Fishery Data Series No. 02-24

Estimates of Chinook Salmon Abundance in the Kenai River Using Split-Beam Sonar, 1999

by

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and

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December 2002

Alaska Department of Fish and Game
Division of Sport Fish

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Weights and measures (metric)

centimeter	cm
deciliter	dL
gram	g
hectare	ha
kilogram	kg
kilometer	km
liter	L
meter	m
metric ton	mt
milliliter	ml
millimeter	mm

Weights and measures (English)

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

Spell out acre and ton.

Time and temperature

day	d
degrees Celsius	°C
degrees Fahrenheit	°F
hour (spell out for 24-hour clock)	h
minute	min
second	s

Spell out year, month, and week.

Physics and chemistry

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

General

All commonly accepted abbreviations.	e.g., Mr., Mrs., a.m., p.m., etc.
All commonly accepted professional titles.	e.g., Dr., Ph.D., R.N., etc.
and	&
at	@
Compass directions:	
east	E
north	N
south	S
west	W
Copyright	©
Corporate suffixes:	
Company	Co.
Corporation	Corp.
Incorporated	Inc.
Limited	Ltd.
et alii (and other people)	et al.
et cetera (and so forth)	etc.
exempli gratia (for example)	e.g.,
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
number (before a number)	# (e.g., #10)
pounds (after a number)	# (e.g., 10#)
registered trademark	®
trademark	™
United States (adjective)	U.S.
United States of America (noun)	USA
U.S. state and District of Columbia abbreviations	use two-letter abbreviations (e.g., AK, DC)

Mathematics, statistics, fisheries

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	C.I.
correlation coefficient	R (multiple)
correlation coefficient	r (simple)
covariance	cov
degree (angular or temperature)	°
degrees of freedom	df
divided by	÷ or / (in equations)
equals	=
expected value	E
fork length	FL
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.
mideye-to-fork	MEF
minute (angular)	'
multiplied by	x
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
standard length	SL
total length	TL
variance	Var

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December 2002

This investigation was partially financed by the Federal Aid in Sport Fish Restoration Act (16 U.S.C. 777-777K) under project F-10-15, Job No. S-2-5b.

The Fishery Data Series was established in 1987 for the publication of technically-oriented results for a single project or group of closely related projects. Fishery Data Series reports are intended for fishery and other technical professionals. Fishery Data Series reports are available through the Alaska State Library and on the Internet: http://www.sf.adfg.state.ak.us/statewide/divreports/html/intersearch.cfm This publication has undergone editorial and peer review.

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This document should be cited as:
Miller, J. D., D. Bosch., and D. Burwen. 2002. Estimates of chinook salmon abundance in the Kenai River using split-beam sonar, 1999. Alaska Department of Fish and Game, Fishery Data Series No. 02-24, Anchorage.

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ABSTRACT

The passage of chinook salmon *Oncorhynchus tshawytscha* in the Kenai River was estimated using side-looking split-beam sonar technology in 1999. 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 migrating adult chinook salmon returning to their natal stream. From 1987 to 1994, a 420 kHz dual-beam sonar was used to generate similar estimates. In 1999, total upstream chinook salmon passage from 16 May through 10 August was an estimated 73,735 (SE = 812) fish, 25,666 (SE = 370) during the early run and 48,069 (SE=723) during the late run. The daily peak of the early run occurred on 25 June with 50% of the run having passed by 17 June. The daily peak of the late run occurred on 17 July, with 50% of the late run having passed by 22 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. The fishery has been politically volatile because the Upper Cook Inlet commercial sockeye fishery and subsistence and personal use fisheries also harvest chinook salmon during the months of July and August.

Chinook salmon returning to the Kenai River are managed as two distinct runs, early and late, which typically peak in mid-June and late July (Burger et al. 1985). Early-run chinook are harvested primarily by sport anglers; late-run chinook by commercial, sport, subsistence, and personal use fisheries. These fisheries may be restricted if the projected run size falls below escapement goals set by the Alaska Board of Fisheries (ADF&G 1990). From 1989 through 1998 these runs were managed for spawning escapement goals of 9,000 for early-run (16 May-30 June) and 22,300 for late-run (1 July-10 August) chinook salmon (McBride et al. 1989). In February 1999, the Alaska Board of Fisheries set new escapement goals based on the escapement of chinook salmon estimated by sonar and our best understanding of its biases (Hammarstrom and Hasbrouck 1998; 1999; Bosch and Burwen 1999). The new escapement goals define a range of escapement levels desired for the early run at 7,700 to 14,000 chinook (5 AAC 56.070 Kenai River early run chinook management plan) and the late run at 23,000 to 37,000 chinook (5 AAC 21.359 Kenai River late run chinook management plan). These escapement goal ranges should provide for a more stable fishing season without compromising either run.

Sonar estimates of inriver return 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 a contentious issue for the state, one that commands much public attention. Restrictions on the sport fishery were imposed in each year from 1989 through 1992 to ensure optimum escapement goals were met. Since 1993, both 1997 and 1998 early runs, and the 1998 late run required a restriction of the sport fishery to meet escapement goals.

The first estimates of chinook abundance were generated for the 1984 late run with a mark-recapture project using drift gillnets (Hammarstrom et al. 1985). The mark-recapture project produced estimates

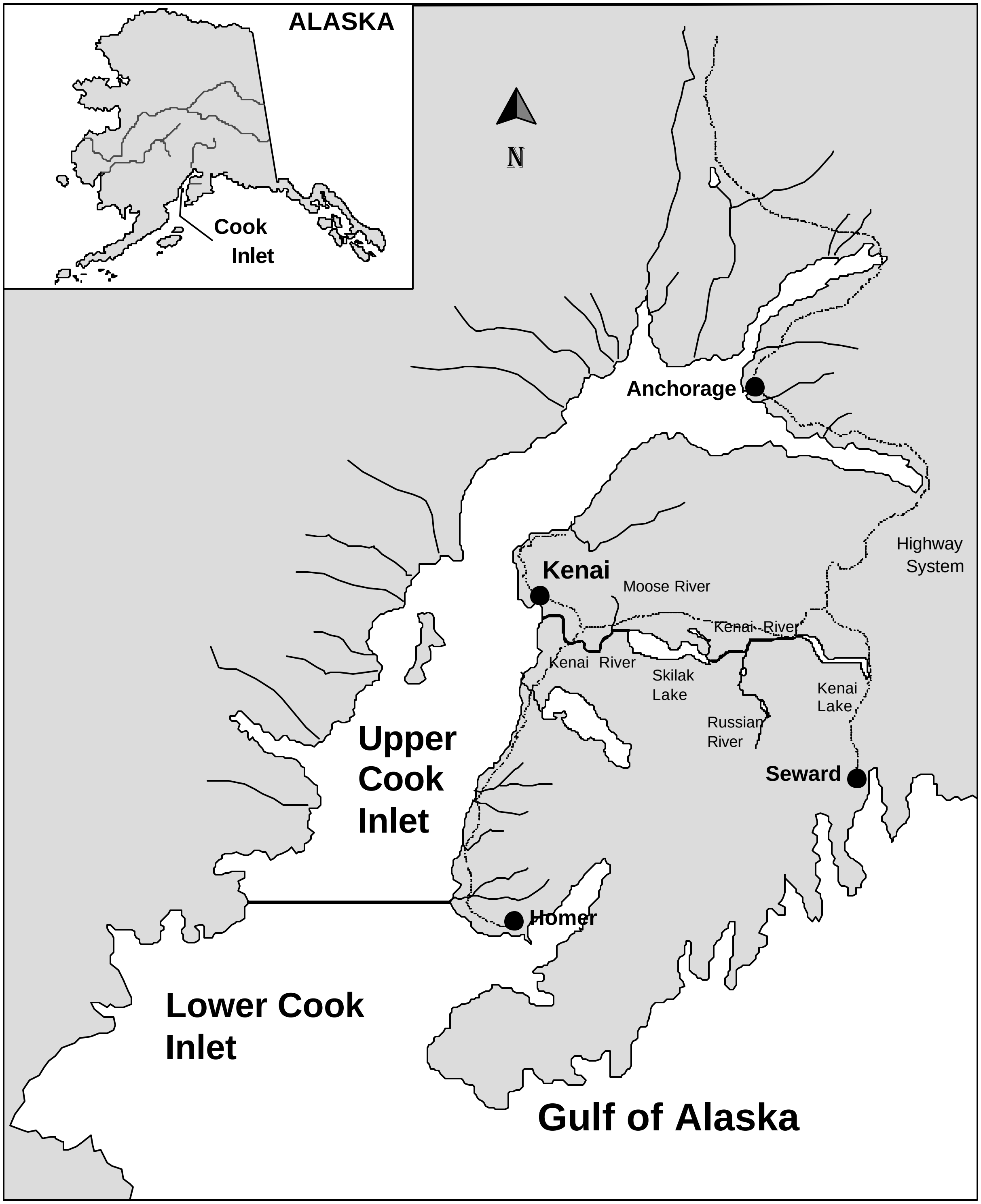

Figure 1.-Cook Inlet showing location of the Kenai River.

of riverine abundance through 1990 (Hammarstrom and Larson 1986); Conrad and Larson 1987; Conrad 1988; Carlon and Alexandersdottir 1989; Alexandersdottir and Marsh 1990). These estimates had low precision and were biased high (Bernard and Hansen 1992). The low precision and high bias were more apparent in the late-run estimates due to lower tagging rates and the "backing out" of marked fish. It was hypothesized that handling of marked fish resulted in a higher fraction of marked fish than unmarked fish moving back downstream into Cook Inlet where they were subsequently harvested in the commercial fishery, thus becoming unavailable for recapture.

In order to obtain timely and accurate estimates of chinook salmon passage, the department initiated studies to determine whether an acoustic assessment program could be developed to provide daily estimates of chinook salmon into the Kenai River (Eggers et al. 1995). Acoustic assessment of chinook salmon in the Kenai River is complicated by the presence of more abundant sockeye salmon *O. nerka*, which migrate concurrently with chinook salmon. Since 1987, sockeye salmon escapement estimates generated by the mile-19 sockeye sonar project have ranged from 630,000 to 1,600,000 (Davis 2000), while late-run chinook salmon escapement estimates generated by the chinook sonar project have ranged from 29,000 to 55,000. Dual-beam sonar was initially chosen for the chinook sonar project because of its ability to estimate acoustic size (target strength), which was to serve as the discriminatory variable to systematically identify and count only large chinook salmon. Due to the considerable size difference between Kenai River chinook salmon and other species of fish present in the river, it was postulated that dual-beam sonar could be used to distinguish the larger chinook salmon from smaller fish (primarily sockeye) and estimate their numbers returning to the river.

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

Daily and seasonal acoustic estimates of chinook salmon have been generated since 1987. Estimates of total passage made with sonar were consistently lower than the mark-recapture estimates for the years 1987 through 1990 (Eggers et al. 1995). The inconsistencies between sonar and mark-recapture estimates were highest during the late run presumably due to the mark-recapture biases discussed earlier.

A more advanced acoustic technology known as split-beam sonar was used to test assumptions and design parameters of the dual-beam configuration in 1994 (Burwen et al. 1995). The split-beam system provided advantages over the dual-beam system in its ability to determine the 3-dimensional position of an acoustic target in the sonar beam. Consequently, the direction of travel for each target and the spatial distribution (three-dimensional) of fish in the acoustic beam could be determined for the first time. The split-beam system operated at a lower frequency, which resulted in an improved (higher) signal-to-noise ratio (SNR). It also interfaced with improved fish-tracking software, which reduced the interference from boat wake, and improved fish-tracking capabilities (Burwen and Bosch 1996). The split-beam system was deployed side-by-side and run concurrently with the dual-beam for much of the 1994 season (Burwen et al. 1995). In a comparative study, both systems performed similarly, detecting comparable numbers of fish. The split-beam data confirmed earlier studies showing that fish were strongly oriented to the river bottom. However, experiments conducted with the split-beam system could not confirm the validity of discriminating chinook salmon from sockeye salmon based on acoustic size. These results supported modeling exercises performed by Eggers (1994) that also questioned the feasibility of discriminating between chinook and sockeye salmon using target strength. It was hypothesized that discrimination between the two species was primarily accomplished using range thresholds on the acoustic data that exploited the spatial segregation of the species (sockeye salmon migrating nearshore and chinook salmon migrating midriver; (Eggers et al. 1995; Burwen et al. 1995). In 1995, the dual-beam system was replaced with the split-beam system in order to take advantage of the additional information on direction of travel and spatial position of targets.

Two ancillary studies (Burwen et al. 1998) were conducted in 1995 directed at providing more definitive answers to remaining questions regarding: (1) the degree to which sockeye and chinook salmon are spatially separated at the site at river km 14 (river mile 8.5), and (2) the utility of using target strength and/or other acoustic parameters as discriminatory variables for species separation. Results of these studies showed the potential for including sockeye salmon in chinook salmon estimates using current methodology. The netting study found that sockeye salmon were present in the middle insonified portion of the river during the study period, and in a concurrent tethered, live-fish experiment, most sockeye salmon tethered in front of the split-beam sonar had mean target strengths exceeding the target strength threshold.

To address concerns raised by these studies, radiotelemetry projects were implemented in 1996 and 1997 to estimate the magnitude of bias introduced during periods of high sockeye passage. These studies were designed to provide an independent and accurate estimate of inriver chinook abundance during the late run when the potential to misclassify sockeye is greatest. Although the precision was similar, the use of radiotelemetry technology avoided certain biases introduced in previous mark-recapture estimates. In both 1996 and 1997, late-run sonar estimates were 21% higher than the telemetry estimates (Hammarstrom and Hasbrouck 1998, 1999).

An alternative site investigation conducted in 1999 (Burwen et al. 2000) attempted to identify alternative sites above tidal influence that might strengthen the bank-orientation of sockeye salmon and thereby increase the effectiveness of range thresholds in filtering sockeye salmon from chinook salmon abundance estimates. The investigation concentrated on a site located at river km 21.2 (river mile 13.2) that was above tidal influence but below areas of major spawning activity. A netting program indicated that there were fewer sockeye salmon in the offshore area at the alternative site than there were at the current site. However, there were still relatively large numbers of sockeye salmon present in the offshore area of the alternative site during peak migration periods as well as high numbers of chinook salmon present in the nearshore area. The alternative sonar site also had several disadvantages over the current site including greater boat traffic, less acoustically favorable bottom topography, and increased background noise resulting in difficult fish tracking conditions.

We continue to pursue improved techniques for separating chinook and sockeye salmon using acoustic information. Studies with tethered and free-swimming fish indicate that there are other acoustic variables that may provide higher discriminatory power than target strength for separating sockeye and chinook salmon (Burwen and Fleischman 1998). We are also developing methods to estimate target strength more accurately (Fleischman and Burwen 2000). Concurrent with ongoing acoustic research, we are investigating alternate sites above tidal influence that may strengthen the bank-orientation of sockeye salmon and thereby increase the effectiveness of the range threshold in filtering sockeye salmon from chinook salmon abundance estimates.

METHODS

STUDY AREA

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

The Kenai River drainage is located in a transitional zone between a maritime climate and a continental climate (USDA 1992). The geographic position and local topography influence both rainfall and temperature throughout the drainage. Average annual rainfall ranges from over 101 cm in the Kenai Mountains at its source, to 46 cm in the City of Kenai at its mouth. Average summer temperatures in the drainage range from 4°C to 18°C; average winter low temperatures range from -23°C to -40°C (USDA 1992).

SITE DESCRIPTION

The 1999 sonar site was located 14 km (8.5 mi) from the mouth of the Kenai River (Figure 2). This site has been used since 1985 and was selected for its acoustic characteristics and its location relative to the sport fishery and known spawning habitat for chinook salmon.

The river bottom in this area has remained stable for the past 14 years despite a 140-year flood during September 1995 (Joe Dorava, United States Geological Survey [USGS], Anchorage, personal communication). The slope from both banks has remained gradual and uniform, which allows a large proportion of the water column to be insonified without acoustic shadowing effects. On the right bank, the bottom is composed primarily of mud, providing an acoustically absorptive rather than reflective surface. This absorptive property improves the signal-to-noise ratio when the beam is aimed along the river bottom. The left-bank bottom gradient is steeper and consists of more acoustically reflective small rounded cobble and gravel.

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

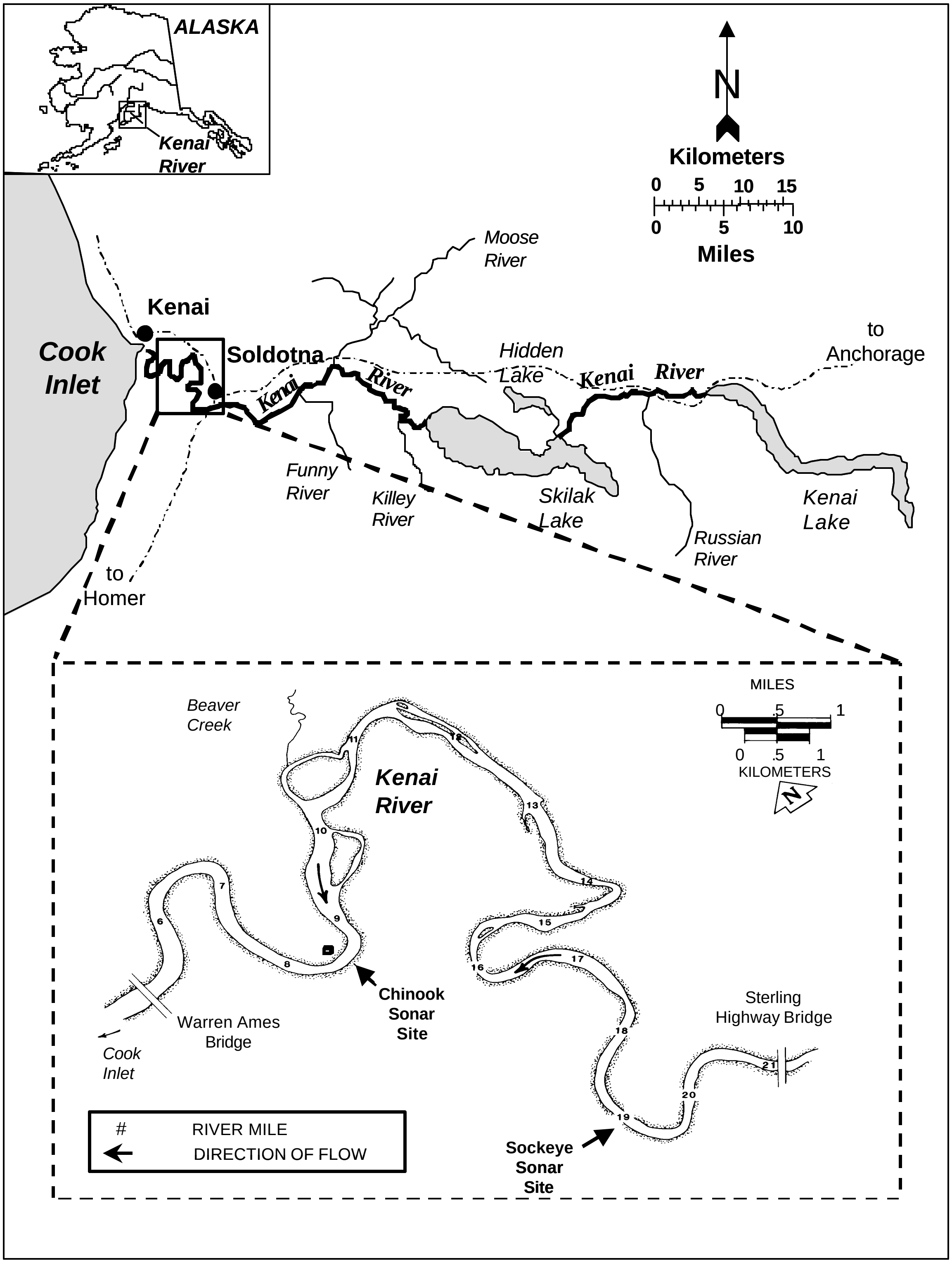

Figure 2.-Kenai River showing location of chinook salmon sonar site, 1999.

ACOUSTIC SAMPLING

A Hydroacoustic Technology Inc. (HTI)[1] split-beam sonar system operated from 16 May through 10 August 1999. Components of the system are listed in Table 1 and are further described in HTI manuals (HTI 1994a, 1994b). A brief explanation of the theory of split-beam sonar and its use in estimating target strength can be found in Appendix A1. A more detailed explanation can be found in (Ehrenberg 1983).

Sonar System Configuration

Sampling on both banks was controlled by electronics housed in a tent located on the right bank of the river. Communication cables led to transducers and their aiming devices on both banks. Cables leading to the left-bank equipment were suspended above the river at a height that would not impede boat traffic (Figure 3). Steel tripods were used to deploy the transducers offshore. One elliptical, split-beam transducer was mounted on each tripod. At the start of the season the transducer tripods were placed on each bank in a position close to shore but still submerged at low tide. During the 16 May to 10 August time frame, water level at low tide rose approximately 1.8 m. As the water level rose, the tripods were periodically moved closer to shore so that the total range insonified by the sonar beams increased from approximately 73 m at the lowest water conditions to 94 m at high water.

Table 1.-Principal components of the split-beam sonar system used in 1999.

System Component	Description
Sounder	Hydroacoustics Technology Inc. (HTI) Model 240 Split-Beam Echo sounder operating at 200 kHz
Signal Processor	HTI Model 340 Digital Echo Processor based in a Dell XPS Pentium 100 personal computer
Transducers	(2) HTI Split-Beam transducers: Left Bank: nominal beam widths: 2.9°x10.2° Right Bank: nominal beam widths: 2.8°X10°
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.

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[1] Hydroacoustic Technology, Inc. Seattle, WA. Use of this company's name does not constitute endorsement, but is included for scientific completeness.

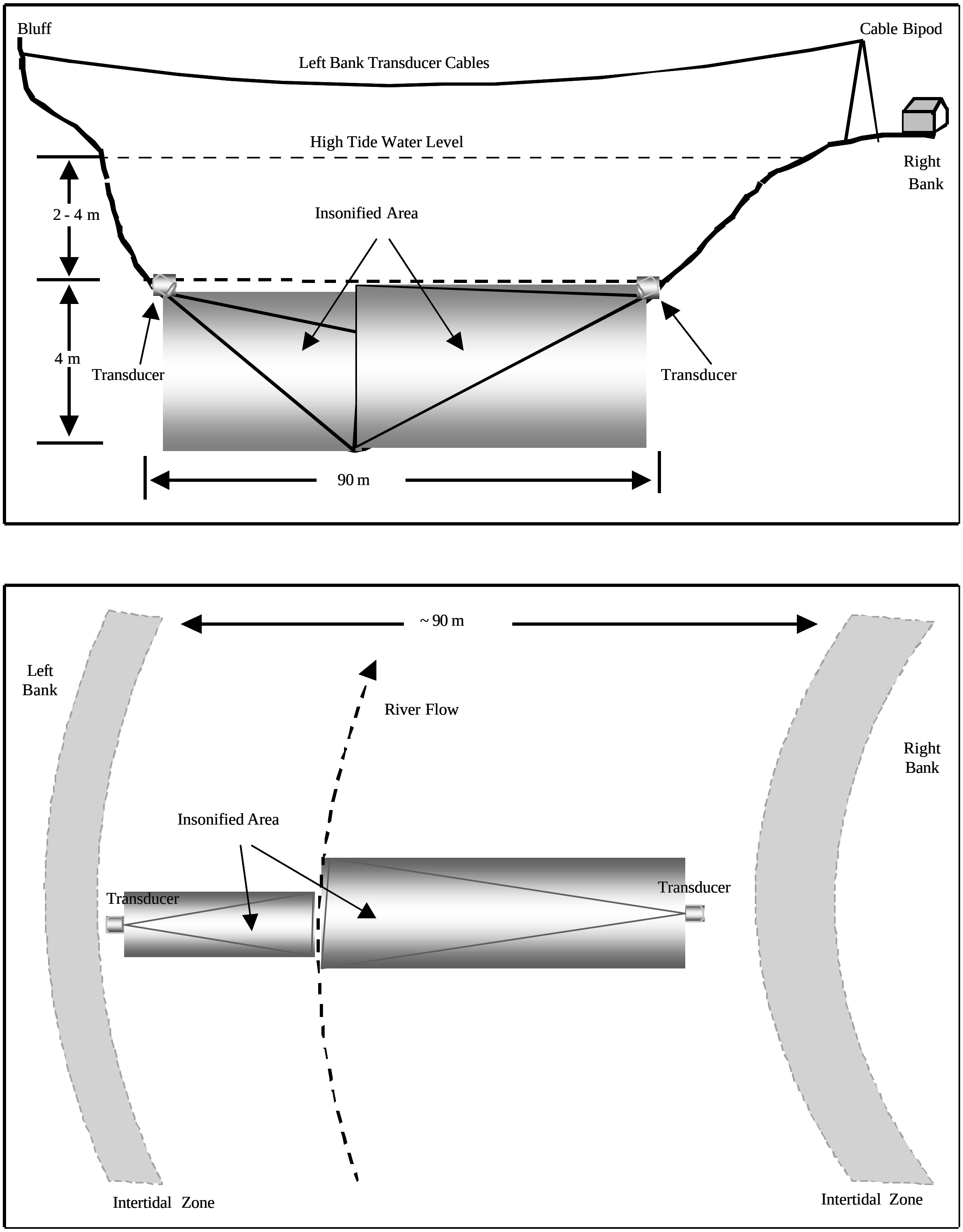

Figure 3.-Cross-sectional (top) and aerial (bottom) views of sonar site showing insonified portions of the Kenai River, 1999.

Vertical and horizontal aiming of each transducer was remotely controlled by a dual-axis electronic pan and tilt system. A digital readout indicated the aiming angle in the vertical and horizontal planes. In the vertical plane, the transducer was aimed using an oscilloscope and chart recorder to verify that the sonar beam was grazing the river bottom. In the horizontal plane, the transducer was aimed perpendicular to the flow of the river to maximize probability of insonifying fish from a lateral aspect. The range encompassed by each transducer was determined by using a depth sounder to find the center of the river channel between the two sonar beams, deploying a large underwater target in midchannel, aiming both sonar transducers at the underwater target and recording the range from each. One half meter was subtracted from each range to prevent overlapping detection of fish from both banks.

System Calibration

HTI performed reciprocity calibrations with a naval standard transducer on 27 April 1999. Calibration results were verified at the calibration facility with a 38.1-mm tungsten carbide sphere (Foote and MacLennan 1984). Further verification was obtained *in situ* by measuring the same standard sphere on 12 May, 28 June, 16 July and 9 August. For each calibration verification, we recorded the maximum background noise level and voltage threshold in addition to the data collected automatically by the onboard signal-processing software (see Data Acquisition).

Sampling Procedure

A systematic sample design (Cochran 1977) was used to sample from each bank for 20 min each hour. Although the sonar system is capable of sampling both banks continuously, data collection was restricted to 20-min samples per hour to limit the data processing time and personnel required to produce daily fish passage estimates. The equipment was automated to sample the right bank for 20 min starting at the top of each hour followed by a 20-min left bank sample. The system was quiescent or activated for ancillary studies during the third 20-min period. This routine was followed 24 hours per day and 7 days per week unless one or both banks were inoperable.

Echo Sounder Settings

Relevant echosounder settings are listed in Table 2 with a more complete summary in Appendix B1 and B2. Most echo sounder settings were identical for each bank and remained consistent throughout the sample period. High power and low gain settings were used to maximize SNR. The transmitted pulse width was set relatively low to maximize resolution of individual fish, and SNR.

Data Acquisition

The digital echo sounder (DES) sent data from each returned echo to the digital echo processor (DEP, Figure 4). The DEP performed the initial filtering of returned echoes based on user-selected criteria (Table 3, Appendices B1 and B2); it also recorded the start time, date and number of pings processed for each sample.

Echoes in the transducer near field (<= 2.0 m) were excluded (MacLennan and Simmonds 1992). Minimum vertical and horizontal off-axis values were used to prevent consideration of unreliable data from transducer side lobes.

Table 2.-HTI model 240 digital echo sounder settings used in 1999.

Echo Sounder Parameters	Value
Transmit Power	25 dB
System Gain	-18 dB
TVG	40logR
Transmitted Pulse Width	0.20 msec
Ping Rate Right Bank	11 pings/sec
Ping Rate Left Bank	16 pings/sec

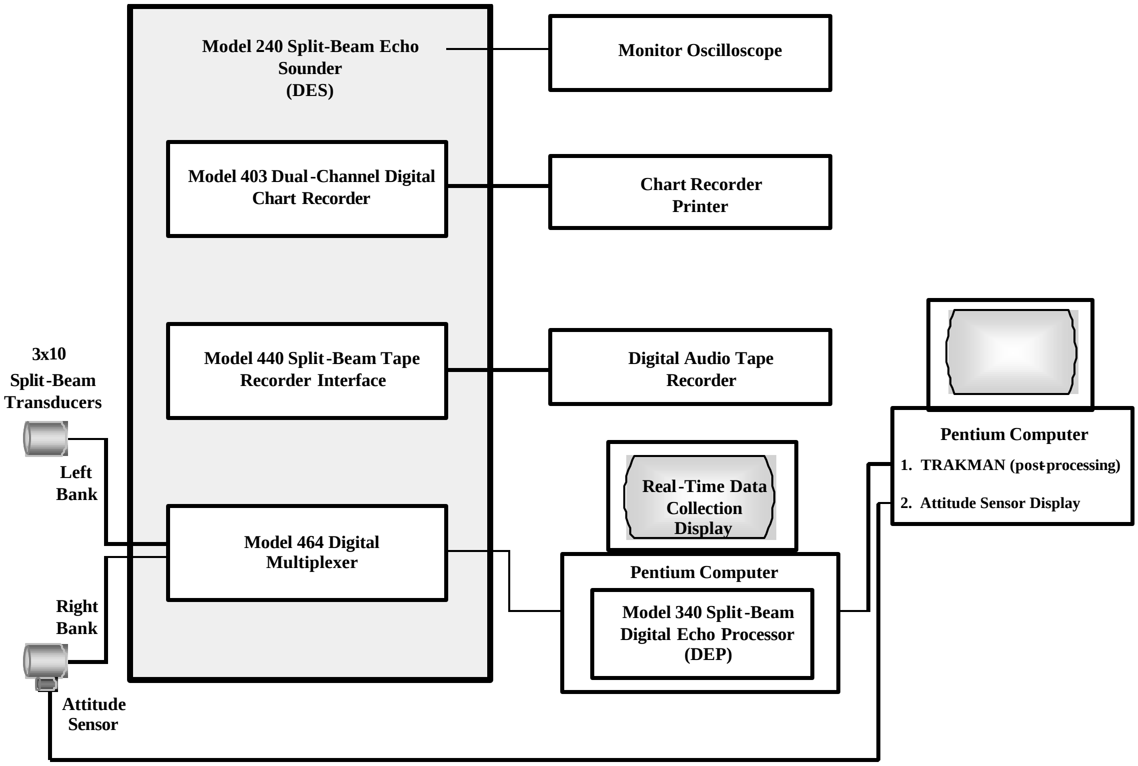

Figure 4.-Schematic of 1999 split-beam sonar system configuration and data flow.

Table 3.-Echo acceptance criteria for digital echo processing, 1999.

Bank	Pulse Width[a] (ms) at -6 dB	Vertical Angle Off-axis (^{o})	Horizontal Angle Off-axis(^{o})	Threshold mV (dB)	Range (m)
Right					
16-May to 10-Aug	0.0 to 2.0	-2.5 to 2.5	-5.0 to 5.0	709 (-35 dB)	2.0
Left					
16-May to 10-Aug	0.0 to 2.0	-2.5 to 2.5	-5.0 to 5.0	446 (-35 dB)	2.0

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

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

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

The sum channel voltage from the Model 240 DES was also output to a dot matrix printer using a HTI Model 403 Digital Chart Recorder, to a Nicolet 310[2] digital storage oscilloscope and to a Harp HC[3] color chart monitor. Chart recorder output was filtered only by a voltage threshold, which was set equal to the DEP threshold. The chart recorder ran concurrently with the echo sounder and produced real-time echograms for each sample. The echograms were used for data backup and transducer aiming, and to aid in manual target tracking. Voltage output to the oscilloscope and color monitor was not filtered. Monitoring the unfiltered color echogram ensured that subthreshold targets were not being unintentionally filtered. Advanced features on the digital oscilloscope aided in performing field

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[2] Nicolet Instrument Technologies, Madison Wisconsin. Use of this company's name does not constitute endorsement but is included for scientific completeness.

[3] Hydroacoustic Assessments, Seattle, Washington. Use of this company's name does not constitute endorsement but is included for scientific completeness.

calibrations with a standard target, and in monitoring the background noise level relative to the voltage threshold level.

FISH TRACKING AND ECHO COUNTING

A diagram illustrating inseason data flow can be found in Appendix C1. Echoes in the *.RAW files were manually grouped (tracked) into fish using HTI proprietary software called TRAKMAN. TRAKMAN produces an electronic chart recording for all valid echoes collected during a 20-min sample on the computer monitor. Selected segments of the chart can be enlarged and echoes viewed on a Cartesian grid. Echoes following a sequential progression through the beam were selected by the user and classified into fish traces. TRAKMAN then produced three output files. The first file contained each echo that was tracked in a valid target (*.MEC file) and included the following data for each echo: estimated X (left-right), Y (up-down), and Z (distance from the transducer) coordinates in meters, where the transducer face is the origin of the coordinate system, pulse widths measured at -6 dB, -12 dB, and -18 dB amplitude levels, combined beam pattern factor in dB, and target strength in dB. The second fixed-record ASCII file (*.MFS file) summarized data from all echoes associated with an individual tracked target and output the following fields by target: total number of echoes tracked, starting X, Y, and Z coordinates, distance traveled (meters) in the X, Y, and Z directions, mean velocity (m/sec), and mean target strength (dB). The third file was identical to the *.RAW file described earlier except that it contained only those echoes combined into tracked targets. Direction of travel was determined using information from the echo coordinates of individually tracked targets. A target was classified as upstream if its ending (X-axis) position in the acoustic beam was located upriver from its starting position and downstream if its ending position was down river from its starting position.

Downstream targets (and occasionally upstream targets during a strong flood tide) were further classified as fish or debris primarily by looking at the angle of passage and degree of movement in the Z-axis (range from transducer) as the target transited the acoustic beam. For debris, the angle of passage through the beam is constant with little change in the range as it passes through the beam. Consequently, debris resembles a line drawn on the echogram with a straight-edge. A fish typically leaves a meandering trace that reflects some level of active movement as it passes through the acoustic beam. In 1999, obvious debris-like downstream targets were excluded from consideration as valid fish targets during the tracking procedure and the remainder of downstream targets was retained to adjust the total estimate of fish passage. Separate summary files were generated for tracked targets classified as debris (i.e. *.DEC and *.DFS files). Except for debris, only targets comprising echoes displaying fish-like behavior were tracked. Erroneous echoes from structure, boat wake and sport-fishing tackle were ignored. During times of high sockeye passage (18 July through 10 August), targets within 35 m of the transducer on the right bank and within 10 m on the left bank were assumed to be sockeye salmon and were not tracked.

DATA ANALYSES

Tidal and Temporal Distribution

Fish passage rates have been shown to be related to tidal stage (Eggers et al. 1995). Therefore tide stage was determined throughout the season using water level measurements taken at the top of each hour and at 20 minutes past each hour from a staff gauge located at the site. For the purpose of this study, falling tide was defined as the period of decreasing staff gauge readings, low tide as the period of low static readings, and rising tide as the period of both increasing readings and high static readings (i.e. high slack tide). The rising and high slack tide were combined into one category due to the very short duration of high slack tide. Data from both banks were combined to summarize fish passage by tide stage (falling, low, and rising) for both upstream and downstream traveling fish. Data were first filtered using target strength and range criteria (see section on Species Discrimination).

Spatial Distribution

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

Range (z-axis) distributions for each bank were plotted separately for upstream and downstream fish. Range distributions were calculated using the midpoint range for each target as follows:

$$z_m = z_s + \left(\frac{d_z}{2}\right), \tag{1}$$

where:

z_m = midpoint range (in meters),

z_s = starting range (in meters), and

d_z = distance traveled in the range (z) direction.

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

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

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 by run and direction (upstream and downstream).

Species Discrimination

Tracked fish were filtered using criteria intended to minimize the number of sockeye salmon counted. Two parameters have been used historically on this project to separate large chinook salmon from smaller species: target strength and distance from the transducer (range). Although recent studies have questioned the ability of these filters to exclude sufficient numbers of sockeye salmon (Eggers 1994, Burwen et al. 1995), we continued their use in 1999 to ensure comparability of passage estimates with those of past years, while continuing to investigate other means of discriminating between fish sizes (Burwen and Fleischman 1998, (Fleischman and Burwen 2000).

Tracked fish with mean target strength less than -28 dB were assumed to be species other than chinook salmon and excluded from further analysis. The majority of fish within the nearshore area were assumed to be smaller species such as sockeye, pink *O. gorbuscha*, and coho *O. kisutch* salmon, so all targets within a particular threshold range were filtered out regardless of target strength. A range threshold of 10 m was used throughout both the early and late run (16 May-10 August) on the left bank. Several range thresholds were applied on right-bank fish, all associated with moving the transducer pod closer to shore and increasing the insonified range. The size of the insonified range used for counting chinook salmon was kept relatively constant by increasing the range threshold as the pod was moved closer to shore. Range thresholds used on the right bank in 1999 were 15 m (16 May-10 June), 20 m (11 June-23 June), 25 m (24 June-17 July), and 35 m (18 July-10 August).

Passage Estimates

To meet fishery management needs, estimates of fish passage were generated for each day, and were generally available by noon of the following day.

An estimate of fish passage was calculated for each hour for which a sample existed. This was usually an exact 20-min count, which was multiplied by 3 for the hourly estimate on each bank. The number of fish passing bank b during hour j ($\hat{y}_{bj}$) was estimated as:

$$\hat{y}_{bj} = \frac{60}{t_{bj}} c_{bj}, \tag{3}$$

where:

t_{bj} = number of minutes sampled on bank b during hour j, and

c_{bj} = sample count for bank b and hour j.

When the sonar system on one bank was not operating (1% of samples), the omission was treated as a “missing datum” with substitution as a correction. If information from the other bank was available for that hour, we applied a ratio estimator $\hat{R}_b$ (Cochran 1977) between banks, using data from those hours when both banks were sampled for the same number of minutes. When the sonar system was not operating on one bank, the chinook passage was estimated as:

$$\hat{y}_{bj} = \hat{R}_b \hat{y}_{b'j}, \tag{4}$$

where:

$$\hat{R}_b = \frac{\sum_{j=1}^{n_B} \hat{y}_{bj}}{\sum_{j=1}^{n_B} \hat{y}_{b'j}}, \tag{5}$$

$\hat{y}_{b'j}$ = estimated passage for opposite bank b' during hour j, and

n_B = number of hours during the season in which both banks were sampled for the same number of minutes.

During the season, for purposes of daily reporting of estimated passage, $\hat{R}_b$ was calculated from the cumulative number, to date, of hours when both banks were sampled for the same number of minutes. Final estimates were generated postseason.

When the sonar system was inoperable on both banks for a full hour, estimated passage on each bank was interpolated as the mean of the estimated passage before and after the missing sample:

$$\hat{y}_{bj} = \frac{\hat{y}_{b(j-1)} + \hat{y}_{b(j+1)}}{2}. \tag{6}$$

Fish passage on day i was estimated as:

$$\hat{y}_i = \sum_{b=1}^{2} \sum_{j=1}^{24} \hat{y}_{bj}, \tag{7}$$

where $\hat{y}_{bj}$ was obtained from either (3), (4), or (6) as appropriate. Finally, the number of chinook salmon migrating into the Kenai River during a run was estimated as:

$$\hat{Y} = \sum_{i=1}^{N_D} \hat{y}_i, \tag{8}$$

where N_D is the number of days in the run. Its variance (successive difference model, Wolter 1985) was estimated, with adjustments for missing data, as:

$$\hat{V}\left[\hat{Y}\right] = \sum_{b=1}^{2} 9N_H^2 (1 - f_S) \frac{\sum_{j=2}^{N_H} \phi_{bj}\phi_{b,j-1}\left(c_{bj} - c_{b,j-1}\right)^2}{2\sum_{j=1}^{N_H} \phi_{bj} \sum_{j=2}^{N_H} \phi_{bj}\phi_{b,j-1}}, \tag{9}$$

where:

N_H = total number of hours during the run, and

f_s = fraction of available periods sampled (0.33), and

ϕ_{bj} = 1 if the sonar was operating on bank b during hour j, or 0 if not.

SAMPLE DESIGN EVALUATION

To test for bias resulting from use of the systematic sample design, estimates of chinook salmon passage (above) were compared with complete, 1-hour census counts of chinook salmon passage for 72-hour periods during each of three tidal phases: neap, spring, and normal. Spring tides were defined as those that occur during or shortly after the new or full moon and that exhibit the largest tidal fluctuation from high to low. Neap tides were defined as tides that occur midway between spring tides and exhibit the smallest tidal fluctuation from high to low. Normal tides were any tide other than a spring or neap tide. Sampling was continuous on the right bank during the 72-hour periods except when the generator was shut down briefly for refueling or when equipment problems were encountered. Each passing target was tracked and enumerated using normal procedures described in this report. The sign test (Hollander and Wolf 1973) was used to test for significant differences between hourly estimates of passage using the 20-minute samples and the 1-hour census counts. Simulations showed that this test had at least 80% power ($1-\beta$) to detect a difference of 15% with the probability of a Type I Error α at 0.05.

COMPARISON OF SONAR ESTIMATES WITH OTHER INDICES

Sonar estimates of chinook abundance were compared with several other indices of chinook and sockeye abundance to aid in evaluating the sonar's accuracy with respect to both species apportionment and run magnitude. The utility of each of these indices varies with certain environmental conditions. In some cases, their usefulness is limited by management decisions related to commercial and sport fisheries.

Inriver Netting Program

Starting in 1998, the inriver chinook salmon AWL netting program was modified to provide catch per unit effort (CPUE) data as an independent index of chinook salmon abundance. A standardized drift zone was defined just downstream from the sonar site and crews fished a standard drift period relative to the tide cycles. Our objective was to use the netting CPUE to ascertain periods when sockeye salmon (or other species) generate a bias in chinook sonar estimates. It was anticipated that in the absence of high levels of sockeye passage (or other species), sonar estimates and CPUE would track reasonably well. Conversely, during periods of high sockeye passage, we expected the two to diverge. If a sufficient number of days of paired CPUE and sonar data were collected where the two estimates tracked closely, the relationship between the two could be exploited to generate adjusted estimates of chinook passage when needed.

The inriver-netting program is considered a reliable index of chinook salmon abundance under consistent water clarity and discharge conditions. The ability to control for these changes statistically is part of a continuing evaluation of the netting program. The program is designed to optimize the catch of chinook salmon and minimize the catch of sockeye by fishing midriver drifts. Catch of all species, however, is recorded and may be used to evaluate the presence or absence of sockeye, coho and pink salmon.

Sport Fishery Catch Rates

Inriver sport fish CPUE is monitored by an intensive creel program (Reimer et al. 2002) and may be a useful index of chinook salmon abundance. But like net CPUE, its performance varies under changing water clarity and discharge conditions. It may also vary with changes in how the sport fishery is prosecuted with respect to bait restrictions and/or closures.

Sockeye Salmon Sonar (Late Run)

An index of inriver sockeye salmon abundance can be obtained from a second sonar site at Kenai River mile 19. This sonar project is run from 1 July through mid August by the Commercial Fisheries Division and targets only nearshore sockeye salmon (Ruesch and Fox 1999). Although travel time between the mile 8.6 chinook sonar site and the mile 19 sockeye sonar site undoubtedly varies, we believe it averages 1 to 2 days. Information from this project aids in determining periods when chinook estimates are most likely to be biased high.

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 -39.41 dB with the right-bank transducer and -39.60 dB with the left-bank transducer (HTI 1999; Table 4). The theoretical value for the sphere is -39.50 dB (MacLennan and Simmonds 1992). During subsequent *in situ* calibration checks using the same sphere, mean target strength varied from -41.27 dB to –39.15 dB on the right bank and from –39.84 to –37.97 on the left bank.

The unusually low standard target measurement of –41.27 dB was collected on the right bank on 16 July when calibration measurements were conducted to investigate an apparent shift in the average target strength of fish passing on this bank. Retrieval of the tripod revealed significant amounts of debris hung up on the tripod and transducer. The tripod and transducer were cleared of the debris and redeployed. Target strength distribution of fish passing on the right bank appeared normal following the redeployment.

TARGET TRACKING

A total of 43,422 targets were manually tracked, 13,565 during the early run and 29,857 during the late run. After filtering for range and target strength criteria and making temporal expansions, the proportion of upstream fish was 96.3% for the early run and 95.8% for the late run (Tables 5 and 6, Appendices D1 and D2).

Table 4.-Results of 1999 *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]	15 April	-39.41	1.59	2,194	5.93	N/A[b]	N/A[b]
Kenai River	12 May	-40.05	1.18	3,956	9.89	N/A[b]	N/A[b]
Kenai River	28 June	-39.15	1.95	3,639	15.14	150	175
Kenai River	16 July	-41.27	2.30	3,640	10.40	175	200
Kenai River	9 August	-39.94	1.13	4,614	10.14	81	200
Left Bank							
HTI[a]	15 April	-39.60	0.83	2,194	5.98	N/A[b]	N/A[b]
Kenai River	12 May	-37.97	0.71	3,425	7.54	N/A[b]	N/A[b]
Kenai River	28 June	-39.84	1.33	3,404	13.01	90	100
Kenai River	9 August	-39.03	1.93	5,152	7.64	50	150

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

[b] Not available.

Table 5.-Estimates of chinook salmon passage by tide stage and direction of travel for the 1999 early run (16 May to 30 June).

1999 Early Run	Total Number of Fish	Rising	Falling	Low
Upstream	25,666	7,076	11,825	6,766
Row %	100.0%	27.6%	46.1%	26.4%
Column %	96.3%	94.3%	96.8%	97.6%
Downstream	990	428	396	165
Row %	100.0%	43.2%	40.0%	16.7%
Column %	3.7%	5.7%	3.2%	2.4%

Test for Independence: Chi-square = 125.32, df = 2, P<<<0.01.

The number of acquired echoes per fish varied by run, bank, and direction of travel. During the early run, upstream fish averaged 35 (SD = 25) and 63 (SD = 43) echoes per fish on the left and right banks, respectively. Downstream fish averaged 41 echoes (SD = 35) on the left bank and 53 echoes (SD = 51) on the right bank. During the late run, the number of echoes per fish increased substantially for fish on both banks. Upstream fish averaged 56 (SD = 43) echoes on the left bank and 88 (SD = 55) echoes on the right bank. Downstream fish averaged 69 (SD = 63) echoes on the left bank and 86 (SD = 83) echoes on the right bank.

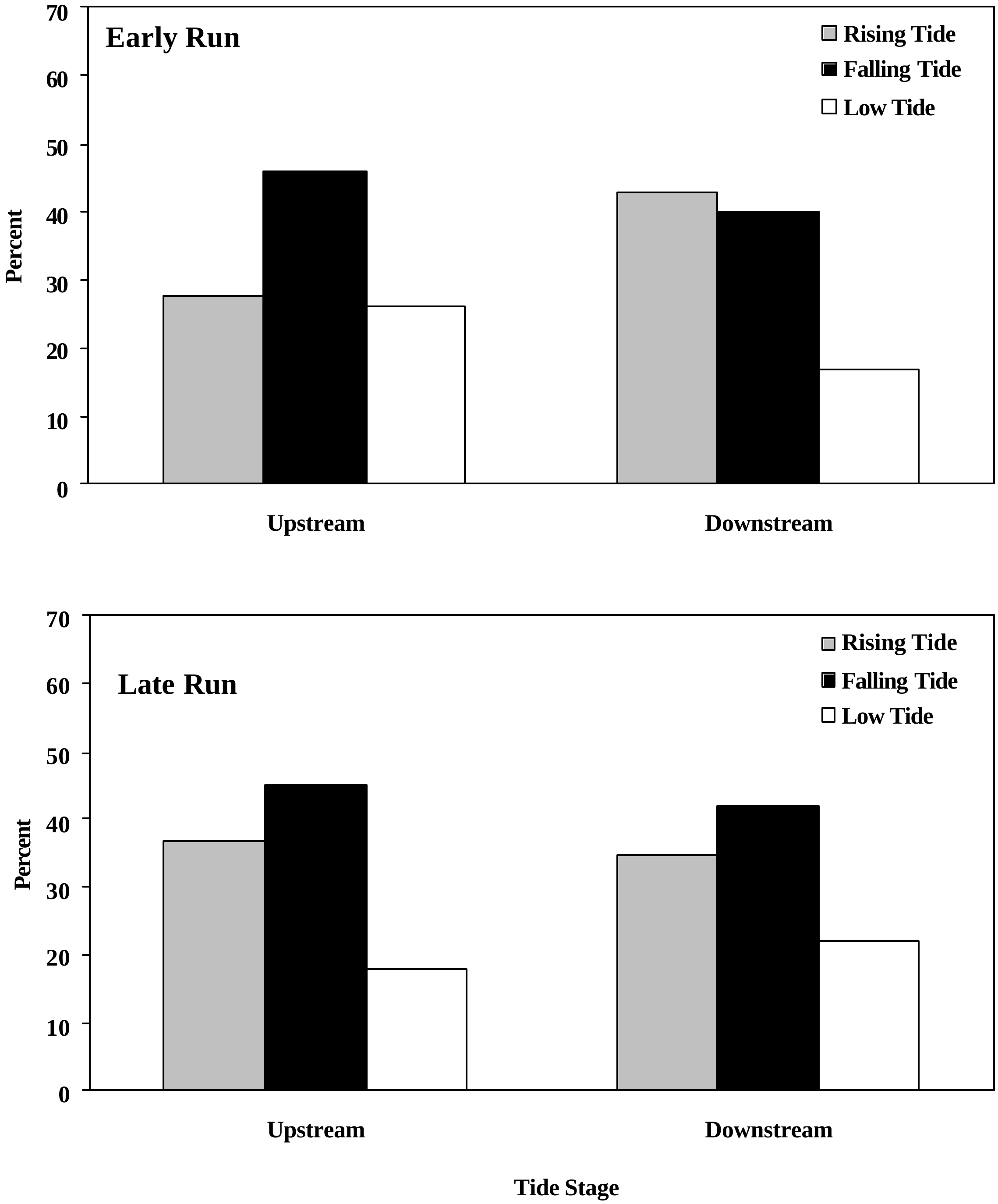
TIDAL AND TEMPORAL DISTRIBUTION

The highest proportion of upstream fish occurred during the falling tide for both early (46.1%) and late (44.8%) runs (Tables 5 and 6, Figure 5). The highest proportion of downstream fish occurred during the rising tides for the early run (43.2%) and during the falling tides for the late run (42.4%).

Table 6.-Estimates of chinook salmon passage by tide stage and direction of travel for the 1999 late run (1 July to 10 August).

1999 Late Run	Total Number of Fish	Rising	Falling	Low
Upstream	48,069	17,930	21,536	8,602
Row %	100.0%	37.3%	44.8%	17.9%
Column %	95.8%	96.0%	96.0%	94.8%
Downstream	2,131	755	903	473
Row %	100.0%	35.4%	42.4%	22.2%
Column %	4.2%	4.0%	4.0%	5.2%

Test for Independence: Chi-square = 25.49, df = 2, P <<<0.01



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

Figure 5.-Distribution of upstream and downstream fish by tide stage during the early run and late run, Kenai River, 1999.

SPATIAL DISTRIBUTION

Vertical Distribution

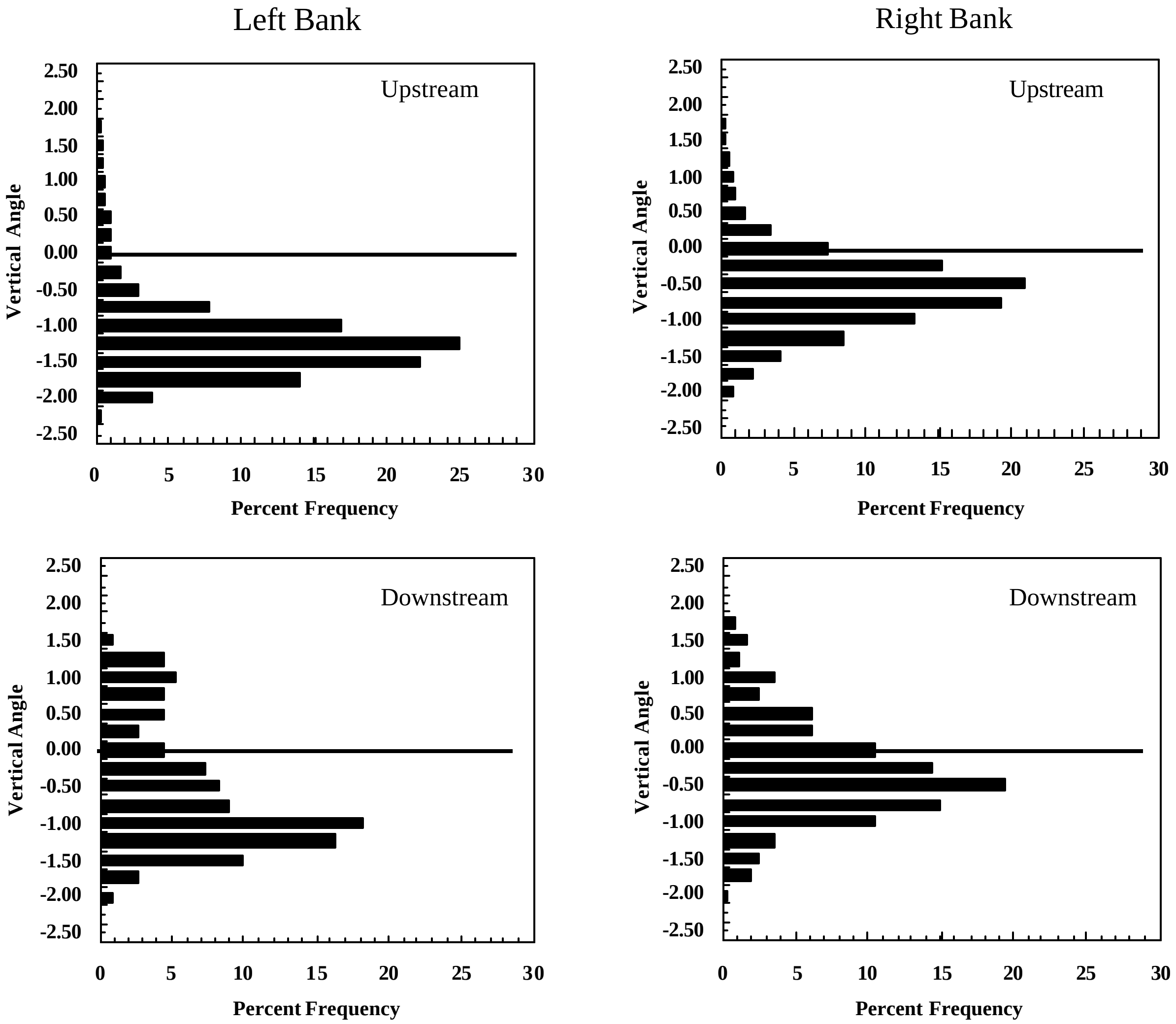
Fish were bottom-oriented during both runs, although vertical distribution did vary somewhat by direction of travel, tide stage, and season (Appendices E1 and E2). During the early run, 95% of the upstream fish on the left bank and 85% on the right bank were below the acoustic axis (Figure 6). Downstream fish were less bottom-oriented. Seventy-three percent of downstream fish on the left bank and 68% on the right bank (Figure 6) were below the acoustic axis. Upstream fish (chinook targets) on the left bank (mean = -1.31°, SD = 0.58, n = 3,477) were on average significantly lower ($P < 0.01$) in the water column than downstream fish (mean = -0.66°, SD = 0.87, n = 110). On the right bank, upstream fish (mean = -0.72°, SD = 0.57, n = 5,739) were also significantly lower in the water column ($P < 0.01$) than downstream fish (mean = -0.44°, SD = 0.69, n = 248). A comparison of vertical distribution of upstream fish by tide stage indicates that slightly more fish were observed above the acoustic axis during rising tides (Figure 7).

Late-run fish also showed a tendency to travel along the river bottom (Figure 8). Ninety-eight percent of upstream fish on the left bank and 61% of upstream fish on the right bank were below the acoustic axis. Ninety-three percent of downstream fish on the left bank and 54% of downstream fish on the right bank were below the acoustic axis. The difference in vertical range distributions between the right and left banks was due in part to the reflective nature of the left-bank bottom substrate. The more reflective left-bank substrate required the acoustic axis to be aimed higher in the water column, while the more absorptive right-bank substrate allowed the acoustic axis to be aimed closer to the river bottom. Upstream fish on the left bank (mean = -1.21 °, SD = 0.40, n = 8,521) traveled lower ($P < 0.01$) in the insonified water column than downstream fish (mean = -1.00 °, SD = 0.50, n = 341). On the right bank, upstream fish (mean = -0.34°, SD = 0.50, n = 8,465) were on average only slightly lower ($P = 0.01$) in the insonified water column than downstream fish (mean = -0.28 °, SD = 0.48, n = 379). On each bank, upstream traveling fish maintained fairly similar vertical range distributions throughout all tide stages (Figure 9).

Range Distribution

Due to transducer tripod relocations resulting in varying range coverage on the right bank, fish range distribution plots were produced by bank for three time periods during the early run (16 May-10 June, 11 June-23 June, and 24 June-30 June) and two time periods during the late run (1 July-15 July and 16 July-10 August). The left-bank tripod remained in the same location throughout the entire early run and throughout much of the late run, with one relocation occurring on 7 August. The right-bank tripod was relocated on 10 June and 23 June during the early run and on 15 July during the late run. During each relocation, the transducer was moved closer to shore and the range coverage extended. To accurately depict the range distribution of targets as the transducer was moved closer to shore, separate plots were generated for each unique transducer location.

During the early run, upstream fish on the left bank exhibited channel-oriented range distributions throughout the run (Figure 10), while right-bank upstream fish exhibited a strong channel orientation through 10 June and a bimodal distribution after that (Figure 11). Fish traveling downstream on the left bank through 10 June were more evenly distributed across the insonified range than were the more

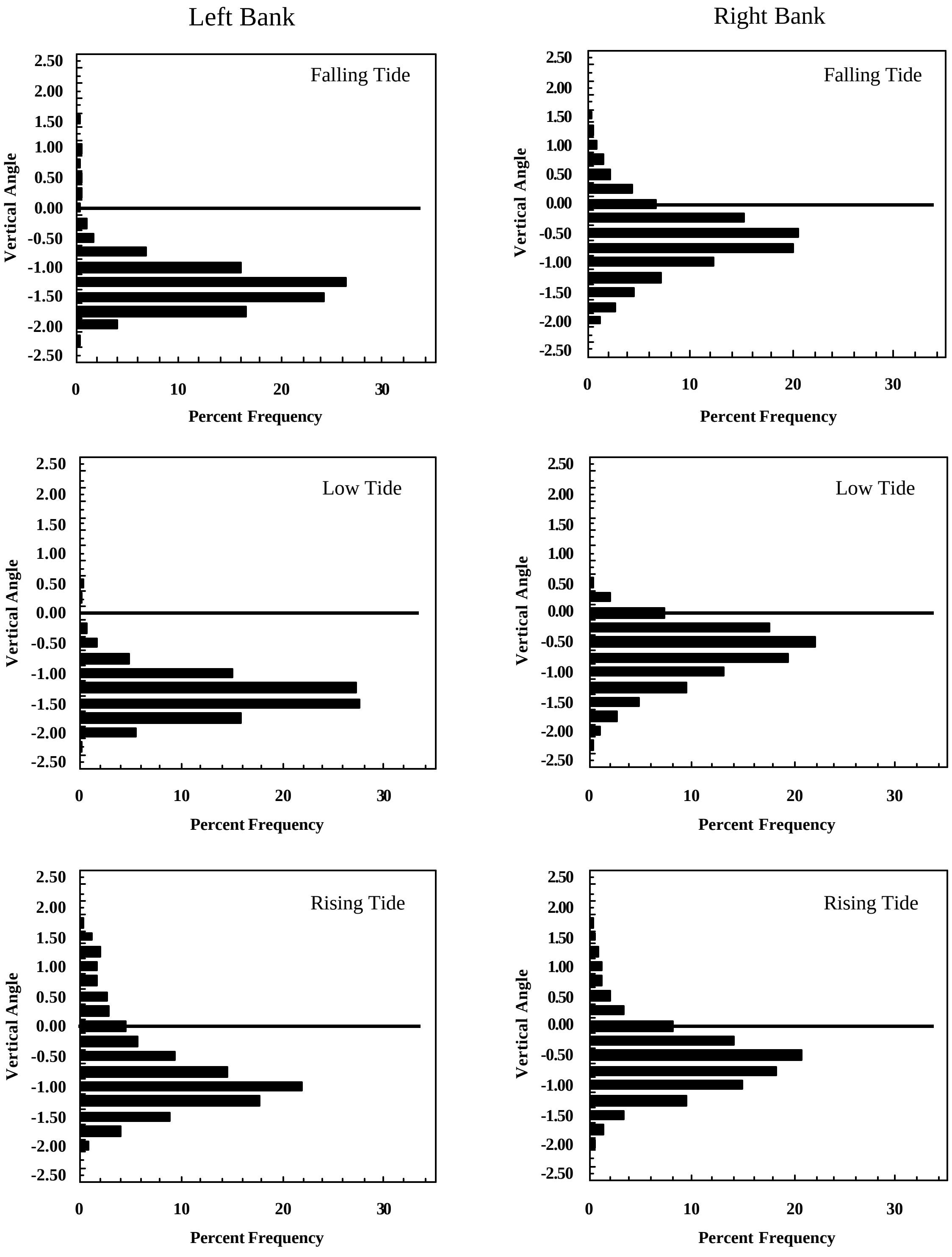


Note: Data have been filtered by range and target strength criteria.

Figure 6.-Vertical distributions of early-run upstream and downstream fish on the left and right banks, Kenai River, 1999.

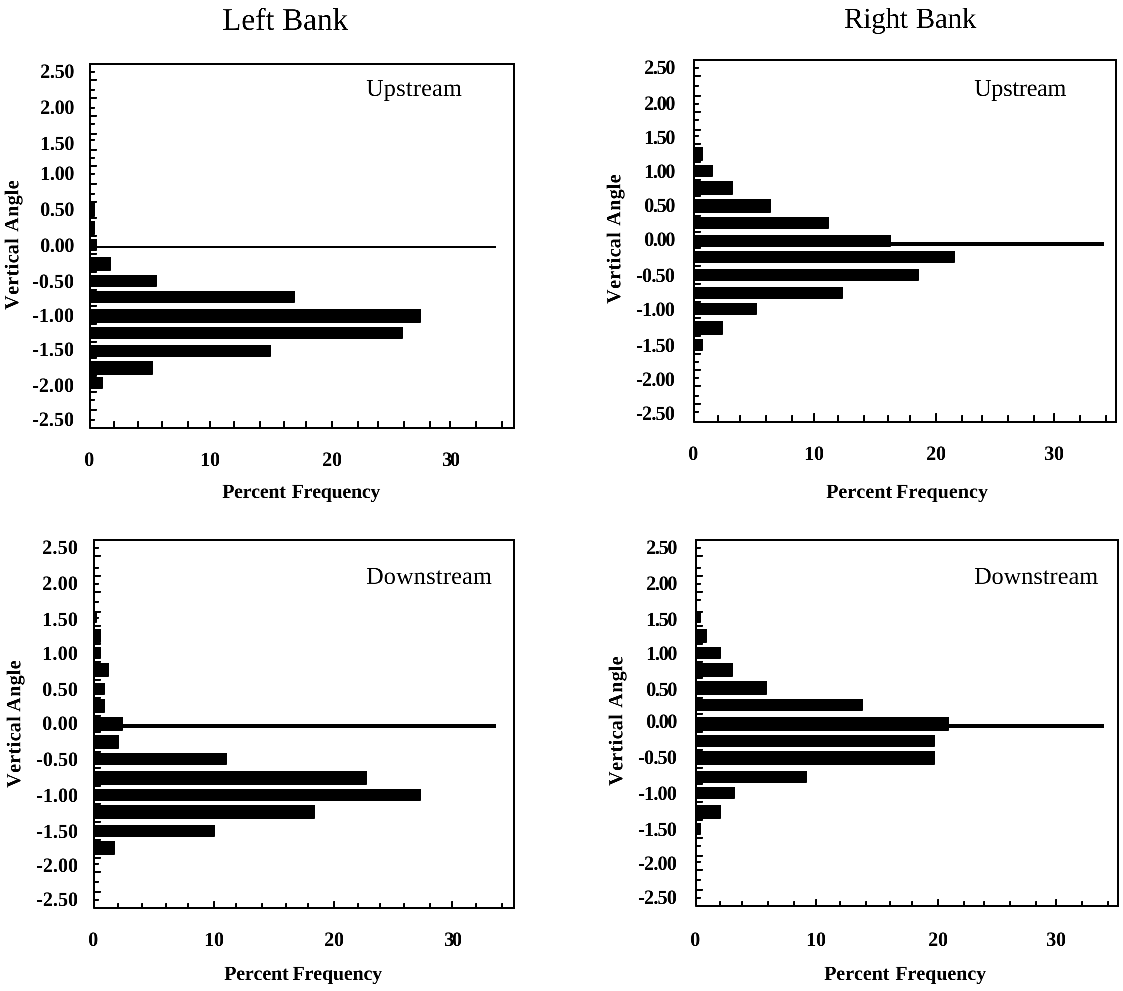
channel-oriented upstream-moving fish (Figure 10). Sample sizes of downstream fish on the left bank after 10 June were inadequate for drawing conclusions. Downstream fish on the right bank were distributed throughout the range for the entire early run (Figure 11). Throughout the early run, upstream fish on both banks were least channel-oriented during rising tides (Figures 12-14).

During the late run, both upstream and downstream fish on the left bank exhibited a channel-oriented range distribution, with downstream fish showing the strongest channel-orientation (Figure 15). Right-bank upstream and downstream fish exhibited a channel-oriented range distribution from 1 July-15 July, but showed a bimodal range distribution after 15 July (Figure 16). For the entire late run, range distributions of upstream traveling fish on the left bank remained channel oriented and



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

Figure 7.-Vertical distributions of early-run upstream fish during falling, low, and rising tide stages on the left and right banks, Kenai River, 1999.

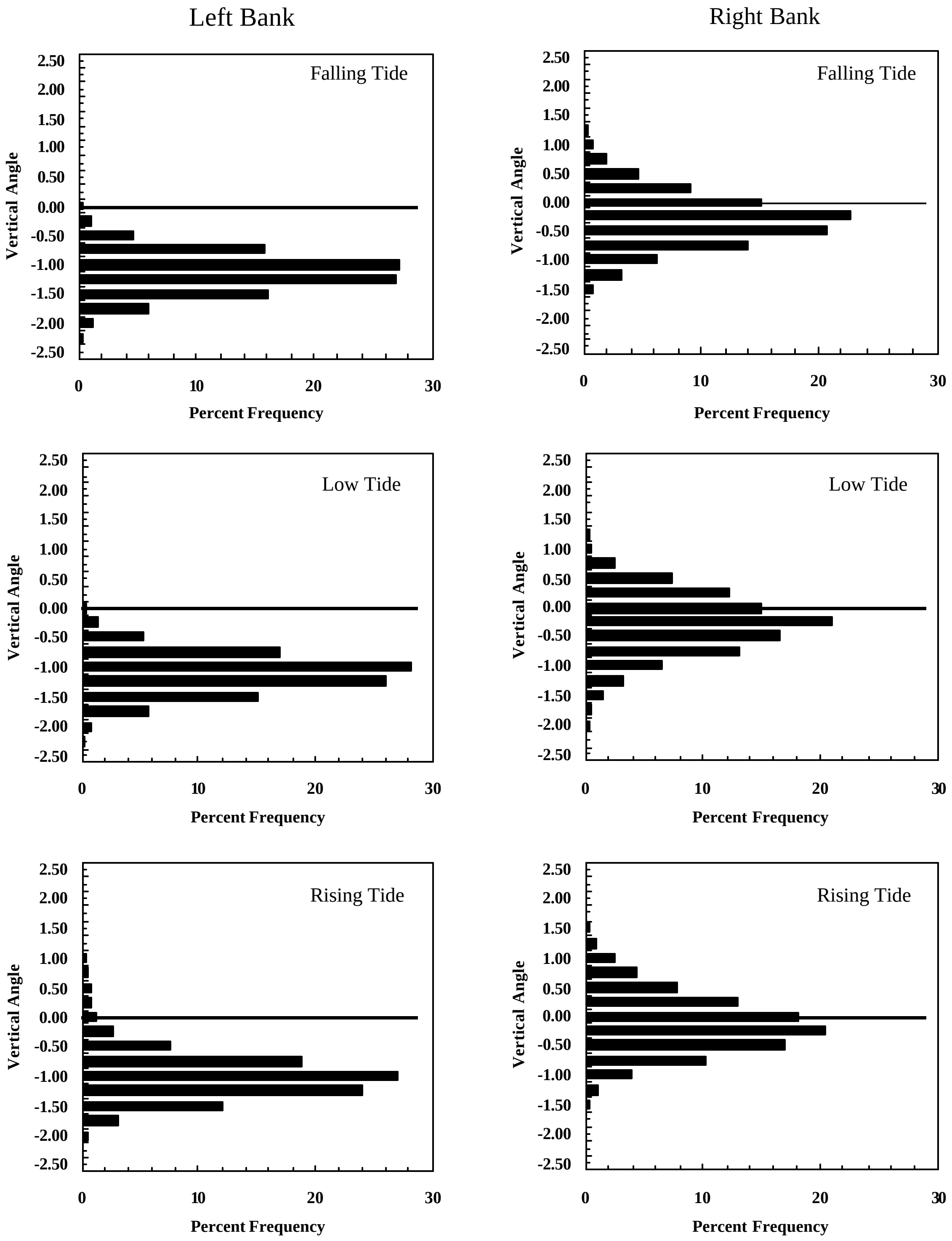


Note: Data have been filtered by range and target strength criteria.

Figure 8.-Vertical distributions of late-run upstream and downstream fish on the left and right banks, Kenai River, 1999.

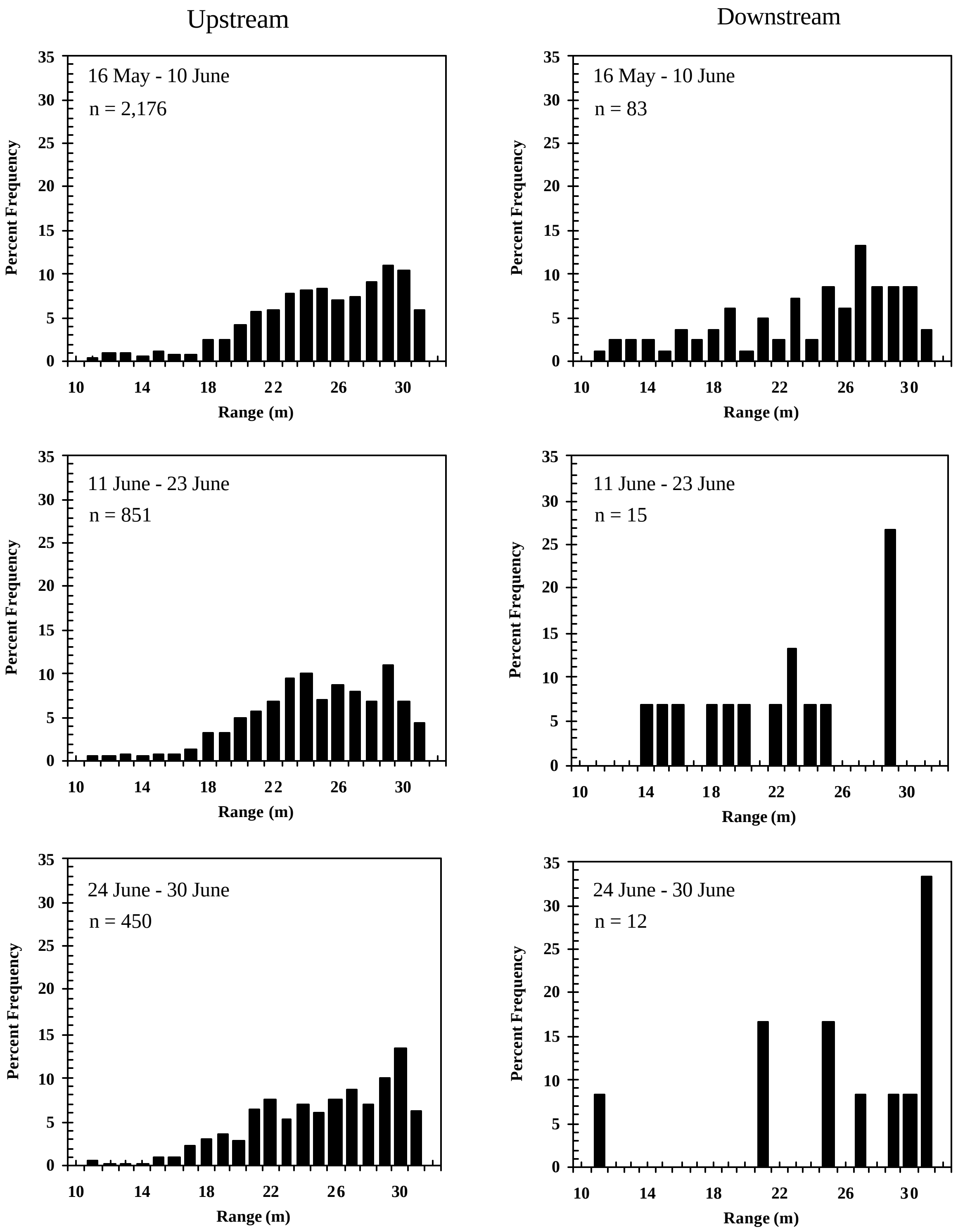
relatively unchanged throughout the falling, low, and rising tide stages (Figures 17 and 18). From 1 July-15 July range distributions of upstream fish on the right bank were similar among tide stages (Figure 17), but from 16 July through 10 August a strong bimodal distribution was observed during the falling and low tide stages while a more even distribution was exhibited during the rising tide stage (Figure 18).

Estimates of fish passage were higher for the left bank than for the right bank during both early and late runs. During the early run 56.1% of the estimated upstream inriver return passed on the left bank while 43.9% of the upstream passage estimate passed on the right bank (Table 7). The late run was similar: 53.3% of the upstream fish passed on the left bank and 46.7% passed on the right bank (Table 8).



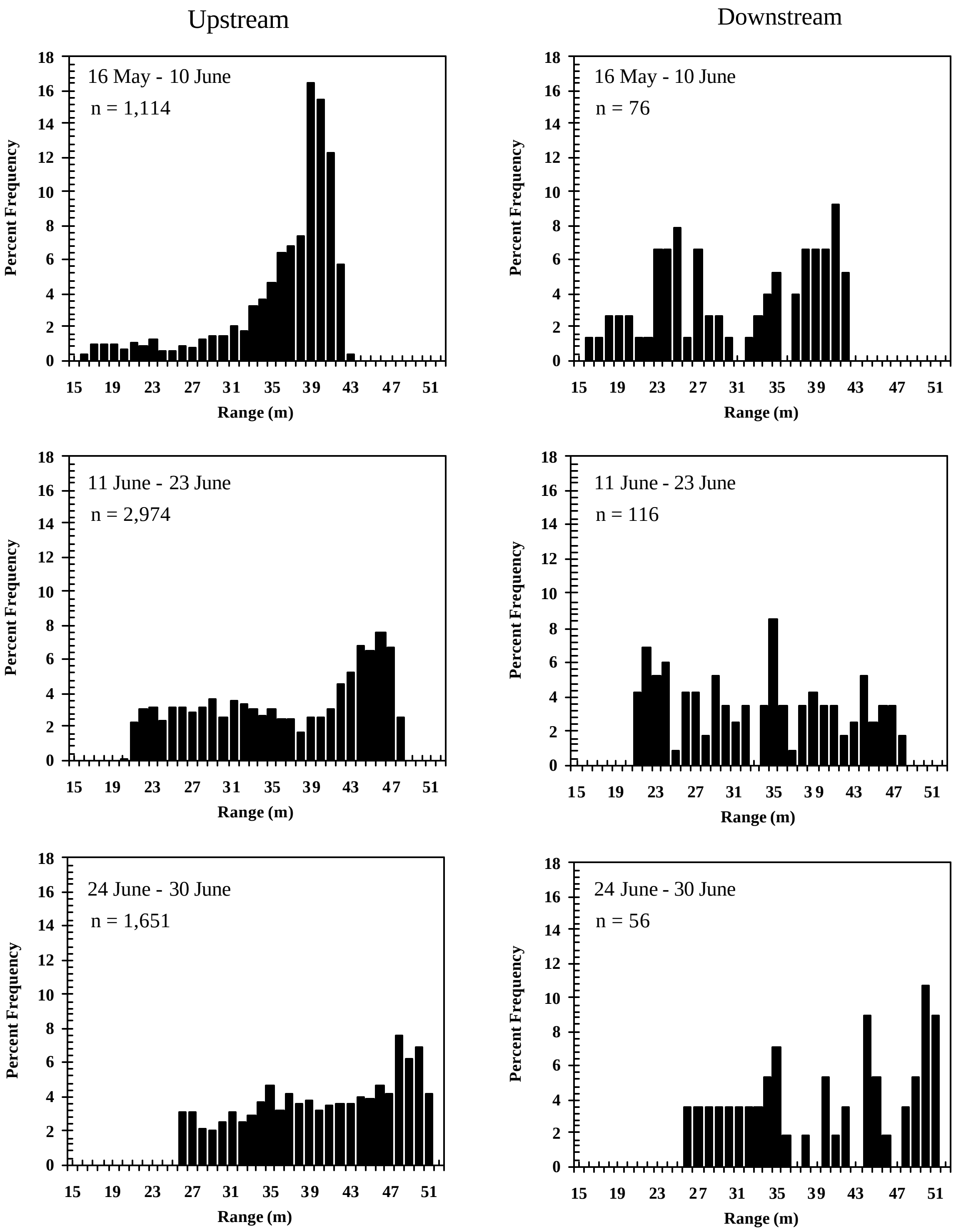
Note: Data have been filtered by range and target strength criteria.

Figure 9.-Vertical distributions of late-run upstream fish during falling, low, and rising tide stages on the left and right banks, Kenai River, 1999.



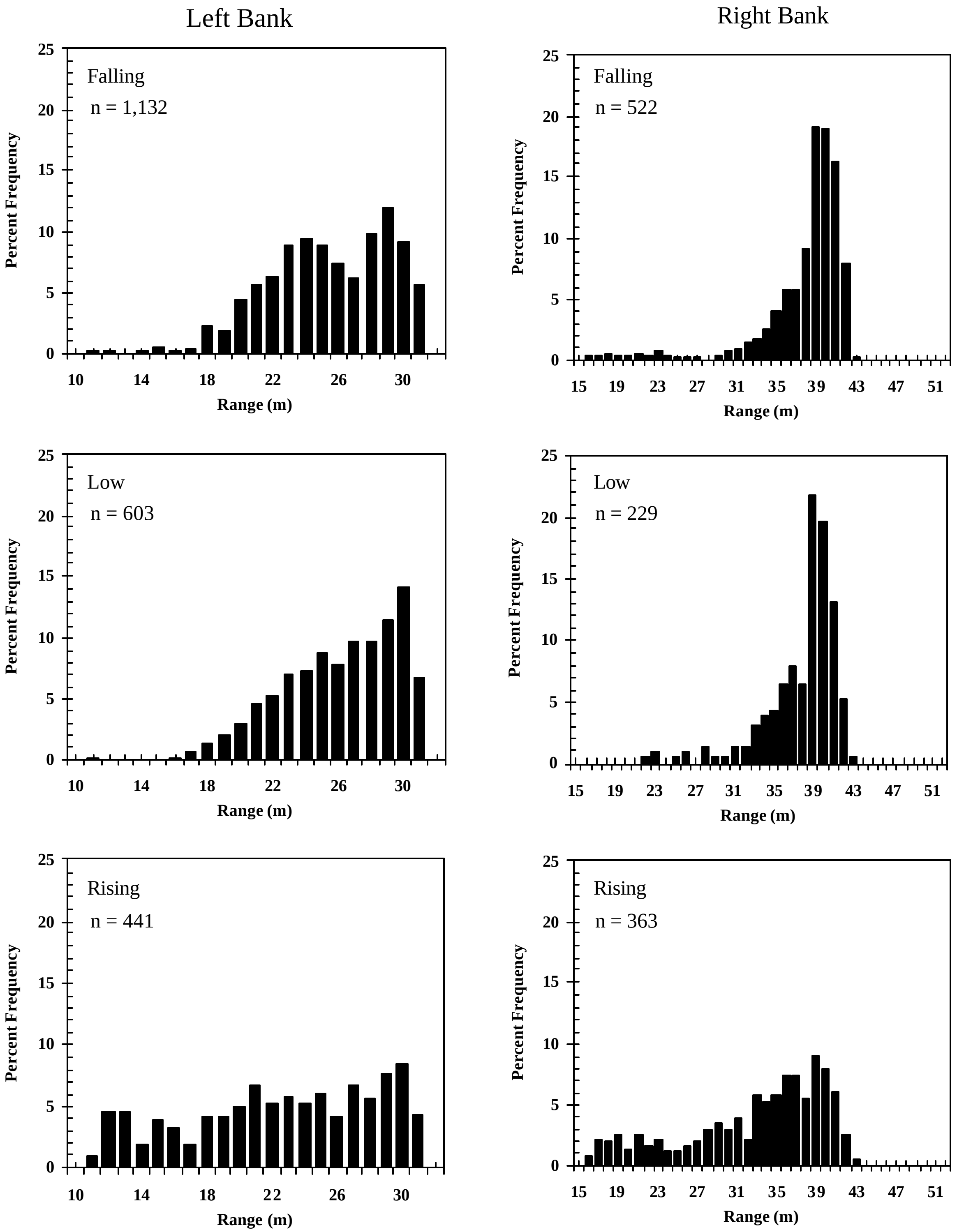
Note: Data have been filtered by range and target strength criteria.

Figure 10.-Range distribution of early-run upstream and downstream fish on the left bank, 16 May-10 June, 11 June-23 June, and 24 June-30 June, Kenai River, 1999.



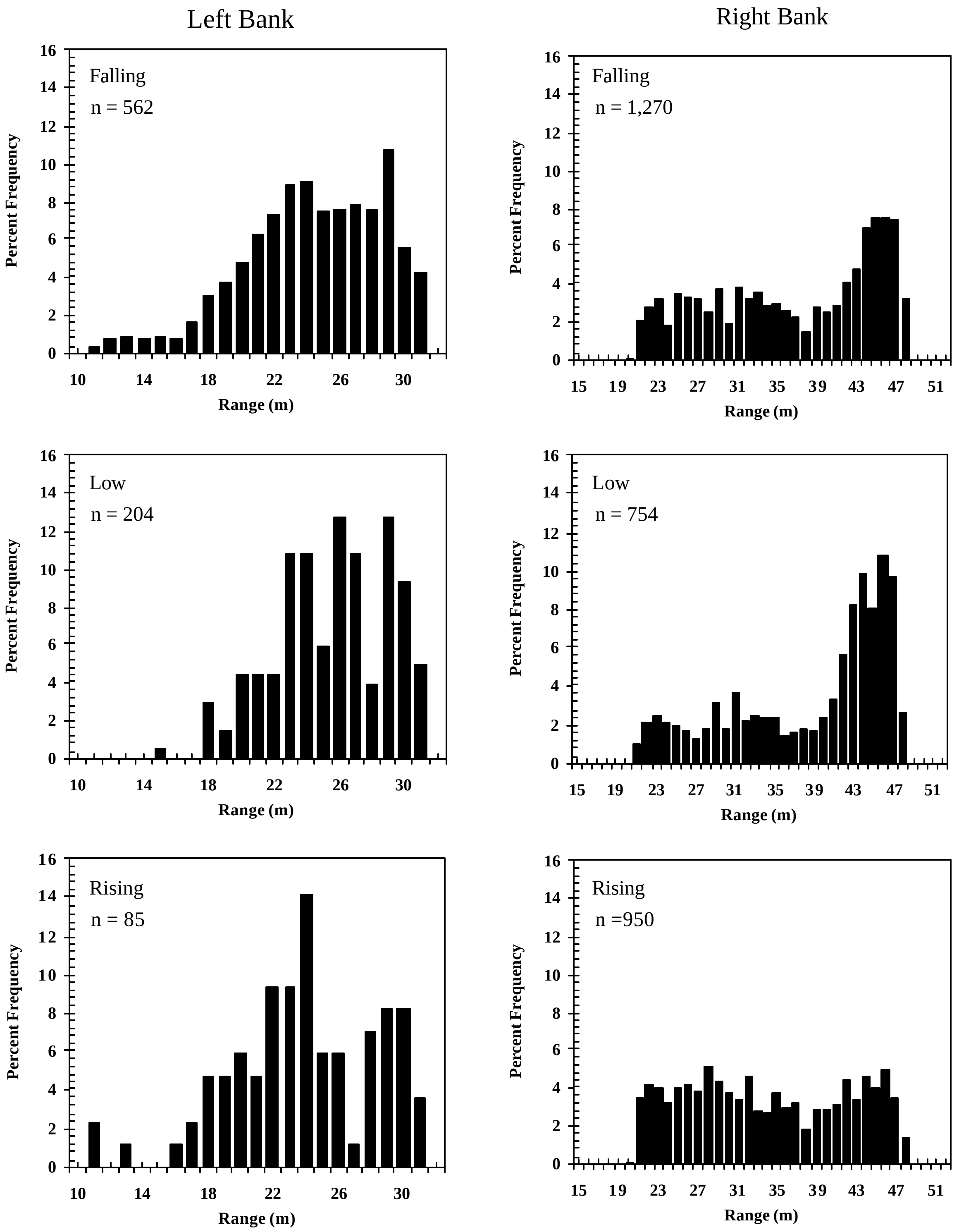
Note: Data have been filtered by range and target strength criteria.

Figure 11.-Range distribution of early-run upstream and downstream fish on the right bank, 16 May-10 June, 11 June-23 June, and 24 June-30 June, Kenai River, 1999.



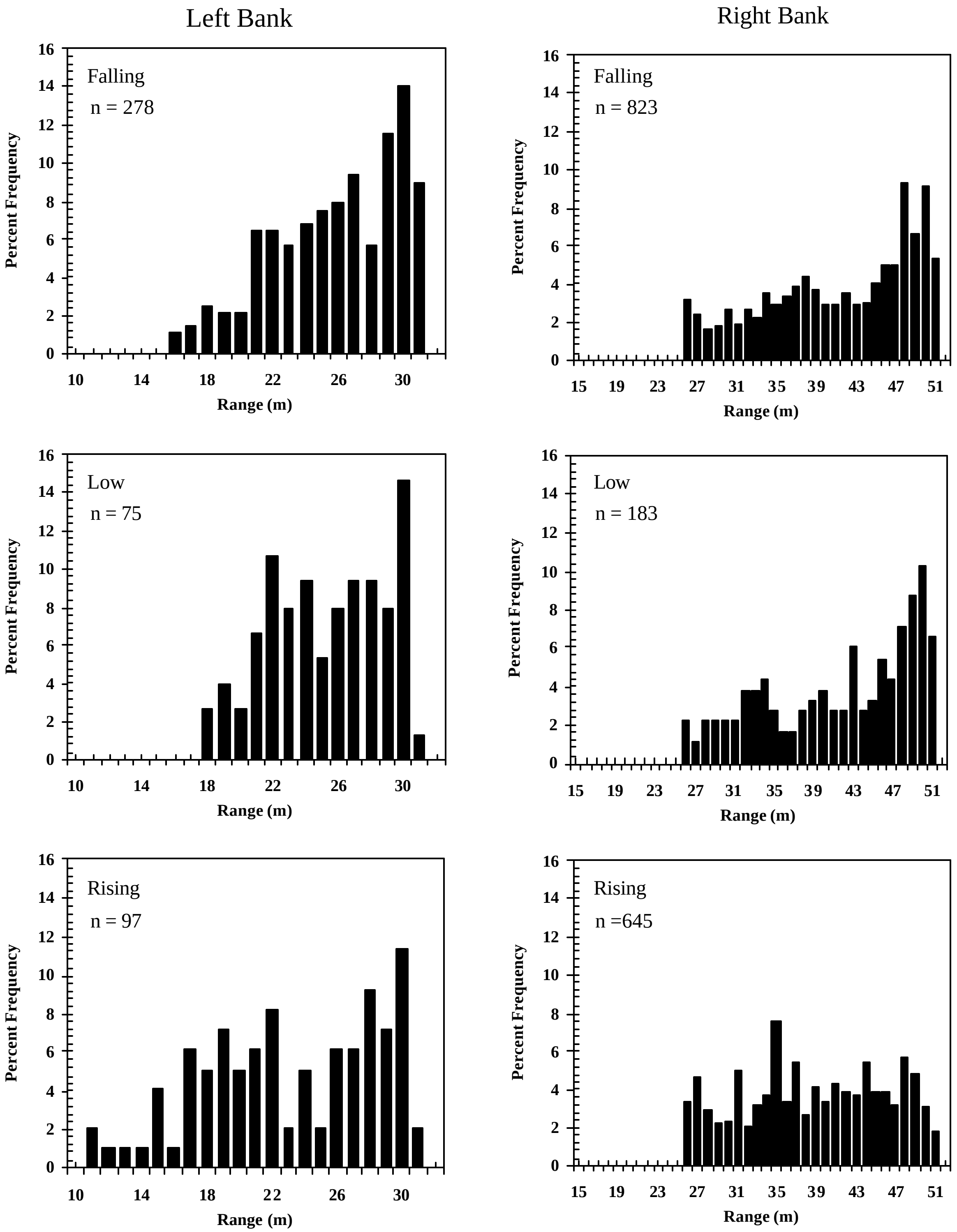
Note: Data have been filtered by range and target strength criteria.

Figure 12.-Range distribution of early-run upstream fish during falling, low, and rising tide stages on the left and right banks, 16 May-10 June, Kenai River, 1999.



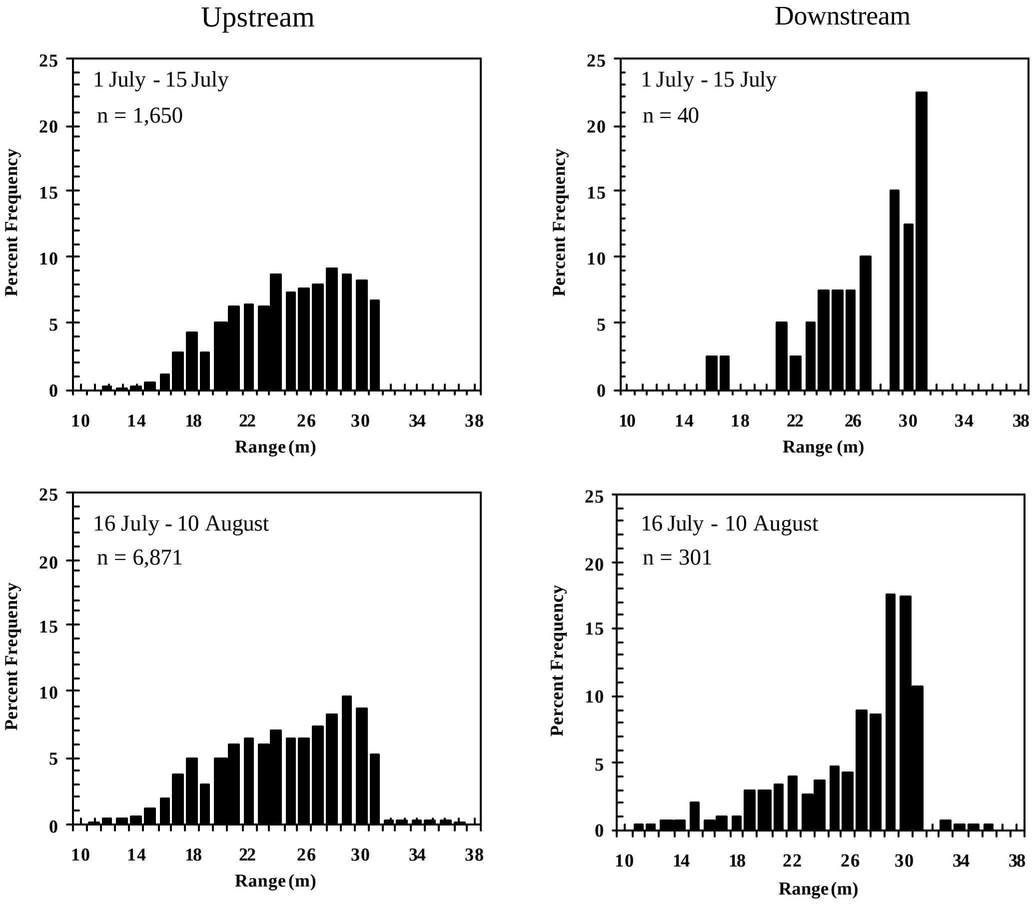
Note: Data have been filtered by range and target strength criteria.

Figure 13.-Range distribution of early-run upstream fish during falling, low, and rising tide stages on the left and right banks, 11 June-23 June, Kenai River, 1999.



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

Figure 14.-Range distribution of early-run upstream fish during falling, low, and rising tide stages on the left and right banks, 24 June-30 June, Kenai River, 1999.



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

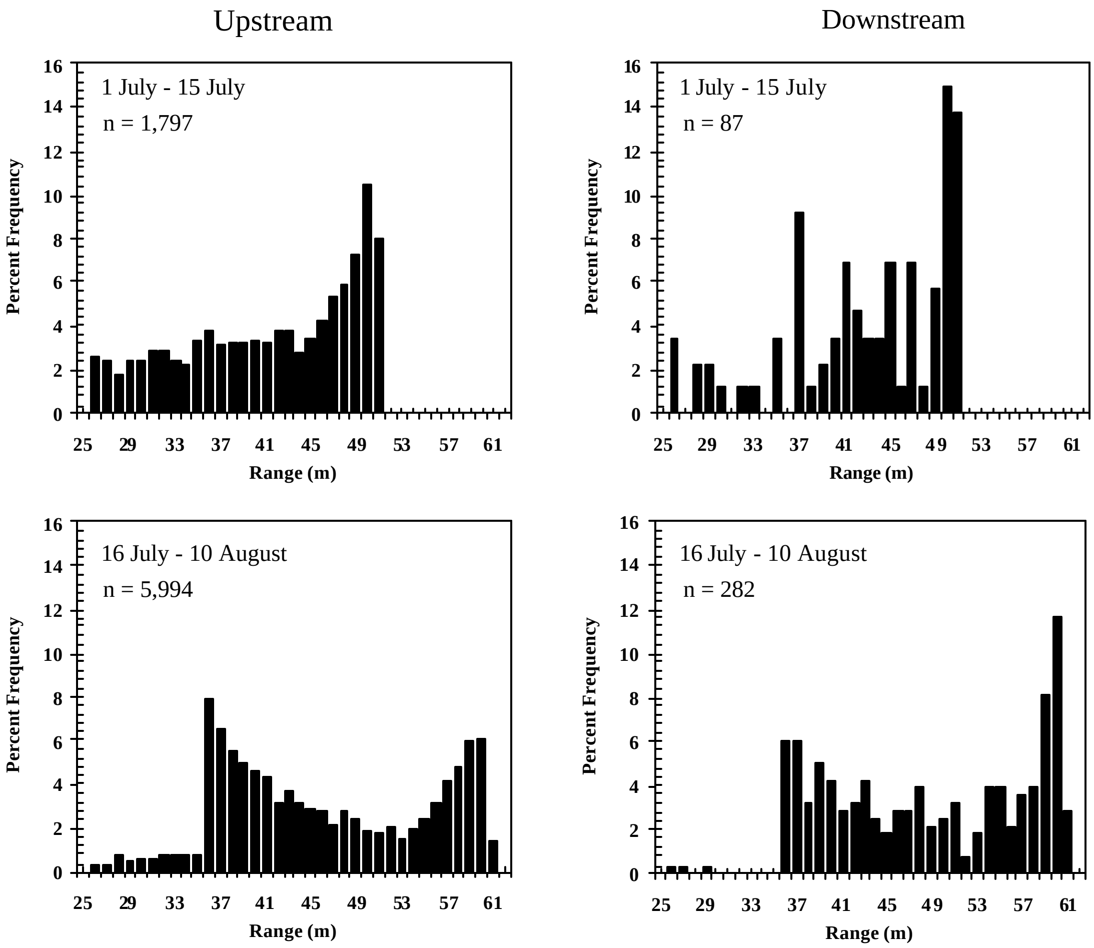
Figure 15.-Range distribution of late-run upstream and downstream fish on the left bank, 1 July-15 July, 16 July-10 August, Kenai River, 1999.

TARGET STRENGTH

Target strength distributions varied by bank, direction of travel, and run. Table 9 shows target strength statistics for fish that met minimum range and target strength criteria, whereas Figures 19 and 20 show target strength distributions and statistics that include all tracked targets.

Mean target strength estimates for all upstream targets on the left bank during the early and late run averaged about 2 dB higher than right-bank estimates (Figures 19 and 20). Mean target strength of upstream and downstream targets differed the most on the left bank during both runs (Figures 19 and 20).

During the early run on the left bank, mean target strength of chinook salmon was higher ($t = -5.48$, $P <<< 0.01$) for upstream fish than for downstream fish (Table 9), but variability was similar ($F = 0.99$, $P = 0.49$). On the right bank, mean target strength measurements for upstream and downstream traveling chinook salmon were similar ($t = -0.32$, $P = 0.75$) as was the variability ($F = 1.13$, $P = 0.07$; Table 9).



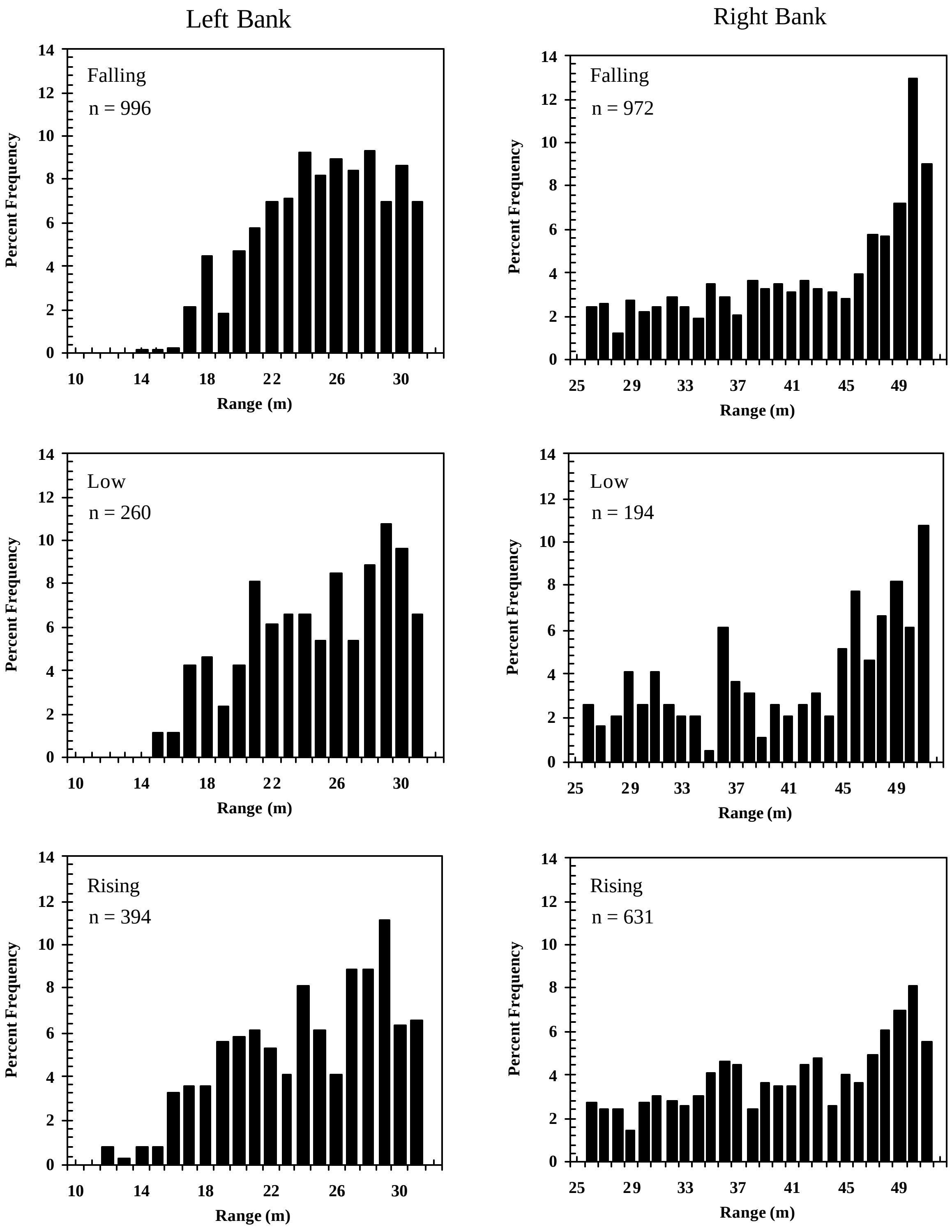
Note: Data have been filtered by range and target strength criteria.

Figure 16.-Range distribution of late-run upstream and downstream fish on the right bank, 1 July-15 July, 16 July-10 August, Kenai River, 1999.

During the late run on the left bank, mean target strength of chinook salmon was higher (t = -7.71, P <<< 0.01) for upstream fish than for downstream fish, as was variability (F = 0.65, P<<< 0.01, Table 9). The difference in target strength, however, was less than 1 dB and the statistical significance may be an artifact of sample size rather than an actual difference in mean target strength. On the right bank, mean target strength estimates between upstream and downstream chinook salmon were similar (t = 0.84, P = 0.39), but variability was slightly higher among downstream fish (F = 1.14, P = 0.03; Table 9).

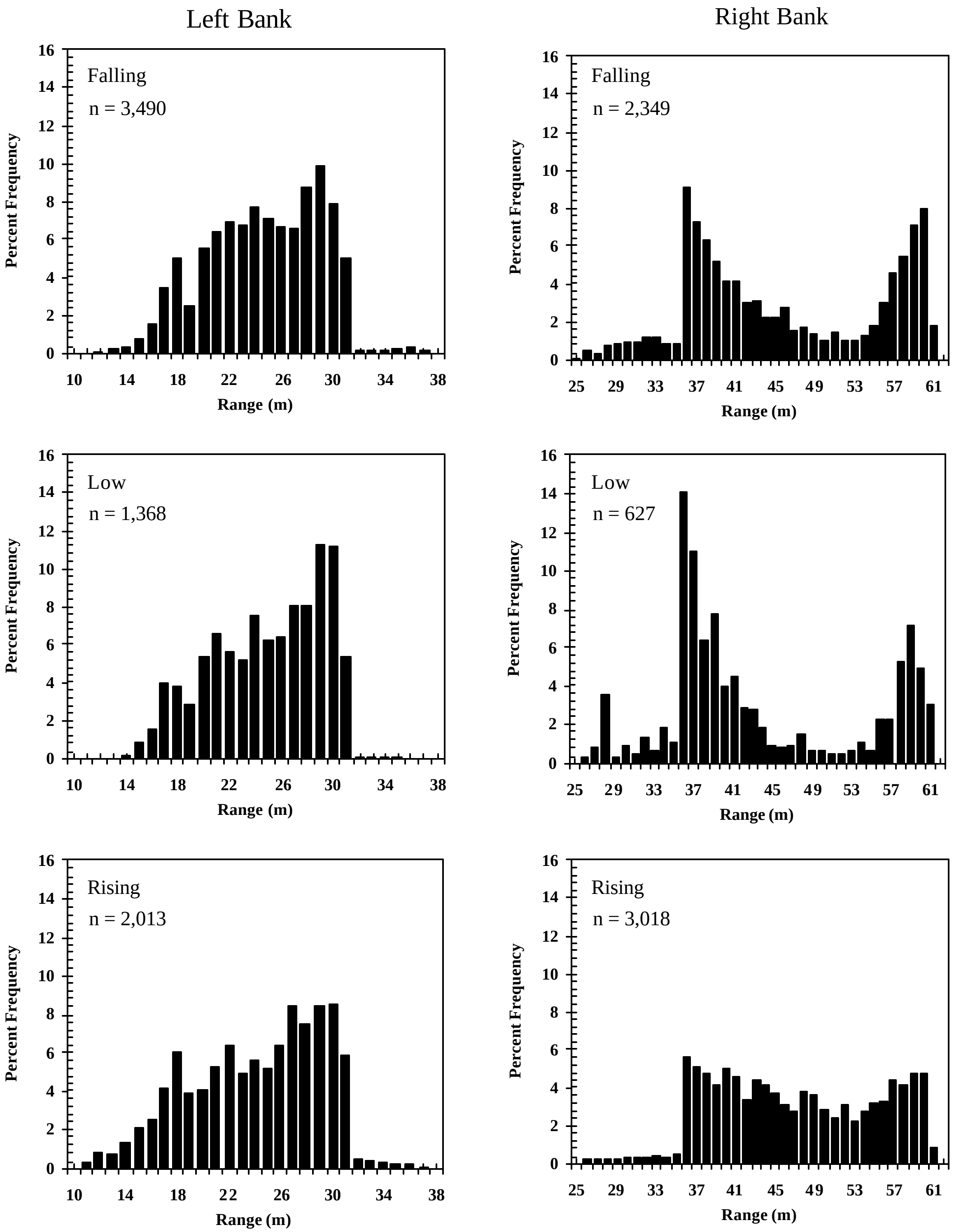
PASSAGE ESTIMATES

Daily estimates of chinook salmon passage were generated for 16 May-10 August. Sampling was terminated at 2300 on 10 August. During the 87-day season, a total of 795 hours of acoustic data were processed from the right bank and 641 hours from the left bank. This represented 38% of the total available sample time on the right bank and 31% on the left bank.



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

Figure 17.-Range distribution of early-run upstream fish during falling, low, and rising tide stages on the left and right banks, 1 July-15 July, Kenai River, 1999.



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

Figure 18.-Range distribution of late-run upstream fish during falling, low, and rising tide stages on the left and right banks, 16 July-10 August, Kenai River, 1999.

Table 7.-Estimates of 1999 early-run chinook salmon passage by direction of travel.

Bank	Estimate of Total Fish Passage[a]		Estimate of Downstream Component[a]		Estimate of Upstream Component[a]	
Right Bank	11,783	(252)	511	(33)	11,272	(251)
Left Bank	14,873	(277)	478	(48)	14,395	(271)
Both Banks	26,656	(374)	990	(59)	25,666	(370)

Note: Standard errors are in parentheses.

[a] Data have been filtered by range and target strength criteria.

Table 8.-Estimates of 1999 late-run chinook salmon passage by direction of travel.

Bank	Estimate of Total Fish Passage[a]		Estimate of Downstream Component[a]		Estimate of Upstream Component[a]	
Right Bank	23,560	(605)	1,104	(57)	22,456	(593)
Left Bank	26,640	(424)	1,027	(59)	25,613	(414)
Both Banks	50,200	(739)	2,131	(82)	48,069	(723)

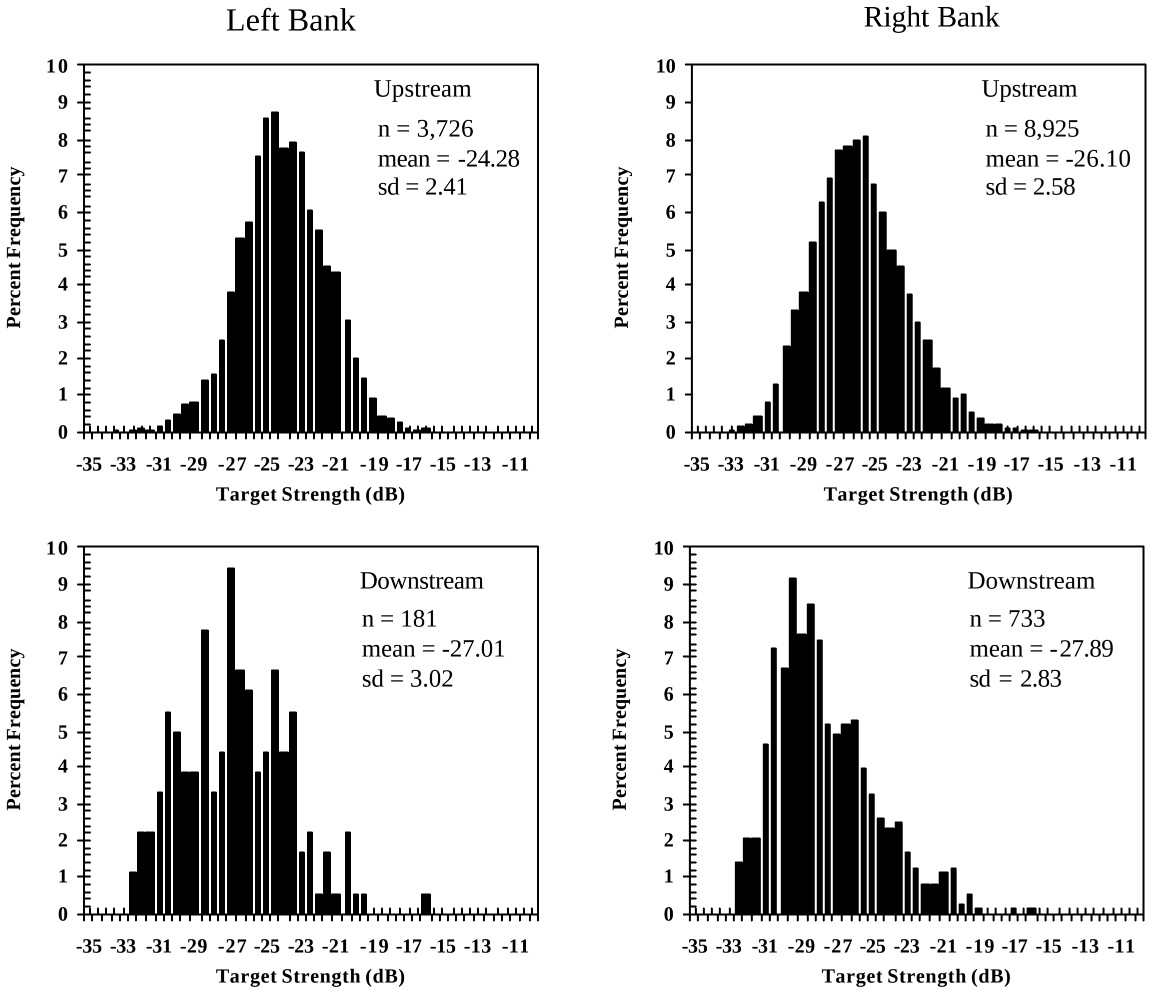
Note: Standard errors are in parentheses.

[a] Data have been filtered by range and target strength criteria.

Table 9.-Mean target strength for upstream and downstream targets by bank during the early (16 May-30 June) and late (1 July-10 August) runs, 1999.

	Upstream			Downstream		
Location	mean[a]	SD[a]	n[a]	mean[a]	SD[a]	n[a]
Early Run						
Left Bank	-23.96	2.12	3,477	-25.09	2.11	110
Right Bank	-25.10	2.11	5,739	-25.15	2.25	248
Late Run						
Left Bank	-25.46	1.61	8,521	-26.02	1.30	341
Right Bank	-26.25	1.42	8,456	-26.19	1.52	379

[a] Data have been filtered by range and target strength criteria.

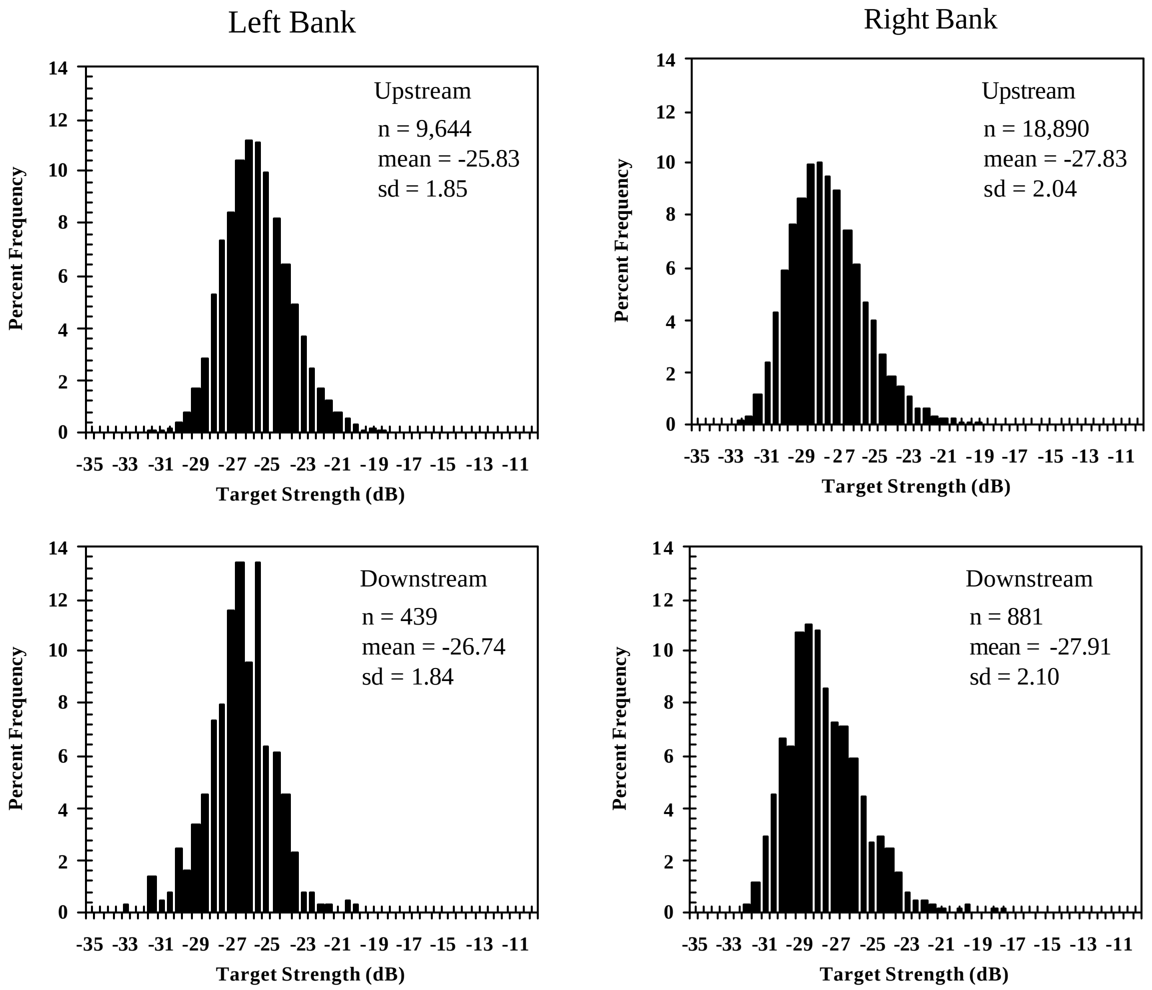


Note: Data have not been filtered by range or target strength criteria.

Figure 19.-Early-run target strength distributions for all upstream and downstream targets on the left and right banks, Kenai River, 1999.

To maintain comparability between recent (1995-1999) estimates of fish passage derived from split-beam sonar and past (1987-1994) estimates generated by dual-beam sonar, two passage estimates were generated. The first estimate, total passage, is comparable with past estimates generated by dual-beam sonar when we were unable to determine direction of travel. It assumes all targets are upstream migrants. The second estimate, upstream passage, includes only those targets (after size and range filters) that were determined to be traveling upstream.

Total chinook salmon passage from 16 May through 10 August was an estimated 76,856 (SE = 828) fish, 26,656 (SE = 374) during the early run and 50,200 (SE = 739) during the late run (Tables 7 and 8).



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

Figure 20.-Late-run target strength distributions for all upstream and downstream targets on the left and right banks, Kenai River, 1999.

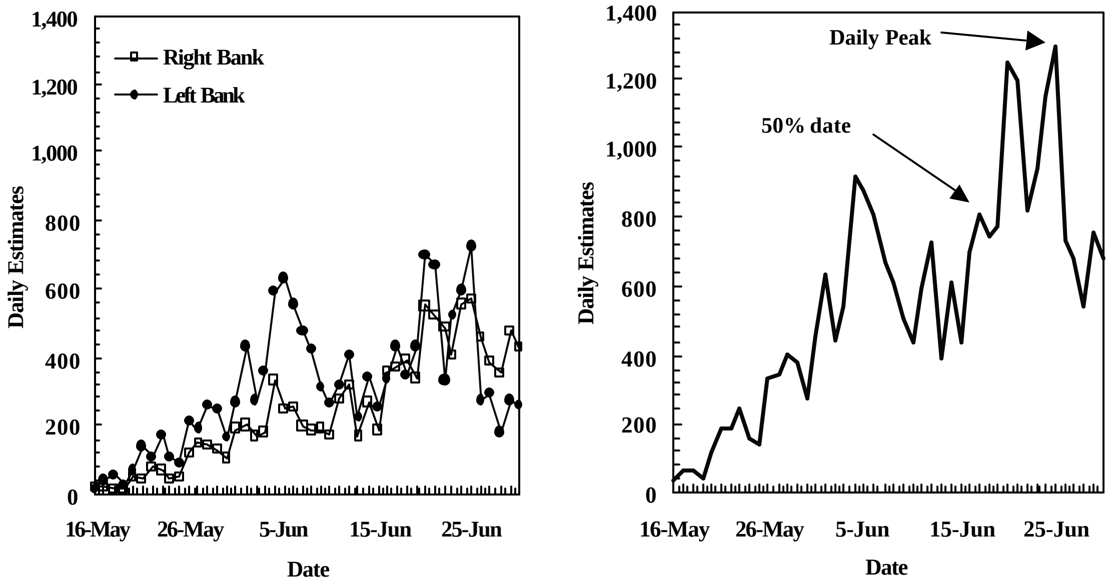
Upstream chinook salmon passage from 16 May through 10 August was an estimated 73,735 (SE = 812) fish, 25,666 (SE = 370) during the early run and 48,069 (SE = 723) during the late run (Tables 7, 8, 10, and 11). The daily peak of the early run occurred on 25 June with 50% of the run having passed by 17 June (Figure 21). Migratory timing for the early run was generally within the historic 95% confidence intervals (Figure 22). An exception to this occurred during an 8-day period beginning 13 June when the 1999 migratory timing fell well behind the historic mean and outside of the historic 95% confidence intervals. The daily peak of the late run occurred on 17 July, with 50% of the late run having passed by 22 July (Figure 23). Late-run migratory timing was within normal historic bounds (Figure 22).

Table 10.-Estimated daily upstream passage of chinook salmon, Kenai River sonar, early run, 1999.

Date	Left Bank	Right Bank	Daily Total	Cumulative Total
16-May	14	18	33	33
17-May	41	22	63	95
18-May	53	14	66	162
19-May	24	15	39	201
20-May	68	48	116	317
21-May	141	45	186	503
22-May	111	81	192	695
23-May	174	69	243	938
24-May	113	47	159	1,098
25-May	90	51	141	1,239
26-May	210	120	330	1,569
27-May	192	150	342	1,911
28-May	255	147	402	2,313
29-May	249	129	378	2,691
30-May	168	105	273	2,964
31-May	267	192	459	3,423
1-Jun	432	201	633	4,056
2-Jun	273	171	444	4,500
3-Jun	357	183	540	5,040
4-Jun	591	333	924	5,964
5-Jun	630	246	876	6,840
6-Jun	555	252	807	7,647
7-Jun	477	195	672	8,319
8-Jun	423	186	609	8,928
9-Jun	312	192	504	9,432
10-Jun	261	178	439	9,871
11-Jun	317	279	596	10,467
12-Jun	406	317	723	11,190
13-Jun	222	172	393	11,583
14-Jun	343	267	610	12,193
15-Jun	250	186	436	12,629
16-Jun	339	357	696	13,325
17-Jun	432	375	807	14,132
18-Jun	349	393	742	14,874
19-Jun	433	338	771	15,644
20-Jun	700	547	1,247	16,891
21-Jun	669	523	1,192	18,083
22-Jun	330	489	819	18,902
23-Jun	525	410	935	19,837
24-Jun	595	556	1,151	20,988
25-Jun	726	567	1,292	22,280
26-Jun	273	458	731	23,012
27-Jun	291	387	678	23,690
28-Jun	183	354	537	24,226
29-Jun	273	480	753	24,979
30-Jun	258	429	687	25,666
Total	14,395 (56.1%)	11,272 (43.9%)	25,666	

Table 11.-Estimated daily upstream passage of chinook salmon, Kenai River sonar, late run, 1999.

Date	Left Bank	Right Bank	Daily Total	Cumulative Total
1-Jul	174	279	453	453
2-Jul	288	324	612	1,065
3-Jul	204	282	486	1,551
4-Jul	207	189	396	1,947
5-Jul	198	171	369	2,316
6-Jul	279	404	683	2,999
7-Jul	363	573	936	3,935
8-Jul	384	646	1,030	4,965
9-Jul	432	615	1,047	6,012
10-Jul	300	417	717	6,729
11-Jul	441	618	1,059	7,788
12-Jul	270	290	560	8,348
13-Jul	237	164	401	8,749
14-Jul	708	261	969	9,718
15-Jul	465	171	636	10,354
16-Jul	515	412	927	11,281
17-Jul	1,749	1,809	3,558	14,839
18-Jul	1,299	1,485	2,784	17,623
19-Jul	978	891	1,869	19,492
20-Jul	2,028	1,443	3,471	22,963
21-Jul	2,502	852	3,354	26,317
22-Jul	1,344	654	1,998	28,315
23-Jul	1,137	738	1,875	30,190
24-Jul	1,031	717	1,748	31,939
25-Jul	1,002	935	1,937	33,875
26-Jul	543	555	1,098	34,973
27-Jul	1,257	1,809	3,066	38,039
28-Jul	705	653	1,358	39,398
29-Jul	636	549	1,185	40,583
30-Jul	636	333	969	41,551
31-Jul	879	429	1,308	42,859
1-Aug	264	327	591	43,450
2-Aug	267	201	468	43,919
3-Aug	378	264	642	44561
4-Aug	225	219	444	45,005
5-Aug	222	214	436	45,440
6-Aug	354	300	654	46,094
7-Aug	297	381	678	46,772
8-Aug	270	534	804	47,576
9-Aug	93	235	328	47,904
10-Aug	52	113	165	48,069
Total	25,613 (53.3%)	22,456 (46.7%)	48,069	



Note: Estimates by bank (left) and total run (right).

Figure 21.-Daily sonar estimates of passage for the early run of chinook salmon returning to the Kenai River, 1999.

SAMPLE DESIGN EVALUATION

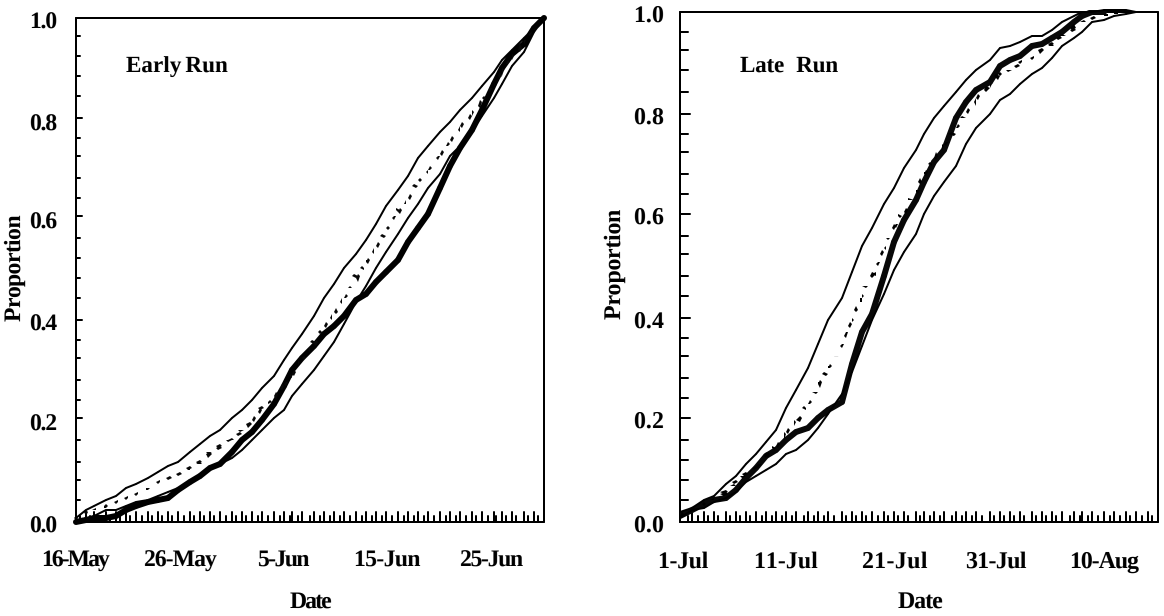
Sample design evaluation was conducted in June after it was determined the early run of chinook salmon was strong, and enough chinook salmon had passed the sonar to establish a reliable ratio estimator. Spring tide sampling occurred from 12 June to 15 June, while neap tide sampling occurred from 19 June to 21 June, and normal tide sampling occurred from 23 June to 25 June. A total of 164 hours of census was collected among the three tide phases to compare with estimates produced by the systematic sample design (Table 12). During this time the census counted a total of 2,639 chinook passing the right bank, while the systematic sample design estimated 2,559, or 3.0% fewer. The sign test failed to reject (P = 0.46) the null hypothesis that there was no difference between the census and the systematic sample design estimate of early-run chinook salmon passing the right bank.

DISCUSSION

SPATIAL DISTRIBUTION

Bank Preference

Historically, the right bank has been heavily favored by migrating fish during both the early and late runs. At the start of the season, there are roughly equal proportions of fish on each bank. However, the proportion of fish traveling up the right bank typically increases as the season progresses (Burwen and Bosch 1995a, 1995b, 1996, 1998; Eggers et al. 1995; Bosch and Burwen 1999). The right bank is the depositional bank, with a more gradual slope and slower water velocities than the left bank. Since the channel is offset to the left bank, the right-bank transducer also covers a greater proportion of the river crosssection (Figure 3). The increase in the proportion of right-bank oriented fish during



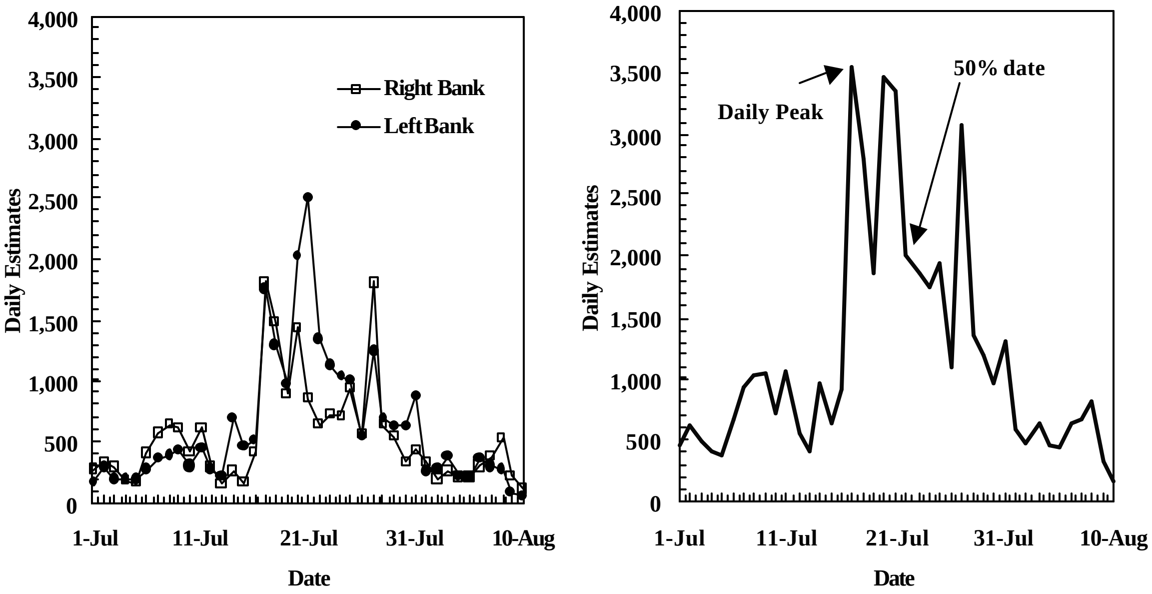
Note: Mean migratory timing curves for the years 1987-1998 (dashed lines), and 95% confidence intervals (thin solid lines) are presented for comparison and are based on estimates of total passage through 1997 and upstream passage after 1997.

Figure 22.-Migratory timing curves for early and late runs of chinook salmon to the Kenai River, 1999 (thick solid lines).

June and July may be a response to the increasing discharge that occurs over the same period. The proportion of the river crosssection covered by the right bank also increases with increasing water levels as the transducers are moved closer to shore. Exceptions to this entry pattern occurred during the early runs in 1996 and 1997 when more fish were consistently detected on the left bank. However, discharge was also far below average during each of these runs (Burwen and Bosch 1998; Bosch and Burwen 1999). In 1999, fish passage was similar to 1996 and 1997 (Tables 10 and 11) with more chinook passing on the left bank during both runs. Discharge levels in 1999 were below average for most of June, July, and August (USGS 1999).

Vertical Distribution

Monitoring the spatial distribution of fish is particularly important at the present site, where tidally-induced changes in water level have been shown to affect fish distribution. A primary concern is that fish may swim over the beam during rising and falling tide stages. Because the site experiences extreme semidiurnal tidal fluctuations that average 4 m and are as high as 7 m (Figure 3), it is not possible to insonify the entire cross-sectional area of the river that can potentially be used by migrating chinook salmon. Fish position data suggest that most upstream fish are within the insonified zone. When sockeye are not present in large numbers, it appears that most fish prefer the offshore, bottom section of the river where beam coverage is maximized. Although there was slightly more fish in the upper half of the beam during the rising tide stage on the left bank during the 1999 early run (Figure 7), very few fish occupied the upper half of the beam overall. Data collected in previous years showed that fish have maintained a strong bottom orientation during all three tide stages during both the early and late runs (Eggers et al. 1995; Burwen et al. 1995; Bosch and Burwen 1999).



Note: Estimates by bank (left) and total run (right).

Figure 23.-Daily sonar estimates of passage for the late run of chinook salmon returning to the Kenai River, 1999.

Table 12.-Sample design test summary for spring, neap and normal tide phases, Kenai River sonar, 1999.

Tide Type	Census	Estimate	Difference	Sample Size (Hours)	Number of Days Sampled	Julian Dates Sampled
Spring Tide	425	450	-25	48	3	163 to 165
Neap Tide	1,111	1,086	25	62	3	170 to 172
Normal Tide	1,103	1,023	80	54	3	174 to 176
Total	**2,639**	**2,559**	**80**	**164**	**9**	

Because the vast majority of fish travel close to the river bottom (Figures 6 and 8), our greatest concern is missing fish passing under the sonar beam. Relatively few fish were detected below the -2.0^{o} beam angle (Figures 6 and 8). Even with the decreased ability to detect targets on the edge of the beam, we assume there would be larger numbers of targets detected in this region if substantial numbers of fish were traveling below the effective beam, given the large acoustic size of chinook salmon.

It should be noted that fish on the right bank only appear to be traveling higher in the water column than fish traveling on the left bank (Figures 6 and 8). The less reflective sediments on the right bank allow for aiming of the sonar beam closer to (and even into) the river bottom. This likely increases our ability to detect bottom-oriented fish on the right bank, but it also shifts the distribution of bottom-oriented fish upward, making fish on this bank appear higher in the water column.

Range Distribution

The distribution of upstream fish on the left bank was relatively stable throughout the early run (Figure 10) while the right bank was distributed heavily offshore prior to 10 June and was more evenly distributed after that date (Figure 11). A similar pattern was exhibited during the late run with the left-bank upstream range distribution remaining relatively stable throughout the run (Figure 15) and the right-bank range distribution exhibiting great variation between the first and second half of the run (Figure 16). From 1 July through 15 July upstream passage on the right bank exhibited a single peak near the end of the counting range. From 16 July through 10 August a bimodal range distribution was exhibited with peaks occurring at 36 m and 60 m from the transducer face (Figure 16).

Note that the observed upstream fish passage beyond 31 m on the left bank during the late run (Figure 15) was the result of a transducer tripod relocation that took place on the left bank on 7 August. The tripod was moved closer to shore, and the insonified range was extended to 36.5 m in order to maintain the same mid-river coverage. Rather than produce a separate range distribution for this short time period (7 August-10 August), we decided to include the data in a plot with the 16 July through 6 August data. Also note that upstream passage on the right bank during the late run appears to truncate at 35 m with very light passage inside of this range (Figure 16). The inshore truncation is the result of the range threshold used for eliminating nearshore sockeye salmon from chinook salmon counts. After moving the right-bank transducer tripod on 16 July, the range threshold was extended from 25 m to 35 m. The light passage inside of 35 m is due to fish passage that occurred in this area between the time the tripod was moved on 16 July and the time the range threshold was extended on 17 July.

TARGET STRENGTH

The effects of threshold-induced bias rather than actual differences in fish size can most likely explain differences in mean target strength between banks (Ehrenberg and Torkelson 1996; Weimer and Ehrenberg 1975). Fish traveling upstream on the left bank may be forced closer to the bottom due to higher water velocities found on this side of the river. Additionally, the sonar beam cannot be aimed as close to the bottom on the left bank because the substrate is composed of more acoustically reflective gravel compared to the acoustically absorptive mud on the right bank. Since left-bank fish are, on average, farther from the acoustic axis than right-bank fish, a greater proportion of small echoes from left-bank fish do not meet the voltage threshold biasing target strength estimates upward. Recent research (Fleischman and Burwen 2000) has also identified a positive bias in target strength associated with measurement error in the echo position estimates. Since higher background noise levels lead to higher variability in positional estimates, this bias is also greater on the left bank.

Downstream unfiltered targets were considerably smaller (2 dB on the right bank, 3 dB on the left bank) than upstream unfiltered targets during the early run (Figure 19). The distribution of unfiltered data was more skewed to the right for downstream fish than for upstream fish. The proportion of downstream targets was also larger in the unfiltered data set than in the filtered data set during the early run (7% vs. 4%, Table 9, Figure 19). This indicates that the target strength threshold is likely filtering out downstream traveling debris that were incorrectly classified as downstream swimming fish, or that smaller fish were more likely to travel downstream. During the late run, downstream targets were only slightly smaller (less than 1 dB on right bank, less than 2 dB on left bank) than upstream targets and the proportion of downstream targets was similar (4%) for filtered and unfiltered data (Table 9, Figure 20).

After applying range and target strength filters, average target strength of upstream and downstream traveling chinook salmon on the left bank during the early run differed by less than 2 dB (Table 9). Average target strength of upstream and downstream chinook salmon on the left bank during the late run and on the right bank during both the early and late runs differed by less than 1 dB (Table 9). This suggests that at least in the data set used to generate chinook salmon estimates, most downstream targets were correctly classified as fish rather than debris.

DIRECTION OF TRAVEL

All tracked targets have been classified by direction of travel since 1995, when split-beam technology was first implemented. Since then, the downstream component of the early run has varied from 6% to 12% and averaged 9%, while the downstream component of the late run has ranged from 4% to 14% and has averaged 6% (Burwen and Bosch 1998; Burwen et al. 1998; Bosch and Burwen 1999, 2000). The downstream component of the late run during 3 of the past 4 years has equaled 5% or less with the exception of the 14% anomaly estimated in 1998 (Bosch and Burwen 2000). Downstream passage in 1999 averaged 4% during both the early and late runs (Tables 5 and 6). The proportion of downstream targets in 1999 was relatively high during the first 10 days of the early run, but was relatively low during the remainder of the early run and throughout the late run (Appendices D1 and D2).

The reason for relatively high numbers of small downstream targets during the early part of the season is not understood. The most likely explanation is that crewmembers become more adept at discriminating debris from downstream traveling fish as the season progresses. Another explanation is that there may be a smaller species of fish (e.g., Dolly Varden *Salvelinus malma*) migrating downstream during the early run. The tendency for downstream traveling targets to have smaller average target strengths than upstream-traveling targets has been documented in prior years (Bosch and Burwen 1999, 2000). Discerning between debris-like traces and a fish traveling downstream can be difficult, and crewmembers are instructed to include downstream targets as valid fish traces when in doubt. Some contamination of fish estimates with downstream-traveling debris is inevitable. This is the reason that this project and many others choose to ignore downstream targets rather than subtract them from upstream estimates even when direction of travel is known. Typically, the proportion of downstream targets is small, and the potential error that would be introduced by misclassifying debris as downstream traveling fish is of greater concern.

PASSAGE ESTIMATES

Based on many years of research, we no longer assume that sonar estimates of chinook abundance are equally reliable under all circumstances. Recent research efforts have focused on identifying conditions when sonar estimates may not be reliable. Our foremost concern is that the sonar may mistake substantial numbers of sockeye as chinook during periods of high sockeye passage.

Early Run

The 1999 early-run inriver return estimate of 25,666 chinook salmon was above average and was the highest early-run sonar estimate recorded since sonar enumeration began in 1988 (Appendix F1). The large estimate might lead one to question whether the presence of sockeye salmon in June may have resulted in an overestimation of chinook passage. Although there are some indications that late June chinook estimates may have been inflated by sockeye, there is no evidence to suggest severe sockeye contamination took place.

A decline in the daily mean –12 dB pulse width in late May and early June (Figure 24) might suggest possible sockeye contamination, but chinook salmon age data from the netting program indicates that the proportion of older (larger) chinook passing the site declined during this time (Figure 25). A decline in chinook size might explain the decline in daily mean –12 dB pulse width.

A comparison of chinook salmon net CPUE with daily chinook sonar estimates (Figure 26) suggests possible overestimation of chinook passage in late June when sonar estimates increased and net CPUE estimates decreased. However, sockeye net CPUE also experienced a decrease in late June (Figure 27). In addition, both chinook and sockeye net CPUE can be influenced by factors other than the presence or absence of these species. For example, an increase in water clarity or discharge during this time (Figure 28) may explain the decrease in both sockeye and chinook net CPUE. So it is difficult to draw conclusions from the net CPUE data alone.

A change in the left-bank proportion of the total daily chinook sonar estimate might also suggest possible inflation by sockeye. A decrease in the left-bank proportion can result from an increase in sockeye passage on the right bank where the bottom slope has less gradient and sockeye are able to pass the site at farther ranges. The steep slope and high current on the left may force sockeye inshore of the transducer tripod where they are not detected by the sonar gear. The left-bank proportion was fairly steady throughout much of the early run, but declined slightly in late June (Figure 29). One cannot conclude definitively whether the increased passage on the right bank resulted from an increase in sockeye or an increase in chinook passage.

The increased number of fish near shore on the right bank in mid to late June (Figure 11) suggests possible inflation due to sockeye. Bottom profiles of the right bank revealed no changes in the bottom contour during mid June that would explain the shift in distribution. However, increased discharge rates in mid to late June may explain the nearshore shift (Figure 28).

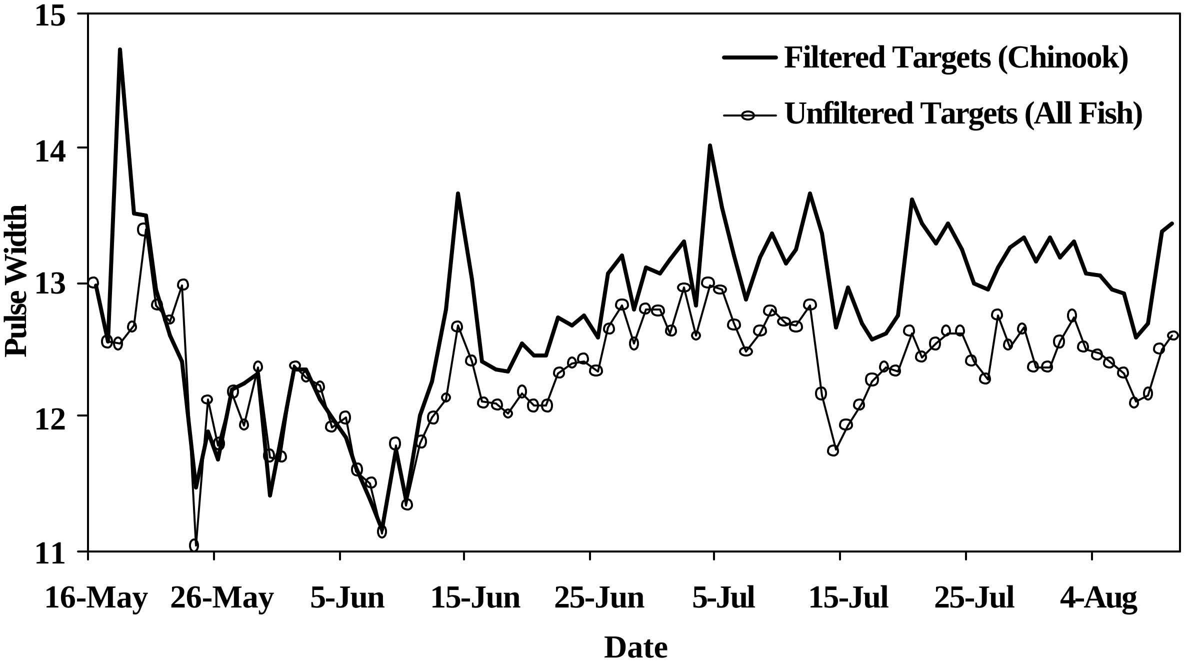


Figure 24.-Daily right-bank mean pulse width (measured at -12 dB down from peak amplitude), 16 May to 10 August, 1999.

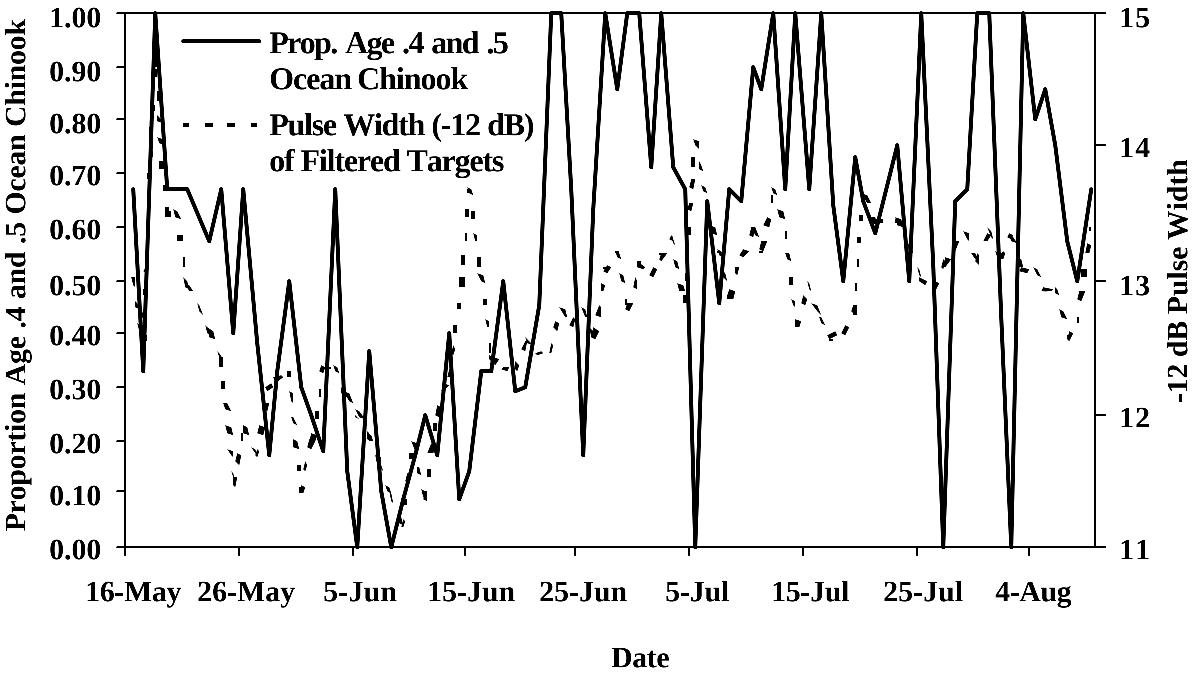


Figure 25.-Daily proportion of age-.4 and -.5 ocean chinook salmon with mean -12 dB pulse width, 16 May to 9 August, 1999.

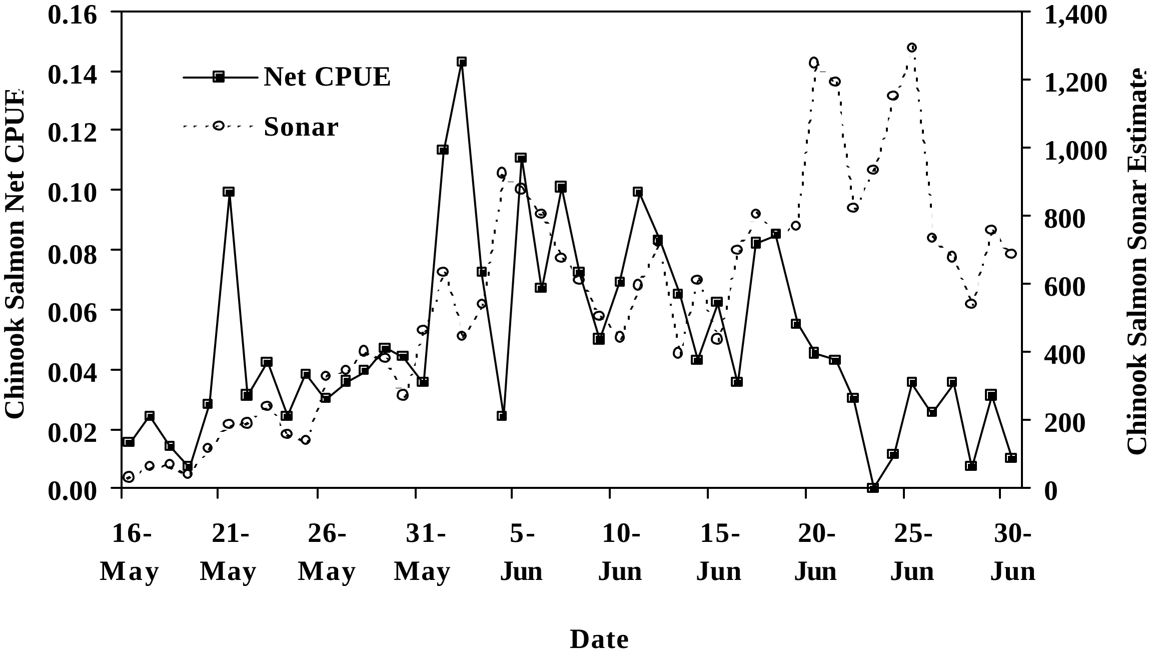


Figure 26.-Daily chinook salmon sonar estimates with chinook salmon inriver net CPUE, early run (16 May-30 June), 1999.

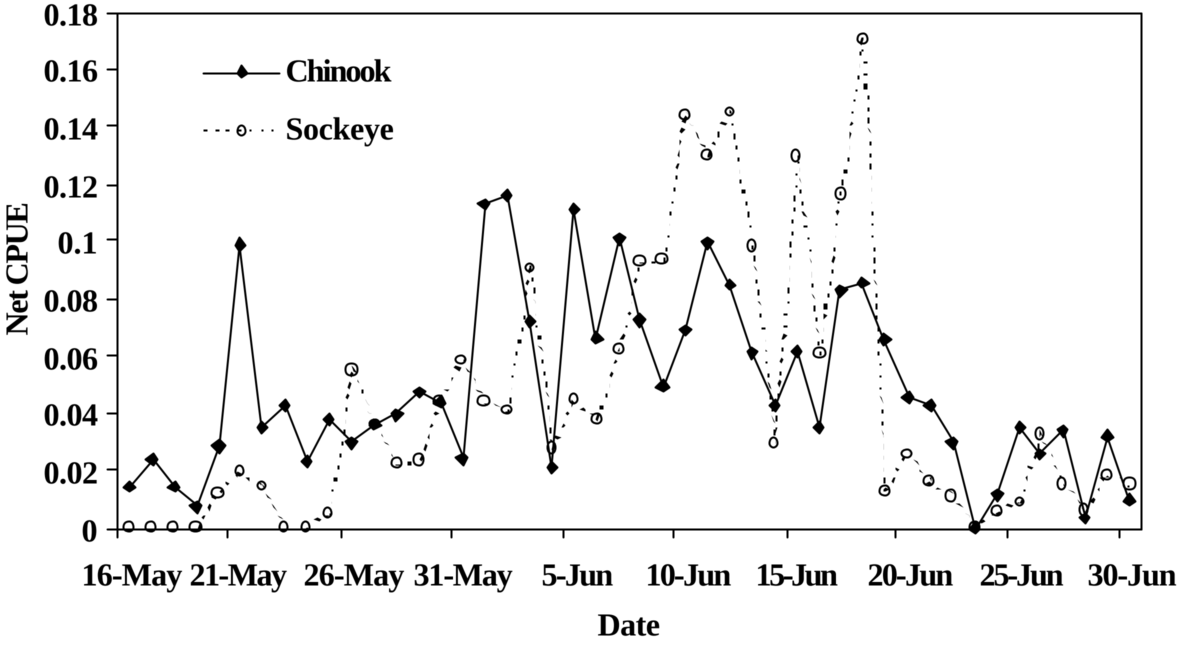


Figure 27.-Daily chinook and sockeye salmon inriver net CPUE, 16 May-30 June, 1999.

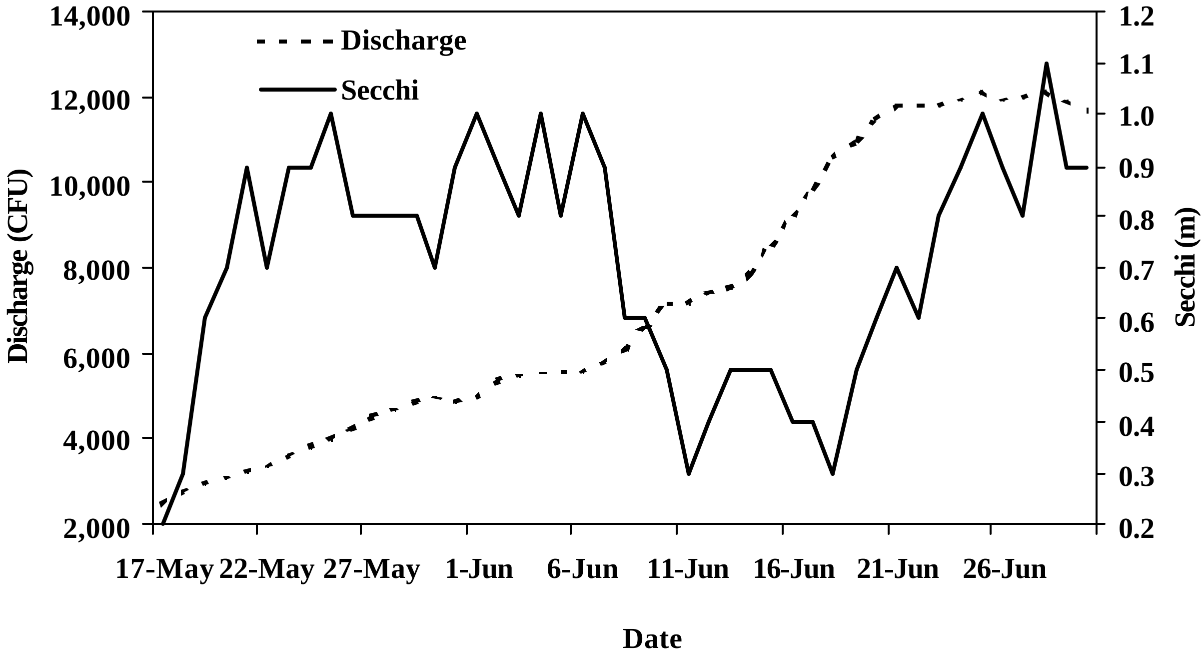


Figure 28.-Daily Secchi depth readings (in front of sonar site) and discharge rates (Soldotna Bridge) for lower Kenai River, early run (15 May-30 June), 1999.

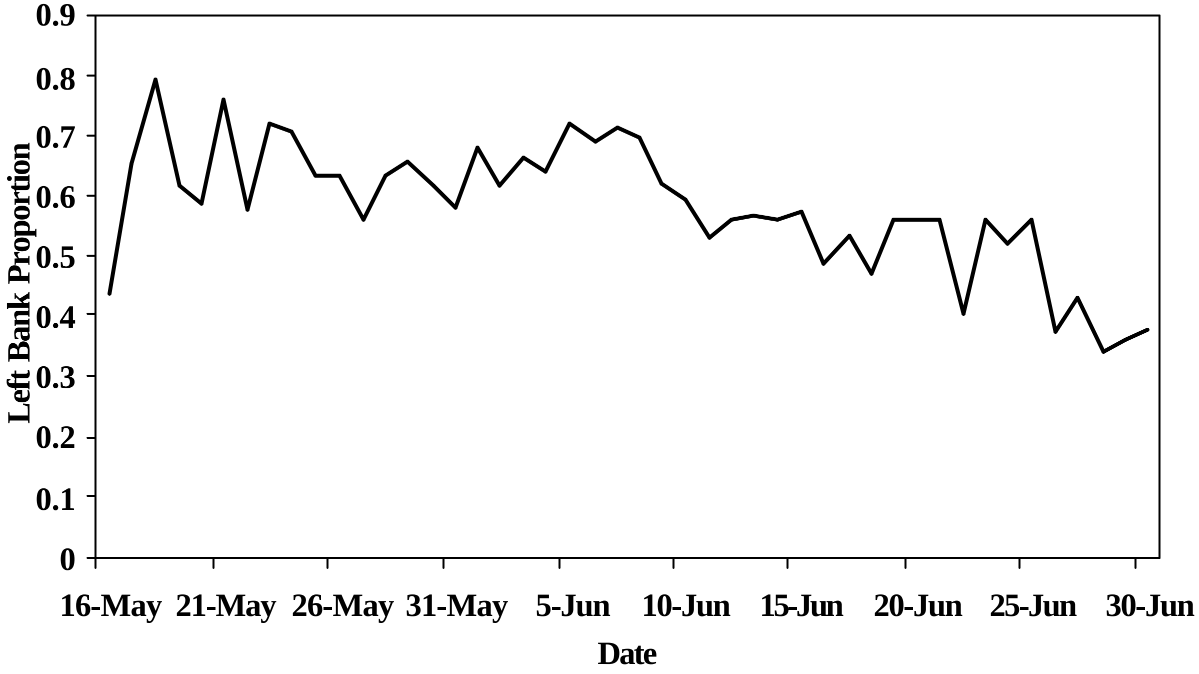


Figure 29.-Left-bank proportion of total daily chinook salmon sonar estimate, early run (16 May-30 June), 1999.

Inseason sport fish CPUE estimates appear to support the large early-run chinook sonar passage estimate in that fishing improved as the early run progressed, and all anglers, both guided and unguided, experienced some of the highest early-run angler success rates recorded (Reimer et al. 2002).

In conclusion, we feel the presence of sockeye salmon in mid to late June had minimal influence on the 1999 early-run chinook salmon passage estimate.

Late Run

The 1999 late-run inriver return of 48,069 chinook salmon was above average (Appendix F2). As with the early run, there were no indications that severe sockeye salmon contamination occurred during the late run. There is evidence, however, that some inflation due to the presence of sockeye was possible.

Sonar estimates appear to track fairly well with inriver net CPUE estimates, except for a few days in mid to late July (Figures 30 and 31). Daily peaks in chinook passage based on the sonar estimates occurred on 17 July, 20 July, and 27 July, while the net CPUE exhibited only one major peak on 20 July. Water clarity based on Secchi depth readings may explain some of the late July disparity between sonar and net CPUE estimates (Figure 32). Clear water in late July may have contributed to net avoidance by chinook salmon resulting in low chinook net CPUE. Water clarity does not, however, explain the disparity experienced on 17 July. A comparison of chinook and sockeye net CPUE estimates also fails to explain the mid July disparity (Figure 33). If increased presence of sockeye salmon were suspected in contributing to high daily chinook passage estimates, one would expect a corresponding increase in sockeye net CPUE when there is an increase in the chinook sonar passage estimate. Although the sockeye net CPUE exhibited an increase on 17 July (Figure 33), the increase was not of the magnitude one would expect to cause the observed increase in the daily chinook sonar estimate (Figure 30). Again, one should be cautious when attempting to draw conclusions from net CPUE and water clarity data.

The chinook salmon bimodal range distribution experienced on the right bank during late July and early August also suggests possible sockeye contamination (Figure 16). Fish targets in early July were more channel-oriented than in late July and early August when the distribution became bimodal, with peaks at 36 m and 60 m. As with the early run, it is difficult to explain this bimodal distribution and whether the inshore mode results from misclassification of sockeye or from an increased passage of chinook at this range. A review of the left-bank proportion of the total daily chinook estimate (Figure 34) fails to support the possibility that the right-bank inshore mode resulted from misclassification of sockeye. If misclassification was occurring on the right bank, one would expect the left-bank proportion of the chinook estimate to decrease as sockeye passage on the right bank increased. On the contrary, the daily left-bank proportion exhibited an increasing trend through late July and early August (Figure 34). This would suggest that the bimodal range distribution reflected an actual bimodal chinook passage and not sockeye misclassification.

Other indicators such as chinook salmon sport fish CPUE and sockeye salmon passage estimates from the mile 19 sockeye sonar site fail to support the possibility of large-scale sockeye contamination of daily chinook estimates. A review of chinook salmon sport fish CPUE data reveals no consistent pattern when compared to daily chinook salmon sonar estimates (Figure 35). The comparison suggests possible overestimation of chinook passage on 17 July and 18 July, but also indicates possible

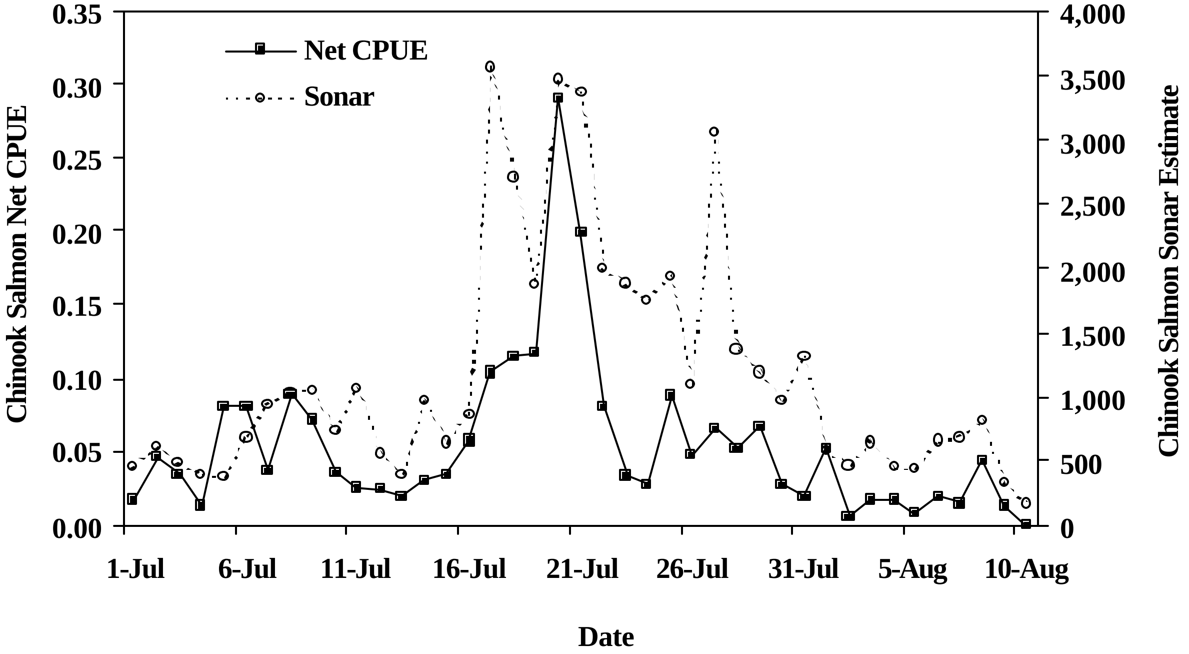


Figure 30.-Daily chinook salmon sonar estimates with inriver net CPUE, late run (1 July-10 August), 1999.

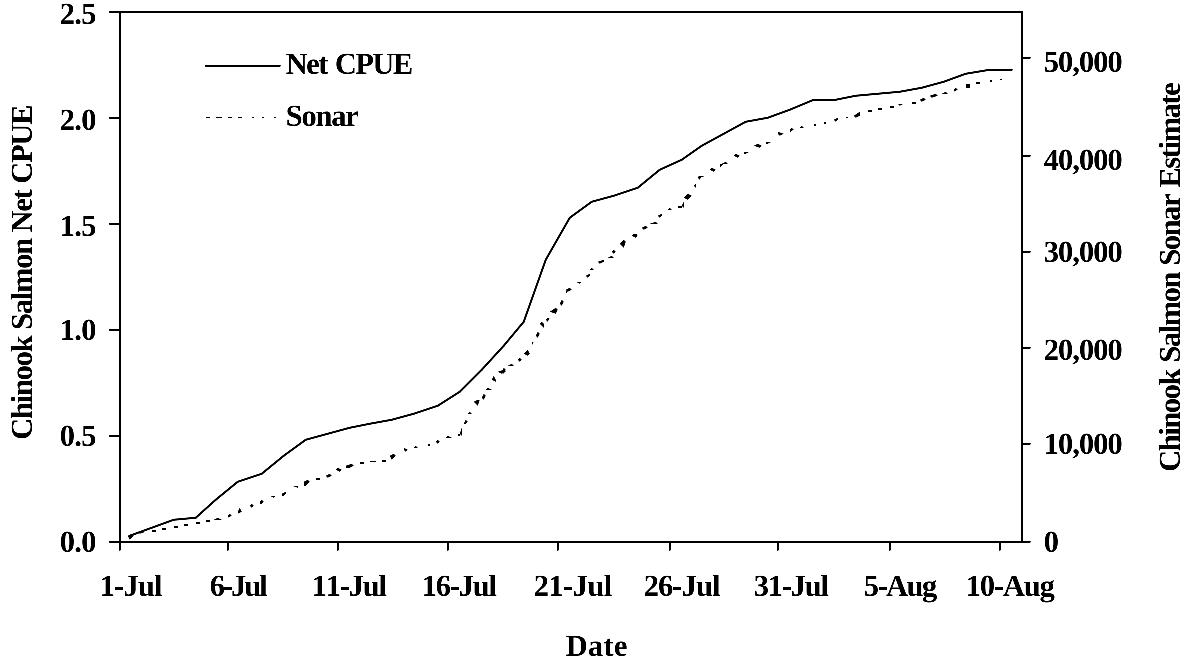


Figure 31.-Cumulative chinook salmon sonar estimates with cumulative inriver net CPUE, late run (1 July-10 August), 1999.

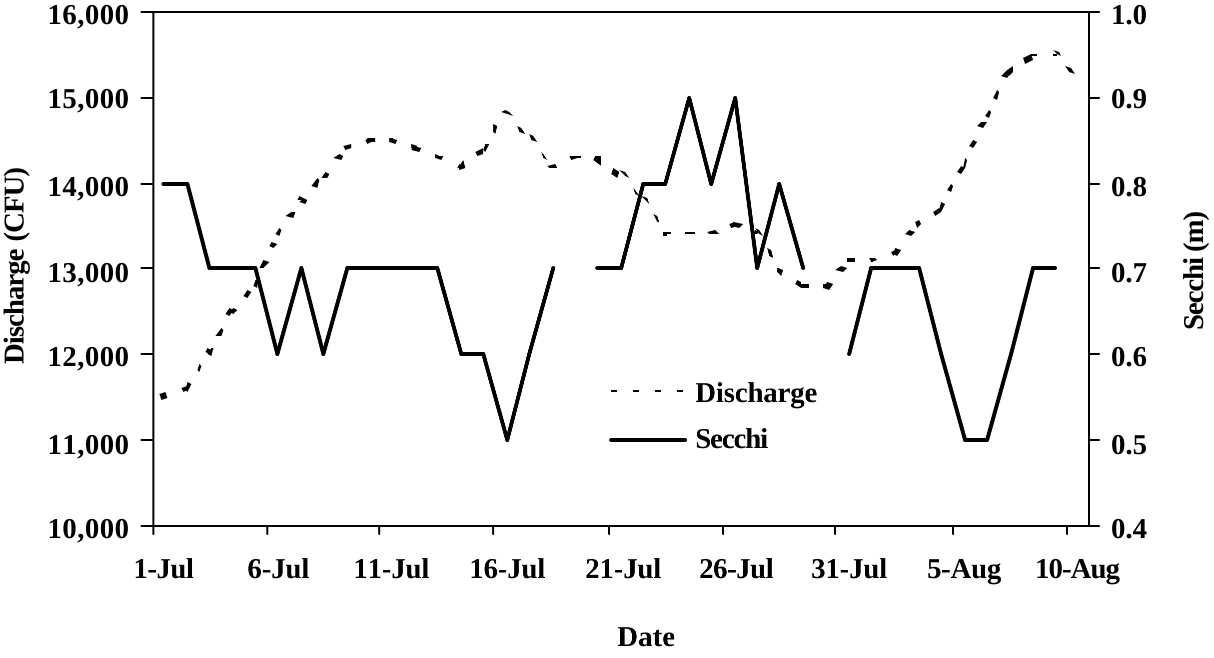


Figure 32.-Daily Secchi depth readings (in front of sonar site) and discharge rates (Soldotna Bridge) for lower Kenai River, late run (1 July-10 August), 1999.

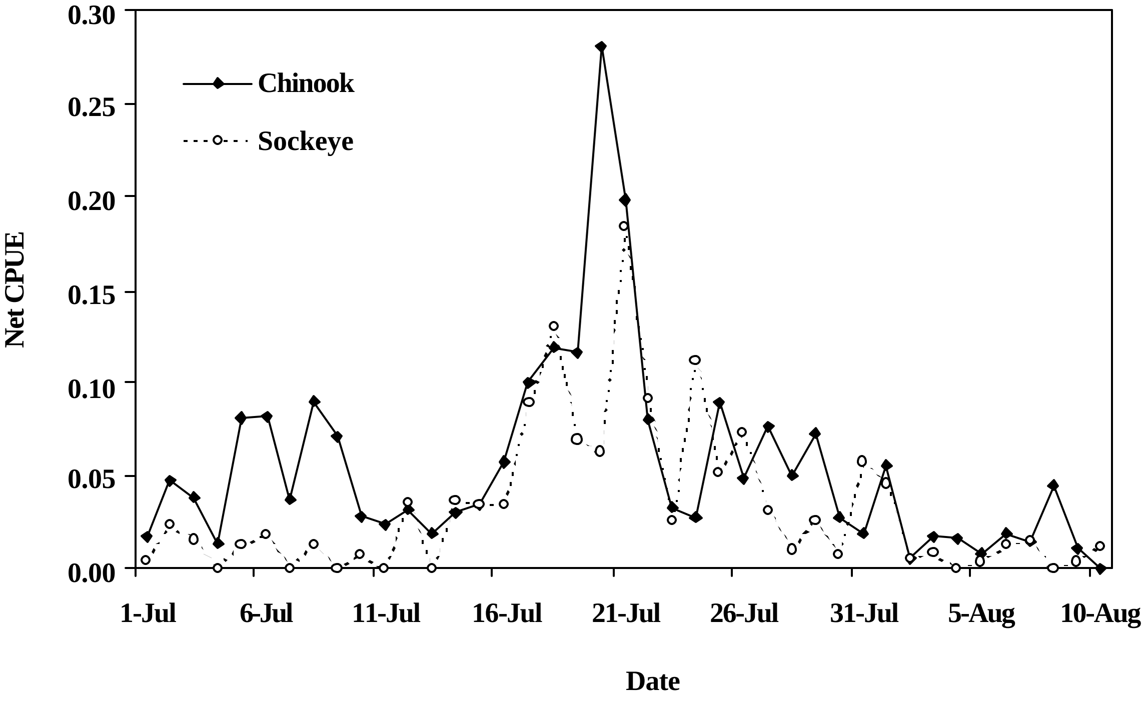


Figure 33.-Daily chinook and sockeye inriver net CPUE, 1 July-10 August, 1999.

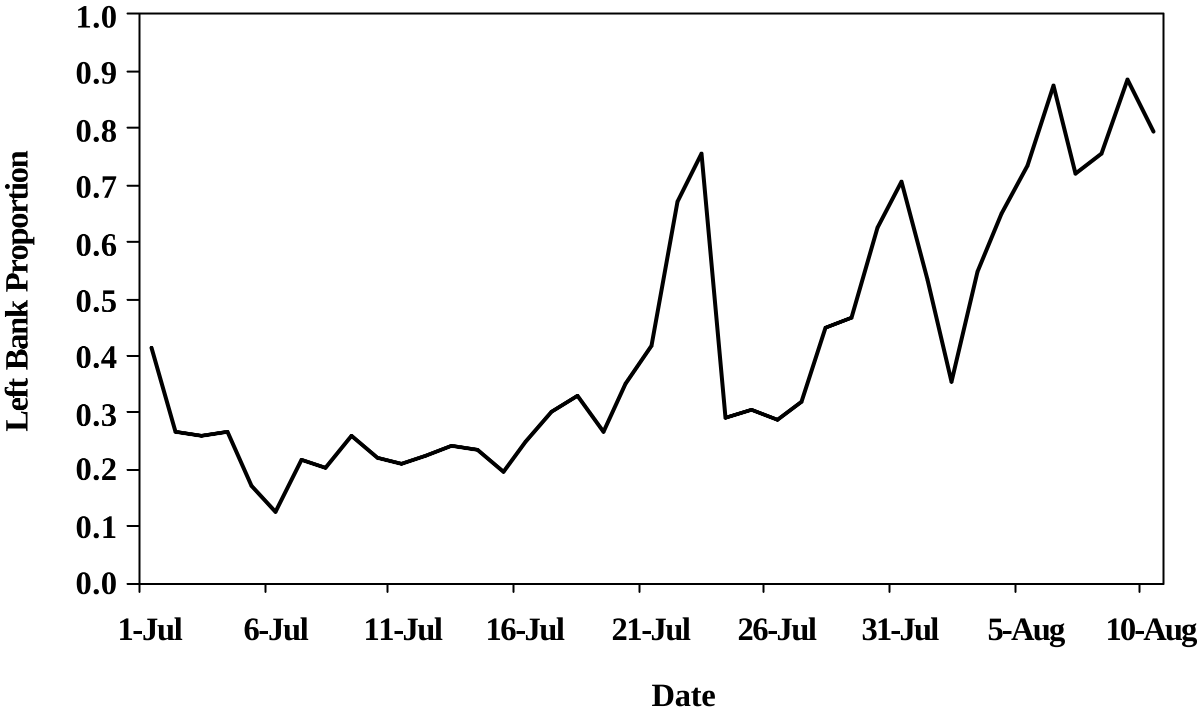


Figure 34.-Left-bank proportion of total daily chinook salmon sonar estimate, late run (1 July-10 August), 1999.

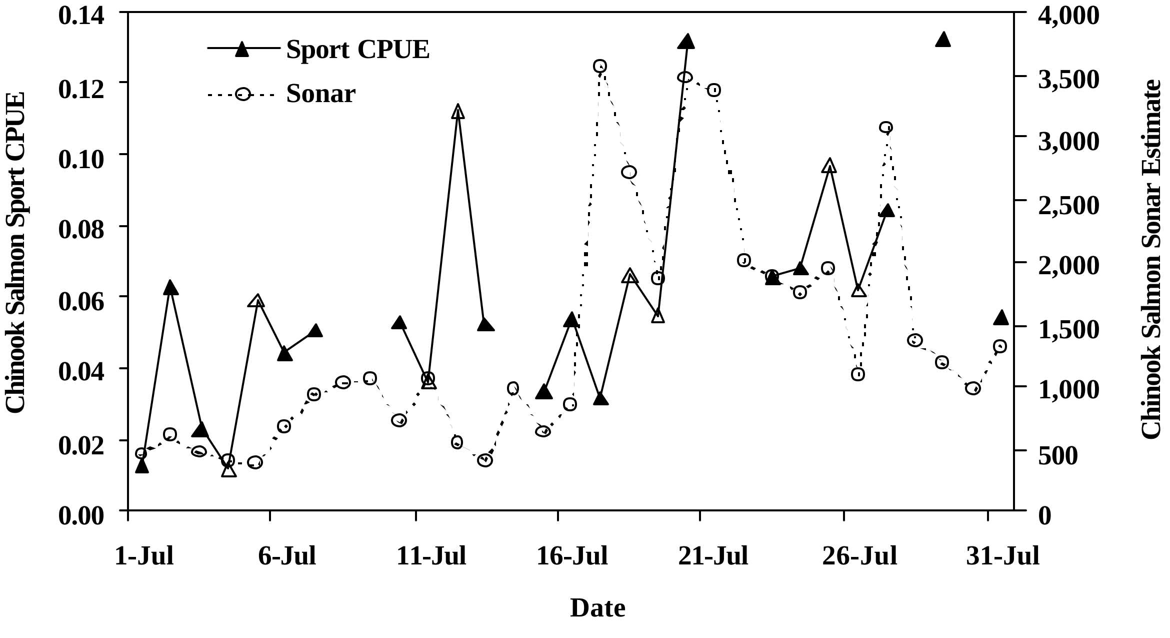


Figure 35.-Daily chinook salmon sonar estimates with chinook salmon sport fish CPUE (open triangles represent days on which only unguided anglers were allowed to fish), late run (1 July-31 July), 1999.

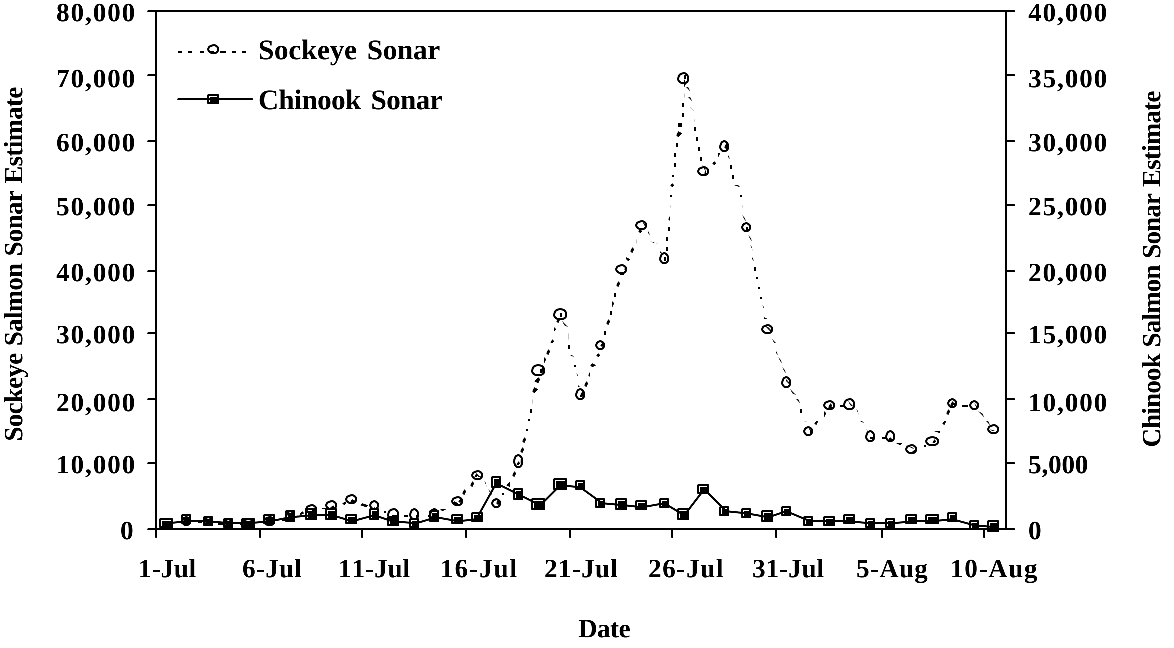


Figure 36.-Daily chinook salmon sonar estimates with mile 19 sockeye salmon sonar estimates lagged one day, late run (1 July–10 August), 1999.

underestimation of chinook passage on several other days. A comparison of the chinook passage estimates with the mile 19 sockeye sonar passage estimates (Figure 36) suggest that although some inflation of chinook counts by sockeye salmon was possible, severe overestimation of chinook counts was not likely. From 16 July to 26 July the increase in sockeye passage at the mile-19 site was an order of magnitude higher than any corresponding increase in chinook passage at the downriver site.

In summary, we believe the late-run chinook passage estimate experienced minimal inflation due to the presence of sockeye salmon.

SAMPLE DESIGN EVALUATION

We do not recommend changing the current systematic sample design to an actual census. Improvement in precision would be relatively small and there would be several disadvantages to implementing a census. Currently, the right-bank and left-bank transducers are deployed directly across the river from each other in order to avoid the risk of counting the same chinook on both banks. Operating the transducers concurrently while deployed directly across the river from each other may require the use of different frequencies on each bank or possibly two different pulse widths in order to avoid possible cross-talk between the systems. Different frequencies or different pulse widths between banks may hamper ongoing species discrimination studies and may be shown to be undesirable dependent upon the outcome of those studies. In addition, continuous sampling on both banks would greatly increase the time required for manual tracking and data analysis, and would increase response time during critical management periods.

OUTLOOK FOR FUTURE IMPROVEMENTS IN SONAR ACCURACY

Exclusive use of acoustics to precisely discriminate fish species is not possible at this time (Horne 2000). However, we are pursuing several options to increase the accuracy of chinook abundance estimates. Some of these options strive to improve chinook estimates by improving our ability to discriminate larger chinook salmon from other smaller species. Additional options involve developing other indices of chinook abundance that may be used to either produce adjusted chinook estimates during periods of high sockeye abundance or at least indicate when sonar estimates may be significantly inflated.

Inriver Netting Program

With 2 years of data available, analyses will continue to determine how well and under what conditions (e.g., water clarity and discharge) netting CPUE correlates with sonar estimates of chinook salmon. Past research using drift gillnet CPUE has revealed that net efficiency may vary with environmental conditions such as water clarity and discharge (Burwen et al. 1998). A critical aspect of analyzing these data will be determining whether confounding effects from these and other variables can be removed. Results of these efforts will be published either in the annual sonar report for 2001 or as a separate Fisheries Data Series report.

Large Fish Index

We continue to pursue improved techniques for separating chinook and sockeye salmon using acoustic information. Results of a tethered fish study conducted in 1995 indicated that echo pulse width may provide higher discriminatory power than target strength for separating sockeye and chinook salmon (Burwen and Fleischman 1998). This relationship was supported again during a study in 1998 using multifrequency sonar (Burwen and Fleischman *In prep*).

The feasibility of using pulse width as a species discriminator is still being investigated. One difficulty with this method is that many smaller chinook salmon are excluded when a pulse width filter sufficient to exclude all sockeye is implemented. Since the methodology does not exist to separate all chinook from all sockeye, we are now focusing on using pulse width data to estimate the abundance of chinook greater than a specified size (e.g. 800 mm fork length). This would provide a conservative approximation of larger chinook salmon that could be relied upon to be uninfluenced by sockeye salmon abundance. A minimum estimate of larger chinook salmon would be useful on days when we believe large numbers of chinook and sockeye are concurrently passing the site and range and target strength filters appear inadequate.

It is also likely that current pulse width measurements can be improved. Pulse width measurements are subject to biases related to poor SNR (Ehrenberg and Johnston 1996) and choice of voltage threshold (Dave Daum, USF&WS, Fairbanks, Alaska, personal communication). More work is required to fully understand the behavior of these measurements as a function of SNR, threshold, fish behavior, and other potentially influential variables. Additional experiments are planned to address these questions and concerns.

Multifrequency Sonar

Most researchers involved in fish species discrimination acknowledge that broadband sonar holds the most promise for discriminating among similar-sized organisms (Simmonds et al. 1996; Zakharia et al. 1996; Lebourges 1990). However, broadband systems are not commercially available and are primarily used by researchers at universities and research institutes that build their own prototypes.

Other acousticians have shown that more readily implemented multifrequency sonar may be a more realistic method to use for classifying targets (McKelvey 1998; Simard 1998; Demer et al. 1999; Cochrane et al. 1991). Both these techniques increase the amount of information available to classify species by increasing the frequency range. The theory is that some acoustic parameter (such as target strength) of each species may change with frequency in a characteristic way.

In 1998, we investigated the use of multifrequency sonar data to assist in discriminating between fish species (Burwen and Fleischman *In prep*). Target strength and other acoustic parameters were measured on tethered chinook and sockeye salmon at 120kHz, 200kHz, and 420kHz; with and without FM slide-encoded pulses. We found: (1) that there was no compelling reason to change frequency at the present time; (2) that upgrading to FM slide technology was warranted based solely upon improved tracking performance; and (3) that it was preferable not to filter data based on pulse width.

Results were inconclusive regarding the utility of multifrequency data for discriminating between chinook and sockeye salmon. The additional information from multiple frequencies substantially improved our ability to predict fish length. However our results were not entirely consistent with those predicted from the models developed by Horne and Clay (1998). Therefore, additional studies would be required to establish the repeatability of the results. More work would also be required to extend the models of Horne and Clay (1998) for larger ratios of fish length to wavelength, to identify which frequencies hold the most promise for our application, and possibly to develop parametric transducers for their implementation. Such work would require more funding, time, and expertise than is available within the department. We do not recommend pursuing this line of investigation unless supported by outside funding and with the cooperation of a university or research lab.

ACKNOWLEDGMENTS

We would like to thank Linda Lowder, Mark Jensen, Sarah Donchi, Dayne Broderson and Mike Hopp for meticulously collecting the sonar data and for their high motivation throughout a long field season. Saree Timmons provided editorial review. Special thanks, also, to the members of the Sport Fish staff in Soldotna who provided logistical support whenever needed.

LITERATURE CITED

ADF&G (Alaska Department of Fish and Game). 1990. Cook Inlet commercial fishing regulations., Alaska Department of Fish and Game, Division of Commercial Fisheries, 1990-1991 Edition. Juneau.

Alexandersdottir, M., and L. Marsh. 1990. Abundance estimates of the escapement of chinook salmon into the Kenai River, Alaska, by analysis of tagging data, 1989. Alaska Department of Fish and Game, Fishery Data Series No. 90-55, Anchorage.

Bernard, D. R., and P. A. Hansen. 1992. Mark-recapture experiments to estimate the abundance of fish: a short course given by the Division of Sport Fish, Alaska Department of Fish and Game in 1991. Alaska Department of Fish and Game, Special Publication No. 92-4, Anchorage.

Bosch, D., and D. Burwen. 1999. Estimates of chinook salmon abundance in the Kenai River using split-beam sonar, 1997. Alaska Department of Fish and Game, Fishery Data Series No. 99-3, Anchorage.

Bosch, D., and D. Burwen. 2000. Estimates of chinook salmon abundance in the Kenai River using split-beam sonar, 1998. Alaska Department of Fish and Game, Fishery Data Series No. 00-12, Anchorage.

LITERATURE CITED (Continued)

Burger, C. V., R. L. Wilmot, and D. B. Wangaard. 1985. Comparison of spawning areas and times for two runs of chinook salmon (Oncorhynchus tshawytscha) in the Kenai River, Alaska. Canadian Journal of Fisheries and Aquatic Sciences 42(4):693-700.

Burwen, D. L., and D. E. Bosch. 1995a. Estimates of chinook salmon abundance in the Kenai River using dual-beam sonar, 1993. Alaska Department of Fish and Game, Fishery Data Series No. 95-31, Anchorage, AK.

Burwen, D. L., and D. E. Bosch. 1995b. Estimates of chinook salmon abundance in the Kenai River using dual-beam sonar, 1994. Alaska Department of Fish and Game, Fishery Data Series No. 95-38, Anchorage.

Burwen, D. L., and D. E. Bosch. 1996. Estimates of chinook salmon abundance in the Kenai River using split-beam sonar, 1995. Alaska Department of Fish and Game, Fishery Data Series No. 96-9, Anchorage.

Burwen, D., and D. Bosch. 1998. Estimates of chinook salmon abundance in the Kenai River using split-beam sonar, 1996. Alaska Department of Fish and Game, Fishery Data Series No. 98-2, Anchorage.

Burwen, D. L., D. E. Bosch, and S. J. Fleischman. 1995. Evaluation of hydroacoustic assessment techniques for chinook salmon on the Kenai River using split- beam sonar. Alaska Department of Fish and Game, Fishery Data Series No. 95-45, Anchorage.

Burwen, D. L., D. E. Bosch, and S. J. Fleischman. 1998. Evaluation of hydroacoustic assessment techniques for chinook salmon on the Kenai River, 1995. Alaska Department of Fish and Game, Fishery Data Series No. 98-3, Anchorage.

Burwen, D. L., and S. J. Fleischman. 1998. Evaluation of side-aspect target strength and pulse width as hydroacoustic discriminators of fish species in rivers. Canadian Journal of Fisheries and Aquatic Sciences 55:2492-2502.

Burwen, D. L., and S. J. Fleischman. In prep. Evaluation of multifrequency fm-slide sonar for estimating fish size in the Kenai River. Alaska Department of Fish and Game, Fishery Data Series, Anchorage.

Burwen, D. L., J. J. Hasbrouck, and D. Bosch. 2000. Investigations of alternate sites for chinook salmon sonar on the Kenai River. Alaska Department of Fish and Game, No. 00-43, Anchorage.

Carlon, J. A., and M. Alexandersdottir. 1989. Abundance estimates of the escapement of chinook salmon into the Kenai River, Alaska, by analysis of tagging data, 1988. Alaska Department of Fish and Game, Fishery Data Series No. 107, Juneau.

Cochran, W. G. 1977. Sampling techniques. Third Edition. John Wiley & Sons, New York.

Cochrane, N. A., A. W. Sameoto, A. W. Herman, and J. Neilson. 1991. Multiple-frequency acoustic backscattering and zooplankton aggregations in the inner Scotian Shelf basins. Canadian Journal of Fisheries and Aquatic Sciences 48:340-355.

Conrad, R. H. 1988. Abundance estimates of the escapement of chinook salmon into the Kenai River, Alaska, by analysis of tagging data, 1987. Alaska Department of Fish and Game, Fishery Data Series No. 67, Juneau.

Conrad, R. H., and L. L. Larson. 1987. Abundance estimates for chinook salmon (*Oncorhynchus tshawytscha*) in the escapement into the Kenai River, Alaska, by analysis of tagging data, 1986. Alaska Department of Fish and Game, Fishery Data Series No. 34, Juneau.

Davis, R. Z. 2000. Upper Cook Inlet salmon escapement studies, 1999. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report No. 2A00-22.

Demer, D. A., M. A. Soule, and R. P. Hewett. 1999. A multiple-frequency method of potentially improving the accuracy and precision of in situ target strength measurements. Journal of the Acoustical Society of America 105:2359-2376.

LITERATURE CITED (Continued)

Eggers, D. M. 1994. On the discrimination of sockeye and chinook salmon in the Kenai River based on target strength determined with 420 kHz dual-beam sonar. Alaska Fishery Research Bulletin 1(2):125-139. Alaska Department of Fish and Game, Juneau.

Eggers, D. E., P. A. Skvorc, and D. L. Burwen. 1995. Abundance estimate for chinook salmon in the Kenai River using dual-beam sonar. Alaska Department of Fish and Game. Alaska Fishery Research Bulletin 2(1):1-22.

Ehrenberg, J. E. 1983. A review of *in situ* target strength estimation techniques. FAO (Food and Agriculture Organization of the United Nations) Fisheries Report 300:85-90.

Ehrenberg, J. E., and S. V. Johnston. 1996. Evaluation of the use of hydroacoustic pulse width data to separate fish by size group. Report of Hydroacoustic Technology, Inc. to Alaska Department of Fish and Game, Sport Fish Division, Anchorage.

Ehrenberg, J. E., and T. C. Torkelson. 1996. Application of dual-beam and split-beam target tracking in fisheries acoustics. International Council for the Exploration of the Sea Journal of Marine Science 53:329-334.

Fleischman, S. J., and D. L. Burwen. 2000. Correcting for position-related bias in estimates of the acoustic backscattering cross-section. Aquatic Living Resources 13:283-290.

Foote, K. G., and D. N. MacLennan. 1984. Comparison of copper and tungsten carbide calibration spheres. Journal of the Acoustical Society of America 75:612-616.

Hammarstrom, S. L., and J. J. Hasbrouck. 1998. Estimation of the abundance of late-run chinook salmon in the Kenai River based on exploitation rate and harvest, 1996. Alaska Department of Fish and Game, Fishery Data Series No. 98-6, Anchorage.

Hammarstrom, S. L., and J. J. Hasbrouck. 1999. Estimation of the abundance of late-run chinook salmon in the Kenai River based on exploitation rate and harvest, 1997. Alaska Department of Fish and Game, Fishery Data Series No. 99-8, Anchorage.

Hammarstrom, S. L., and L. L. Larson. 1986. Kenai River salmon escapement. Alaska Department of Fish and Game. Federal Aid in Fish Restoration, Annual Performance Report, 1985-1986, Project F-10-1, 27 (S-32-2), Juneau.

Hammarstrom, S. L., L. Larson, M. Wenger, and J. Carlon. 1985. Kenai Peninsula chinook and coho salmon studies. Alaska Department of Fish and Game. Federal Aid in Fish Restoration. Annual Performance Report, 1984-1985, Project F-9-17, 26 (G-II-L), Juneau.

Hollander, M., and D. A. Wolf. 1973. Nonparametric statistical methods. John Wiley & Sons, New York, NY.

Horne, J. K. 2000. Acoustic approaches to remote species identification: a review. Fisheries Oceanography 9:356-371.

Horne, J. K., and C. S. Clay. 1998. Sonar systems and aquatic organisms: matching equipment and model parameters. Canadian Journal of Fisheries and Aquatic Sciences 55:1296-1306.

HTI (Hydroacoustic Technology Inc). 1994a. Model 240 split beam digital echo sounder operator's manual, version 1.2. Hydroacoustic Technology Inc., Seattle, WA.

HTI (Hydroacoustic Technology Inc). 1994b. Model 340 digital echo processor (split-beam) operator's manual, version 1.04D. Hydroacoustic Technology Inc., Seattle, WA.

HTI (Hydroacoustic Technology Inc). 1999. Transducer calibration for HTI Model 240 split-beam system, April 21, 1999. Report of Hydroacoustic Technology Inc. to Alaska Department of Fish and Game, Sport Fish Division, Anchorage.

Lebourges, A. 1990. Species recognition based on the spectral signature of individual targets. ICES CM/1990/B:9.

MacLennan, D. N., and E. J. Simmonds. 1992. Fisheries Acoustics. Chapman & Hall, London, UK.

LITERATURE CITED (Continued)

McBride, D. N., M. Alexandersdottir, S. Hammarstrom, and D. Vincent-Lang. 1989. Development and implementation of an escapement goal policy for the return of chinook salmon to the Kenai River. Alaska Department of Fish and Game, Fishery Manuscript No. 8, Juneau.

McKelvey, D. R. 1998. The use of two frequencies to interpret acoustic scattering layers. Proceedings of the 16th International Congress on Acoustics and the 135th Meeting of the Acoustical Society of America Meeting, Seattle, WA, 20-26 June 1998.

Mulligan, T. J., and R. Kieser. 1996. A split-beam echo-counting model for riverine use. International Council for the Exploration of the Sea Journal of Marine Science 53:403-406.

Nelson, D. C., D. Athons, P. Berkhahn, and S. Sonnichsen. 1999. Area management report for the recreational fisheries of the Kenai Peninsula, 1995-1997. Alaska Department of Fish and Game, Fishery Management Report No. 99-3, Anchorage.

Reimer, A. M., W. W. Jones, and L. E. Marsh. 2002. Chinook salmon creel survey and inriver gillnetting study, lower Kenai River, Alaska, 1999 and 2000. Alaska Department of Fish and Game, Fishery Data Series No. 02-25, Anchorage.

Ruesch, P. H., and J. Fox. 1999. Upper Cook Inlet Commercial Fisheries Annual Management Report, 1998. Alaska Department of Fish and Game, Commercial Fisheries Division, Regional Information Report No. 2A99-21.

Simard, Y. 1998. Fish'n krill: a 38/120 kHz acoustic separation. Proceedings of the 16th International Congress on Acoustics and the 135th Meeting of the Acoustical Society of America Meeting, Seattle, WA 20-26 June 1998.

Simmonds, E. J., F. Armstrong, and P. J. Copland. 1996. Species identification using wideband backscatter with neural network and discriminant analysis. International Council for the Exploration of the Sea Journal of Marine Science 53:189-195.

USDA (United States Department of Agriculture). 1992. Kenai River landowner's guide. D. Lehner, editor. Prepared by the U. S. Department of Agriculture, Soil conservation Service (SCS) for the Kenai Soil and Water Conservation District., Kenai, Alaska.

USGS (United States Geological Survey). 1999. Water resources data, Alaska water year 1999. Website Soldotna Gauging Station. http://waterdata.usgs.gov/nvis-w/AK/data.components/hist.cgi?statnum=15266300,

Weimer, R. T., and J. E. Ehrenberg. 1975. Analysis of threshold-induced bias inherent in acoustic scattering cross-section estimates of individual fish. Journal Fisheries Research Board of Canada 32:2547-2551.

Wolter, K. M. 1985. Introduction to variance estimation. Springer-Verlag, New York.

Zakharia, M. A., F. Magnand, F. Hetroit, and N. Diner. 1996. Wideband sounder for fish species identification at sea. International Council for the Exploration of the Sea Journal of Marine Science 53:203-208.

APPENDIX A. TARGET STRENGTH ESTIMATION

Appendix A1.-Using the sonar equation to estimate target strength with dual- and split-beam applications.

Target strength, in decibels (dB), of an acoustic target located at range R (in meters), 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 not corrected for 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.-System parameters used for data collection on the right bank (transducer 733).

* Start Processing at Port 1 -FILE_PARAMETERS- Wed June 30 01:00:00 1999

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

100	-1	1	MUX argument #1 - multiplexer port to activate
101	-1	0	percent - sync pulse switch, ping rate determiner NUS
102	-1	32767	maxp - maximum number of pings in a block NUS
103	-1	32767	maxbott - maximum bottom range in samples NUS
104	-1	5	N_th_layer - number of threshold layers
105	-1	15	max_tbp - maximum time between pings in pings
106	-1	8	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
111	-1	3	plot_up_fish - number of fish between stbar updates
112	-1	1	echogram_on - flag for DEP echogram enable 0=off, 1=on
113	-1	1	f_inst->o_raw - write raw file flag 1 = on, -1 or 0=off
114	-1	0	f_inst->o_ech - write echo file flag 1 = on, -1 or 0=off
115	-1	0	f_inst->o_fsh - write fish file flag 1 = on, -1 or 0=off
116	-1	0	f_inst->o_sum - write summary table file flag 1 or 0=on
117	-1	0	print summary table on printer, 1 = on, -1 or 0=off
118	-1	25	maxmiss - maximum number of missed pings in auto bottom
119	-1	0	bottom_code - bottom tracking, 0=fix, 1=man, 2=auto
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	1	N_int_layers-number of integration strata
123	-1	1	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
129	-1	1	FILTER argument #1 - filter number
200	-1	0.0000	sigma_flag - if!=0.0000, sigma is output, not ts
201	-1	220.8000	sl - transducer source level
202	-1	-170..8000	gn - transducer through system gain at one meter
203	-1	-18.0000	rg - receiver gain used to collect data
204	-1	2.8000	narr_ax_bw - vertical nominal beam width
205	-1	10.0000	wide_ax_bw - horizontal axis nominal beam width
206	-1	0.0000	narr_ ax_corr - vertical axis phase correction
207	-1	0.0000	wide_ax_corr - horizontal axis phase correction
208	-1	11.0000	ping_rate - pulses per second
209	-1	0.0000	echogram start range in meters
210	-1	55.0000	echogram stop range in meters
211	-1	709.0000	echogram threshold in millivolts
212	-1	13.2000	print width in inches
213	-1	-40.0000	ts plot minimum target strength in dB
214	-1	-10.0000	ts plot maximum target strength in dB

-continued-

Appendix B1.-Page 2 of 3.

215	-1	0.0000	range plot minimum in meters
216	-1	75.0000	range plot maximum in meters
217	-1	-2.5000	min_angoff_v - minimum angle off axis vertical
218	-1	2.5000	max_angoff_v - maximum angle off axis vertical
219	-1	-5.0000	min_angoff_h - minimum angle off axis horiz.
220	-1	5.0000	max_angoff_ h - maximum angle off axis horiz.
221	-1	-24.0000	max_dB_off - maximum angle off in dB
222	-1	-7.9885	ux - horizontal electrical to mechanical angle ratio
223	-1	-16.3571	uy - vertical electrical to mechanical angle ratio
224	-1	0.0000	ud_coef_a - a coeff. for up-down beam pattern eq.
225	-1	-0.0039	ud_coef_b - b coeff. for up-down beam pattern eq.
226	-1	-2.7493	ud_coef_c - c coeff. for up-down beam pattern eq.
227	-1	0.0144	ud_coef_d - d coeff. for up-down beam pattern eq.
228	-1	-0.1327	ud_coef_e - e coeff. for up-down beam pattern eq.
229	-1	0.0000	lr_coef_a - a coeff. for left-rt beam pattern eq.
230	-1	-0.0000	lr_coef_b - b coeff. for left-rt beam pattern eq.
231	-1	-0.2098	lr_coef_c - c coeff . for left-rt beam pattern eq.
232	-1	0.0006	lr_coef_d - d coeff. for left-rt beam pattern eq.
233	-1	-0.0002	lr_coef_e - ecoeff. for left-rt beam pattern eq.
234	-1	100.0000	maximum fish velocity in meters per second
235	-1	10.0000	thd_up_time - minutes between 3d plot updates
236	-1	0.5000	maxpw - pulse width search window size
237	-1	2.0000	cltop - start of processing in meters
238	-1	50.6000	bottom - bottom depth in meters
239	-1	0.0000	init_slope - initial slope for tracking in m/ping
240	-1	0.3000	exp_cont - exponent for expanding tracking window
241	-1	0.1500	max_ch_rng - maximum change in range in m/ping
242	-1	0.0000	pw_criteia->min_pw_6-min -6 dB pulse width
243	-1	2.0000	pw_criteria->max_pw_6-max -6 dB pulse width
244	-1	0.0000	pw_criteria->min_pw_12 - min -12 dB pulse width
245	-1	2.0000	pw_criteria->max_pw_12 - max -12 dB pulse width
246	-1	0.0000	pw_criteria->min_pw_18 - min -18 dB pulse width
247	-1	2.0000	pw_criteria->max_pw_18 - max -18 dB pulse width
248	-1	1.0000	Intake width to weight fish to (in meters)
249	-1	10.0000	maximum echo voltage to accept (Volts - peak)
250	-1	0.2000	TX argument #1 - pulse width in milliseconds
251	-1	25.0000	TX argument #2 - transmit power in dB-watts
252	-1	-6.0000	RX argument #1 - receiver gain
253	-1	90.9091	REP argument #1 - ping rate in ms per ping
254	-1	10.0000	REP argument #2 - pulsed cal tone separation
255	-1	1.0000	TVG argument #1 - TVG start range in meters
256	-1	100.0000	TVG argument #2 - TVG end range in meters
257	-1	40.0000	TVG argument #3 - TVG function (XX Log Range)
258	-1	-12.0000	TVG argument #4 - TVG gain
259	-1	0.0000	TVG argument #5 - alpha (spreading loss) in dB/Km
260	-1	0.5000	minimum absolute distance fish must travel in x plane
261	-1	0.0000	minimum absolute distance fish must travel in y plane
262	-1	0.0000	minimum absolute distance fish must travel in z plane
263	-1	2.0000	bottom_window - auto tracking bottom window (m)

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264	-1	3.0000	bottom_threshold - auto tracking bottom threshold (V)
265	-1	11.2200	TVG argument #7 - 20/40 log crossover (meters)
266	-1	1.0000	
267	-1	5.0000	
401	0	5.0000	th_layer[0] - bottom of first threshold layer (m)
401	1	16.0000	th_layer[1] - bottom of second threshold layer (m)
401	2	24.5000	th_layer[2] - bottom of third threshold layer (m)
401	3	60.0000	th_layer[3] - bottom of forth threshold layer (m)
401	4	75.0000	th_layer[4] - bottom of fifth threshold layer (m)
402	0	709.0000	th_val[0] - thr. for 1st layer (mV)
402	1	709.0000	th_val[1] - thr. for 2nd layer (mV)
402	2	709.0000	th_val[2] - thr. for 3rd layer (mV)
402	3	709.0000	th_val[3] - thr. for 4th layer (mV)
402	4	709.0000	th_val[4] - thr. for 5th layer (mV)
403	0	1.0000	Integration layer 1 top (m)
403	1	50.0000	Integration layer 1 bottom (m)
404	0	50.0000	Integration threshold layer 1 bottom (m)
405	0	50.0000	Integration threshold layer 1 value (mV)
601	-1	HTI-SB-200kHz	Echo sounder type
602	-1	SN-305785	Echo sounder serial number
603	-1	HTISB-2.8X10	Transducer type
604	-1	306733	Transducer serial number
605	-1	Spd-3	Echogram paper speed
606	-1	9_pin	Echogram resolution
607	-1	Board_External	Trigger option
608	-1	Left_to_Right-->	River flow direction
609	-1	All_Fish	Fish included in 3d plot
610	-1	ON	Echogram enable flag
611	-1	C:\SBDATA\K	Drive and first letter to send files

Appendix B2.-System parameters used for data collection on the right bank (transducer 738).

* Start Processing at Port 2 -FILE_PARAMETERS- Wed June 30 02:00:00 1999

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

100	-1	2	MUX argument #1 - multiplexer port to activate
101	-1	0	percent - sync pulse switch, ping rate determiner NUS
102	-1	32767	maxp - maximum number of pings in a block NUS
103	-1	32767	maxbott - maximum bottom range in samples NUS
104	-1	5	N_th_layer - number of threshold layers
105	-1	15	max_tbp - maximum time between pings in pings
106	-1	8	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
111	-1	3	plot_up_fish - number of fish between stbar updates
112	-1	1	echogram_on - flag for DEP echogram enable 0=off, 1=on
113	-1	1	f_inst->o_raw - write raw file flag 1 = on, -1 or 0=off
114	-1	1	f_inst->o_ech - write echo file flag 1 = on, -1 or 0=off
115	-1	1	f_inst->o_fsh - write fish file flag 1 = on, -1 or 0=off
116	-1	0	f_inst->o_sum - write summary table file flag 1 or 0=on
117	-1	0	print summary table on printer, 1 = on, -1 or 0=off
118	-1	25	maxmiss - maximum number of missed pings in auto bottom
119	-1	0	bottom_code - bottom tracking, 0=fix, 1=man, 2=auto
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	1	N_int_layers-number of integration strata
123	-1	1	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
129	-1	1	FILTER argument #1 - filter number
200	-1	0.0000	sigma_flag - if!=0.0000, sigma is output, not ts
201	-1	218.0000	sl - transducer source level
202	-1	-172.0000	gn - transducer through system gain at one meter
203	-1	-18.0000	rg - receiver gain used to collect data
204	-1	2.8000	narr_ax_bw - vertical nominal beam width
205	-1	10.0000	wide_ax_bw - horizontal axis nominal beam width
206	-1	0.0000	narr_ ax_corr - vertical axis phase correction
207	-1	0.0000	wide_ax_corr - horizontal axis phase correction
208	-1	16.0000	ping_rate - pulses per second
209	-1	0.0000	echogram start range in meters
210	-1	35.0000	echogram stop range in meters
211	-1	446.0000	echogram threshold in millivolts
212	-1	13.2000	print width in inches
213	-1	-40.0000	ts plot minimum target strength in dB
214	-1	-10.0000	ts plot maximum target strength in dB

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215	-1	0.0000	range plot minimum in meters
216	-1	60.0000	range plot maximum in meters
217	-1	-2.5000	min_angoff_v - minimum angle off axis vertical
218	-1	2.5000	max_angoff_v - maximum angle off axis vertical
219	-1	-5.0000	min_angoff_h - minimum angle off axis horiz.
220	-1	5.0000	max_angoff_ h - maximum angle off axis horiz.
221	-1	-24.0000	max_dB_off - maximum angle off in dB
222	-1	-8.0041	ux - horizontal electrical to mechanical angle ratio
223	-1	-28.6908	uy - vertical electrical to mechanical angle ratio
224	-1	0.0000	ud_coef_a - a coeff. for up-down beam pattern eq.
225	-1	-0.0002	ud_coef_b - b coeff. for up-down beam pattern eq.
226	-1	-2.8113	ud_coef_c - c coeff. for up-down beam pattern eq.
227	-1	-0.1010	ud_coef_d - d coeff. for up-down beam pattern eq.
228	-1	-0.1241	ud_coef_e - e coeff. for up-down beam pattern eq.
229	-1	0.0000	lr_coef_a - a coeff. for left-rt beam pattern eq.
230	-1	0.0000	lr_coef_b - b coeff. for left-rt beam pattern eq.
231	-1	-0.2139	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	-0.0002	lr_coef_e - ecoeff. for left-rt beam pattern eq.
234	-1	100.0000	maximum fish velocity in meters per second
235	-1	10.0000	thd_up_time - minutes between 3d plot updates
236	-1	0.5000	maxpw - pulse width search window size
237	-1	2.0000	cltop - start of processing in meters
238	-1	30.6000	bottom - bottom depth in meters
239	-1	0.0000	init_slope - initial slope for tracking in m/ping
240	-1	0.3000	exp_cont - exponent for expanding tracking window
241	-1	0.1500	max_ch_rng - maximum change in range in m/ping
242	-1	0.0000	pw_criteria->min_pw_6-min -6 dB pulse width
243	-1	2.0000	pw_criteria->max_pw_6-max -6 dB pulse width
244	-1	0.0000	pw_criteria->min_pw_12 - min -12 dB pulse width
245	-1	2.0000	pw_criteria->max_pw_12 - max -12 dB pulse width
246	-1	0.0000	pw_criteria->min_pw_18 - min -18 dB pulse width
247	-1	2.0000	pw_criteria->max_pw_18 - max -18 dB pulse width
248	-1	1.0000	Intake width to weight fish to (in meters)
249	-1	10.0000	maximum echo voltage to accept (Volts - peak)
250	-1	0.2000	TX argument #1 - pulse width in milliseconds
251	-1	25.0000	TX argument #2 - transmit power in dB-watts
252	-1	-6.0000	RX argument #1 - receiver gain
253	-1	62.5000	REP argument #1 - ping rate in ms per ping
254	-1	10.0000	REP argument #2 - pulsed cal tone separation
255	-1	1.0000	TVG argument #1 - TVG start range in meters
256	-1	100.0000	TVG argument #2 - TVG end range in meters
257	-1	40.0000	TVG argument #3 - TVG function (XX Log Range)
258	-1	-12.0000	TVG argument #4 - TVG gain
259	-1	0.0000	TVG argument #5 - alpha (spreading loss) in dB/Km
260	-1	0.5000	minimum absolute distance fish must travel in x plane
261	-1	0.0000	minimum absolute distance fish must travel in y plane
262	-1	0.0000	minimum absolute distance fish must travel in z plane
263	-1	2.0000	bottom_window - auto tracking bottom window (m)

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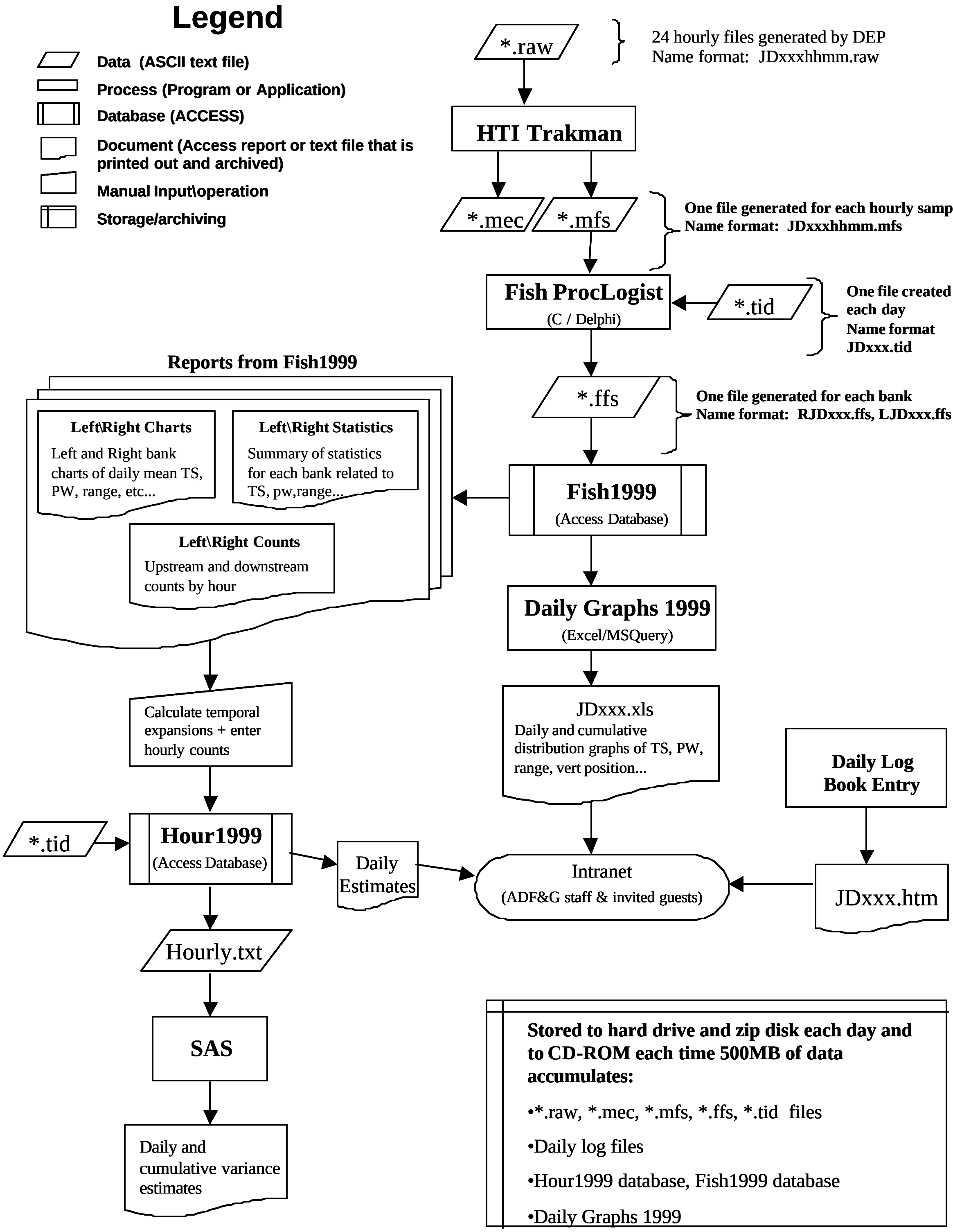
264	-1	3.0000	bottom_threshold - auto tracking bottom threshold (V)
265	-1	11.2200	TVG argument #7 - 20/40 log crossover (meters)
266	-1	1.0000	
267	-1	5.0000	
268	-1	20.0000	
401	0	5.0000	th_layer[0] - bottom of first threshold layer (m)
401	1	16.0000	th_layer[1] - bottom of second threshold layer (m)
401	2	20.0000	th_layer[2] - bottom of third threshold layer (m)
401	3	50.0000	th_layer[3] - bottom of third threshold layer (m)
401	4	100.0000	th_layer[4] - bottom of forth threshold layer (m)
402	0	446.0000	th_val[0] - thr. for 1st layer (mV)
402	1	446.0000	th_val[1] - thr. for 2nd layer (mV)
402	2	446.0000	th_val[2] - thr. for 3rd layer (mV)
402	3	446.0000	th_val[3] - thr. for 4th layer (mV)
402	4	446.0000	th_val[4] - thr. for 5th layer (mV)
403	0	1.0000	Integration layer 1 top (m)
403	1	50.0000	Integration layer 1 bottom (m)
404	0	50.0000	Integration threshold layer 1 bottom (m)
405	0	50.0000	Integration threshold layer 1 value (mV)
601	-1	HTI-SB-200kHz	Echo sounder type
602	-1	SN-305785	Echo sounder serial number
603	-1	HTISB-2.8X10	Transducer type
604	-1	306738	Transducer serial number
605	-1	Spd-3	Echogram paper speed
606	-1	9_pin	Echogram resolution
607	-1	Board_External	Trigger option
608	-1	Right_to_Left-->	River flow direction
609	-1	All_Fish	Fish included in 3d plot
610	-1	OFF	Echogram enable flag
611	-1	C:\SBDATA\K	Drive and first letter to send files

APPENDIX C. DATA FLOW

Appendix C1.-Inseason data flow diagram for the Kenai River chinook salmon sonar project, 1999.



APPENDIX D. DAILY PROPORTIONS OF UPSTREAM AND DOWNSTREAM FISH FOR THE 1999 EARLY AND LATE KENAI RIVER CHINOOK SALMON RUNS

Appendix D1.-Daily proportions of upstream and downstream fish for the 1999 Kenai River early chinook run.

Date	Downstream Count	Upstream Count	Daily Total	% Downstream	% Upstream
16 May	2	33	34	5.2%	94.8%
17 May	2	63	65	2.8%	97.2%
18 May	3	66	69	4.3%	95.7%
19 May	21	39	60	35.0%	65.0%
20 May	15	116	131	11.4%	88.6%
21 May	21	186	207	10.1%	89.9%
22 May	18	192	210	8.6%	91.4%
23 May	15	243	258	5.8%	94.2%
24 May	6	159	165	3.6%	96.4%
25 May	36	141	177	20.3%	79.7%
26 May	24	330	354	6.8%	93.2%
27 May	18	342	360	5.0%	95.0%
28 May	9	402	411	2.2%	97.8%
29 May	30	378	408	7.3%	92.7%
30 May	21	273	294	7.1%	92.9%
31 May	27	459	486	5.6%	94.4%
1 June	21	633	654	3.2%	96.8%
2 June	18	444	462	3.9%	96.1%
3 June	21	540	561	3.7%	96.3%
4 June	63	924	987	6.4%	93.6%
5 June	24	876	900	2.7%	97.3%
6 June	12	807	819	1.5%	98.5%
7 June	9	672	681	1.3%	98.7%
8 June	9	609	618	1.5%	98.5%
9 June	15	504	519	2.9%	97.1%
10 June	15	439	454	3.3%	96.7%
11 June	15	596	611	2.5%	97.5%
12 June	24	723	747	3.2%	96.8%
13 June	53	393	446	11.9%	88.1%
14 June	42	610	651	6.4%	93.6%
15 June	33	436	469	7.0%	93.0%
16 June	33	696	729	4.5%	95.5%
17 June	15	807	822	1.8%	98.2%
18 June	21	742	763	2.8%	97.2%
19 June	27	771	798	3.4%	96.6%
20 June	16	1,247	1,263	1.3%	98.7%
21 June	18	1,192	1,210	1.5%	98.5%
22 June	12	819	831	1.4%	98.6%
23 June	26	935	961	2.7%	97.3%
24-Jun	19	1,151	1,170	1.6%	98.4%
25-Jun	59	1,292	1,351	4.4%	95.6%
26-Jun	21	731	752	2.8%	97.2%
27-Jun	12	678	690	1.7%	98.3%
28-Jun	6	537	543	1.1%	98.9%
29-Jun	24	753	777	3.1%	96.9%
30-Jun	39	687	726	5.4%	94.6%
Total	990	25,666	26,656	3.7%	96.3%

Appendix D2.-Daily proportions of upstream and downstream fish for the 1999 Kenai River late chinook run.

Date	Downstream Count	Upstream Count	Daily Total	% Downstream	% Upstream
1 July	15	453	468	3.2%	96.8%
2 July	30	612	642	4.7%	95.3%
3 July	12	486	498	2.4%	97.6%
4 July	18	396	414	4.3%	95.7%
5 July	9	369	378	2.4%	97.6%
6 July	49	683	732	6.7%	93.3%
7 July	42	936	978	4.3%	95.7%
8 July	36	1,030	1,066	3.4%	96.6%
9 July	69	1,047	1,116	6.2%	93.8%
10 July	18	717	735	2.4%	97.6%
11 July	15	1,059	1,074	1.4%	98.6%
12 July	18	560	578	3.1%	96.9%
13 July	18	401	419	4.3%	95.7%
14 July	9	969	978	0.9%	99.1%
15 July	27	636	663	4.1%	95.9%
16 July	30	927	957	3.1%	96.9%
17 July	54	3,558	3,612	1.5%	98.5%
18 July	102	2,784	2,886	3.5%	96.5%
19 July	84	1,869	1,953	4.3%	95.7%
20 July	138	3,471	3,609	3.8%	96.2%
21 July	171	3,354	3,525	4.9%	95.1%
22 July	120	1,998	2,118	5.7%	94.3%
23 July	114	1,875	1,989	5.7%	94.3%
24 July	66	1,748	1,814	3.6%	96.4%
25 July	69	1,937	2,006	3.4%	96.6%
26 July	111	1,098	1,209	9.2%	90.8%
27 July	144	3,066	3,210	4.5%	95.5%
28 July	60	1,358	1,418	4.2%	95.8%
29 July	120	1,185	1,305	9.2%	90.8%
30 July	102	969	1,071	9.5%	90.5%
31 July	42	1,308	1,350	3.1%	96.9%
1 August	27	591	618	4.4%	95.6%
2 August	24	468	492	4.9%	95.1%
3 August	15	642	657	2.3%	97.7%
4 August	21	444	465	4.5%	95.5%
5 August	40	436	475	8.3%	91.7%
6 August	18	654	672	2.7%	97.3%
7 August	32	678	710	4.5%	95.5%
8 August	30	804	834	3.6%	96.4%
9 August	6	328	334	1.8%	98.2%
10 August	6	165	171	3.5%	96.5%
Total	2,131	48,069	50,199	4.2%	95.8%

APPENDIX E. AVERAGE VERTICAL ANGLE BY TIDE STAGE, RUN, BANK, AND FISH ORIENTATION (UPSTREAM OR DOWNSTREAM) FOR THE 1999 KENAI RIVER CHINOOK SALMON RUNS

Appendix E1.-Average vertical angle by tide stage and orientation for the 1999 early Kenai River chinook run.

Tide Stage / Fish Orientation	Average Vertical Angle	Standard Deviation	Sample Size
1999 Early Run, Left Bank			
Falling			
Downstream	-0.89	0.81	35
Upstream	-1.38	0.51	1,972
Tide Stage Total	-1.14	0.96	2007
Low			
Downstream	-0.96	0.80	9
Upstream	-1.46	0.41	884
Tide Stage Total	-1.21	0.90	893
Rising			
Downstream	-0.50	0.88	66
Upstream	-0.85	0.73	623
Tide Stage Total	-0.67	1.15	689
Left Bank Total	-1.01	1.74	3,589
1999 Early Run, Right Bank			
Falling			
Downstream	-0.48	0.62	117
Upstream	-0.71	0.58	2,615
Tide Stage Total	-0.60	0.85	2,732
Low			
Downstream	-0.47	0.59	43
Upstream	-0.81	0.48	1,166
Tide Stage Total	-0.64	0.76	1,209
Rising			
Downstream	-0.37	0.81	88
Upstream	-0.68	0.59	1,958
Tide Stage Total	-0.52	1.00	2,046
Right Bank Total	-0.58	1.52	5,987

Appendix E2.-Average vertical angle by tide stage and orientation for the 1999 late Kenai River chinook run.

Tide Stage / Fish Orientation	Average Vertical Angle	Standard Deviation	Sample Size
<u>1999 Late Run, Left Bank</u>			
Falling			
Downstream	-0.97	0.51	146
Upstream	-1.25	0.37	4,486
Tide Stage Total	-1.11	0.63	4,632
Low			
Downstream	-1.11	0.38	95
Upstream	-1.24	0.34	1,628
Tide Stage Total	-1.17	0.51	1,723
Rising			
Downstream	-0.94	0.55	100
Upstream	-1.11	0.46	2,407
Tide Stage Total	-1.03	0.72	2,507
Left Bank Total	-1.10	1.09	8,862
<u>1999 Late Run, Right Bank</u>			
Falling			
Downstream	-0.31	0.49	176
Upstream	-0.43	0.48	3,697
Tide Stage Total	-0.37	0.68	3,873
Low			
Downstream	-0.31	0.48	50
Upstream	-0.40	0.52	975
Tide Stage Total	-0.36	0.71	1,007
Rising			
Downstream	-0.25	0.46	153
Upstream	-0.24	0.51	3,802
Tide Stage Total	-0.24	0.69	3,955
Right Bank Total	-0.32	1.20	8,835

APPENDIX F. HISTORIC ESTIMATES OF INRIVER RETURN BY YEAR AND DATE (1987–1999).

Appendix F1.-Kenai River early-run chinook salmon sonar estimates of inriver return, by year and date.

Date	1987	1988	1989	**1990**	**1991**	**1992**	1993	1994	1995	1996	**1997**	**1998**[a]	1999[a]
7 May	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	6	NA
8 May	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	18	NA
9 May	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	3	NA
10 May	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	3	NA
11 May	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	12	NA
12 May	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	12	NA
13 May	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	27	NA
14 May	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	43	NA
15 May	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	63	NA
16 May	NA	188	180	78	30	54	64	238	98	60	114	48	33
17 May	NA	415	319	57	12	48	85	342	99	91	99	45	63
18 May	NA	259	264	93	65	88	91	260	78	63	93	57	66
19 May	NA	260	180	136	55	40	66	302	149	96	165	36	39
20 May	NA	406	147	93	68	78	69	369	228	177	84	54	116
21 May	NA	184	245	69	51	90	165	327	465	165	129	33	186
22 May	NA	182	164	75	111	108	117	246	265	156	114	15	192
23 May	NA	231	186	63	66	150	160	212	286	159	162	12	243
24 May	NA	288	279	51	66	126	141	303	265	159	138	33	159
25 May	NA	351	300	76	57	79	150	170	198	153	165	81	141
26 May	NA	393	270	70	81	93	168	150	189	240	220	43	330
27 May	NA	387	419	87	81	66	150	267	165	204	325	60	342
28 May	NA	483	357	61	78	78	361	258	159	330	317	63	402
29 May	NA	713	269	221	51	45	538	347	222	512	288	63	378
30 May	NA	333	164	154	51	111	388	321	351	348	350	129	273
31 May	NA	501	157	175	69	114	266	369	282	474	318	93	459
1 June	NA	556	258	153	150	106	187	321	357	603	213	111	633
2 June	NA	545	194	294	240	107	412	266	369	741	241	189	444
3 June	NA	598	233	225	362	232	324	298	549	873	376	192	540
4 June	NA	755	246	178	177	190	255	304	693	1,051	324	186	924
5 June	NA	782	280	192	316	166	276	351	429	943	427	162	876
6 June	NA	493	384	156	**296**	319	327	198	807	741	327	150	807
7 June	NA	506	545	**304**	**215**	515	198	384	843	773	591	283	672
8 June	NA	771	890	**414**	**243**	375	297	306	999	918	441	300	609
9 June	NA	569	912	**339**	**444**	**486**	378	462	789	1,140	391	234	504
10 June	NA	333	913	**272**	**275**	**264**	453	432	876	684	527	327	439
11 June	NA	320	710	**453**	**334**	**234**	549	423	774	882	512	600	596
12 June	NA	302	577	**568**	**400**	**394**	600	329	417	864	537	1,168	723
13 June	NA	188	599	**445**	**369**	**236**	951	376	492	1,071	681	719	393
14 June	NA	289	458	**330**	**268**	**174**	811	514	691	1,111	424	912	610
15 June	NA	510	335	**658**	**441**	**312**	407	306	636	1,116	318	951	436
16 June	NA	808	397	**485**	**615**	**239**	616	453	648	420	348	770	696
17 June	NA	535	514	**267**	**330**	**339**	567	315	750	495	**405**	**675**	807
18 June	NA	533	464	**238**	**493**	**320**	606	435	808	697	**315**	**498**	742
19 June	NA	200	295	**331**	**437**	**390**	422	636	419	657	**399**	**510**	771
20 June	NA	175	498	**369**	**314**	**548**	504	402	594	315	**408**	**351**	1,247
21 June	NA	373	520	**257**	**457**	**372**	621	570	438	351	**252**	**309**	1,192
22 June	NA	312	614	**267**	**433**	**297**	399	366	375	396	**390**	**273**	819
23 June	NA	375	547	**240**	**396**	**213**	607	550	178	401	**225**	**294**	935
24 June	NA	674	564	**322**	**251**	**337**	720	696	450	573	**285**	**288**	1,151
25 June	NA	582	374	**258**	**235**	**362**	808	734	429	684	**332**	**228**	1,292
26 June	NA	436	369	**322**	**261**	**330**	1,051	597	334	504	**381**	**219**	731
27 June	NA	549	309	**231**	**340**	**291**	1,158	639	946	228	**363**	**207**	678
28 June	NA	827	425	**240**	**327**	**253**	798	681	696	303	**297**	**308**	537
29 June	NA	495	376	**208**	**258**	**121**	728	929	984	234	**570**	**363**	753
30 June	NA	915	292	**193**	**270**	**197**	660	649	615	351	**582**	**276**	687
Total		20,880	17,992	10,768	10,939	10,087	19,669	18,403	21,884	23,505	14,963	13,103	25,666

Note: Bold numbers represent the dates that the chinook fishery was restricted to catch and release due to low inriver return.

[a] Upstream moving fish only reported.

Appendix E2.-Kenai River late-run chinook salmon sonar estimates of inriver return, by year and date.

Date	1987	1988	1989	**1990**	1991	**1992**	1993	1994	1995	1996	1997	**1998**[a]	1999[a]
1 July	507	526	769	578	267	364	539	663	350	341	486	491	453
2 July	429	404	489	305	300	297	432	342	398	240	642	597	612
3 July	405	398	353	486	333	320	325	625	353	303	600	480	486
4 July	628	292	566	436	519	198	397	858	439	393	633	450	396
5 July	596	482	1,106	853	316	225	429	705	667	1,067	657	606	369
6 July	523	654	879	795	242	331	884	1,069	720	879	627	612	683
7 July	769	379	680	929	186	247	1,572	1,050	931	780	1,158	660	936
8 July	483	725	776	432	139	170	1,855	655	417	867	1,221	462	1,030
9 July	384	471	1,404	309	393	205	1,876	744	519	768	1,618	480	1,047
10 July	314	1,732	560	359	481	221	820	1,275	450	1,023	3,486	450	717
11 July	340	1,507	2,010	778	403	143	1,238	509	325	1,146	5,649	171	1,059
12 July	751	1,087	2,763	557	330	1,027	676	828	276	714	4,497	192	560
13 July	747	2,251	910	1,175	308	605	3,345	1,066	570	1,128	5,373	262	401
14 July	761	2,370	2,284	1,481	572	689	3,177	1,332	714	4,437	2,031	368	969
15 July	913	2,405	1,111	1,149	542	745	2,233	2,211	750	3,222	4,042	1,118	636
16 July	1,466	1,259	1,344	1,011	1,029	703	2,329	3,825	1,962	3,494	3,420	1,416	927
17 July	1,353	1,520	963	2,395	2,052	570	2,037	4,692	1,128	2,253	4,584	1,424	3,558
18 July	841	2,180	1,382	2,113	3,114	853	1,438	2,157	3,942	2,820	2,334	1,638	2,784
19 July	2,071	1,724	425	1,363	1,999	1,128	715	3,493	4,692	2,236	1,146	1,146	1,869
20 July	3,709	2,670	820	1,499	1,422	1,144	1,348	2,317	4,779	2,609	1,578	741	3,471
21 July	3,737	3,170	916	787	1,030	799	981	1,695	3,132	3,435	894	1,608	3,354
22 July	1,835	1,302	583	573	1,050	619	1,166	1,386	3,465	2,250	1,840	1,411	1,998
23 July	1,700	1,502	756	642	2,632	1,449	1,163	1,050	2,421	3,050	1,441	808	1,875
24 July	2,998	1,386	783	1,106	2,204	**711**	1,344	1,232	831	3,634	1,080	933	1,748
25 July	1,915	999	495	810	1,306	**1,713**	2,245	1,412	840	3,240	532	542	1,937
26 July	1,968	924	432	671	1,216	**1,296**	1,421	1,378	1,683	2,319	519	723	1,098
27 July	1,523	960	618	755	1,195	**1,561**	1,952	1,244	1,806	1,782	438	807	3,066
28 July	2,101	1,398	538	**603**	1,901	**1,957**	1,915	2,180	789	861	333	**954**	1,358
29 July	1,923	1,400	441	**546**	1,146	**1,533**	1,363	1,327	558	474	401	**1,255**	1,185
30 July	2,595	1,158	391	**382**	791	**1,198**	1,628	1,776	510	621	450	**1,556**	969
31 July	2,372	910	383	**316**	974	**951**	862	1,808	480	1,548	420	**1,344**	1,308
1 August	470	925	351	**393**	897	**921**	767	1,037	474		247	**909**	591
2 August	314	781	201	**388**	867	**1,018**	613	1,226	369		291	**1,512**	468
3 August	263	989	132	**533**	392	**837**	337	1,081	447		213	**1,006**	642
4 August	835	1,524	142	**717**	331	**862**	463	658	519			**1,131**	444
5 August	904	1,091	107	**723**	174	**861**	711	536	404			**1,094**	436
6 August	648	1,333	107	**552**	343	**654**	1,079	1,042	408			**864**	654
7 August	694	1,186	65	**516**	618	**558**	656	797	279			**843**	678
8 August	658	1,449		**682**	600	**217**	669		267			**750**	804
9 August	368	1,132		**679**		**165**	422		272			**570**	328
10 August	312	755		**678**		**249**	252					**496**	165
11 August		698		**547**									
12 August				**362**									
13 August				**221**									
14 August				**139**									
15 August				**150**									
Total	48,123	52,008	29,035	**33,474**	34,614	**30,314**	49,674	53,281	44,336	53,934	54,881	**34,878**	48,069

[a] Upstream fish only reported.

Note: Shaded numbers represent dates when the chinook fishery was restricted to catch and release due to low inriver return.