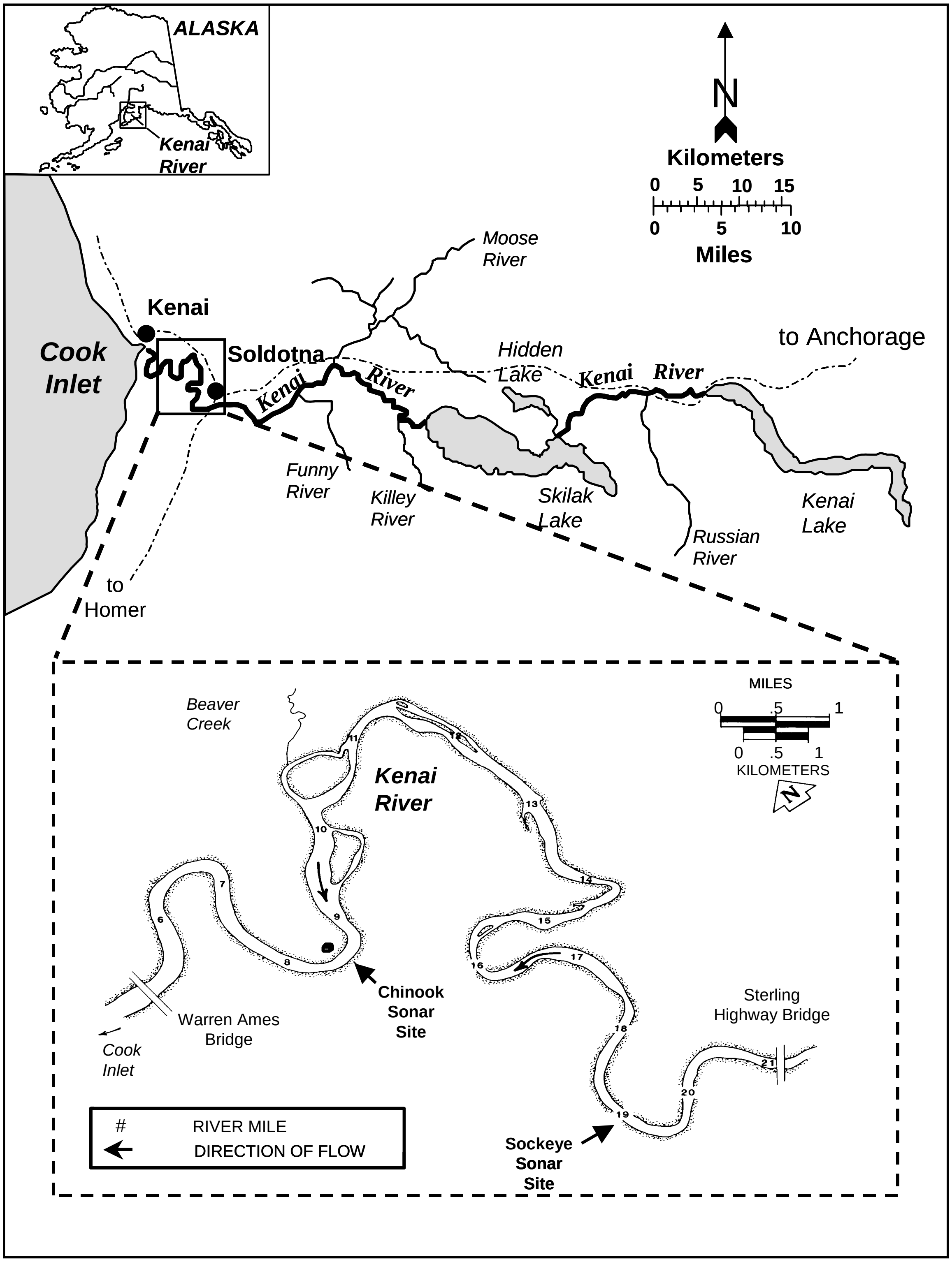


Figure 2.-Kenai River sonar site locations, 2006.

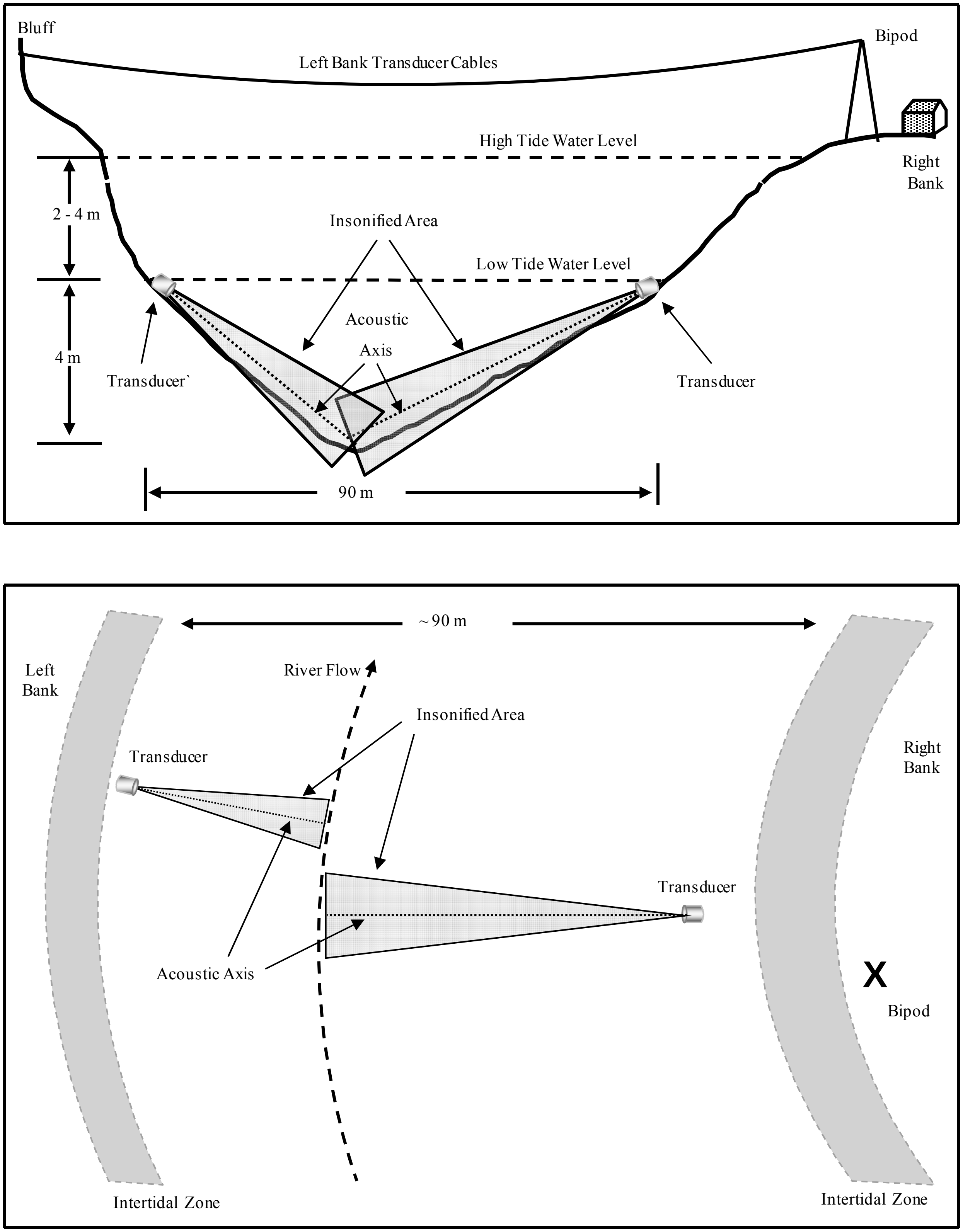


Figure 3.-Cross-sectional (top) and aerial (bottom) diagrams of sonar site illustrating insonified portions of the Kenai River, 2006.

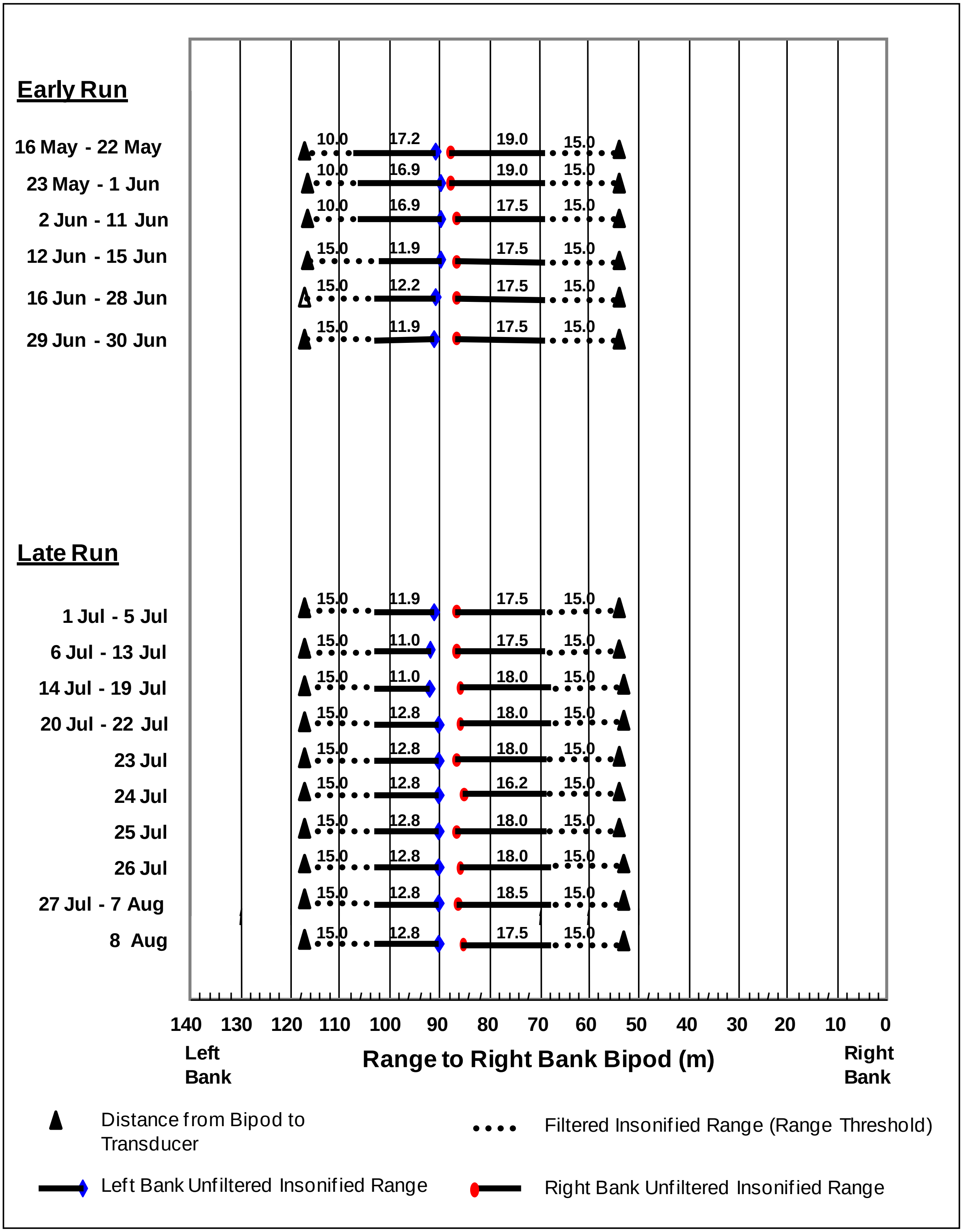


Figure 4.-Daily right- and left-bank transducer placement and insonified ranges relative to bipod tower located on the right bank, Kenai River, 2006. Distance from bipod to thalweg is approximately 88 m.

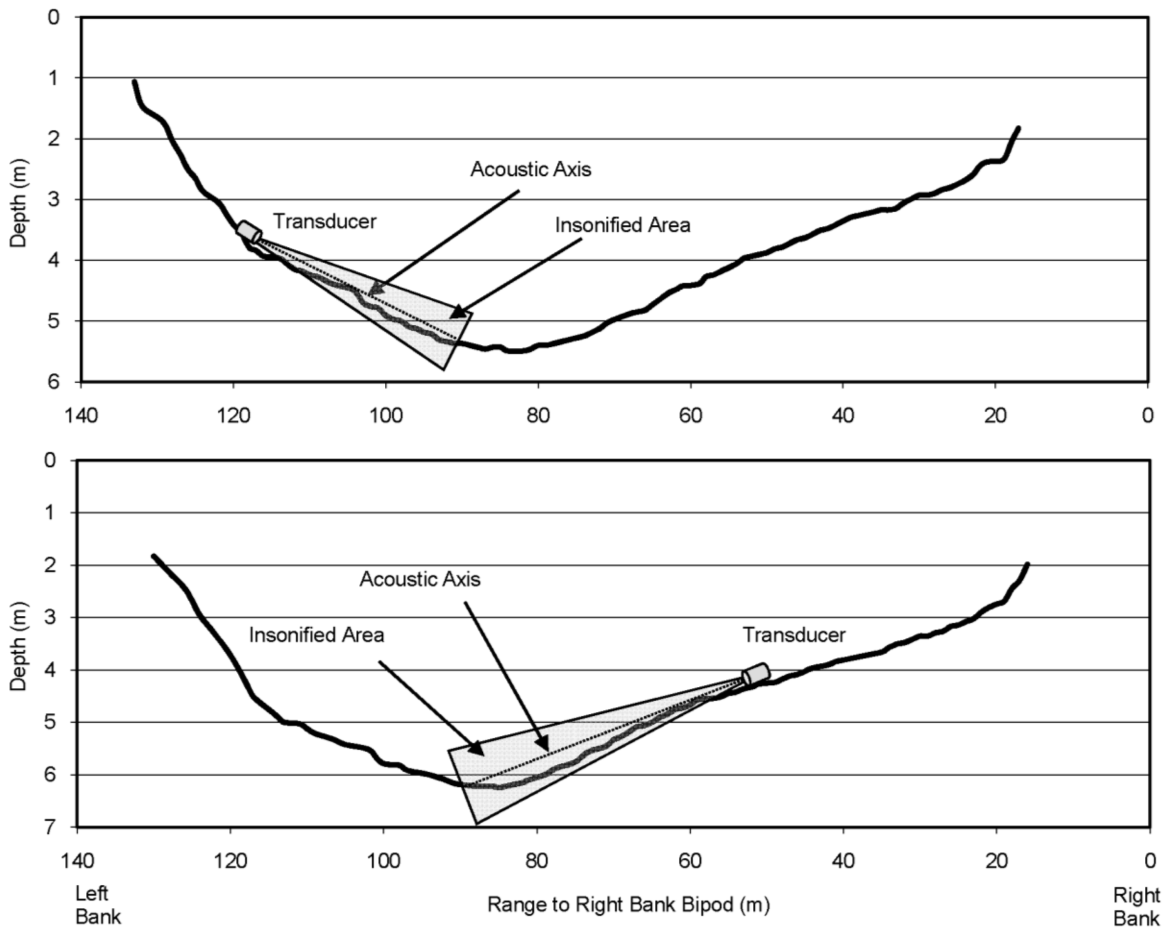


Figure 5.-Bottom profiles by bank for the Kenai River Chinook sonar site with approximate transducer placement and sonar beam coverage for 16 May 2006.

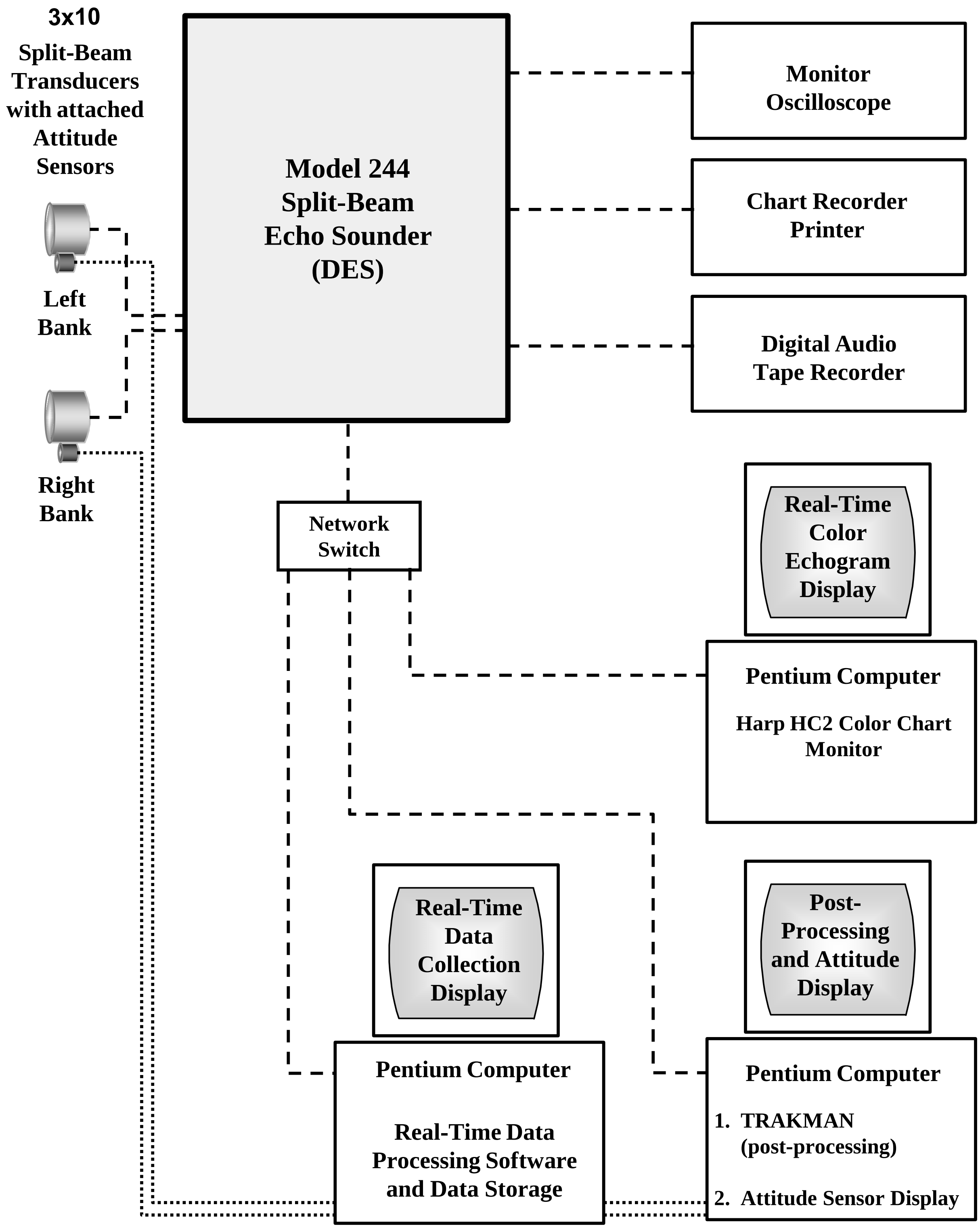
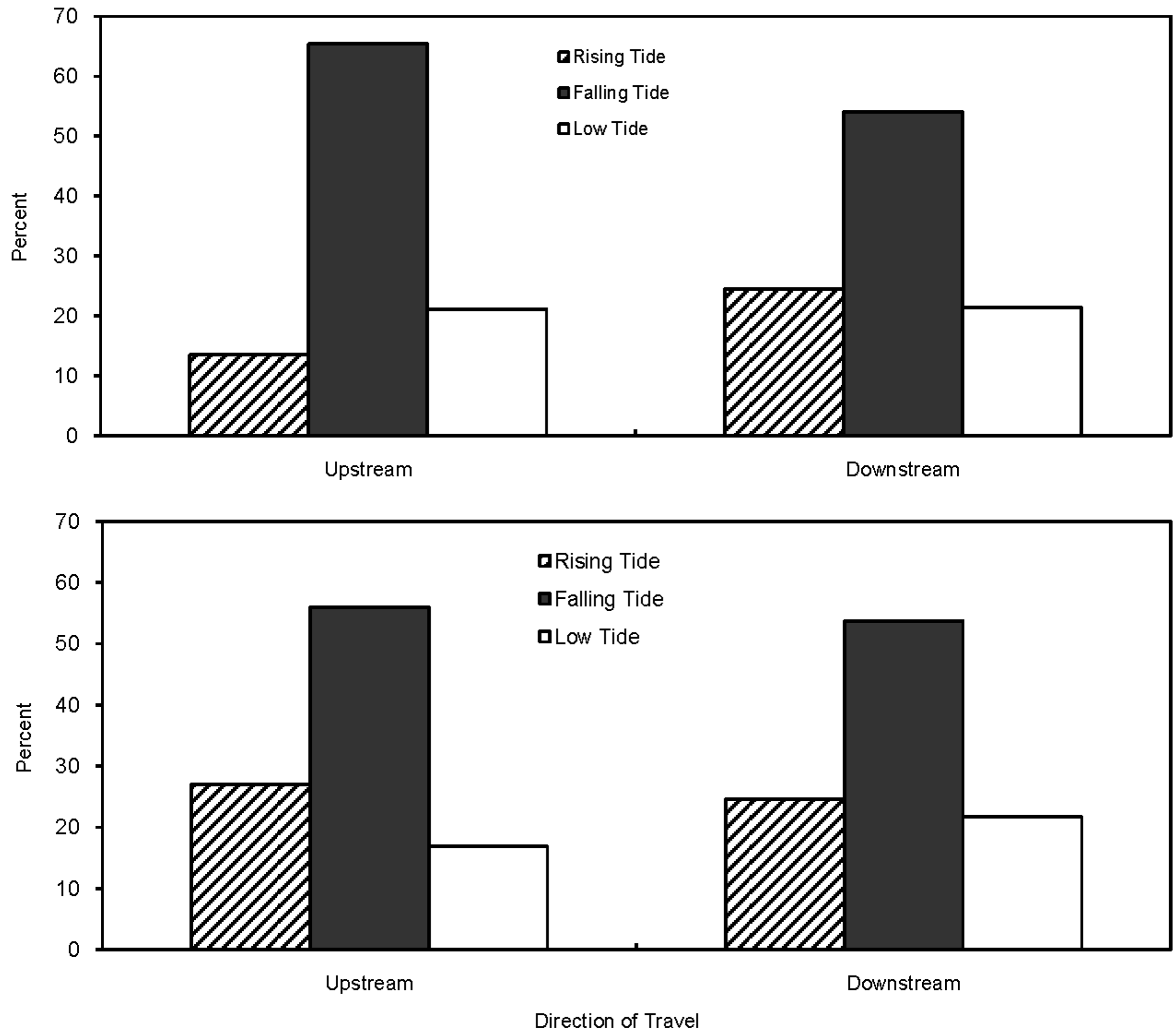
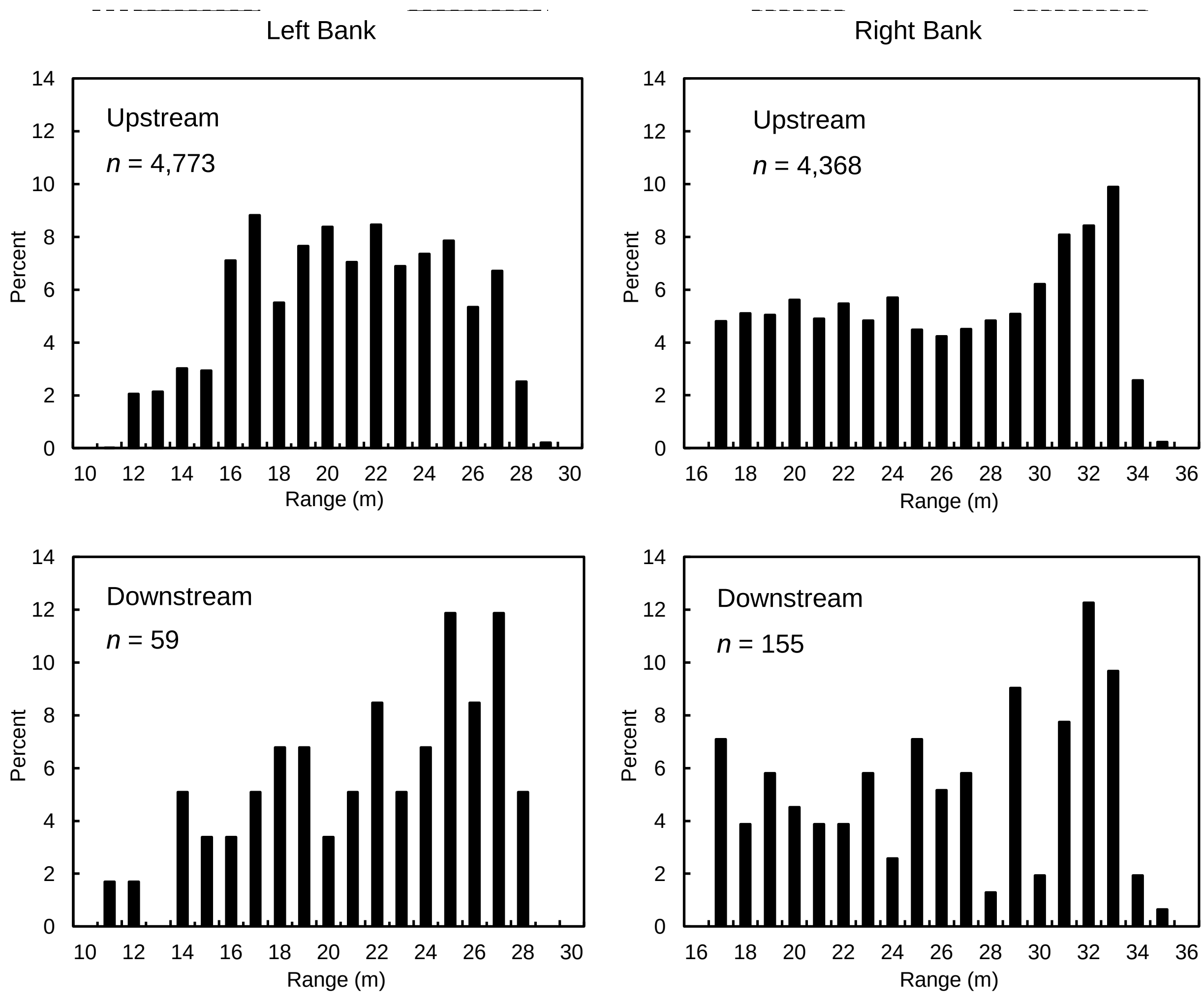


Figure 6.-Diagram of 2006 split-beam sonar system configuration and data flow.



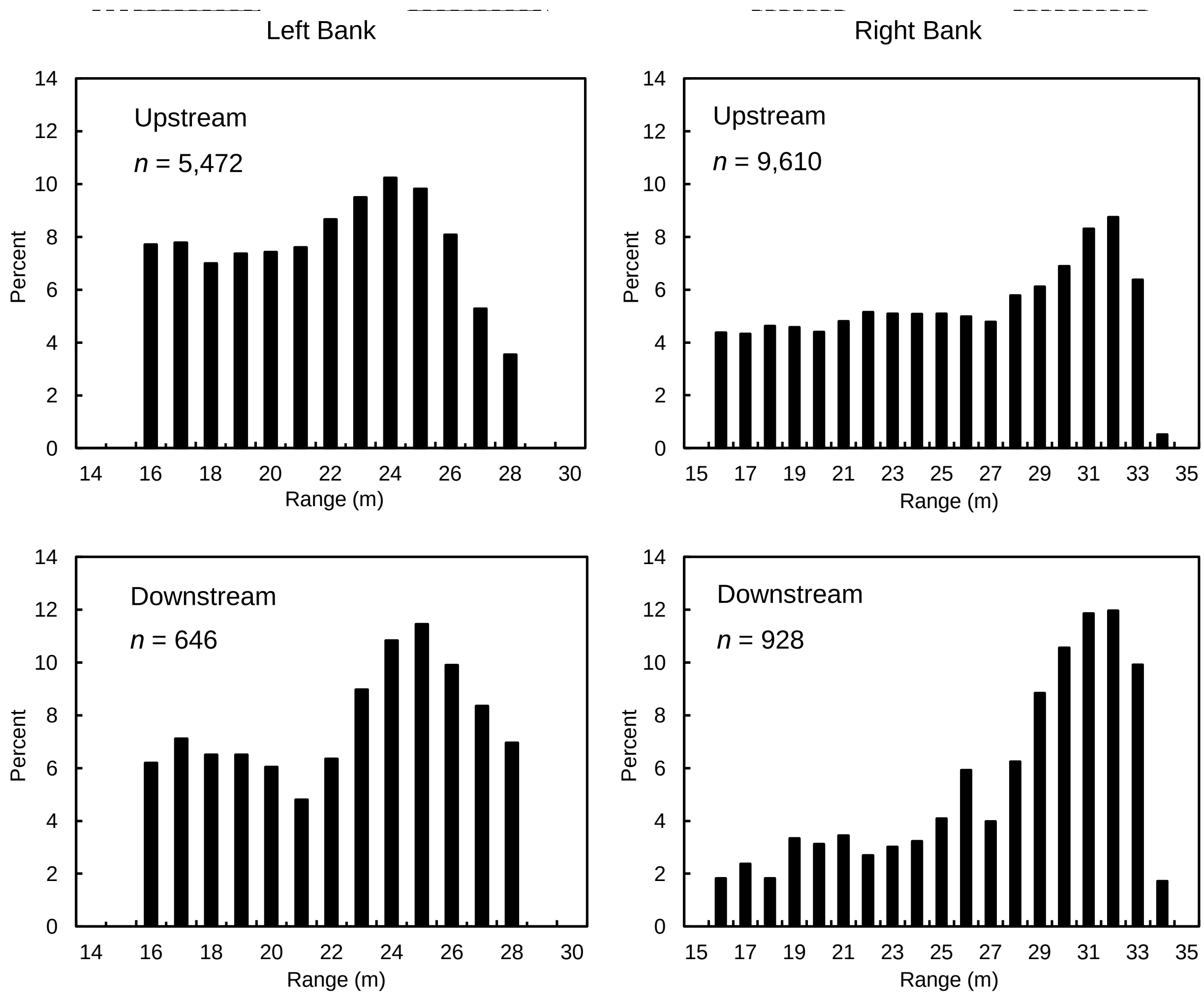
Note: Data have been filtered by range (distance from transducer) and target strength criteria.

Figure 7.-Percentage of upstream and downstream moving Chinook salmon by tide stage during the early (top) and late (bottom) runs, Kenai River, 2006.



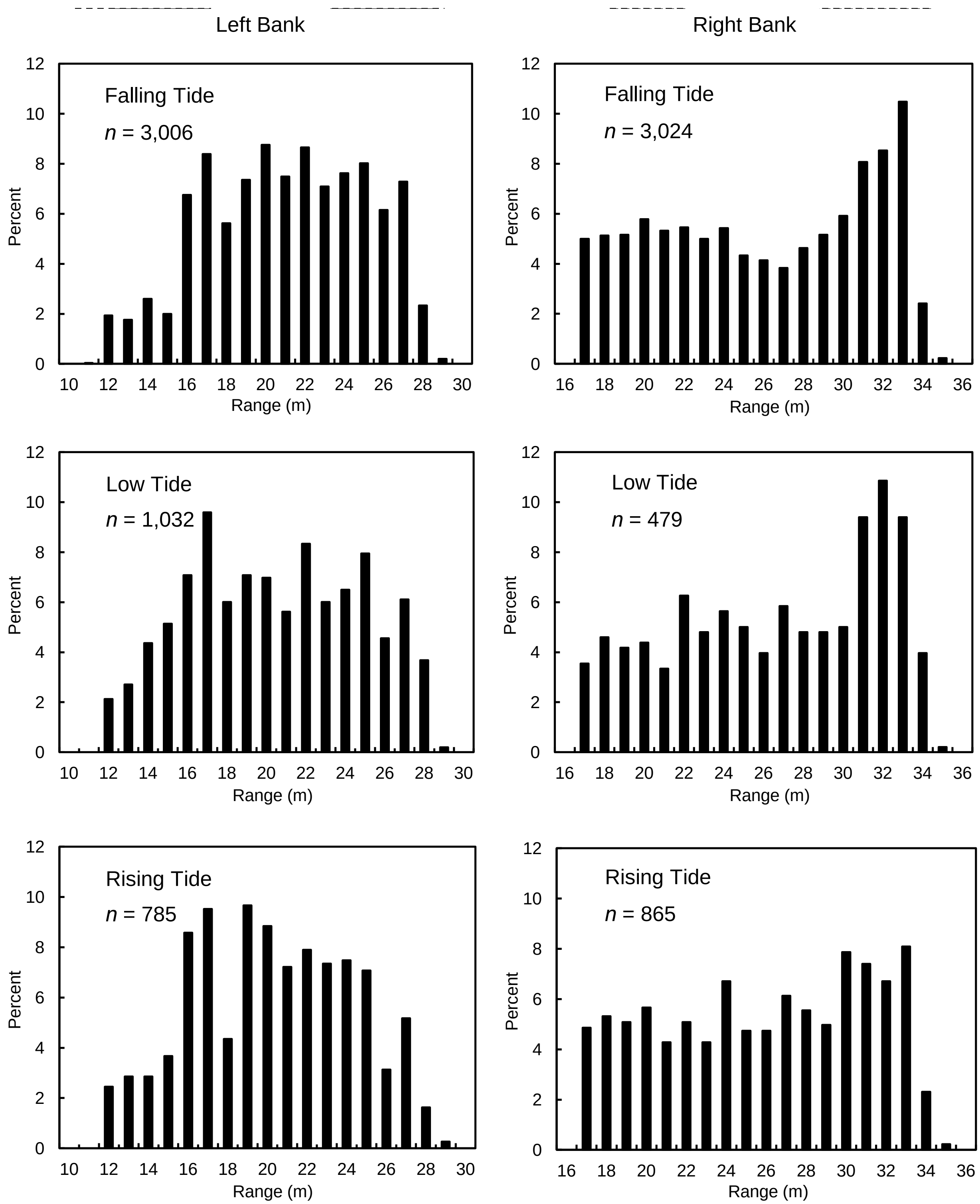
Note: Data have been filtered by range (distance from transducer) and target strength criteria.

Figure 8.-Standardized distance from transducer of early-run upstream and downstream moving Chinook salmon by bank, Kenai River, 2006.



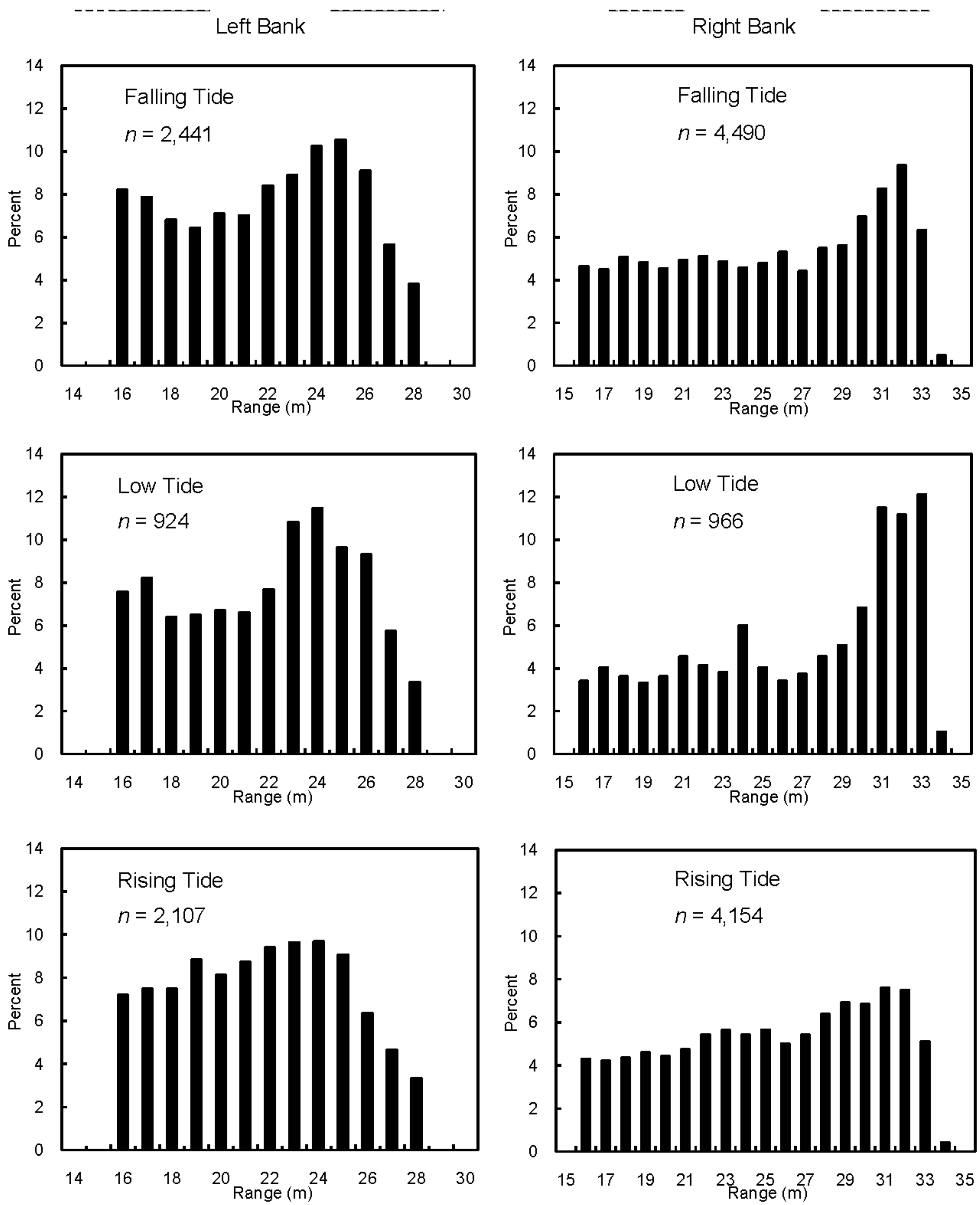
Note: Data have been filtered by range (distance from transducer) and target strength criteria.

Figure 9.-Standardized distance from transducer of late-run upstream and downstream moving Chinook salmon by bank, Kenai River, 2006.



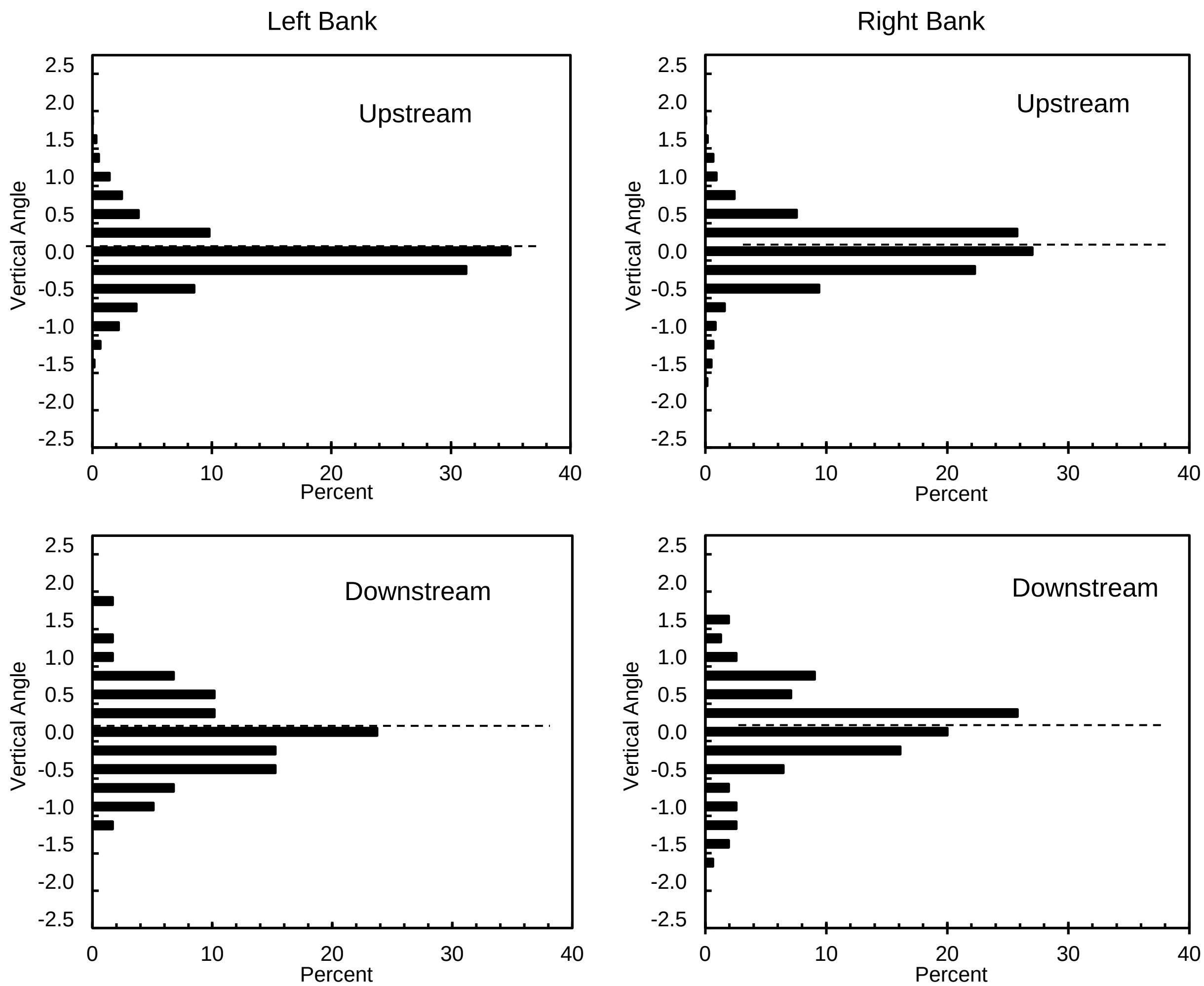
Note: Data have been filtered by range (distance from transducer) and target strength criteria.

Figure 10.-Standardized distance from transducer of early-run upstream moving Chinook salmon by tide stage and bank, Kenai River, 2006.



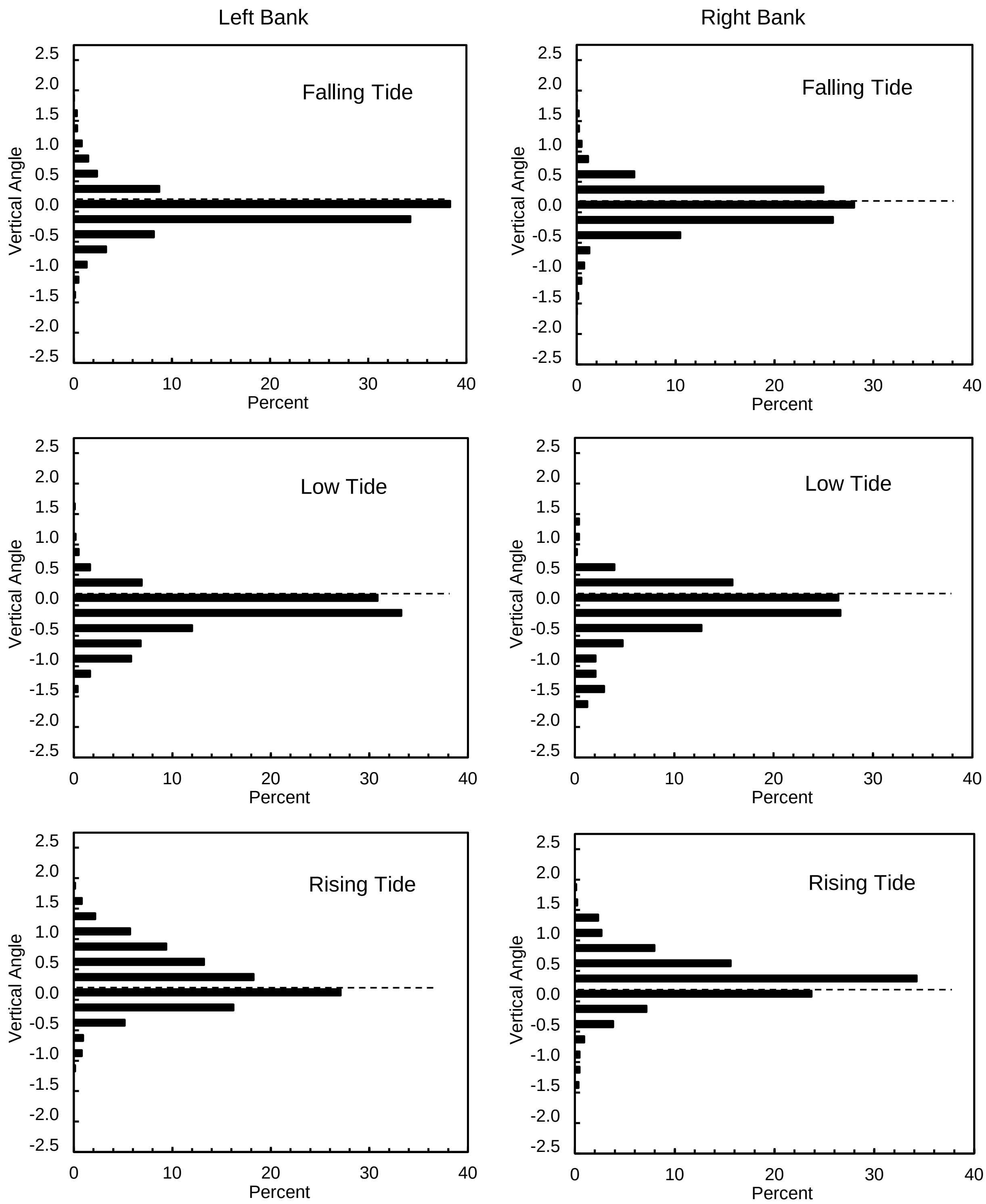
Note: Data have been filtered by range (distance from transducer) and target strength criteria.

Figure 11.-Standardized distance from transducer of late-run upstream moving Chinook salmon by tide stage and bank, Kenai River, 2006.



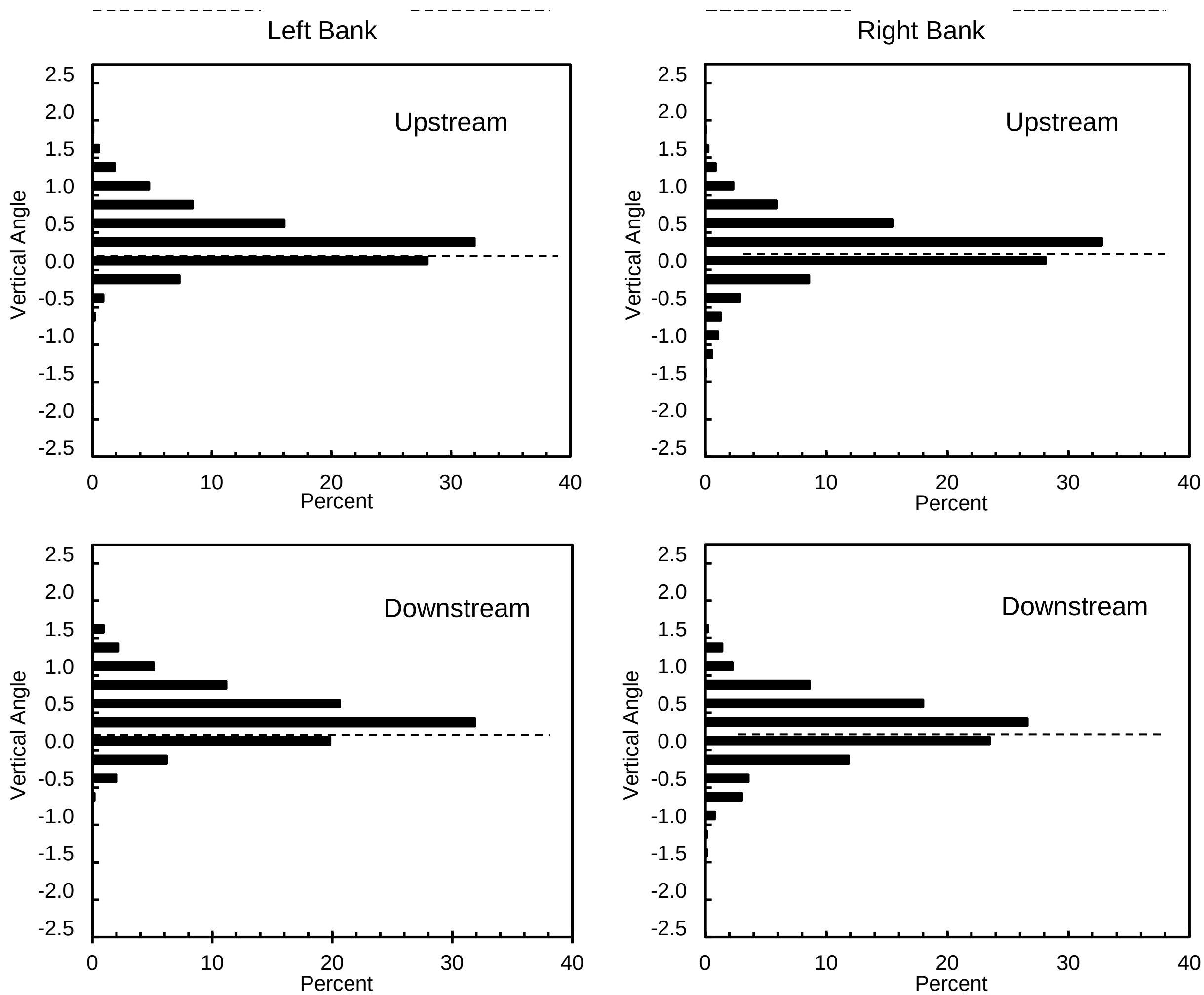
Note: Data have been filtered by range (distance from transducer) and target strength criteria. Acoustic axis = 0.0.

Figure 12.-Vertical distributions above and below the acoustic axis of early-run upstream and downstream moving Chinook salmon by bank, Kenai River, 2006.



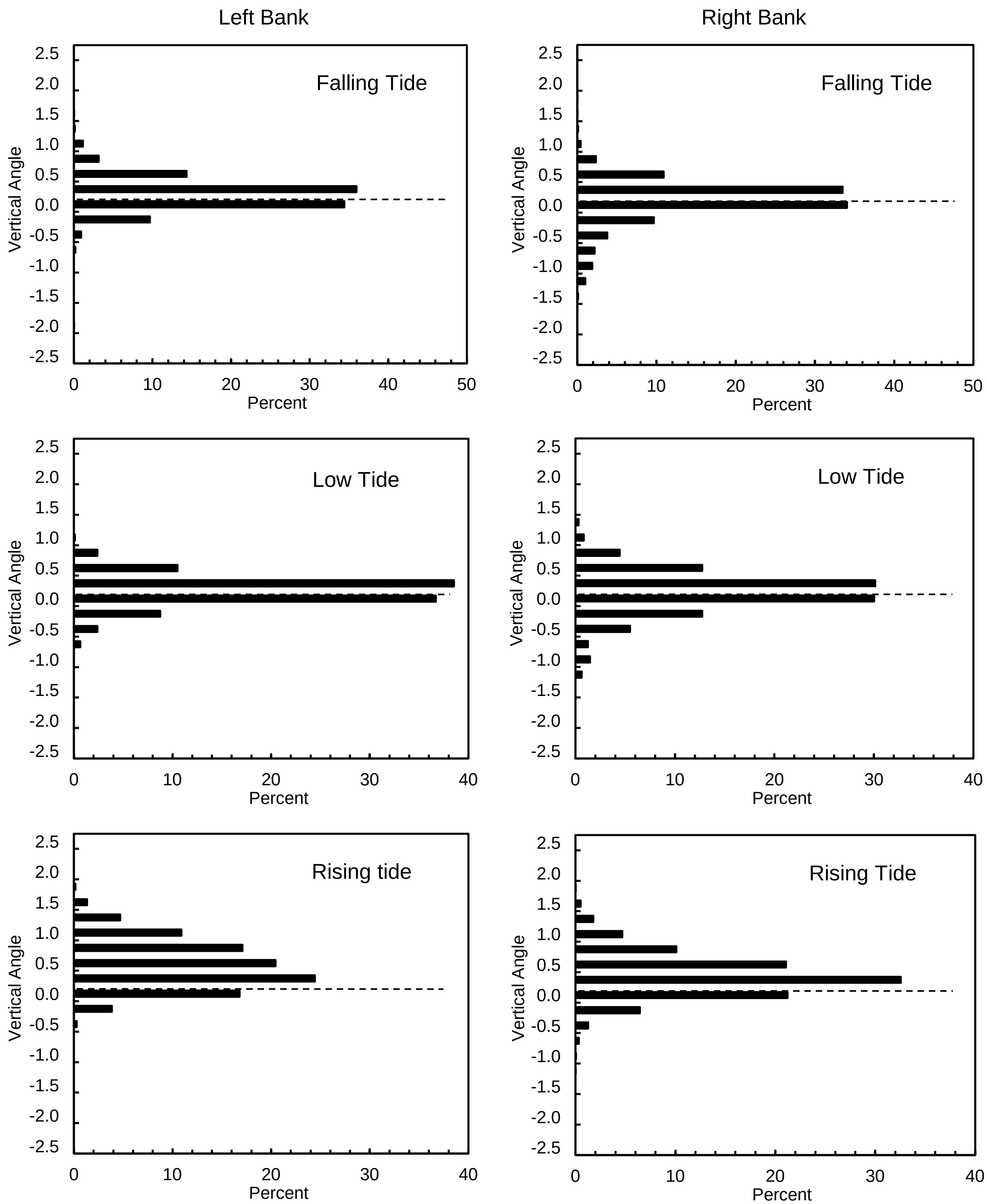
Note: Data have been filtered by range (distance from transducer)and target strength criteria. Acoustic axis = 0.0.

Figure 13.-Vertical distributions above and below the acoustic axis of early-run upstream moving Chinook salmon by tide stage and bank, Kenai River, 2006.



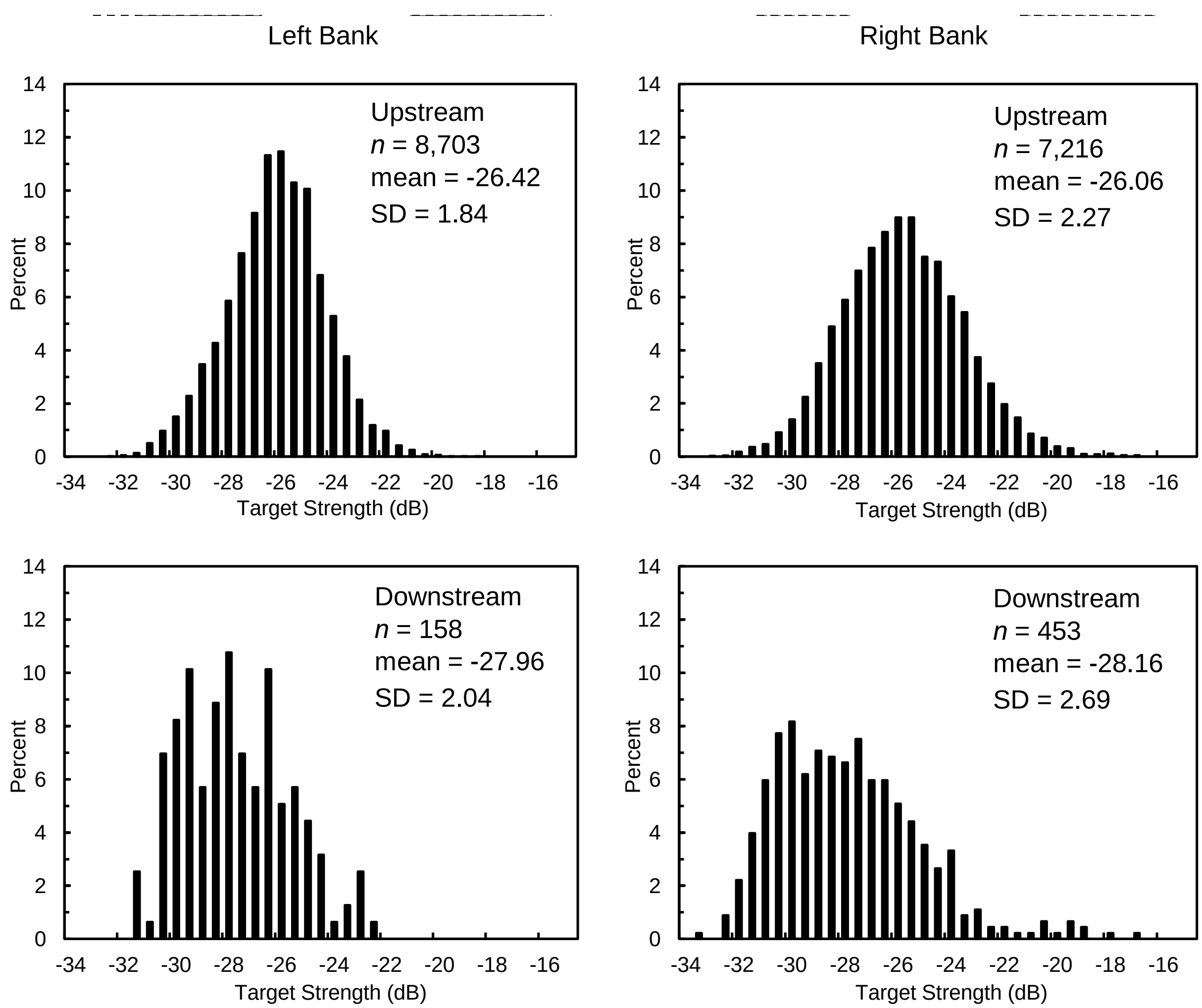
Note: Data have been filtered by range (distance from transducer) and target strength criteria. Acoustic axis = 0.0.

Figure 14.-Vertical distributions above and below the acoustic axis of late-run upstream and downstream moving Chinook salmon by bank, Kenai River, 2006.



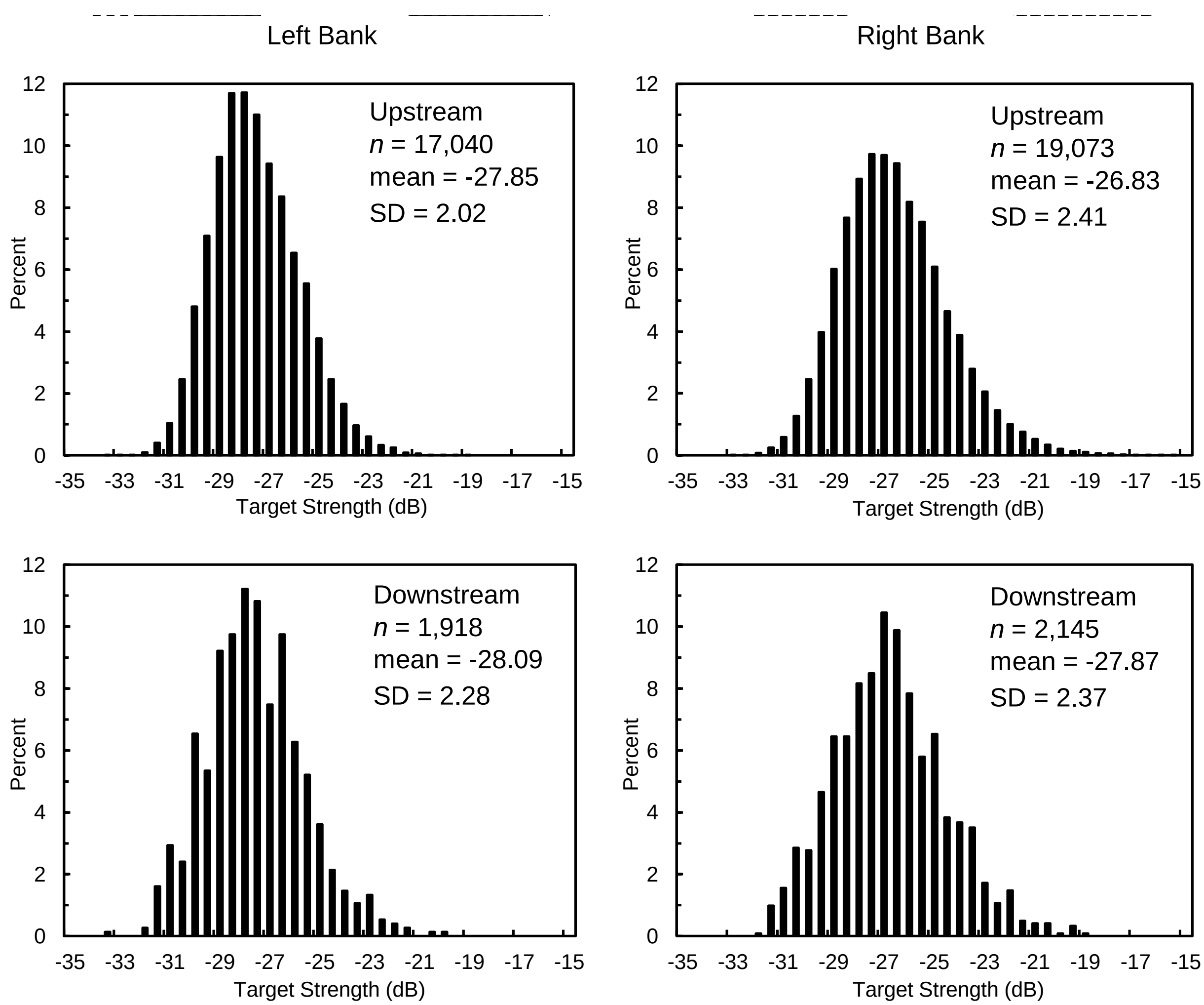
Note: Data have been filtered by range (distance from transducer)and target strength criteria. Acoustic axis = 0.0.

Figure 15.-Vertical distributions above and below the acoustic axis of late-run upstream moving Chinook salmon by tide stage and bank, Kenai River, 2006.



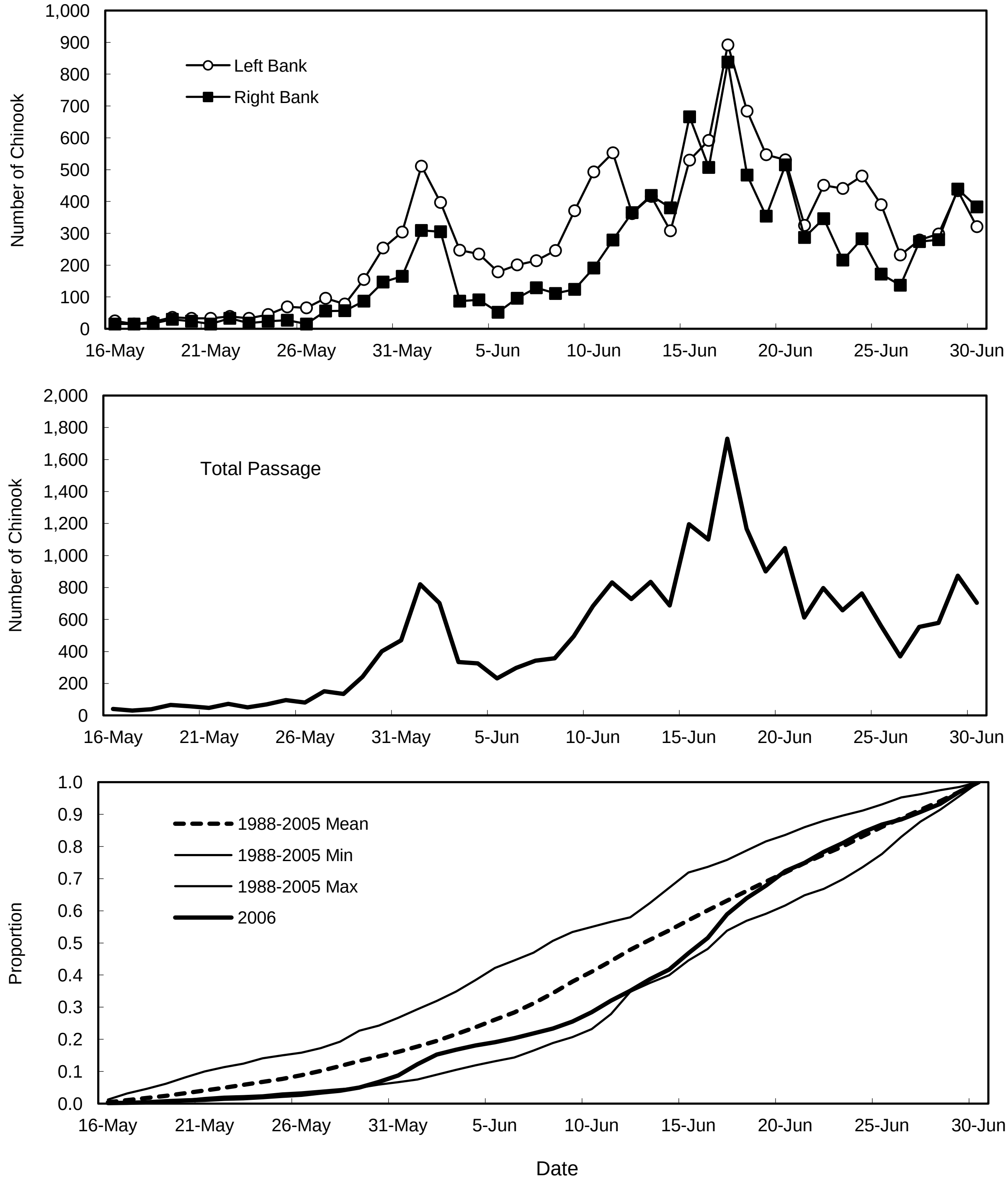
Note: Data have not been filtered by range (distance from transducer) and target strength criteria.

Figure 16.-Early-run target strength (acoustic size) for all upstream and downstream moving targets by bank, Kenai River, 2006.



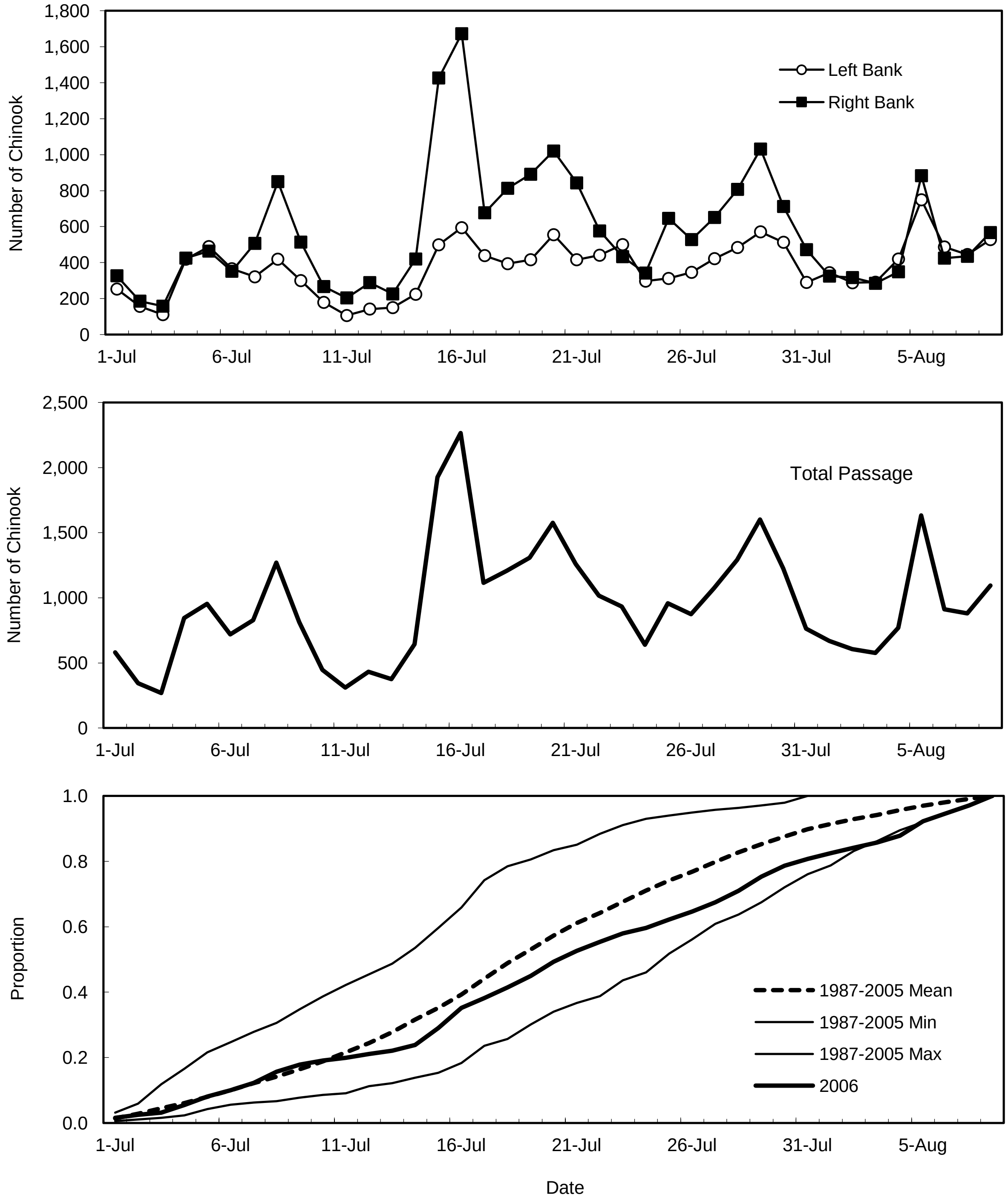
Note: Data have not been filtered by range (distance from transducer) and target strength criteria.

Figure 17.-Late-run target strength (acoustic size) for all upstream and downstream moving targets by bank, Kenai River, 2006.



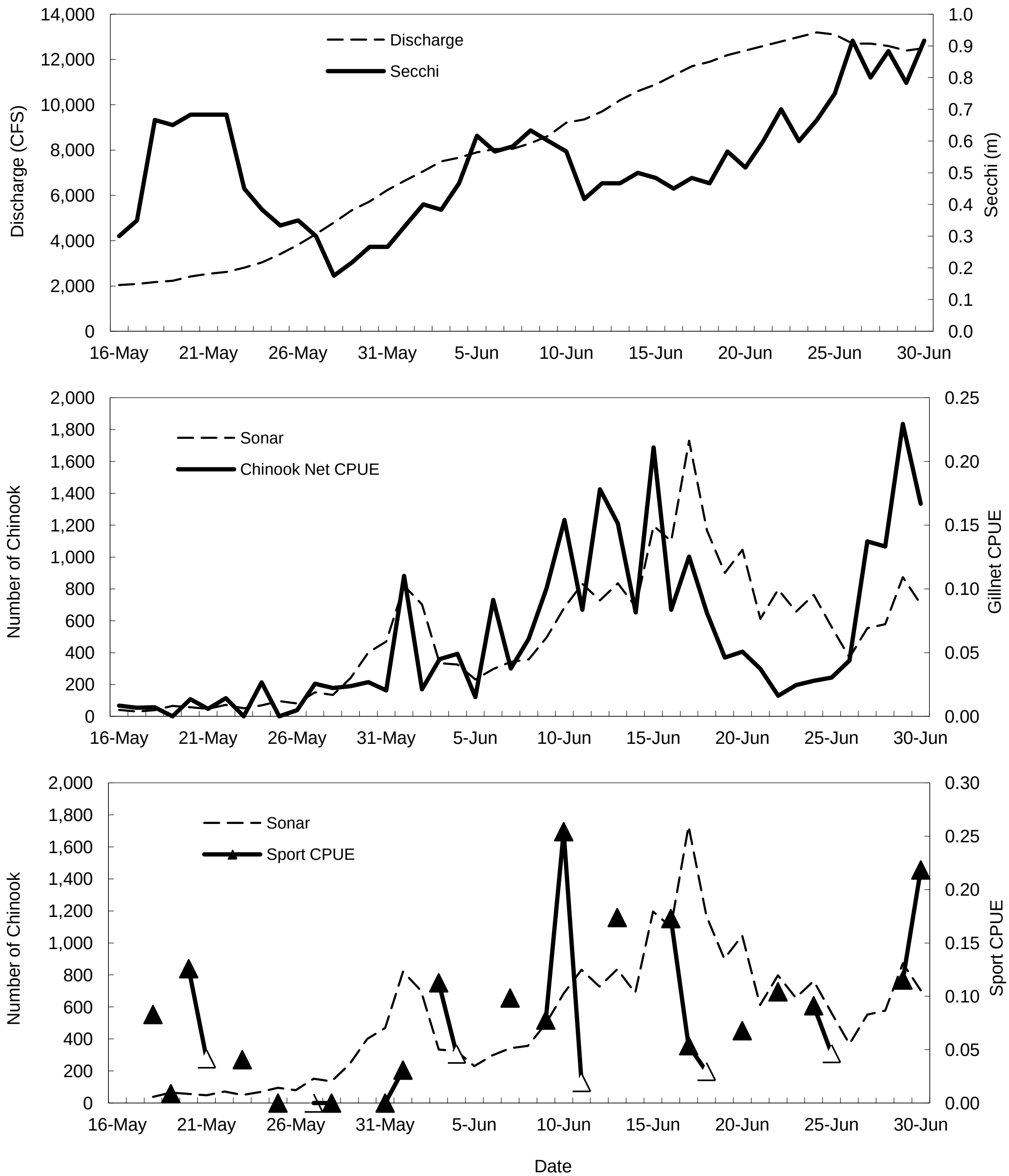
Note: Mean in bottom panel is based on estimates of total passage for 1988-1997 and upstream passage for 1998-2005.

Figure 18.-Daily sonar passage estimates by bank (top), total passage (center), and historical cumulative proportions (bottom) for the Chinook salmon early run returning to the Kenai River, 2006.



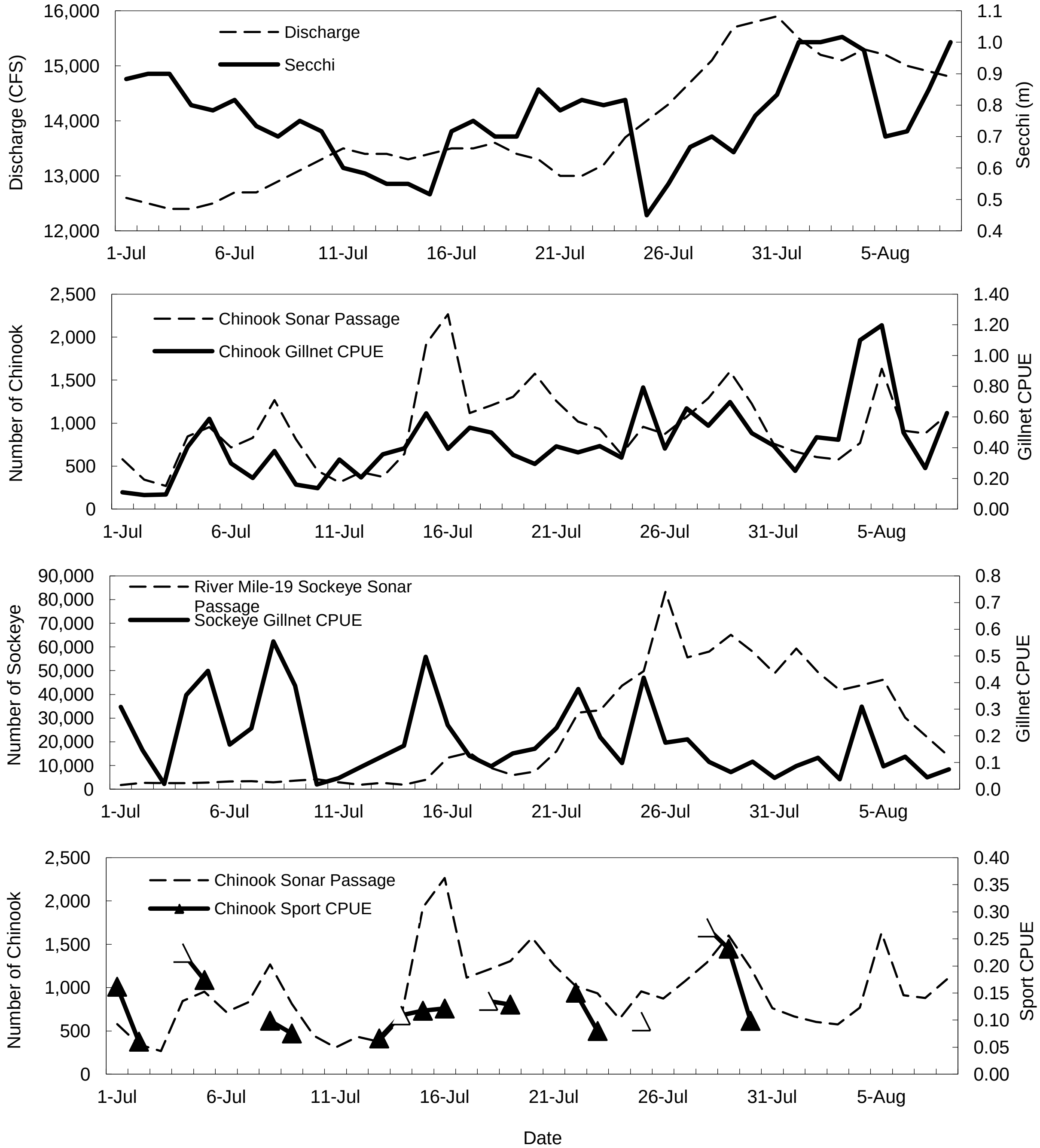
Note: Mean in bottom panel is based on passage through 8 August and on estimates of total passage for 1987-1997 and upstream passage for 1998-2005.

Figure 19.-Daily sonar passage estimates by bank (top), total passage (center), and historical cumulative proportions (bottom) for the Chinook salmon late run returning to the Kenai River, 2006.



Note: Discharge taken from USGS (2006). Gillnet CPUE and sport fish CPUE taken from Eskelin (2009). Open triangles represent days on which only unguided anglers were allowed to fish.

Figure 20. Daily discharge rates collected at the Soldotna Bridge, Secchi disk readings taken at the sonar site, Chinook salmon sonar passage estimates, inriver gillnet CPUE, and Chinook salmon sport fish CPUE, early run (16 May-30 June), Kenai River, 2006.



Note: Discharge taken from USGS (2006). River mile-19 sockeye sonar estimates taken from Westerman and Willette (2007). Gillnet CPUE and sport fish CPUE taken from Eskelin (2009). The Chinook salmon sport fishery closed by regulation on 31 July, so no sport fish CPUE data were available after this date. Open triangles represent days when only unguided anglers were allowed to fish.

Figure 21.-Daily discharge rates collected at the Soldotna Bridge, Secchi disk readings taken at the sonar site, Chinook salmon sonar passage estimates, inriver gillnet CPUE, river mile-19 sockeye sonar passage estimates, and Chinook salmon sport fish CPUE, late run (1 July-8 August), Kenai River, 2006.

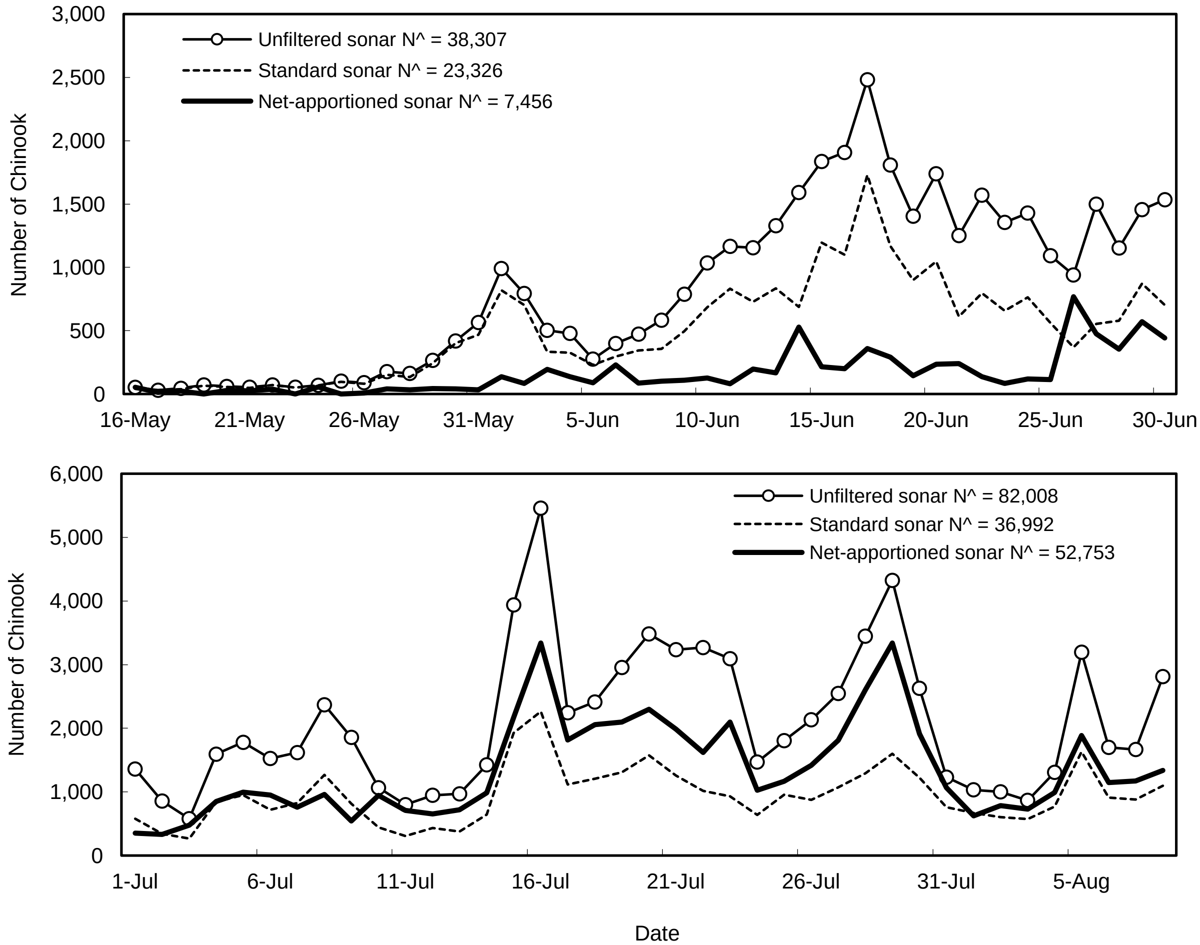


Figure 22.-Early- (16 May-30 June; top) and late-run (1 July-8 August; bottom) fish passage estimates based on unfiltered sonar (all species), standard filtered sonar (Chinook salmon only), and net-apportioned sonar (alternative estimate, Chinook salmon only), Kenai River, 2006.

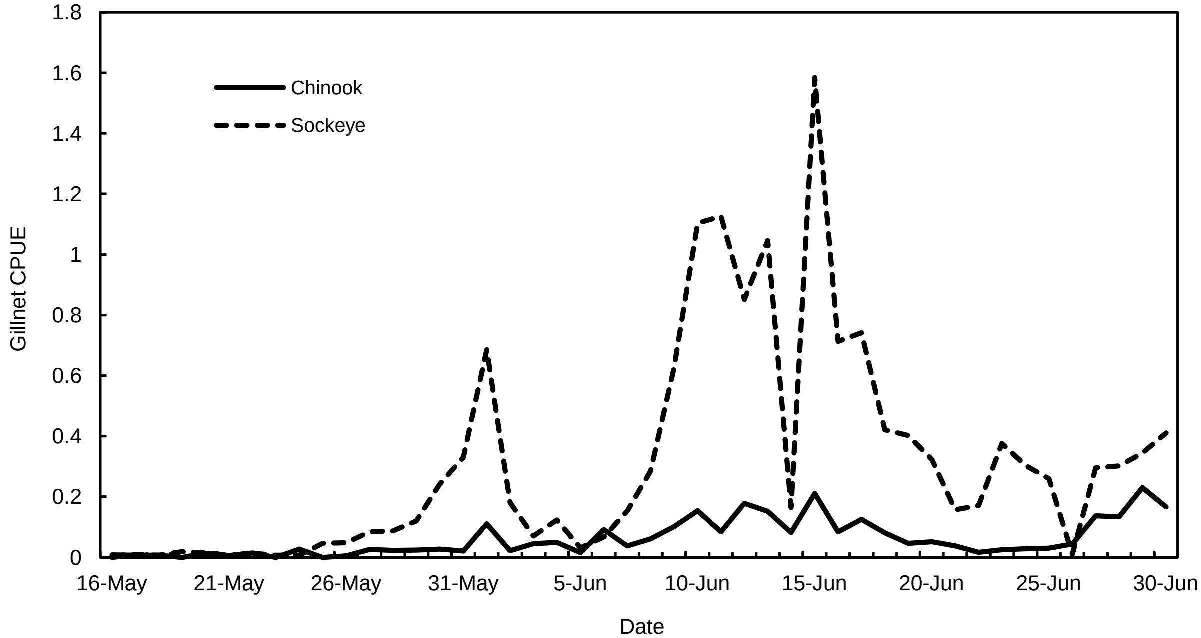


Figure 23.-Daily Chinook and sockeye salmon inriver gillnetting CPUE, early run (16 May-30 June), Kenai River, 2006.

APPENDIX A. TARGET STRENGTH ESTIMATION

Appendix A1.-The sonar equation used to estimate target strength (dB) with dual- and split-beam applications.

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

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

where:

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

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

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

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

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

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

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

APPENDIX B. SYSTEM PARAMETERS

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

Parameter Number	Subfield Number[a]	Parameter Value	Parameter Description
100	-1	1	MUX argument #1 - multiplexer port to activate
101	-1	0	percent - sync pulse switch, ping rate determiner NUS
102	-1	13201	maxp - maximum number of pings in a block NUS
103	-1	32767	maxbott - maximum bottom range in samples NUS
104	t	13	N_th_layer - number of threshold layers
105	-1	5	max_tbp - maximum time between pings in pings
106	-1	5	min_pings - minimum number of pings per fish
507	-1	FED5	timval - 0xFED5 corresponds to about 20 kHz NUS
108	-1	1	mux_on - means multiplexing enabled on board NUS
109	-1	200	mux_delay - samples delay between sync and switching NUS
110	-1	0	decimate_mask - decimate input samples flag NUS
112	-1	1	echogram_on - flag for DEP echogram enable 0=off, 1=on
113	-1	1	Hourly Sampling flag 1=On 0=Off
118	-1	5	maxmiss - maximum number of missed pings in auto bottom
119	-1	0	bottom-0=fix,1=man,2=scope,3=acq_chan1,4=acq_chan2,5=auto_1,6=auto_chan2
120	-1	0	sb_int_code - sb only=0, sb-int: 40log a bot=1, 20log=2
121	-1	0	sb_int_code2 - sb only=0, sb-int 40log eg=0, 20log=2
122	-1	13	N_int_layers-number of integration strata
123	-1	13	N_int_th_layers - number of integration threshold strata
124	-1	0	int_print - print integrator interval results to printer
125	-1	0	circular element transducer flag for bpf calculation
126	-1	80	grid spacing for Model 404 DCR (in samples, 16 s/m)
127	-1	1	TRIG argument #1 - trigger source
128	-1	0	TRIG argument #2 - digital data routing
130	-1	0	TVG Blank (0=Both Start/End,1=Stop Only,2=Start Only,3=None)
200	-1	20	sigma flag 0.0 = no sigma, else sigma is output
201	-1	221.18	sl - transducer source level
202	-1	-169.37	gn - transducer through system gain at one meter
203	-1	-18	rg - receiver gain used to collect data
204	-1	2.8	narr_ax_bw - vertical nominal beam width
205	-1	10	wide_ax_bw - horizontal axis nominal beam width
206	-1	0	narr_ ax_corr - vertical axis phase correction
207	-1	0	wide_ax_corr - horizontal axis phase correction
208	-1	11.0011	ping_rate - pulses per second
209	-1	0	echogram start range in meters
210	-1	47.3	echogram stop range in meters
211	-1	733	echogram threshold in millivolts
212	-1	13.2	print width in inches
213	-1	0	Chirp Bandwidth (0.0 = CHIRP OFF)
214	-1	20	Sampling within Hour Ending Time (in Decimal Minutes)
215	-1	1500	Speed of Sound (m/s)
216	-1	200	The Transducer's Frequency (kHz)
217	-1	-2.5	min_angoff_v - minimum angle off axis vertical
218	-1	2	max_angoff_v - maximum angle off axis vertical
219	-1	-5	min_angoff_h - minimum angle off axis horiz.

-continued-

Parameter Number	Subfield Number[a]	Parameter Value	Parameter Description
220	-1	5	max_angoff_ h - maximum angle off axis horiz.
221	-1	-24	max_dB_off - maximum angle off in dB
222	-1	-16.1163	ux - horizontal electrical to mechanical angle ratio
223	-1	-28.8329	uy - vertical electrical to mechanical angle ratio
224	-1	0	ud_coef_a - a coeff. for up-down beam pattern eq.
225	-1	-0.0152	ud_coef_b - b coeff. for up-down beam pattern eq.
226	-1	-2.3219	ud_coef_c - c coeff. for up-down beam pattern eq.
227	-1	0.1387	ud_coef_d - d coeff. for up-down beam pattern eq.
228	-1	-0.168	ud_coef_e - e coeff. for up-down beam pattern eq.
229	-1	0	lr_coef_a - a coeff. for left-rt beam pattern eq.
230	-1	0.0005	lr_coef_b - b coeff. for left-rt beam pattern eq.
231	-1	-0.2094	lr_coef_c - c coeff . for left-rt beam pattern eq.
232	-1	0.0001	lr_coef_d - d coeff. for left-rt beam pattern eq.
233	-1	-0.0002	lr_coef_e - ecoeff. for left-rt beam pattern eq.
234	-1	4	maximum fish velocity in meters per second
235	-1	1	Echo Scope Bottom Location
236	-1	0.4	maxpw - pulse width search window size
238	-1	45	bottom - bottom depth in meters
239	-1	0	init_slope - initial slope for tracking in m/ping
240	-1	0.2	exp_cont - exponent for expanding tracking window
241	-1	0.2	max_ch_rng - maximum change in range in m/ping
242	-1	0.04	pw_criteia->min_pw_6-min -6 dB pulse width
243	-1	10	pw_criteria->max_pw_6-max -6 dB pulse width
244	-1	0.04	pw_criteria->min_pw_12 - min -12 dB pulse width
245	-1	10	pw_criteria->max_pw_12 - max -12 dB pulse width
246	-1	0.04	pw_criteria->min_pw_18 - min -18 dB pulse width
247	-1	10	pw_criteria->max_pw_18 - max -18 dB pulse width
249	-1	10	maximum voltage to allow in .RAW file
250	-1	0.2	TX argument #1 - pulse width in milliseconds
251	-1	25	TX argument #2 - transmit power in dB-watts
252	-1	-12	RX argument #1 - receiver gain
253	-1	90.9	REP argument #1 - ping rate in ms per ping
254	-1	10	REP argument #2 - pulsed cal tone separation
255	-1	1	TVG argument #1 - TVG start range in meters
256	-1	100	TVG argument #2 - TVG end range in meters
257	-1	40	TVG argument #3 - TVG function (XX Log Range)
258	-1	-6	TVG argument #4 - TVG gain
259	-1	0	TVG argument #5 - alpha (spreading loss) in dB/Km
260	-1	0.2	minimum absolute distance fish must travel in x plane
261	-1	0.2	minimum absolute distance fish must travel in y plane
262	-1	0.2	minimum absolute distance fish must travel in z plane
263	-1	2	bottom_window - auto tracking bottom window (m)
264	-1	3	bottom_threshold - auto tracking bottom threshold (V)
265	-1	11.2	TVG argument #7 - 20/40 log crossover (meters)
266	-1	0	rotator - which rotator to aim
267	-1	0	aim_pan - transducer aiming angle in pan (x, lf/rt)
268	-1	0	aim_tilt - transducer aiming angle in tilt (y, u/d)

-continued-

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

Note: Start processing at Port 1 -FILE_PARAMETERS- Saturday, 1 July 12:00:09, 2006

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

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

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

Parameter Number	Subfield Number[a]	Parameter Value	Parameter Description
100	-1	2	MUX argument #1 - multiplexer port to activate
101	-1	0	percent - sync pulse switch, ping rate determiner NUS
102	-1	19200	maxp - maximum number of pings in a block NUS
103	-1	32767	maxbott - maximum bottom range in samples NUS
104	-1	69	N_th_layer - number of threshold layers
105	-1	5	max_tbp - maximum time between pings in pings
106	-1	5	min_pings - minimum number of pings per fish
507	-1	FED5	timval - 0xFED5 corresponds to about 20 kHz NUS
108	-1	1	mux_on - means multiplexing enabled on board NUS
109	-1	200	mux_delay - samples delay between sync and switching NUS
110	-1	0	decimate_mask - decimate input samples flag NUS
112	-1	1	echogram_on - flag for DEP echogram enable 0=off, 1=on
113	-1	1	Hourly Sampling flag 1=On 0=Off
118	-1	5	maxmiss - maximum number of missed pings in auto bottom
119	-1	0	bottom-0=fix,1=man,2=scope,3=acq_chan1,4=acq_chan2,5=auto_1,6=auto_chan2
120	-1	0	sb_int_code - sb only=0, sb-int: 40log a bot=1, 20log=2
121	-1	0	sb_int_code2 - sb only=0, sb-int 40log eg=0, 20log=2
122	-1	69	N_int_layers-number of integration strata
123	-1	69	N_int_th_layers - number of integration threshold strata
124	-1	0	int_print - print integrator interval results to printer
125	-1	0	circular element transducer flag for bpf calculation
126	-1	80	grid spacing for Model 404 DCR (in samples, 16 s/m)
127	-1	1	TRIG argument #1 - trigger source
128	-1	0	TRIG argument #2 - digital data routing
130	-1	0	TVG Blank (0=Both Start/End,1=Stop Only,2=Start Only,3=None)
200	-1	20	sigma flag 0.0 = no sigma, else sigma is output
201	-1	218.37	sl - transducer source level
202	-1	-170.89	gn - transducer through system gain at one meter
203	-1	-18	rg - receiver gain used to collect data
204	-1	2.8	narr_ax_bw - vertical nominal beam width
205	-1	10	wide_ax_bw - horizontal axis nominal beam width
206	-1	0	narr_ ax_corr - vertical axis phase correction
207	-1	0	wide_ax_corr - horizontal axis phase correction
208	-1	16	ping_rate - pulses per second
209	-1	0	echogram start range in meters
210	-1	29.5	echogram stop range in meters
211	-1	479	echogram threshold in millivolts
212	-1	13.2	print width in inches
213	-1	0	Chirp Bandwith (0.0 = CHIRP OFF)
214	-1	40	Sampling within Hour Ending Time (in Decimal Minutes)
215	-1	1500	Speed of Sound (m/s)
216	-1	200	The Transducer's Frequency (kHz)
217	-1	-2.5	min_angoff_v - minimum angle off axis vertical
218	-1	2	max_angoff_v - maximum angle off axis vertical
219	-1	-5	min_angoff_h - minimum angle off axis horiz.

-continued-

Parameter Number	Subfield Number[a]	Parameter Value	Parameter Description
220	-1	5	max_angoff_ h - maximum angle off axis horiz.
221	-1	-24	max_dB_off - maximum angle off in dB
222	-1	-16.0303	ux - horizontal electrical to mechanical angle ratio
223	-1	-53.8422	uy - vertical electrical to mechanical angle ratio
224	-1	0	ud_coef_a - a coeff. for up-down beam pattern eq.
225	-1	0.0062	ud_coef_b - b coeff. for up-down beam pattern eq.
226	-1	-2.5614	ud_coef_c - c coeff. for up-down beam pattern eq.
227	-1	-0.1478	ud_coef_d - d coeff. for up-down beam pattern eq.
228	-1	-0.1434	ud_coef_e - e coeff. for up-down beam pattern eq.
229	-1	0	lr_coef_a - a coeff. for left-rt beam pattern eq.
230	-1	0	lr_coef_b - b coeff. for left-rt beam pattern eq.
231	-1	-0.2238	lr_coef_c - c coeff . for left-rt beam pattern eq.
232	-1	-0.0004	lr_coef_d - d coeff. for left-rt beam pattern eq.
233	-1	-0.0001	lr_coef_e - ecoeff. for left-rt beam pattern eq.
234	-1	4	maximum fish velocity in meters per second
235	-1	1	Echo Scope Bottom Location
236	-1	0.4	maxpw - pulse width search window size
238	-1	27.8	bottom - bottom depth in meters
239	-1	0	init_slope - initial slope for tracking in m/ping
240	-1	1	exp_cont - exponent for expanding tracking window
241	-1	0	max_ch_rng - maximum change in range in m/ping
242	-1	0.04	pw_criteria->min_pw_6-min -6 dB pulse width
243	-1	10	pw_criteria->max_pw_6-max -6 dB pulse width
244	-1	0.04	pw_criteria->min_pw_12 - min -12 dB pulse width
245	-1	10	pw_criteria->max_pw_12 - max -12 dB pulse width
246	-1	0.04	pw_criteria->min_pw_18 - min -18 dB pulse width
247	-1	10	pw_criteria->max_pw_18 - max -18 dB pulse width
249	-1	10	maximum voltage to allow in .RAW file
250	-1	0.2	TX argument #1 - pulse width in milliseconds
251	-1	25	TX argument #2 - transmit power in dB-watts
252	-1	-12	RX argument #1 - receiver gain
253	-1	62.5	REP argument #1 - ping rate in ms per ping
254	-1	10	REP argument #2 - pulsed cal tone separation
255	-1	2	TVG argument #1 - TVG start range in meters
256	-1	100	TVG argument #2 - TVG end range in meters
257	-1	40	TVG argument #3 - TVG function (XX Log Range)
258	-1	-6	TVG argument #4 - TVG gain
259	-1	0	TVG argument #5 - alpha (spreading loss) in dB/Km
260	-1	0.2	minimum absolute distance fish must travel in x plane
261	-1	0.2	minimum absolute distance fish must travel in y plane
262	-1	0.2	minimum absolute distance fish must travel in z plane
263	-1	2	bottom_window - auto tracking bottom window (m)
264	-1	3	bottom_threshold - auto tracking bottom threshold (V)
265	-1	11.2	TVG argument #7 - 20/40 log crossover (meters)
266	-1	0	rotator - which rotator to aim
267	-1	0	aim_pan - transducer aiming angle in pan (x, lf/rt)
268	-1	0	aim_tilt - transducer aiming angle in tilt (y, u/d)

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Parameter Number	Subfield Number[a]	Parameter Value	Parameter Description
401	0-68	1-35	th_layer[0-68], bottom of 1st threshold layer – bottom of 69th threshold layer (i.e. 69 threshold layers in 0.5 m increments and numbered 0 through 68)
402	0-67	479	th_val[0-67], threshold for 1st through 68th layer in millivolts
402	68	9999	th_val[68], threshold for 69th layer in millivolts
405	0-67	100	Integration threshold value for layer 1-68 (mV)
405	68	9999	Integration threshold value for layer 69 (mV)
602	-1	1017536	Echo sounder serial number
604	-1	306738	Transducer serial number
605	-1	Spd-4	Echogram paper speed
606	-1	9_pin	Echogram resolution
607	-1	Board_Exte	Trigger option
608	-1	LeftToRight	River flow direction

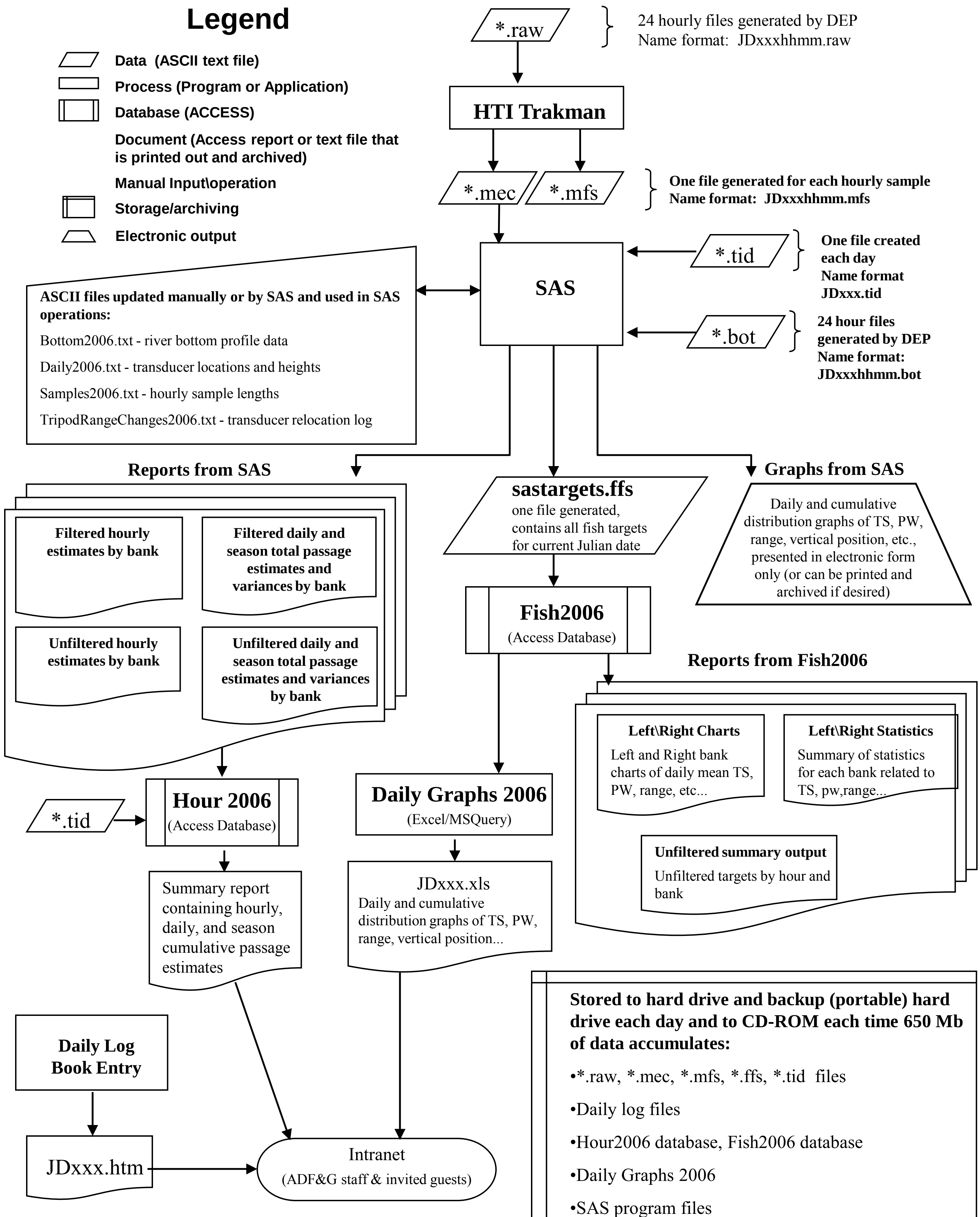
Note: Start processing at Port 2 -FILE_PARAMETERS- Saturday, 1 July 12:20:09, 2006

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

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

APPENDIX C. DATA FLOW

Appendix C1.-Data flow diagram for the Kenai River Chinook salmon sonar project, 2006.



APPENDIX D. EXCLUDED HOURLY SAMPLES

Appendix D1.-Hourly samples excluded by bank from calculation of early- and late-run Chinook salmon daily passage estimates, Kenai River, 2006.

Date	Excluded Sample Hours	
	Left Bank	Right Bank
EARLY RUN		
3-June	0920	-
4-June	2220-2320	2200
7-June	2320	-
8-June	0020, 1320	1300
9-June	1120, 1420, 1720	1400, 1700
10-June	0520, 0620	0500
11-June	1820	1500
14-June	1120, 1220	1000, 1100
15-June	0720-0820, 1220	0900
16-June	2220	1200-1300
17-June	0720, 2020, 2220	0700, 2200
18-June	0820	0800-0900
19-June	-	1100
20-June	1220	1200-1300, 2300
21-June	1220-1420, 1620	1200-1400, 1700
22-June	1720-2020	1800-2000
23-June	0520-0720, 1420-1520, 1720-1820	0700, 1400-1800
24-June	1520-1620, 1820-1920	1500-1900, 2100
25-June	0520, 1620-2020	1600-2100
26-June	0620, 0920, 1920	0600, 0900, 1900, 2100
27-June	1720, 1920, 2020-2220	0900-1000, 1700, 1900-2200
28-June	0420, 2020	0400, 1000, 1200, 2000-2100
29-June	1820-1920	0500, 0800, 1800-1900, 2100
30-June	1020, 1920, 2220	0600, 1000, 1200, 1900-2000, 2200
LATE RUN		
1-July	0720, 0920, 2020	0700-0900, 2000-2200
2-July	2220	0900, 2000-2200
3-July	-	2200
4-July	-	1200
5-July	-	2300
6-July	-	1300,1500
7-July	1420	1300-1400
8-July	-	1400-1500
9-July	1520	1500-1600, 2000
10-July	1620	0700, 1600
14-July	-	0800-0900
15-July	-	0800-1000
16-July	0720-1020, 1920	0700-1000, 1900
17-July	-	1000, 2100
18-July	-	1000, 1200, 2200
19-July	2320	1100-1300, 2200-2300
20-July	1220	1200-1400, 1700-1900, 2300
21-July	0020, 1320-1420	0000-0100, 1400-1700
22-July	1420-1520	0100, 0700-0800, 1400-1600

-continued-

Appendix D1.-Page 2 of 2.

Date	Excluded Sample Hours	
	Left Bank	Right Bank
23-July	1520-1620	0200, 1500-1700, 1900
24-July	-	1500-1600
25-July	1620	1600
26-July	1620	1600-1700
27-July	-	1700-1900
28-July	1720-1820	0700-0800, 1800-2000
29-July	0620-0720, 1820	0600-0800, 1800-2000
30-July	-	0700-0800, 1900-2200
5-August	0620, 2020	0600
6-August	1420	1400
7-August	1420	-
8-August	1520-1720	1500-1700, 1900-2000

APPENDIX E. DAILY PROPORTION OF UPSTREAM AND DOWNSTREAM MOVING FISH FOR THE CHINOOK SALMON EARLY AND LATE RUNS, KENAI RIVER, 2006

Appendix E1.-Daily proportion of upstream and downstream moving fish for the Chinook salmon early run, Kenai River, 2006.

Date	Downstream Count	Upstream Count	Daily Total	% Downstream	% Upstream
16 May	6	40	46	13%	87%
17 May	9	30	39	23%	77%
18 May	19	39	58	33%	67%
19 May	18	66	84	21%	79%
20 May	18	57	75	24%	76%
21 May	9	48	57	16%	84%
22 May	12	72	84	14%	86%
23 May	6	51	57	11%	89%
24 May	3	69	72	4%	96%
25 May	0	96	96	0%	100%
26 May	12	81	93	13%	87%
27 May	15	152	167	9%	91%
28 May	15	135	150	10%	90%
29 May	12	242	254	5%	95%
30 May	6	401	407	1%	99%
31 May	15	469	484	3%	97%
1 June	6	820	826	1%	99%
2 June	3	702	705	0%	100%
3 June	9	334	343	3%	97%
4 June	2	326	328	1%	99%
5 June	0	231	231	0%	100%
6 June	18	297	315	6%	94%
7 June	3	343	346	1%	99%
8 June	11	357	368	3%	97%
9 June	26	495	521	5%	95%
10 June	8	684	692	1%	99%
11 June	18	832	850	2%	98%
12 June	15	727	742	2%	98%
13 June	18	835	853	2%	98%
14 June	8	688	696	1%	99%
15 June	8	1,196	1,204	1%	99%
16 June	22	1,099	1,121	2%	98%
17 June	38	1,730	1,768	2%	98%
18 June	14	1,167	1,181	1%	99%
19 June	9	901	910	1%	99%
20 June	8	1,046	1,054	1%	99%
21 June	2	612	614	0%	100%
22 June	4	797	801	0%	100%
23 June	14	657	671	2%	98%
24 June	5	763	768	1%	99%
25 June	11	562	573	2%	98%
26 June	4	369	373	1%	99%
27 June	11	553	564	2%	98%
28 June	7	578	585	1%	99%
29 June	38	873	911	4%	96%
30 June	39	704	743	5%	95%
Total	554	23,326	23,880	2%	98%

Appendix E2.-Daily proportion of upstream and downstream moving fish for the Chinook salmon late run, Kenai River, 2006.

Date	Downstream Count	Upstream Count	Daily Total	% Downstream	% Upstream
1 July	17	580	597	3%	97%
2 July	24	343	367	7%	93%
3 July	21	269	290	7%	93%
4 July	50	844	894	6%	94%
5 July	60	953	1,013	6%	94%
6 July	73	718	791	9%	91%
7 July	37	828	865	4%	96%
8 July	40	1,269	1,309	3%	97%
9 July	41	814	855	5%	95%
10 July	25	446	471	5%	95%
11 July	42	310	352	12%	88%
12 July	31	431	462	7%	93%
13 July	25	376	401	6%	94%
14 July	95	644	739	13%	87%
15 July	92	1,925	2,017	5%	95%
16 July	56	2,266	2,322	2%	98%
17 July	71	1,116	1,187	6%	94%
18 July	97	1,207	1,304	7%	93%
19 July	78	1,307	1,385	6%	94%
20 July	87	1,575	1,662	5%	95%
21 July	88	1,259	1,347	7%	93%
22 July	83	1,017	1,100	8%	92%
23 July	59	933	992	6%	94%
24 July	89	639	728	12%	88%
25 July	126	958	1,084	12%	88%
26 July	88	874	962	9%	91%
27 July	95	1,073	1,168	8%	92%
28 July	88	1,291	1,379	6%	94%
29 July	81	1,602	1,683	5%	95%
30 July	112	1,225	1,337	8%	92%
31 July	152	762	914	17%	83%
1 August	162	669	831	19%	81%
2 August	216	605	821	26%	74%
3 August	147	576	723	20%	80%
4 August	156	769	925	17%	83%
5 August	237	1,632	1,869	35%	65%
6 August	298	912	1,210	35%	65%
7 August	249	880	1,129	35%	65%
8 August	401	1,095	1,496	27%	73%
Total	3,989	36,992	40,981	10%	90%

APPENDIX F. AVERAGE VERTICAL ANGLE BY TIDE STAGE, RUN, BANK, AND FISH ORIENTATION (UPSTREAM OR DOWNSTREAM) FOR THE CHINOOK SALMON EARLY AND LATE RUNS, KENAI RIVER, 2006

Appendix F1.-Average vertical angle by tide stage and orientation for the Chinook salmon early run, Kenai River, 2006.

Tide Stage /Fish Orientation	Average Vertical Angle	Standard Deviation	Sample Size
	Left Bank		
Falling			
Downstream	-0.18	0.64	33
Upstream	-0.24	0.33	3,006
Tide Stage Total	-0.24	0.33	3,039
Low			
Downstream	-0.00	0.34	13
Upstream	-0.37	0.36	1,032
Tide Stage Total	-0.37	0.36	1,045
Rising			
Downstream	-0.29	0.51	13
Upstream	0.08	0.45	735
Tide Stage Total	0.07	0.46	748
Left Bank Total	-0.22	0.39	4,832
	Right Bank		
Falling			
Downstream	-0.06	0.60	83
Upstream	-0.16	0.34	3,024
Tide Stage Total	-0.16	0.35	3,107
Low			
Downstream	-0.15	0.53	29
Upstream	-0.33	0.47	479
Tide Stage Total	-0.32	0.47	508
Rising			
Downstream	-0.03	0.59	43
Upstream	-0.10	0.40	865
Tide Stage Total	-0.09	0.41	908
Right Bank Total	-0.12	0.40	4,523

Appendix F2.-Average vertical angle by tide stage and orientation for the Chinook salmon late run, Kenai River, 2006.

Tide Stage /Fish Orientation	Average Vertical Angle	Standard Deviation	Sample Size
Left Bank			
Falling			
Downstream	0.16	0.32	313
Upstream	0.04	0.26	2,441
Tide Stage Total	0.06	0.27	2,754
Low			
Downstream	0.07	0.31	141
Upstream	0.00	0.24	924
Tide Stage Total	0.01	0.25	1,065
Rising			
Downstream	0.39	0.42	192
Upstream	0.35	0.40	2,107
Tide Stage Total	0.35	0.40	2,299
Left Bank Total	0.16	0.35	6,118
Right Bank			
Falling			
Downstream	0.05	0.40	472
Upstream	-0.05	0.35	4,490
Tide Stage Total	-0.04	0.36	4,962
Low			
Downstream	-0.02	0.39	152
Upstream	-0.04	0.36	966
Tide Stage Total	-0.03	0.36	1,118
Rising			
Downstream	0.11	0.42	304
Upstream	0.19	0.35	4,154
Tide Stage Total	0.18	0.36	4,458
Right Bank Total	0.05	0.38	10,538

APPENDIX G. HISTORIC PASSAGE BY YEAR AND DATE (1987–2006)

Appendix G1.-Kenai River early-run Chinook salmon sonar passage estimates, 1987-2006.

Date/Year	1987[a]	1988	1989	**1990**	**1991**	**1992**	1993	1994	1995	1996	**1997**	**1998[bc]**	1999[c]	**2000[c]**	2001[c]	**2002[c]**	2003[c]	2004[c]	2005[c]	2006[c]
7 May												6								
8 May												18								
9 May												3								
10 May												3								
11 May												12								
12 May												12								
13 May												27								
14 May												43								
15 May												63								
16 May		188	180	78	30	54	64	238	98	60	114	48	33	18	62	24	35	24	54	40
17 May		415	319	57	12	48	85	342	99	91	99	45	63	49	111	21	35	30	51	30
18 May		259	264	93	65	88	91	260	78	63	93	57	66	54	117	54	63	31	27	39
19 May		260	180	136	55	40	66	302	149	96	165	36	39	84	133	60	81	57	21	66
20 May		406	147	93	68	78	69	369	228	177	84	54	116	64	156	66	123	48	66	57
21 May		184	245	69	51	90	165	327	465	165	129	33	186	84	101	42	162	84	108	48
22 May		182	164	75	111	108	117	246	265	156	114	15	192	123	128	36	174	61	78	72
23 May		231	186	63	66	150	160	212	286	159	162	12	243	132	81	36	237	153	96	51
24 May		288	279	51	66	126	141	303	265	159	138	33	159	147	147	33	168	129	76	69
25 May		351	300	76	57	79	150	170	198	153	165	81	141	234	175	48	129	138	93	96
26 May		393	270	70	81	93	168	150	189	240	220	43	330	186	278	65	195	240	75	81
27 May		387	419	87	81	66	150	267	165	204	325	60	342	177	314	75	192	324	97	152
28 May		483	357	61	78	78	361	258	159	330	317	63	402	84	291	103	180	452	140	135
29 May		713	269	221	51	45	538	347	222	512	288	63	378	204	323	57	248	233	203	242
30 May		333	164	154	51	111	388	321	351	348	350	129	273	105	440	90	183	156	195	401
31 May		501	157	175	69	114	266	369	282	474	318	93	459	117	276	85	225	128	244	469

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Date/Year	1987[a]	1988	1989	**1990**	**1991**	**1992**	1993	1994	1995	1996	**1997**	**1998**[b,c]	1999[c]	**2000**[c]	2001[c]	**2002**[c]	2003[c]	2004[c]	2005[c]	2006[c]
1 June		556	258	153	150	106	187	321	357	603	213	111	633	192	259	210	294	148	342	820
2 June		545	194	294	240	107	412	266	369	741	241	189	444	250	316	216	195	91	335	702
3 June		598	233	225	362	232	324	298	549	873	376	192	540	282	328	119	389	72	255	334
4 June	1,059	755	246	178	177	190	255	304	693	1,051	324	186	924	266	255	144	435	143	551	326
5 June	552	782	280	192	316	166	276	351	429	943	427	**162**	876	139	519	120	381	301	671	231
6 June	1,495	493	384	156	**296**	319	327	198	807	741	327	**150**	807	186	432	165	464	239	908	297
7 June	1,145	506	545	**304**	**215**	515	198	384	843	773	591	**283**	672	237	427	140	422	474	784	343
8 June	602	771	890	**414**	**243**	375	297	306	999	918	441	**300**	609	108	486	202	615	665	1,063	357
9 June	1,024	569	912	**339**	**444**	**486**	378	462	789	1,140	391	**234**	504	135	591	466	605	730	969	495
10 June	985	333	913	**272**	**275**	**264**	453	432	876	684	527	**327**	439	207	639	246	395	784	861	684
11 June	1,004	320	710	**453**	**334**	**234**	549	423	774	882	512	**600**	596	315	575	211	446	754	1,135	832
12 June	1,044	302	577	**568**	**400**	**394**	600	329	417	864	537	**1,168**	723	165	1,357	118	284	525	939	727
13 June	2,168	188	599	**445**	**369**	**236**	951	376	492	1,071	681	**719**	393	**337**	939	**142**	153	438	587	835
14 June	1,297	289	458	**330**	**268**	**174**	811	514	691	1,111	424	**912**	610	**309**	647	**118**	292	282	712	688
15 June	975	510	335	**658**	**441**	**312**	407	306	636	1,116	318	**951**	436	**571**	600	**138**	291	446	548	1,196
16 June	786	808	397	**485**	**615**	**239**	616	453	648	420	348	**770**	696	**441**	499	**110**	204	440	594	1,099
17 June	612	535	514	**267**	**330**	**339**	567	315	750	495	**405**	**675**	807	**765**	364	**251**	205	422	443	1,730
18 June	783	533	464	**238**	**493**	**320**	606	435	808	697	**315**	**498**	742	**591**	607	**243**	137	383	636	1,167
19 June	771	200	295	**331**	**437**	**390**	422	636	419	657	**399**	**510**	771	**348**	559	**201**	313	581	597	901
20 June	682	175	498	**369**	**314**	**548**	504	402	594	315	**408**	**351**	1,247	**319**	418	**187**	365	461	661	1,046
21 June	517	373	520	**257**	**457**	**372**	621	570	438	351	**252**	**309**	1,192	**522**	417	**228**	474	461	394	612
22 June	487	312	614	**267**	**433**	**297**	399	366	375	396	**390**	**273**	819	**456**	345	**213**	428	532	440	797
23 June	529	375	547	**240**	**396**	**213**	607	550	178	401	**225**	**294**	935	**462**	272	**153**	386	552	344	657
24 June	303	674	564	**322**	**251**	**337**	720	696	450	573	**285**	**288**	1,151	**408**	240	**193**	522	666	344	763
25 June	564	582	374	**258**	**235**	**362**	808	734	429	684	**332**	**228**	1,292	**186**	213	**330**	450	520	557	562
26 June	731	436	369	**322**	**261**	**330**	1,051	597	334	504	**381**	**219**	731	**359**	203	**381**	414	240	479	369
27 June	452	549	309	**231**	**340**	**291**	1,158	639	946	228	**363**	**207**	678	615	220	**310**	237	255	380	553
28 June	587	827	425	**240**	**327**	**253**	798	681	696	303	**297**	**308**	537	489	224	**186**	231	426	459	578
29 June	371	495	376	**208**	**258**	**121**	728	929	984	234	**570**	**363**	753	516	191	**231**	362	530	687	873
30 June	388	915	292	**193**	**270**	**197**	660	649	615	351	**582**	**276**	687	441	403	**295**	506	649	1,151	704
Total	21,913[a]	20,880	17,992	**10,768**	**10,939**	**10,087**	19,669	18,403	21,884	23,505	**14,963**	**13,103**	25,666	**12,479**	16,676	**7,162**	13,325	15,498	20,450	23,326

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, 1987-2006.

Date/Year	1987	1988	1989	**1990**	1991	**1992**	1993[a]	1994[a]	1995	1996	1997	**1998**[b]	1999[b]	2000[b]	2001[b]	2002[b]	2003[b]	2004[b]	2005[b]	2006[b]
1 July	507	526	769	578	267	364	619	663	350	341	486	491	453	461	697	563	727	1,167	1,283	580
2 July	429	404	489	305	300	297	525	342	398	240	642	597	612	373	766	1,596	735	1,125	1,109	343
3 July	405	398	353	486	333	320	404	625	353	303	600	480	486	370	1,075	2,456	982	1,053	1,204	269
4 July	628	292	566	436	519	198	468	858	439	393	633	450	396	488	714	1,855	1,212	715	778	844
5 July	596	482	1,106	853	316	225	429	705	667	1,067	657	606	369	787	676	1,949	1,684	842	1,454	953
6 July	523	654	879	795	242	331	996	975	720	879	627	612	683	778	645	1,205	1,462	1,231	1,020	718
7 July	769	379	680	929	186	247	1,746	1,050	931	780	1,158	660	936	1,020	887	1,241	1,322	1,932	863	828
8 July	483	725	776	432	139	170	2,142	655	417	867	1,221	462	1,030	1,713	751	1,069	1,666	1,287	882	1,269
9 July	384	471	1,404	309	393	205	2,078	744	519	768	1,618	480	1,047	1,632	568	1,618	1,183	815	1,687	814
10 July	314	1,732	560	359	481	221	955	1,289	450	1,023	3,486	450	717	1,461	908	1,533	1,880	757	1,616	446
11 July	340	1,507	2,010	778	403	143	1,402	509	325	1,146	5,649	171	1,059	1,038	858	1,369	1,693	1,061	1,475	310
12 July	751	1,087	2,763	557	330	1,027	671	828	276	714	4,497	192	560	1,506	575	1,245	1,289	1,208	2,557	431
13 July	747	2,251	910	1,175	308	605	3,572	1,072	570	1,128	5,373	262	401	2,327	1,148	1,288	1,227	2,567	1,643	376
14 July	761	2,370	2,284	1,481	572	689	3,425	1,332	714	4,437	2,031	368	969	2,709	1,448	1,034	697	2,577	1,203	644
15 July	913	2,405	1,111	1,149	542	745	2,353	2,221	750	3,222	4,042	1,118	636	2,808	1,338	450	1,212	1,943	1,427	1,925
16 July	1,466	1,259	1,344	1,011	1,029	703	2,421	3,802	1,962	3,494	3,420	1,416	927	2,264	1,201	1,253	1,107	2,718	1,811	2,266
17 July	1,353	1,520	963	2,395	2,052	570	2,098	4,692	1,128	2,253	4,584	1,424	3,558	1,915	2,415	1,481	1,482	2,262	1,710	1,116
18 July	841	2,180	1,382	2,113	3,114	853	1,472	2,157	3,942	2,820	2,334	1,638	2,784	2,154	2,065	1,001	1,731	2,008	1,142	1,207
19 July	2,071	1,724	425	1,363	1,999	1,128	714	3,504	4,692	2,236	1,146	1,146	1,869	1,919	1,568	915	1,773	1,753	1,786	1,307
20 July	3,709	2,670	820	1,499	1,422	1,144	1,383	2,328	4,779	2,609	1,578	741	3,471	1,155	994	964	1,384	1,566	1,091	1,575
21 July	3,737	3,170	916	787	1,030	799	959	1,695	3,132	3,435	894	1,608	3,354	933	786	970	1,153	1,757	847	1,259
22 July	1,835	1,302	583	573	1,050	619	1,140	1,386	3,465	2,250	1,840	1,411	1,998	702	497	845	2,159	1,401	752	1,017
23 July	1,700	1,502	756	642	2,632	1,449	1,146	1,050	2,421	3,050	1,441	808	1,875	760	526	1,637	1,693	1,812	712	933
24 July	2,998	1,386	783	1,106	2,204	**711**	1,376	1,320	831	3,634	1,080	933	1,748	1,868	529	1,175	1,774	2,044	662	639
25 July	1,915	999	495	810	1,306	**1,713**	2,253	1,444	840	3,240	532	542	1,937	1,761	676	974	1,525	1,107	782	958
26 July	1,968	924	432	671	1,216	**1,296**	1,421	1,432	1,683	2,319	519	723	1,098	1,034	667	930	1,149	941	1,050	874
27 July	1,523	960	618	755	1,195	**1,561**	1,945	1,289	1,806	1,782	438	807	3,066	992	775	591	1,449	2,277	985	1,073
28 July	2,101	1,398	538	**603**	1,901	**1,957**	1,906	2,226	789	861	333	**954**	1,358	999	1,070	707	909	1,540	814	1,291
29 July	1,923	1,400	441	**546**	1,146	**1,533**	1,400	1,333	558	474	401	**1,255**	1,185	1,029	928	406	808	1,724	989	1,602
30 July	2,595	1,158	391	**382**	791	**1,198**	1,680	1,769	510	621	450	**1,556**	969	577	508	571	691	1,523	1,059	1,225
31 July	2,372	910	383	**316**	974	**951**	873	1,808	480	1,548	420	**1,344**	1,308	549	883	540	751	1,480	819	762
1 August	470	925	351	**393**	897	**921**	776	1,037	474		247	**909**	591	695	455	642	377	1,078	689	669
2 August	314	781	201	**388**	867	**1,018**	626	1,223	369		291	**1,512**	468	421	459	553	394	688	682	605
3 August	263	989	132	**533**	392	**837**	350	1,078	447		213	**1,006**	642	294	504	752	379	722	660	576

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Date/Year	1987	1988	1989	**1990**	1991	**1992**	1993[a]	1994[a]	1995	1996	1997	**1998[b]**	1999[b]	2000[b]	2001[b]	2002[b]	2003[b]	2004[b]	2005[b]	2006[b]
4 August	835	1,524	142	**717**	331	**862**	467	658	519			**1,131**	444	453	840	995		754	587	769
5 August	904	1,091	107	**723**	174	**861**	711	536	404			**1,094**	436	489	581	575		940	464	1,632
6 August	648	1,333	107	**552**	343	**654**	1,076	1,042	408			**864**	654	504	417	754[c]		1,009[c]	776[c]	912
7 August	694	1,186	65	**516**	618	**558**	655	797	279			**843**	678	366	618	676[c]		905[c]	696[c]	880
8 August	658	1,449		**682**	600	**217**	682		267			**750**	804	417	467	636[c]		854[c]	657[c]	1,095
9 August	368	1,132		**679**		**165**	424		272			**570**	328	399	232	456[c]		611[c]	470[c]	444[j]
10 August	312	755		**678**		**249**	252					**496**	165	397	200	337[c]		451[c]	347[c]	307[j]
11 August		698		**547**																
12 August				**362**																
13 August				**221**																
14 August				**139**																
15 August				**150**																
Total	48,123	52,008	29,035[d]	**33,474**	34,614	**30,314**	51,991	53,474[e]	44,336[f]	53,934[g]	54,881[h]	**34,878**	48,069	44,517	33,916	41,807	41,659[i]	56,205	43,240	37,743

Note: Bold and outlined numbers represent dates when the Chinook salmon fishery was restricted because of 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-b).

[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 3 consecutive days of passage less than 1% of the cumulative passage.

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

APPENDIX H. ECHO-LENGTH STANDARD DEVIATION MIXTURE MODEL ESTIMATES OF SPECIES COMPOSITION AND CHINOOK SALMON ABUNDANCE, EARLY RUN, KENAI RIVER, 2006

Appendix H1.-Echo-length standard deviation mixture model estimates of species composition and Chinook salmon abundance, early run, Kenai River, 2006.

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

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

Consequently, we have developed other methods, based on mixture models, which extract information about species composition from the frequency distribution of echo-length measurements. Because the mixture model approach incorporates information about fish size distributions, and because it explicitly models the expected variability in hydroacoustic measurements, it is not subject to the above pitfalls. There is no bias against extreme proportions, and the estimates are germane to the entire population of Chinook salmon, not just those Chinook larger than sockeye. Finally, as long as length and hydroacoustic measurements are paired in time, mixture model estimates of species proportions are unbiased in the presence of temporal changes in fish size distribution. An abbreviated description of the approach is presented here, along with results from the 2006 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:

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

where m was the number of echoes and w_j was the length of the j^{th} echo measured in 48 kHz sample units at –12 dB or higher, depending on peak echo amplitude. If peak amplitude was >12 dB above the voltage threshold, then echo length was measured at 12 dB below peak amplitude. If peak amplitude was 6-12 db above the threshold, echo length was measured at the threshold. If peak amplitude was <6 dB above threshold, w_j was not defined.

Recent work (unpublished) indicates that targets with less than m = 8 measurements of w have unstable estimates of ELSD. Most of these fish are located where the beam is narrow near shore are likely to be sockeye salmon. Therefore, only those fish with $m \geq 8$ were used in the analysis. These fish comprised >97% of all fish in the 2006 early run dataset. The remaining <3% were assumed to be sockeye salmon.

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

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

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

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

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

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

Thus, the component distributions $f_S(y)$ and $f_C(y)$ were functions of the length distributions $f_S(x)$ and $f_C(x)$ and the linear model parameters β_0, β_1, γ, and σ^2 (Figure H2). The species proportions π_S and π_C were the parameters of interest.

Length measurements were obtained from fish captured by gillnets (Reimer 2004) immediately downstream of the sonar site. Length data were paired with hydroacoustic data from the same time periods. In this analysis, we assume no gillnet size selectivity.

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

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

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

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

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

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

The overall design was a mixture of (transformed) mixtures. That is, the observed hydroacoustic data were modeled as a two-component mixture of *y*, each component of which was transformed from a three-component normal mixture of *x*. WinBUGS (Bayes Using Gibbs Sampler) code can be found in Appendix Table H1.

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 (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. Age proportion priors were informative $\{\theta_{Sa}\}$~Dirichlet(0.01,0.5,3.5) and $\{\theta_{Ca}\}$~Dirichlet(4,10,29), developed from a hierarchical analysis of all 2005 data. 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[8] (Appendix Table H2).

WinBUGS uses Markov chain Monte Carlo methods to sample from the joint posterior distribution of all unknown quantities in the model. We started three Markov chains for each run and monitored Gelman-Rubin statistics to assess convergence. Some parameters exhibited slow mixing and large positive autocorrelations. Therefore, relatively long burn-ins of 10,000 or more samples were used and samples thereafter, were thinned up to 10 to 1. At least 10,000 samples per chain were retained.

The end product of a Bayesian analysis is the joint posterior probability distribution of all unknowns in the model. For our model, this distribution has many dimensions and cannot be presented in its entirety. Generally, what is of interest are the marginal (one-dimensional) probability distributions of the parameters. These probability distributions can be graphed, and one can extract whichever statistics are needed, such as the mean, standard deviation, and/or various percentiles like 2.5, 5, 25, 50 (the median), 75, 95, 97.5. For values that can be interpreted as point estimates, we have chosen the posterior median. The interpretation of this value is as follows: there is an even (50/50) chance that the true value of the parameter lies above or below the posterior median. The posterior standard deviation (SD) is analogous to the standard error of an estimate from a classical (non-Bayesian) statistical analysis.

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 day *i*, from 30 May through 30 June.

$$\hat{y}_i'' = \hat{\pi}_{Ci}\hat{x}_i \qquad \text{(H8)}$$

[8] Rather than attempt to specify a multivariate prior distribution for the regression intercept, slope, and error variance based on the tethered fish results, the model and data for the tethered fish experiments were run concurrently with each daily/weekly iteration of the mixture model. Thus the informative multivariate prior for the regression parameters was effectively re-created with every run of the mixture model.

Sample size limitations necessitated pooling the data to obtain estimates of the Chinook proportion by week for the first two weeks (16-22 May and 23-29 May). These were multiplied by the weekly sum of unfiltered sonar estimates to obtain abundance estimates for week w.

$$\hat{y}''_w = \hat{\pi}_{Cw} \sum_{i \in w} \hat{x}_i \qquad \text{(H9)}$$

For graphical comparisons with previous years (Figure H3), weekly estimates of the proportions for the remaining weeks were calculated, as follows:

$$\hat{\pi}'_{Cw} = \frac{\sum_{i \in w} \hat{y}''_i}{\sum_{i \in w} \hat{x}_i} \qquad \text{(H10)}$$

Results

Statistics from the marginal posterior distributions of model parameters are summarized in Table H1. With few exceptions, posterior distributions of regression parameters shifted only slightly among days / weeks. Mixture model estimates totaled 15,738 (SE = 604) for the early run, lower than the official estimate of 23,326 (SE = 394) and higher than the net-apportioned estimate of 7,456 (SE = 505). Modeled ELSD frequency distributions fit the ELSD data well (Figure H4). Mixture model estimates were between net-apportioned estimates and official estimates for most of the season (Figure H5). Weekly estimates of Chinook salmon proportion by the two alternative methods have shown reasonably good agreement during 2002-2006 (Figure H3). Further comparisons of alternative early-run abundance estimates can be found in this report (see Results).

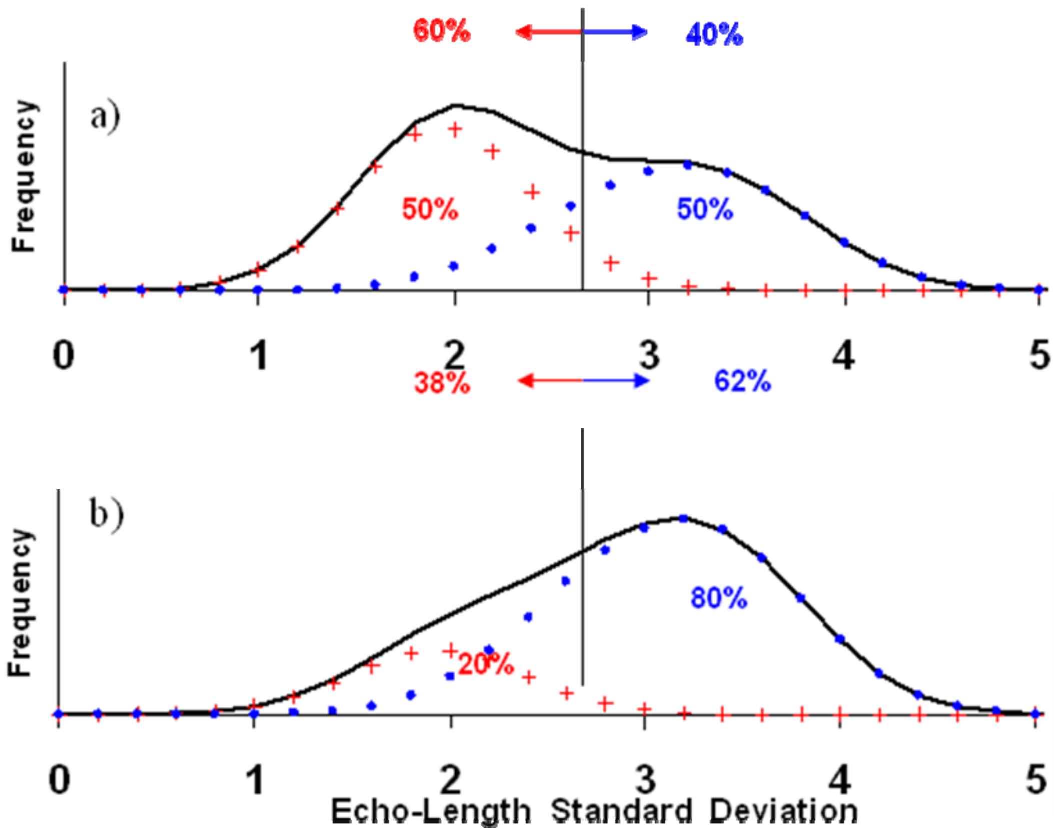


Figure H1.-Threshold-based discrimination is subject to bias when discriminating variables are imprecise. Solid lines are simulated frequency distributions of echo-length standard deviation arising from component distributions due to sockeye salmon (plus symbols) and Chinook salmon (solid symbols). a)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

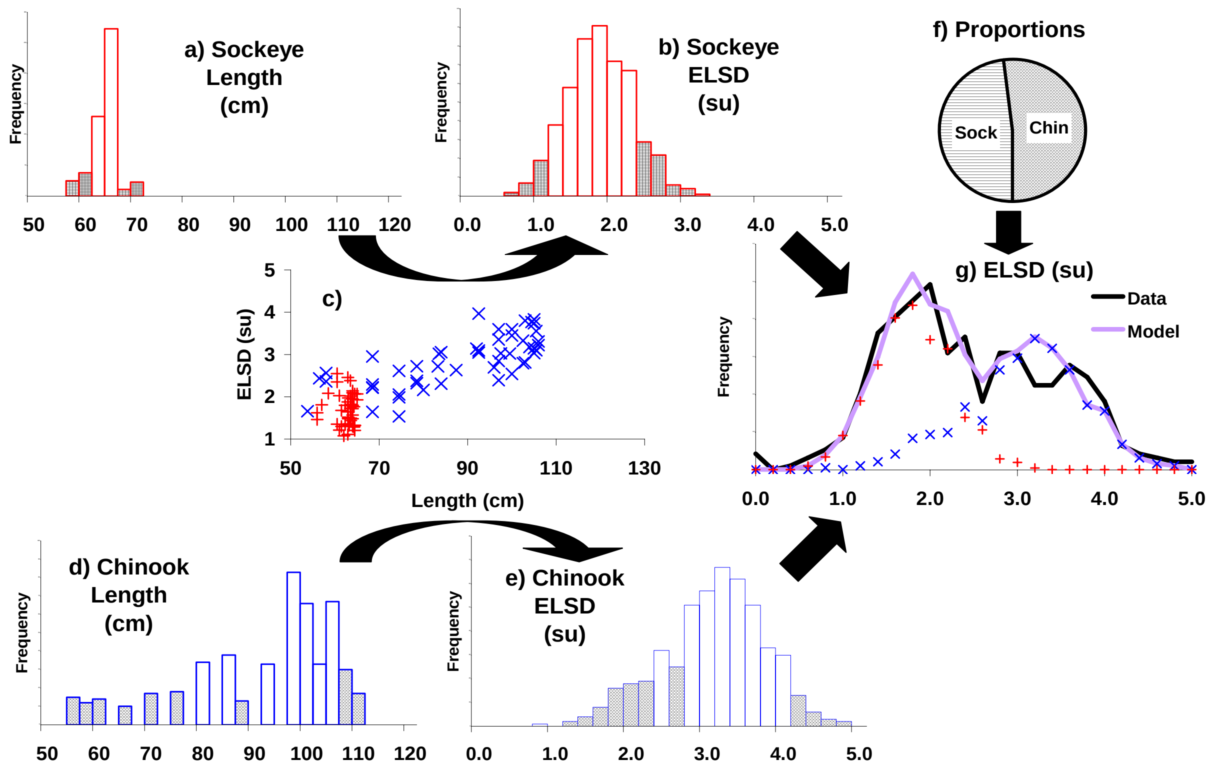


Figure H2.-Flow chart of mixture model. The frequency distribution of echo-length standard deviation (ELSD, panel g) is modeled as a weighted mixture of species-specific ELSD distributions (panels b and e), which in turn are the products of species-specific size distributions (panels a and d) and the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

Appendix Table H1.-WinBUGS code for ELSD mixture model fit to 2006 early-run Kenai River Chinook salmon sonar, gillnetting, and tethered fish data.

```
model{
  beta0 ~ dnorm(0,1.0E-4)
  beta1 ~ dnorm(0,1.0E-4)
  gamma ~ dnorm(0,1.0E-4)
  sigma.elsd ~ dunif(0,2)
  sigma.beta0 ~ dunif(0,2)
  tau.elsd  <- 1 / sigma.elsd / sigma.elsd
  tau.beta0 <- 1 / sigma.beta0 / sigma.beta0
  ps[1:2] ~ ddirch(D.species[])
  pa[1,1:3] ~ ddirch(D.age.chinook[])
  pa[2,1:3] ~ ddirch(D.age.sockeye[])
  p.chin <- ps[1] * p_n
  Lsig[1] <- 75
  Lsig[2] <- 25
  Ltau[1] <- 1 / Lsig[1] / Lsig[1]
  Ltau[2] <- 1 / Lsig[2] / Lsig[2]
  mu[1,1] ~ dnorm(636,0.0006)
  mu[1,2] ~ dnorm(816,0.0070)
  mu[1,3] ~ dnorm(1032,0.0006)
  mu[2,1] ~ dnorm(380,0.003)
  mu[2,2] ~ dnorm(500,0.006)
  mu[2,3] ~ dnorm(580,0.006)
  D.age.chinook[1] <- 1
  D.age.chinook[2] <- 2
  D.age.chinook[3] <- 7
  D.age.sockeye[1] <- 0.01
  D.age.sockeye[2] <- 0.5
  D.age.sockeye[3] <- 3.5
  for (y in 1:3) {
    beta0.y[y] ~ dnorm(beta0,tau.beta0)
    }
  beta0.predict ~ dnorm(beta0,tau.beta0)
  for (k in 1:141) {
    elsd1[k] ~ dnorm(mu.elsd1[k],tau.elsd)
    mu.elsd1[k] <- beta0.y[year[k]] + beta1 * cm75[k] + gamma * sock.indic[k]
    }
  for (i in 1:nfish) {
    age[i] ~ dcat(pa[species[i],1:3])
    mefl[i] ~ dnorm(mu[species[i],age[i]],Ltau[species[i]])
    }
  for (j in 1:ntgts) {
    species2[j] ~ dcat(ps[])
    age2[j] ~ dcat(pa[species2[j],1:3])
    mefl2[j] ~ dnorm(mu[species2[j],age2[j]],Ltau[species2[j]])
    elsd2[j] ~ dt(mu.elsd2[j],tau.elsd,8)
    cm75t[j] <- (mefl2[j] / 10) - 75;
    sock.indic2[j] <- species2[j] - 1;
    mu.elsd2[j] <- beta0.predict + gamma*sock.indic2[j] + beta1 * cm75t[j]
    }
}
```

Appendix Table H2.-Prior and posterior medians and standard deviations of model parameters, and the resulting estimates of Chinook salmon passage, from a Bayesian mixture model of Kenai River sonar and gillnetting data, 2006.

Date	Sonar n	Netting n	β_0	SD(β_0)	β_1	SD(β_1)	γ	SD(γ)	σ	SD(σ)	π_C	SD(π_C)	$\hat{y}''$	se($\hat{y}''$)
inf. prior[a]			2.87	0.27	0.032	0.003	-0.33	0.11	0.43	0.03				
16-22 May	13	117	2.88	0.11	0.038	0.003	-0.31	0.12	0.48	0.03	0.536	0.051	207	25
23-29 May	36	292	2.54	0.09	0.033	0.003	-.036	0.11	0.43	0.02	0.221	0.032	204	31
30-May	134	35	2.36	0.10	0.032	0.003	-0.34	0.11	0.43	0.02	0.216	0.045	91	21
31-May	185	1	2.76	0.10	0.032	0.003	-0.31	0.11	0.45	0.02	0.287	0.050	162	32
1-Jun	325	71	2.65	0.10	0.033	0.003	-0.31	0.12	0.45	0.02	0.268	0.043	266	47
2-Jun	239	3	2.76	0.10	0.032	0.003	-0.31	0.11	0.45	0.02	0.287	0.050	228	47
3-Jun	166	13	2.67	0.11	0.032	0.003	-0.33	0.12	0.45	0.02	0.252	0.054	127	35
4-Jun	158	10	2.70	0.10	0.032	0.003	-0.34	0.11	0.43	0.02	0.353	0.052	169	32
5-Jun	90	7	2.49	0.13	0.033	0.003	-0.33	0.12	0.45	0.03	0.388	0.074	107	24
6-Jun	129	8	2.84	0.12	0.033	0.003	-0.32	0.11	0.45	0.03	0.430	0.080	172	40
7-Jun	151	23	2.76	0.11	0.033	0.003	-0.34	0.11	0.44	0.03	0.476	0.075	225	43
8-Jun	189	5	2.69	0.11	0.034	0.003	-0.33	0.12	0.46	0.02	0.350	0.049	204	37
9-Jun	251	68	2.57	0.10	0.032	0.003	-0.35	0.11	0.43	0.02	0.387	0.065	305	56
10-Jun	339	14	2.73	0.10	0.032	0.003	-0.32	0.12	0.46	0.02	0.326	0.063	337	72
11-Jun	380	78	2.61	0.09	0.031	0.003	-0.33	0.11	0.42	0.02	0.292	0.075	340	91
12-Jun	384	14	2.66	0.10	0.031	0.003	-0.33	0.11	0.42	0.02	0.305	0.049	352	61
13-Jun	439	76	2.67	0.10	0.030	0.003	-0.33	0.11	0.42	0.02	0.426	0.067	566	99
14-Jun	528	8	2.79	0.09	0.031	0.003	-0.32	0.10	0.41	0.02	0.328	0.054	522	119
15-Jun	639	82	2.84	0.09	0.032	0.003	-0.34	0.11	0.43	0.02	0.355	0.057	652	120
16-Jun	690	10	2.87	0.09	0.032	0.003	-0.35	0.11	0.42	0.02	0.253	0.039	482	87
17-Jun	802	52	2.82	0.08	0.031	0.003	-0.33	0.11	0.42	0.02	0.283	0.043	702	112
18-Jun	596	11	2.79	0.09	0.031	0.002	-0.34	0.10	0.40	0.02	0.391	0.060	707	121
19-Jun	460	35	2.86	0.10	0.033	0.003	-0.30	0.12	0.47	0.02	0.269	0.050	378	76
20-Jun	572	5	2.95	0.09	0.032	0.003	-0.30	0.11	0.43	0.02	0.314	0.048	546	94
21-Jun	414	26	2.87	0.11	0.033	0.003	-0.28	0.12	0.47	0.02	0.461	0.080	577	123
22-Jun	518	2	2.82	0.13	0.032	0.003	-0.31	0.11	0.45	0.02	0.682	0.135	1,071	231
23-Jun	448	29	2.97	0.10	0.031	0.003	-0.30	0.11	0.45	0.02	0.466	0.095	631	136
24-Jun	466	3	2.89	0.12	0.032	0.003	-0.31	0.12	0.44	0.03	0.480	0.119	686	181
25-Jun	355	36	2.85	0.10	0.033	0.003	-0.29	0.11	0.46	0.03	0.513	0.071	560	89
26-Jun	309	4	2.92	0.12	0.032	0.003	-0.31	0.11	0.44	0.02	0.656	0.084	617	123
27-Jun	495	44	2.82	0.10	0.032	0.003	-0.34	0.12	0.45	0.02	0.666	0.079	998	159
28-Jun	371	14	2.89	0.11	0.033	0.003	-0.31	0.12	0.46	0.02	0.551	0.083	635	111
29-Jun	470	47	2.96	0.10	0.032	0.002	-0.36	0.11	0.44	0.02	0.634	0.081	923	131
30-Jun	485	14	2.84	0.15	0.034	0.003	-0.28	0.11	0.45	0.02	0.645	0.126	989	209
total													15,738	604

[a] informative prior on regression parameters from tethered fish experiments.

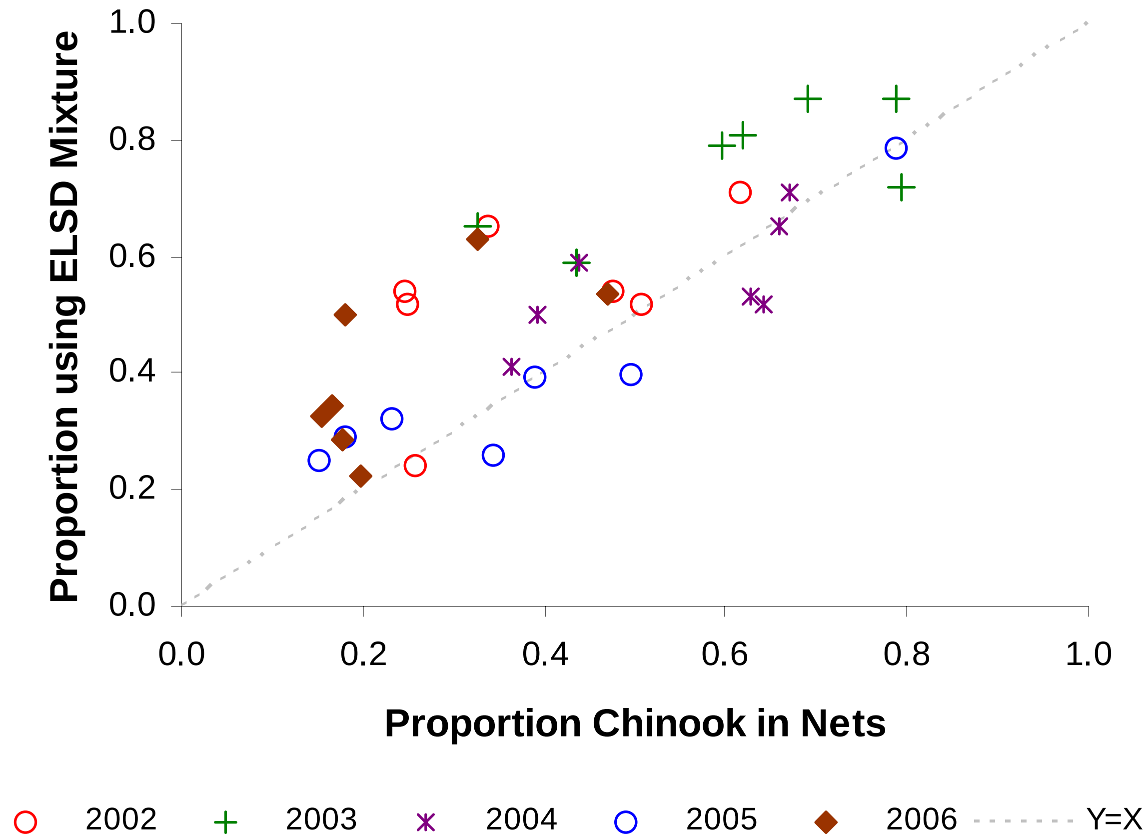


Figure H3.-Weekly ELSD mixture model estimates vs. net-apportioned estimates of the proportion of fish passing the Kenai River sonar site that are Chinook salmon, early run, 2002-2006.

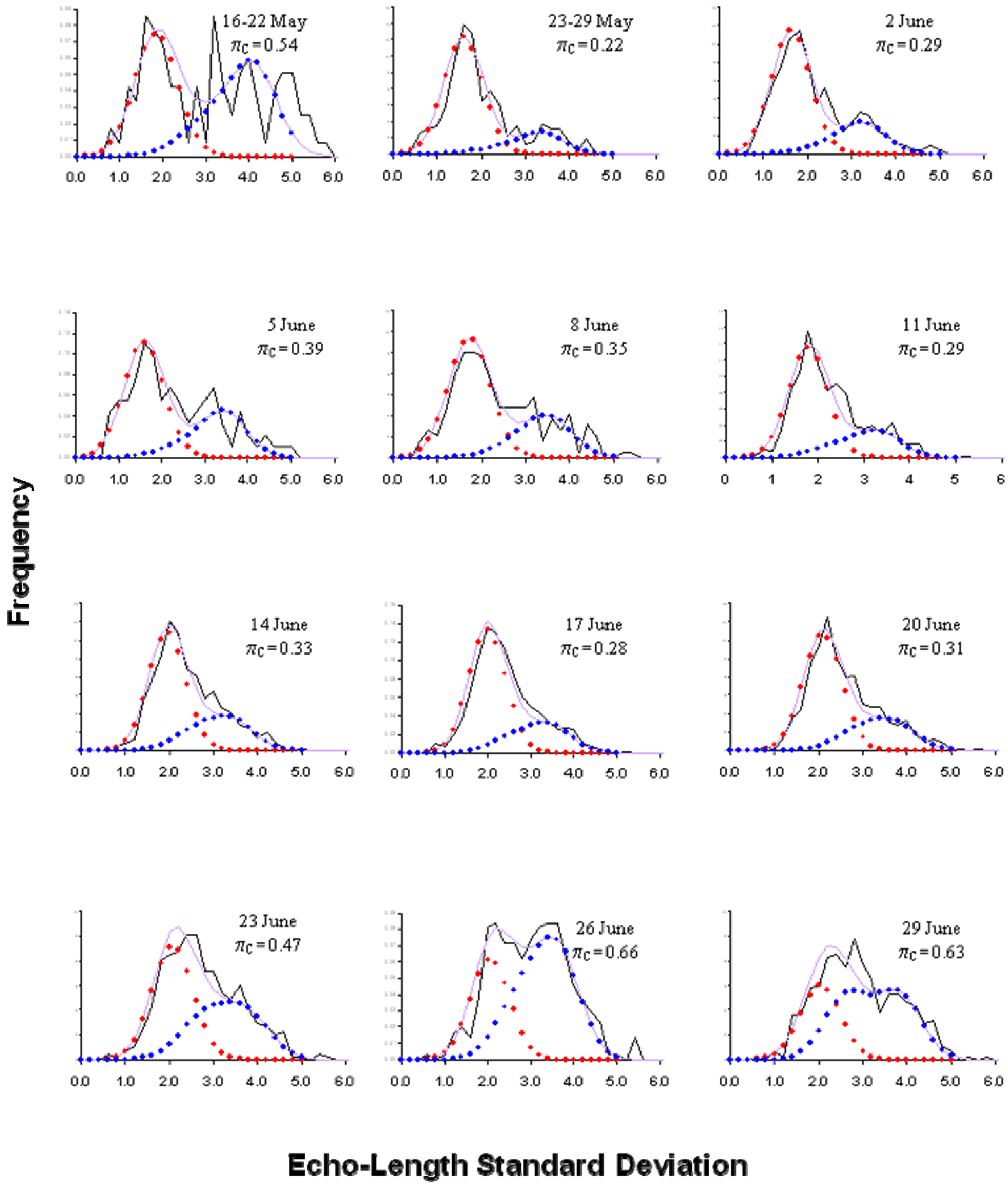
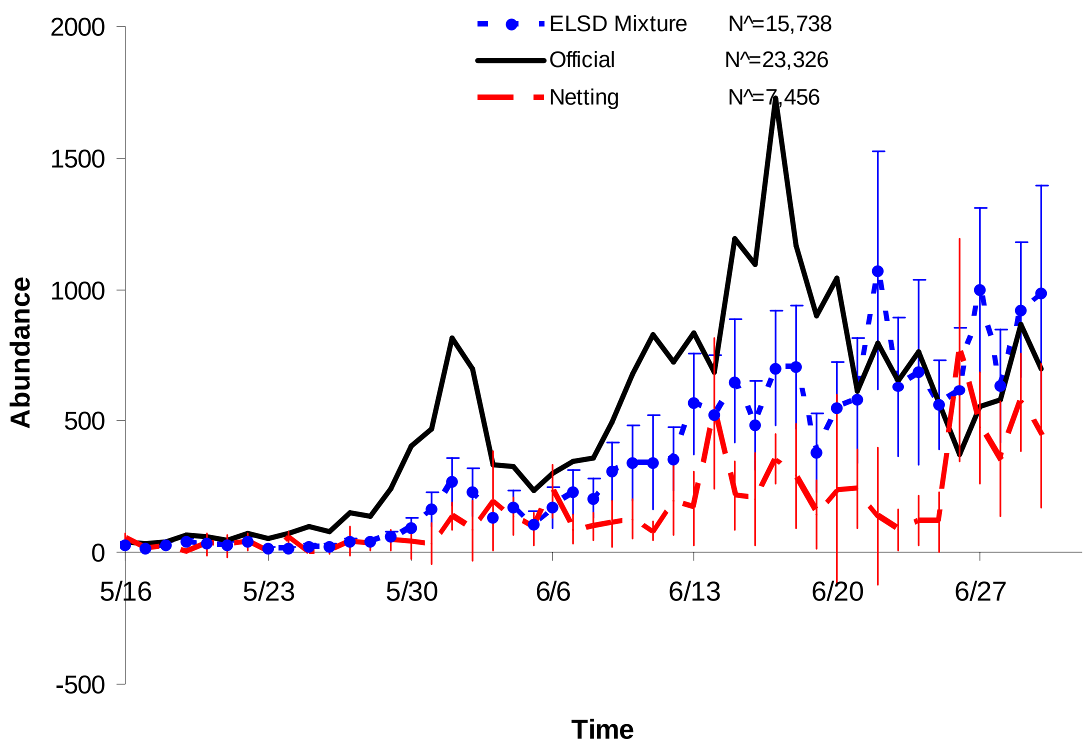


Figure H4.-Observed (black) and fitted (gray) frequency distributions of echo-length standard deviation (ELSD) for selected days of the 2006 early run. Dotted-lines are the component distributions from sockeye (left) and Chinook salmon (right). The posterior median of the proportion of Chinook salmon p_C is listed in the header of each panel.



Solid-line = official estimates; dashed-line = net –apportioned estimates; dotted-line = ELSD mixture model estimates. Error bars represent 95% CI for gillnetting and mixture estimates.

Figure H5.-Chinook salmon abundance estimates for the 2006 Kenai River early run.

APPENDIX I. FILTERED (CONVENTIONAL), UNFILTERED, AND NET-APPORTIONED CHINOOK SALMON PASSAGE ESTIMATES, KENAI RIVER SONAR, EARLY AND LATE RUNS, 2006

Appendix I1.-Estimated fish passage based on unfiltered sonar (all species), standard filtered sonar (Chinook salmon only), and net-apportioned sonar (alternative Chinook salmon only), Kenai River, early run, 2006.

	Unfiltered		Filtered (Standard)		Net-Apportioned	
Date	Passage	SE	Passage	SE	Passage	SE
16-May	53	10	40	7	53	10
17-May	30	8	30	8	13	4
18-May	45	13	39	10	23	6
19-May	72	13	66	12	0	0
20-May	60	6	57	5	29	20
21-May	54	11	48	11	26	22
22-May	72	15	72	15	37	17
23-May	54	11	51	10	0	0
24-May	69	10	69	10	55	13
25-May	102	14	96	14	0	0
26-May	90	21	81	20	8	7
27-May	177	18	152	17	42	28
28-May	163	14	135	14	33	14
29-May	266	23	242	24	44	19
30-May	419	44	401	44	42	34
31-May	565	55	469	39	33	38
1-Jun	991	74	820	64	137	27
2-Jun	794	92	702	89	84	58
3-Jun	503	88	334	28	196	96
4-Jun	479	57	326	34	136	35
5-Jun	276	33	231	26	90	31
6-Jun	399	57	297	42	231	52
7-Jun	473	53	343	45	87	29
8-Jun	583	69	357	39	101	26
9-Jun	788	59	495	57	108	46
10-Jun	1,035	96	684	70	127	38
11-Jun	1,166	89	832	67	81	18
12-Jun	1,155	76	727	49	198	68
13-Jun	1,329	103	835	80	166	71
14-Jun	1,591	253	688	85	528	148
15-Jun	1,836	166	1,196	95	214	66
16-Jun	1,907	184	1,099	108	200	89
17-Jun	2,481	127	1,730	103	359	51
18-Jun	1,808	136	1,167	90	291	101
19-Jun	1,404	115	901	69	144	67
20-Jun	1,739	140	1,046	87	236	184
21-Jun	1,251	159	612	66	240	75
22-Jun	1,570	137	797	65	136	132
23-Jun	1,355	99	657	95	83	41
24-Jun	1,429	132	763	81	120	47
25-Jun	1,092	84	562	70	115	57
26-Jun	940	145	369	60	767	217
27-Jun	1,499	160	553	51	476	109
28-Jun	1,153	104	578	65	353	111
29-Jun	1,456	92	873	70	571	97
30-Jun	1,534	125	704	63	443	141
Total	38,307	659	23,326	394	7,456	505

Appendix I2.-Estimated fish passage based on unfiltered sonar (all species), standard filtered sonar (Chinook salmon only), and net-apportioned sonar (alternative Chinook salmon only), Kenai River, late run, 2006.

Date	Unfiltered		Filtered (Standard)		Net-Apportioned	
	Passage	SE	Passage	SE	Passage	SE
1-Jul	1,360	131	580	48	355	126
2-Jul	857	83	343	37	332	74
3-Jul	580	49	269	21	478	82
4-Jul	1,593	91	844	45	852	127
5-Jul	1,779	125	953	77	997	117
6-Jul	1,526	118	718	64	953	149
7-Jul	1,618	136	828	69	762	122
8-Jul	2,369	139	1,269	79	962	85
9-Jul	1,857	181	814	70	544	122
10-Jul	1,066	95	446	52	945	105
11-Jul	800	86	310	39	709	93
12-Jul	948	83	431	31	654	100
13-Jul	970	105	376	46	721	121
14-Jul	1,426	125	644	76	985	252
15-Jul	3,938	266	1,925	146	2,166	491
16-Jul	5,458	410	2,266	188	3,339	637
17-Jul	2,244	202	1,116	95	1,814	191
18-Jul	2,413	206	1,207	102	2,057	177
19-Jul	2,955	245	1,307	100	2,100	333
20-Jul	3,482	332	1,575	109	2,298	436
21-Jul	3,235	280	1,259	116	1,989	406
22-Jul	3,268	339	1,017	73	1,619	575
23-Jul	3,093	344	933	108	2,096	345
24-Jul	1,470	169	639	58	1,027	158
25-Jul	1,806	215	958	68	1,165	229
26-Jul	2,134	263	874	74	1,420	242
27-Jul	2,547	248	1,073	71	1,812	198
28-Jul	3,447	322	1,291	104	2,607	414
29-Jul	4,323	408	1,602	137	3,339	351
30-Jul	2,628	167	1,225	87	1,914	193
31-Jul	1,232	105	762	77	1,065	113
1-Aug	1,034	66	669	70	623	89
2-Aug	1,002	63	605	41	787	85
3-Aug	868	49	576	40	731	51
4-Aug	1,308	59	769	43	994	79
5-Aug	3,195	185	1,632	80	1,886	261
6-Aug	1,700	155	912	59	1,145	190
7-Aug	1,667	118	880	95	1,171	171
8-Aug	2,812	246	1,095	111	1,340	120
Total	82,008	1,285	36,992	526	52,753	1,596