Fishery Data Series No. 00-12

Estimates of Chinook Salmon Abundance in the Kenai River Using Split-Beam Sonar, 1998

by

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and

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August 2000

Alaska Department of Fish and Game
Division of Sport Fish

Symbols and Abbreviations

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Weights and measures (metric)

centimeter	cm
deciliter	dL
gram	g
hectare	ha
kilogram	kg
kilometer	km
liter	L
meter	m
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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ABSTRACT

The passage of chinook salmon *Oncorhynchus tshawytscha* in the Kenai River was estimated using side-looking split-beam sonar technology. Early (16 May-30 June) and late (1 July-10 August) runs of Kenai River chinook salmon have been monitored acoustically since 1987. A 200 kHz split-beam sonar system has been used since 1995 to estimate numbers of 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 1998, sonar operations started on 7 May, 9 days earlier than the conventional startup date of 16 May. Total upstream chinook salmon passage from 7 May through 10 August was estimated at 47,981 (SE = 550) fish, 13,103 (SE = 230) during the early run and 34,878 (SE = 500) during the late run. The daily peak of the early run occurred on 12 June with 50% of the run having passed by 14 June. The daily peak of the late run occurred on 18 July, with 50% of the late run having passed by 23 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 support one of the largest and most intensively managed recreational fisheries in Alaska (Nelson 1994). 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 fish are harvested primarily by sport anglers; late-run fish by commercial, sport, subsistence, and personal use fisheries. In November 1988, the Alaska Board of Fisheries set optimum spawning escapement goals of 9,000 and 22,300 for early-run (16 May-30 June) and late-run (1 July-10 August) chinook salmon, respectively (McBride et al. 1989). Commercial, sport, subsistence, and personal use fisheries can be restricted if the projected run size falls below these set escapement goals.

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 late run of 1984 with a mark-recapture project using drift gillnets (Hammarstrom et al. 1985). The mark-recapture project produced estimates of riverine abundance through 1990 (Hammarstrom and Larson 1986; Conrad and Larson 1987; Conrad 1988; Carlon and Alexandersdottir 1989; Alexandersdottir and Marsh 1990). These estimates had low precision and 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 unaccounted-for tag loss. The unaccounted-for tag loss arose because some marked fish emigrated from the river back into Upper Cook Inlet and were subsequently harvested in the commercial fishery.

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. Dual-beam sonar was initially chosen for 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 number 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 (Eggers et al. 1995). 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 separation of the two species was primarily accomplished by range thresholds combined with spatial segregation (sockeye salmon nearshore and chinook salmon 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, 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. Use of radiotelemetry technology also avoided certain biases introduced in previous mark-recapture estimates. In both 1996 and 1997, late-run sonar estimates were both estimated to be 21% higher than the telemetry estimates (Hammarstrom and Hasbrouck 1998, 1999).

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 *In prep*). 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 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, influences both rainfall and temperature throughout the drainage. The average annual rainfall in the drainage 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 1998 sonar site was located 14 km from the mouth of the Kenai River (Figure 1). 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.

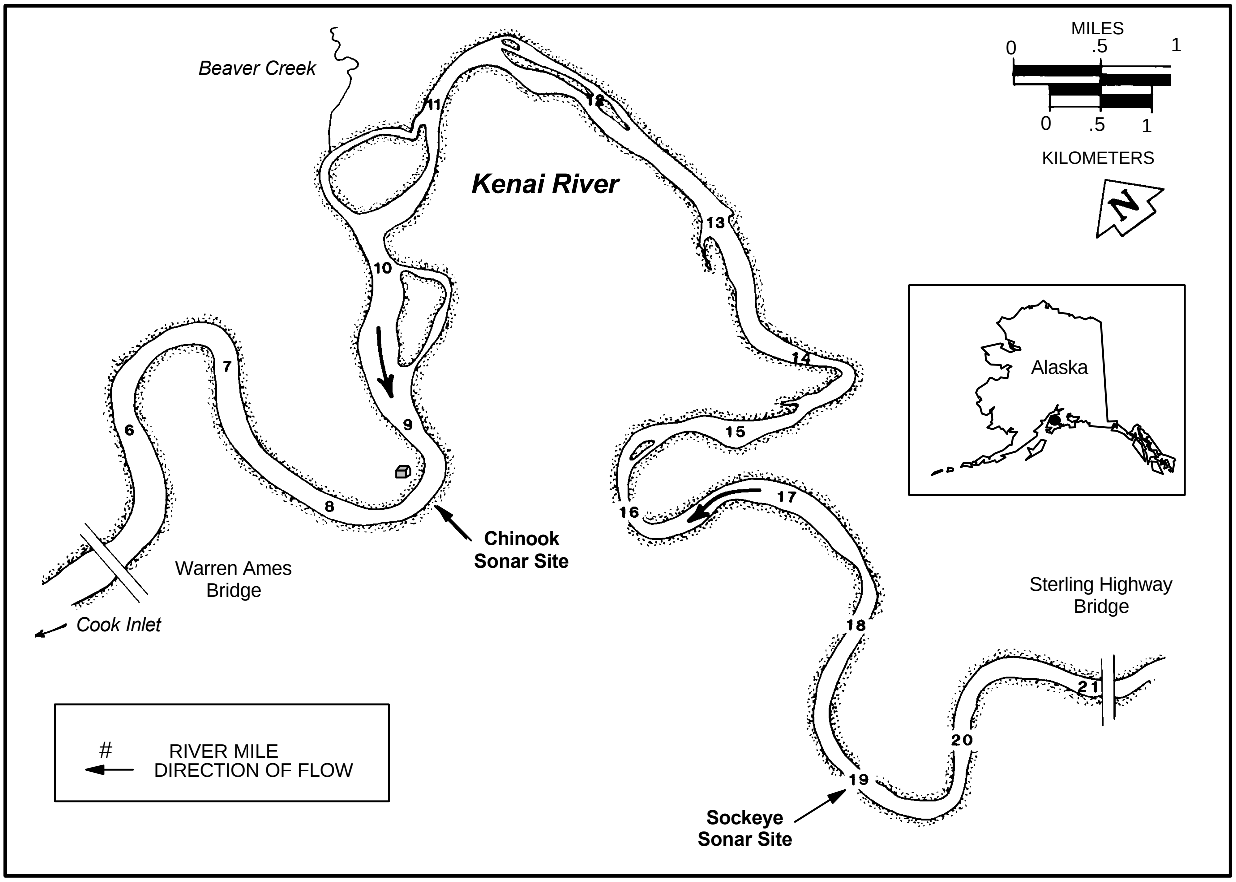

Figure 1.-Map of lower Kenai River showing location of the 1998 chinook salmon sonar site.

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 upstream of this site. In recent years, however, fishing has rapidly increased in front of and below the sonar site, mostly during the late run.

ACOUSTIC SAMPLING

The sonar system operated from 7 May through 10 August 1998. Components of the system are listed in Table 1. 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, with cables leading to the left bank equipment suspended above the river (Figure 2). 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 7 May to 10 August time frame, water level at low tide rose approximately 1.7 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 97 m at high water.

Table 1.-Principal components of the split-beam sonar system used in 1998.

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^{o}x10.2^{o} Right Bank: nominal beam widths: 2.8^{o}X10^{o}
Chart Recorder	HTI model 403 digital dual-channel chart recorder
Oscilloscope	Nicolet model 310 digital storage oscilloscope
Video Display	Hydroacoustic Assessments HARP-HC
Remote Pan and Tilt Aiming Controller	Remote Ocean Systems Model PTC-1 Pan and Tilt Controller
Remote Pan and Tilt Aiming Unit	Remote Ocean Systems Model PT-25 Remote Pan and Tilt Unit

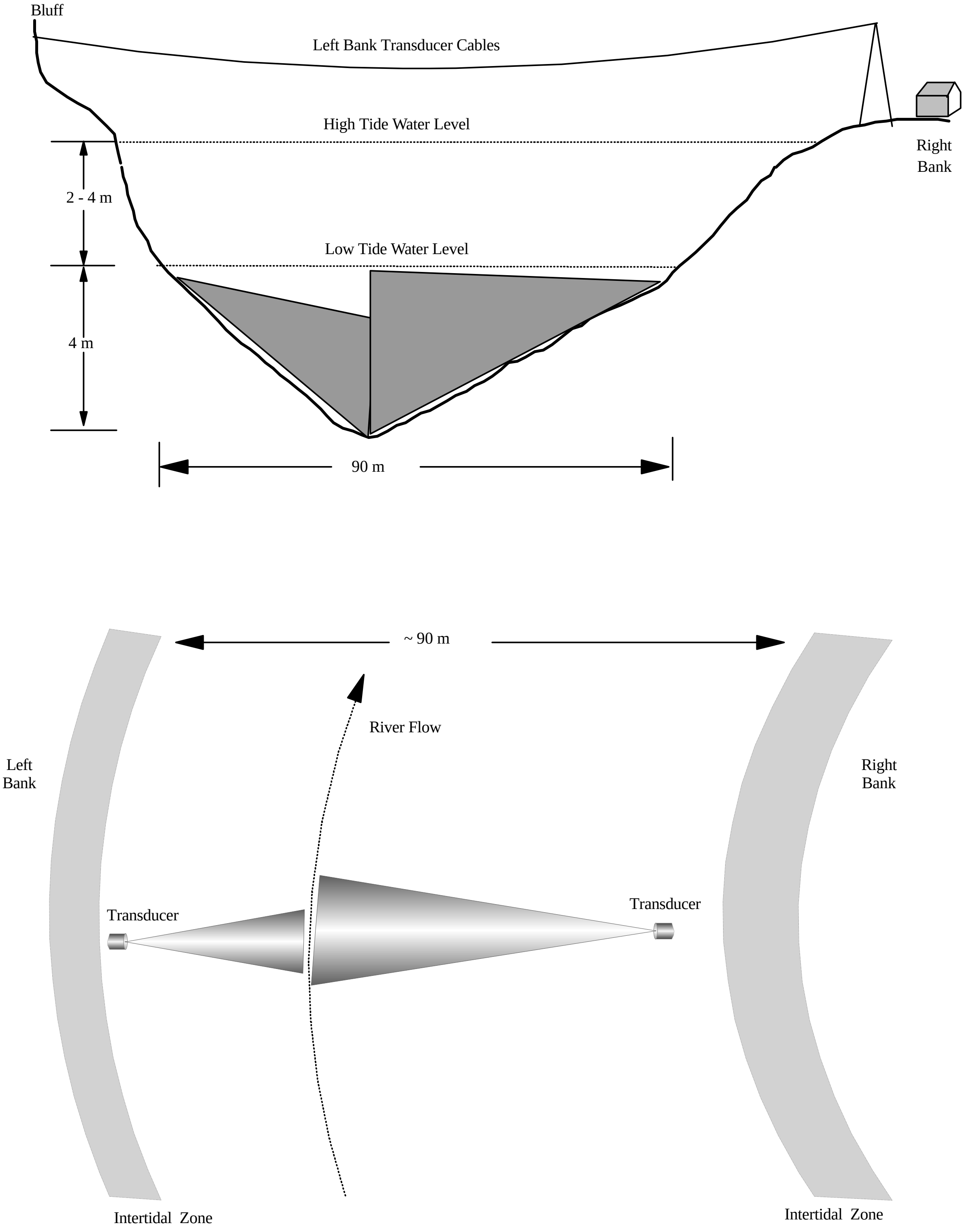

Figure 2.-Aerial and cross-sectional views of sonar site showing insonified portions of the Kenai River, 1998.

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

Reciprocity calibrations with a naval standard transducer were performed by Hydroacoustic Technology, Inc. (HTI)[1] in Seattle. 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 7 May, 12 June and 10 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 B1and Appendix B2. Most echo sounder settings were identical for each bank and remained consistent throughout the sample period. High power and low gain settings were used to maximize SNR. The transmitted pulse width was set relatively low to maximize resolution of individual fish, and SNR.

Data Acquisition

The digital echo sounder (DES) sent data from each returned echo to the digital echo processor (DEP, Figure 3). The DEP performed the initial filtering of returned echoes based on user-selected criteria (Table 3, Appendix B1 and Appendix 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. Pulse width filters used in past years (Burwen and Bosch 1998)

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

were removed in 1997 and 1998 in order to examine the distribution of pulse widths from valid fish targets without truncation. Conventionally, pulse width filters are used to aid in excluding echoes from multiple targets. However, multiple targets are not considered an issue on this project due to low passage rates of chinook salmon that typically produce large well-spaced targets.

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.

Table 2.-1998 settings for HTI model 240 digital echo sounder.

Echo Sounder Parameters	Value
Transmit Power	25 dB
System Gain	-18 dB
TVG	40logR
Transmitted Pulse Width	0.20 msec
Maximum Right Bank Range	65 m
Maximum Left Bank Range	45 m
Ping Rate Right Bank	11 pings/sec
Ping Rate Left Bank	16 pings/sec

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 postprocessing 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 Model 403 Digital Chart Recorder. 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.

FISH TRACKING AND ECHO COUNTING

Echoes in the *.RAW files were manually grouped (tracked) into fish using HTI proprietary software called TRAKMAN^{Ó}. TRAKMAN^{Ó} 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^{Ó} 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.

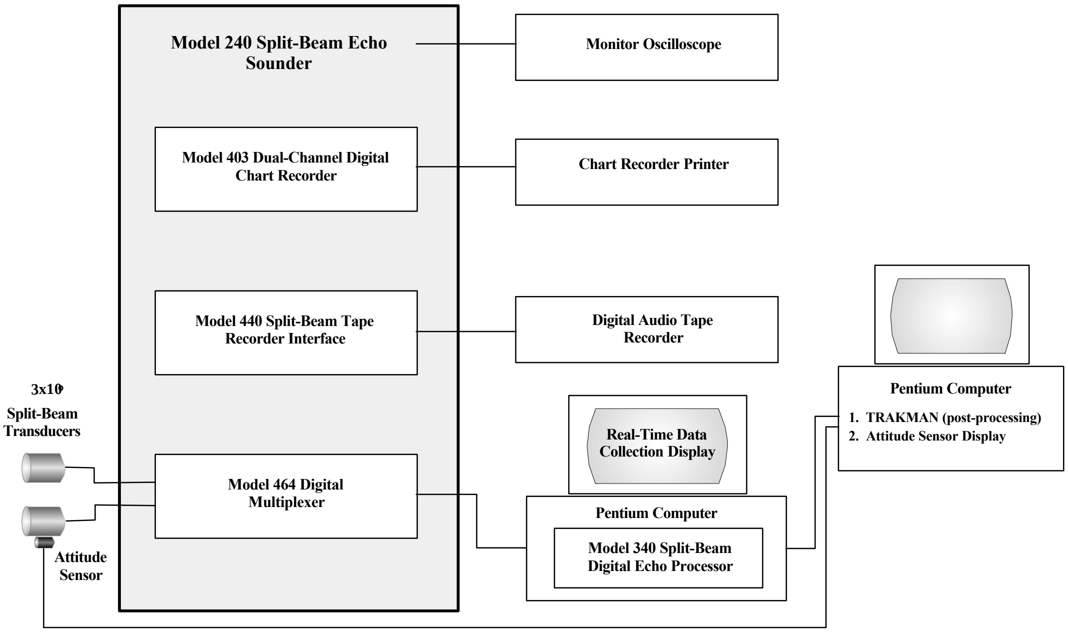


Figure 3.-Schematic diagram of 1998 split-beam sonar system configuration and data flow.

Table 3.-Echo acceptance criteria for digital echo processing, 1998.

Bank	Pulse Width (ms) at -6 dB	Vertical Angle Off-axis (°)	Horizontal Angle Off-axis(°)	Threshold mV (dB)	Range (m)
Right					
7 May to 27 June[a]	0.0 to 2.0	-2.0 to 2.0	-5.0 to 5.0	> 662 (-35 dB)	>2.0
27 June to 10 Aug	0.0 to 2.0	-2.5 to 2.0	-5.0 to 5.0	>662 (-35 dB)	>2.0
Left					
7 May to 10 Aug	0.0 to 2.0	-2.5 to 2.5	-5.0 to 5.0	> 413 (-35 dB)	>2.0

[a] This parameter was expanded at 1600 hours on 27 May.

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 transits 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. Fish typically leave a meandering trace that reflects some level of active movement as it passes through the acoustic beam. In 1998, 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 (10 July through 3 August), targets within 25 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). Data from both banks were combined to summarize fish passage by tide stage (low, falling, 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:

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

where:

z_m = midpoint range (m),

z_s = starting range (m), and

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

Vertical distributions were plotted separately for upstream and downstream fish by three tide stages (low, falling, rising). Vertical distributions were calculated from the midpoint angle off-axis in the vertical plane as follows:

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

where:

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

y_s = starting vertical coordinate (m), and

d_y = distance traveled in vertical direction (m).

Target Strength Distribution

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

Species Discrimination

Tracked fish were filtered using criteria intended to minimize the number of sockeye salmon counted. Two parameters have been used historically on this project to separate large chinook salmon from smaller species: target strength and distance from the transducer (range). Although recent studies have questioned the usefulness of these parameters for our application (Eggers 1994, Burwen et al. 1995), we continued their use in 1998 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 *In prep*).

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. Fish within 10 m (7 May-10 August) on the left bank were deleted as were right-bank fish within 25 m (7 May-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. In this case, 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 (Cochran 1977) between banks, using data from those hours when both banks were sampled for the same number of minutes. For a bank that was not operating, 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 both banks were down 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 (1), (2), or (4) 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} = if the sonar was operating on bank b during hour j, or 0 if not.

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

In 1998, we modified the inriver chinook salmon AWL netting program 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 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 (Marsh *In prep*) and may be a useful index of chinook salmon abundance. But like net CPUE, its performance varies under changing water clarity conditions. It may also vary with changes in how the sport fishery is prosecuted with respect to bait restrictions and/or closures.

Commercial Nets (Late Run)

Commercial catch of chinook salmon in eastside set nets can be a useful index of late-run chinook salmon abundance. This information is obtained from the Commercial Fisheries Division (Ruesch and Fox 1999). Its utility is limited to times during the late run when that specific fishery is active.

Sockeye 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.

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 –38.5 dB for both the right and left bank systems (Table 4). The theoretical value for the sphere is -39.5 dB (MacLennan and Simmonds 1992). During subsequent *in situ* calibration checks using the same sphere, mean target strength varied from –37.9 dB to –38.9 dB on the right bank and from –37.7 to –38.9 on the left bank.

TARGET TRACKING

A total of 26,364 targets were manually tracked, 6,610 during the early run (7 May-30 June) and 19,754 during the late run (1 July-10 August). After filtering for range and target strength criteria and making temporal expansions, the proportion of upstream fish was 93.9% for the early run and 86.4% for the late run (Table 5, Table 6, Figure 4). Conversely, the proportions of downstream fish during the early and late runs were 6.1% and 13.6%, respectively (Appendix C2). Most downstream activity took place on the right bank during the last 2 weeks of the late run.

The number of acquired echoes per fish varied by run, bank, and direction of travel. During the early run, upstream fish averaged 49 (SD = 43) and 73 (SD = 53) echoes per fish on the left and right banks, respectively. Downstream fish averaged 83 echoes (SD = 85) on the left bank and 70 echoes (SD = 74) on the right bank. During the late run, the number of echoes per fish increased substantially for upstream moving fish on both banks. Upstream fish averaged 60 (SD = 48) echoes on the left bank and 99 (SD = 66) echoes on the right bank. Downstream fish averaged 65 (SD = 51) echoes on the left bank and 45 (SD = 10) echoes per fish on the right bank.

TIDAL AND TEMPORAL DISTRIBUTION

The highest proportion of upstream fish occurred during the falling tide for both early (50.5%) and late (41.7%) runs (Table 5, Table 6, Figure 5). The highest proportion of downstream fish

Table 4.-Results of 1998 *in situ* calibration verifications using a 38.1 mm tungsten carbide standard sphere.

Location	Date	Mean Target Strength (dB)	SD	N	Range (m)	Noise (mV)	Threshold (mV)
Right Bank							
HTI[a]	14 April	-38.5	0.5			N/A[b]	
Kenai River	7 May	-37.9	1.8	4,334	17.6	100	150
Kenai River	12 June	-38.8	3.2	2,613	13.2	~100	200
Kenai River	10 August	-38.9	2.8	1,065	17.4	100	250
Left Bank							
HTI[a]	14 April	-38.5	0.6			N/A[b]	
Kenai River	7 May	-37.7	1.5	3,009	15.4	<100	125
Kenai River	12 June	-38.2	1.2	3,841	6.8	<100	100
Kenai River	11 August	-38.9	1.8	1,817	9.6	<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 1998 early run (7 May to 30 June).

1997 Early Run	Total Number of Fish	Rising Tide	Falling Tide	Low Tide
Upstream	13,103	4,176	6,613	2,314
Row %	100.0%	31.9%	50.5%	17.7%
Column %	93.9%	96.3%	94.0%	89.7%
Downstream	848	162	421	265
Row %	100.0%	19.1%	49.6%	31.3%
Column %	6.1%	3.7%	6.0%	10.3%

Test for Independence: Chi-square = 121.43, df = 2, P<<<0.0001.

Table 6.-Estimates of chinook salmon passage by tide stage and direction of travel for the 1998 late run (1 July to 10 August).

1997 Late Run	Total Number of Fish	Rising Tide	Falling Tide	Low Tide
Upstream	34,878	13,930	14,540	6,408
Row %	100.0%	39.9%	41.7%	18.4%
Column %	86.4%	85.8%	89.2%	81.7%
Downstream	5,505	2,304	1,768	1,433
Row %	100.0%	41.9%	32.1%	26.0%
Column %	13.6%	14.2%	10.8%	18.3%

Test for Independence: Chi-square = 255.82, df = 2, P <<<0.0001.

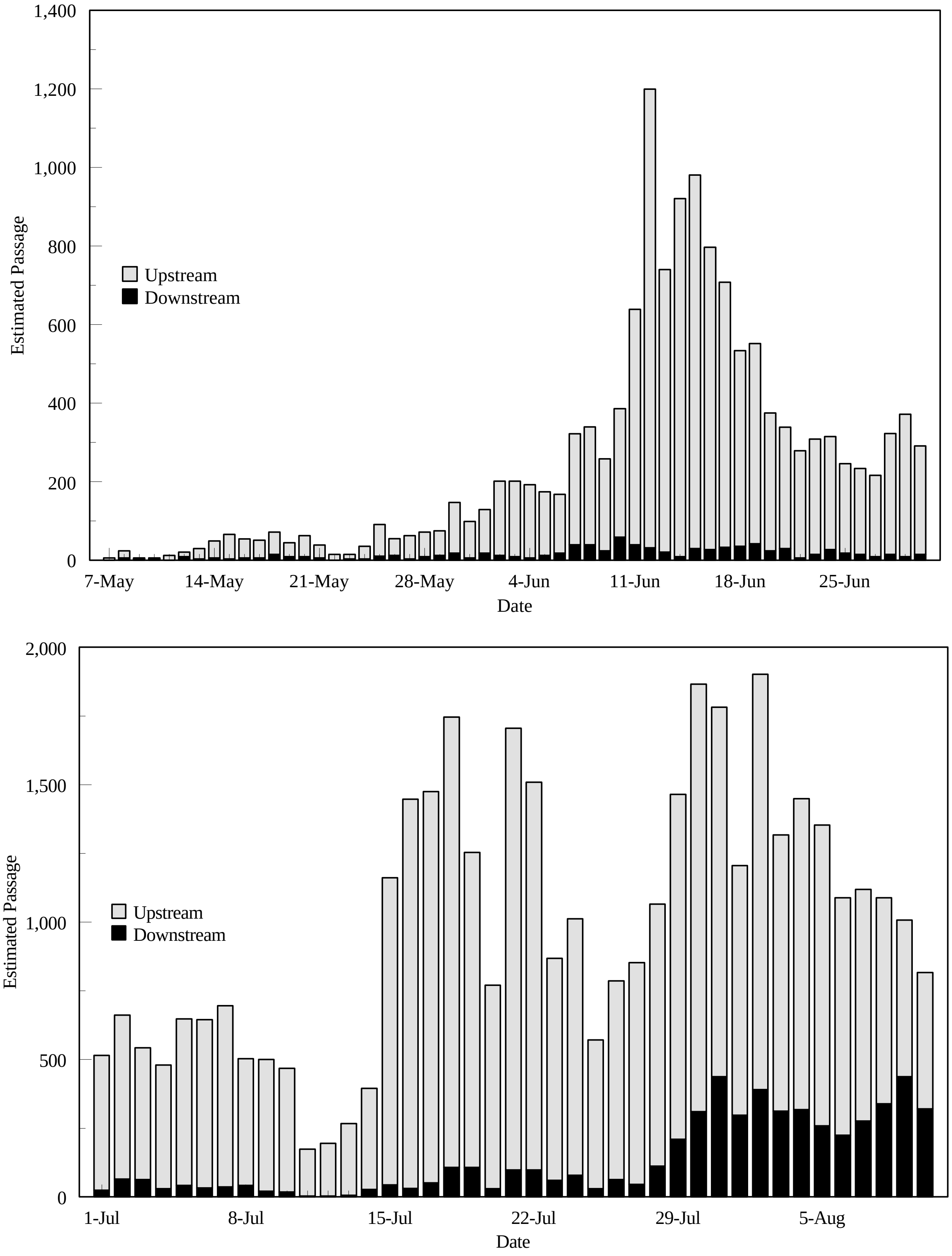


Figure 4.-Upstream and downstream components of the early (top) and late (bottom) runs of chinook salmon to the Kenai River, 1998.

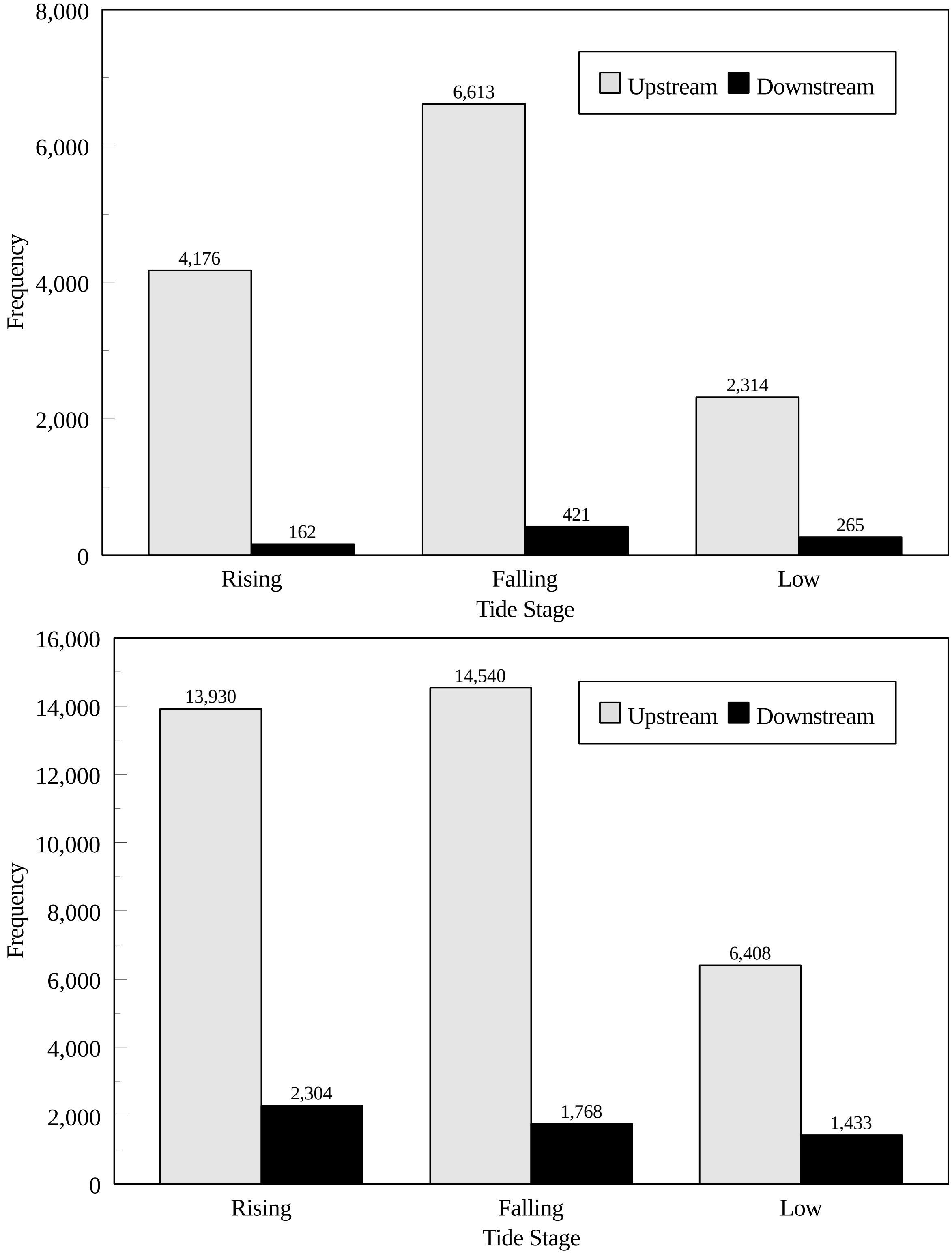


Figure 5.-Distribution of upstream and downstream fish by tide stage during the early run (top) and late run (bottom).

occurred during the falling tides for the early run (49.6%) and during the rising tides for the late run (41.9%).

SPATIAL DISTRIBUTION

Fish were bottom-oriented during both runs, although vertical distribution did vary somewhat by direction of travel, tide stage, and season (Appendices D1 and D2). During the early run, 81% of the upstream fish on the left bank and 83% on the right bank were below the acoustic axis (Figure 6). Downstream fish were less bottom-oriented (Appendix D1). Sixty-three percent of downstream fish on both banks (Figure 6) were below the acoustic axis. Upstream fish on the left bank (mean = -0.95°, SD = 0.88, n = 1,136) were on average significantly lower ($P << 0.001$) in the water column than downstream fish (mean = -0.56 °, SD = 0.92, n = 110). On the right bank, upstream fish (mean = -0.77 °, SD = 0.63, n = 4,185) were also significantly lower in the water column ($P << 0.001$) than downstream fish (mean = -0.33 °, SD = 0.71, n = 232). There was a greater tendency for early-run, upstream fish traveling on the left bank to rise off the bottom during the rising tide phase than for right bank fish (Figure 7).

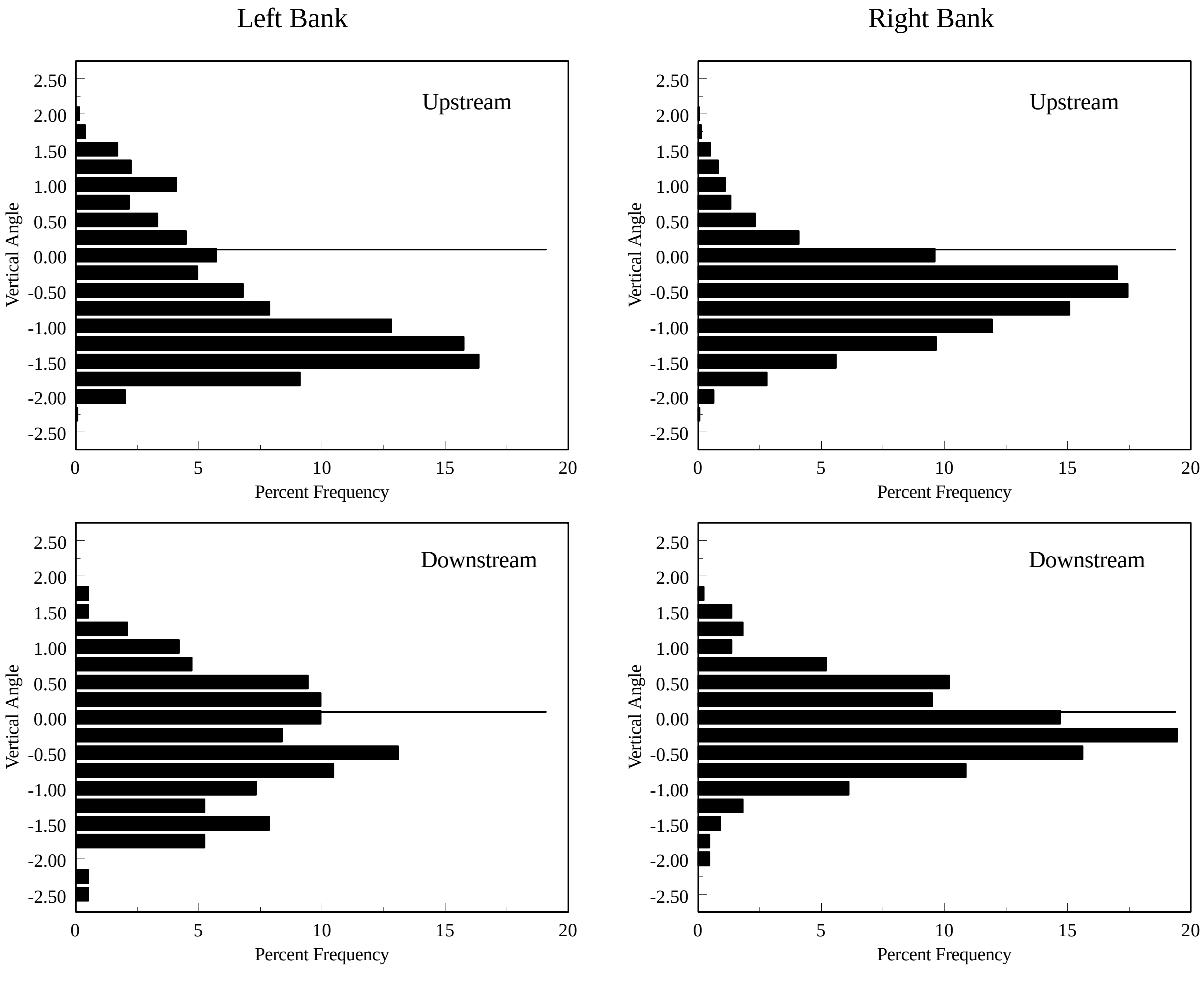


Figure 6.-Vertical distributions of early-run upstream and downstream fish, on the left and right banks, Kenai River, 1998.

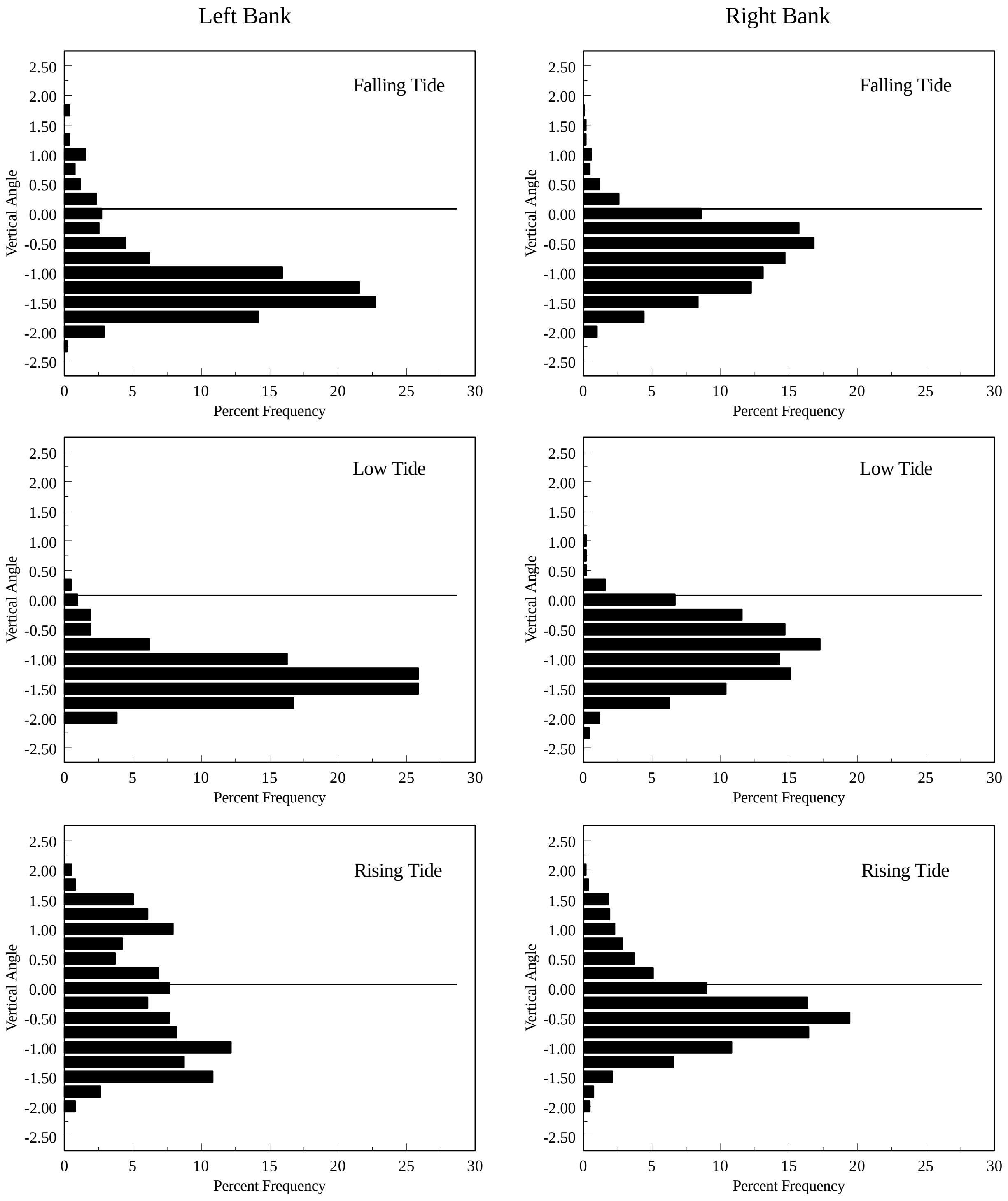


Figure 7.-Vertical distribution of early-run, upstream-traveling fish during falling (top), low (middle), and rising (bottom) tide stages on the left and right banks, Kenai River, 1998.

Late-run fish also showed a tendency to travel along the river bottom (Figure 8, Appendix D2). Ninety percent of upstream fish on the left bank and 64% of upstream fish on the right bank were below the acoustic axis. Ninety percent of downstream fish on the left bank and 79% of downstream fish on the right bank were below the acoustic axis. Upstream fish on the left bank (mean = -1.16 ^{o}, SD = 0.68, n = 2,722) traveled, on average, in the same area (P = 0.09) in the water column as downstream fish (mean = -1.11 ^{o}, SD = 0.65, n = 641). On the right bank, upstream fish (mean = -0.45^{o}, SD = 0.54, n = 8,659) were on average higher (P << 0.001) in the water column than downstream fish (mean = -0.65 ^{o}, SD = 0.53, n = 1,170). Upstream traveling fish on both banks maintained similar vertical range distributions through all tide stages (Figure 9). Left bank traveling fish exhibited a very strong bottom orientation while right bank traveling fish were distributed closely about the acoustic axis.

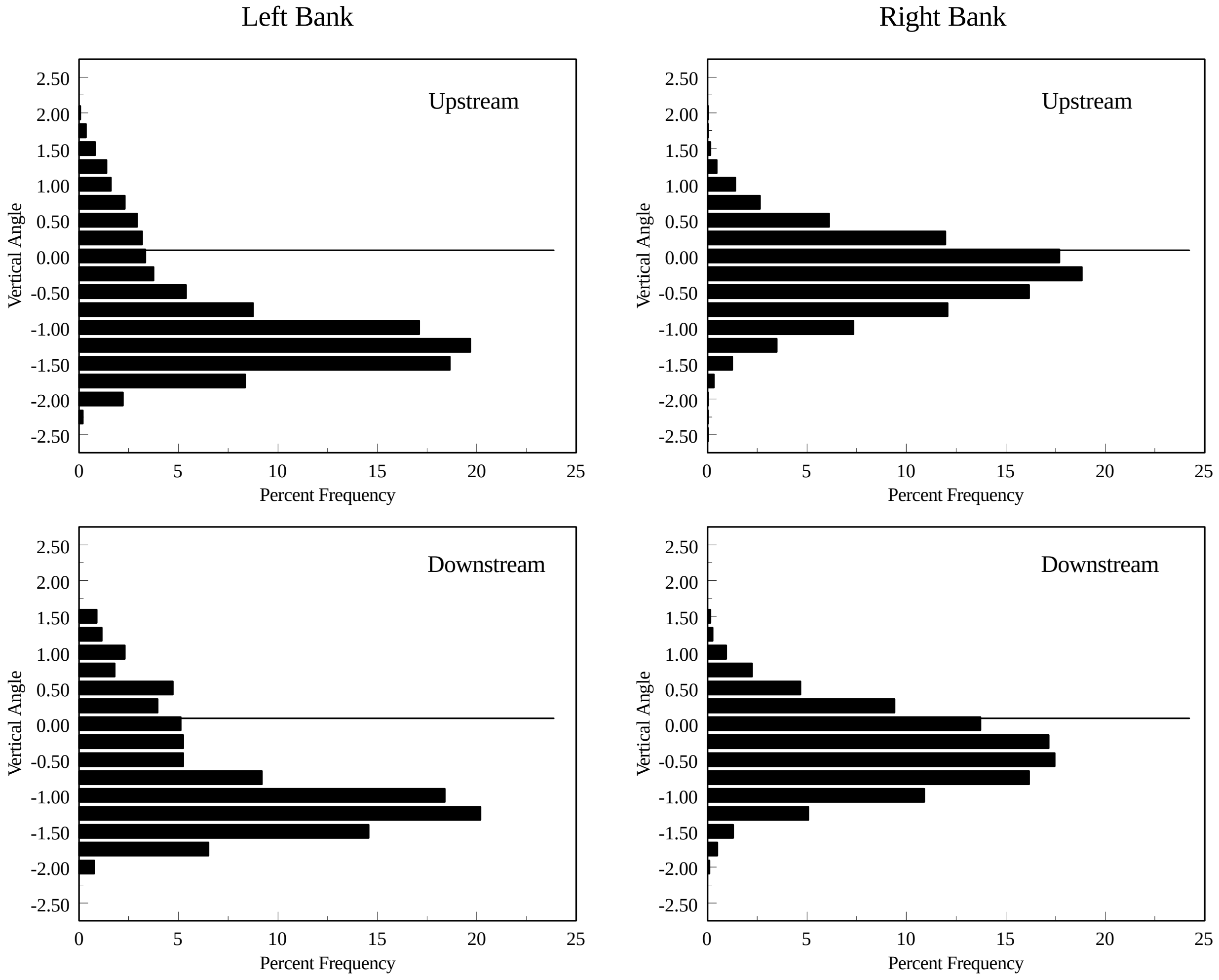


Figure 8.-Vertical distributions of late-run upstream- and downstream-traveling fish, on the left and right banks, Kenai River, 1998.

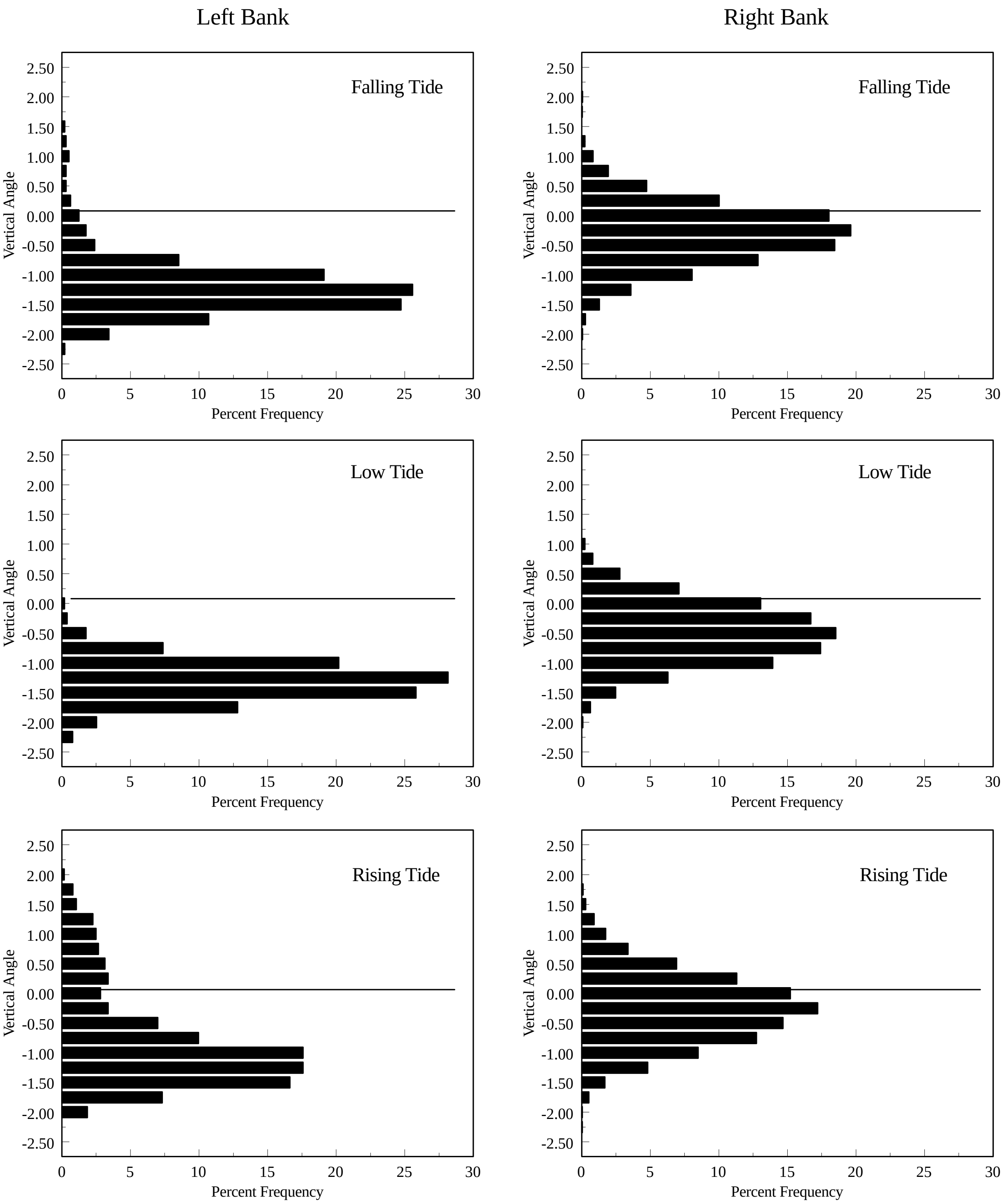


Figure 9.-Vertical distribution of late-run upstream-traveling fish during falling (top), low (middle), and rising (bottom) tide stages on the left and right banks, Kenai River, 1998.

During the early run, fish on the left bank were more channel-oriented than fish on the right bank (Figure 10). There was no significant difference between the range distributions of upstream and downstream fish traveling (Table 7) on the left bank (Anderson-Darling, P = 0.60). On the right bank, a majority of the downstream moving fish passed in the 25 m to 40 m area leading to a significant difference (P <<< 0.001, Table 7, Figure 10) in range distributions between upstream and downstream moving fish. Range distributions on both banks appeared to be more channel-oriented during falling tides (Figure 11). Fish were least channel-oriented during the low tide on both banks (Figure 11) and also during the rising tide on the right bank.

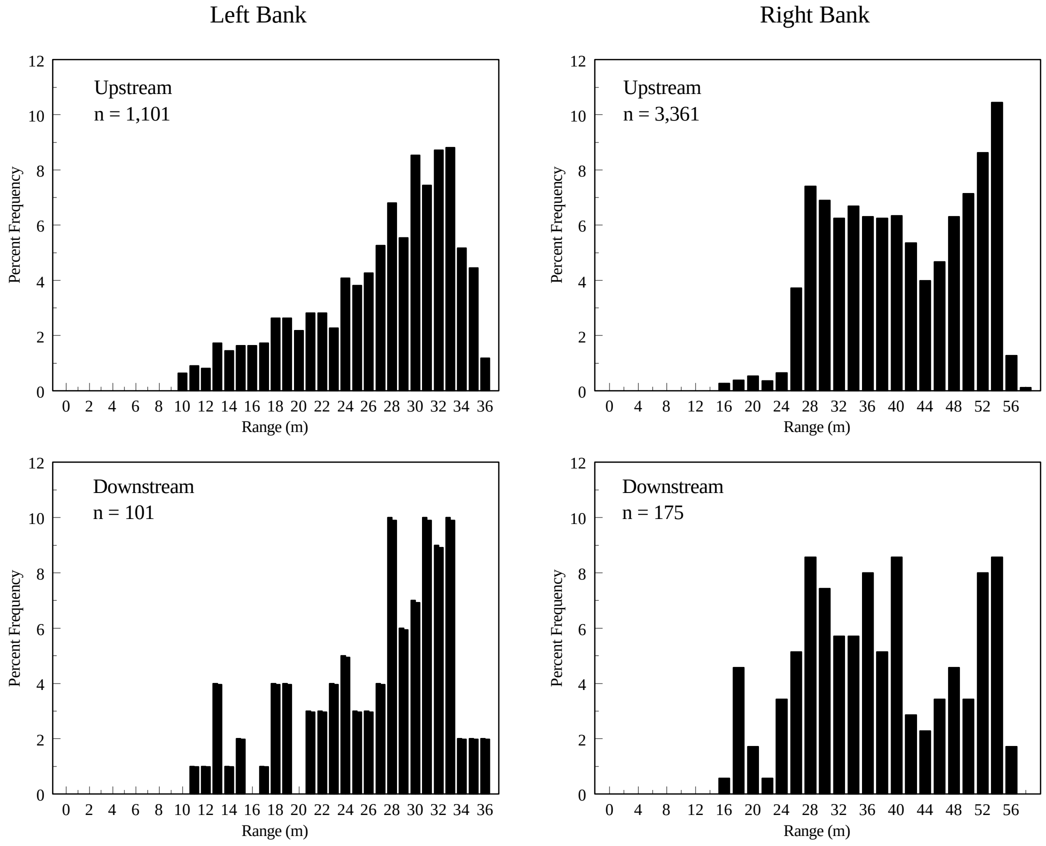


Figure 10.-Range distributions of early-run upstream and downstream fish, on the left and right banks, Kenai River, 1998.

During the late run, upstream moving fish on the left bank remained channel-oriented, while upstream moving fish on the right bank maintained a bimodal range distribution (Figure 12). Upstream moving fish differed significantly from the more channel-oriented downstream fish on both left (Anderson-Darling, P << 0.001) and right (P<<<0.001) banks (Table 8, Figure 12). Left bank range distributions remained channel oriented and relatively unchanged throughout the falling, low and rising tide phases (Figure 13). Right-bank range distribution during the falling and low tides appeared bimodal compared to a more even distribution of fish during the rising tide phase (Figure 13).

Table 7.-Range distribution (5 m increments) for upstream and downstream traveling fish during the 1998 early run (7 May to 30 June).

Range	Upstream	Downstream	Percent of Total Upstream	Percent of Total Downstream	Percent Upstream of Range	Percent Downstream of Range
Left Bank						
10 - 14.99	61	7	5.5	6.9	89.7	10.3
15 - 19.99	113	11	10.3	10.9	91.1	8.9
20 - 24.99	156	15	14.2	14.9	91.2	8.8
25 - 29.99	283	26	25.7	25.7	91.6	8.4
30 – 34.99	427	38	38.7	37.6	91.8	8.2
35 – 39.99	62	4	5.6	4.0	93.9	6.1
Bank Total	1,102	101	100.0	100.0	91.6	8.4
Right Bank						
15 - 19.99	40	12	1.2	6.9	76.9	23.1
20 - 24.99	46	10	1.4	5.7	82.1	17.9
25 - 29.99	594	34	17.7	19.4	94.6	5.4
30 - 34.99	530	25	15.8	14.3	95.5	4.5
35 - 39.99	540	33	16.1	18.9	94.2	5.8
40 - 44.99	394	13	11.7	7.4	96.8	3.2
45 - 49.99	529	16	15.7	9.1	97.1	2.9
50 – 54.99	684	32	20.4	18.3	95.5	4.5
55 – 59.99	4	0	0.1	0.0	100.0	0.0
Bank Total	3,361	175	100.0	100.0	95.1	4.9

The left bank produced lower passage estimates than the right bank during both early and late runs. During the early run 74.3% of the estimated inriver return passed on the right bank (Table 9) and 25.7% of the upstream passage estimate passed by on the left bank. The late run had almost identical upstream passage estimates with 74.6% on the right bank and 25.4% passing on the left bank (Table 10).

TARGET STRENGTH

Target strength distributions varied by bank, direction of travel, and run. Table 11 shows target strength statistics for fish that have met minimum range and target strength criteria, whereas Figures 14 and 15 show target strength distributions and statistics that include all tracked targets that have not been filtered by range or size criteria. Mean target strength estimates for upstream and downstream moving fish were similar between banks during the early run (Table 11, Figure 14). During the late run, target strength estimates for left bank fish were on average larger than right bank estimates (Table 11, Figure 15). Mean target strength of upstream and downstream fish varied the most between banks during the late run (Figure 15).

During the early run, for fish traveling on the left bank, mean target strength was higher ($t = -4.85$, $P << 0.001$) and slightly more variable ($F = 0.95$, $P = 0.37$) for upstream fish than

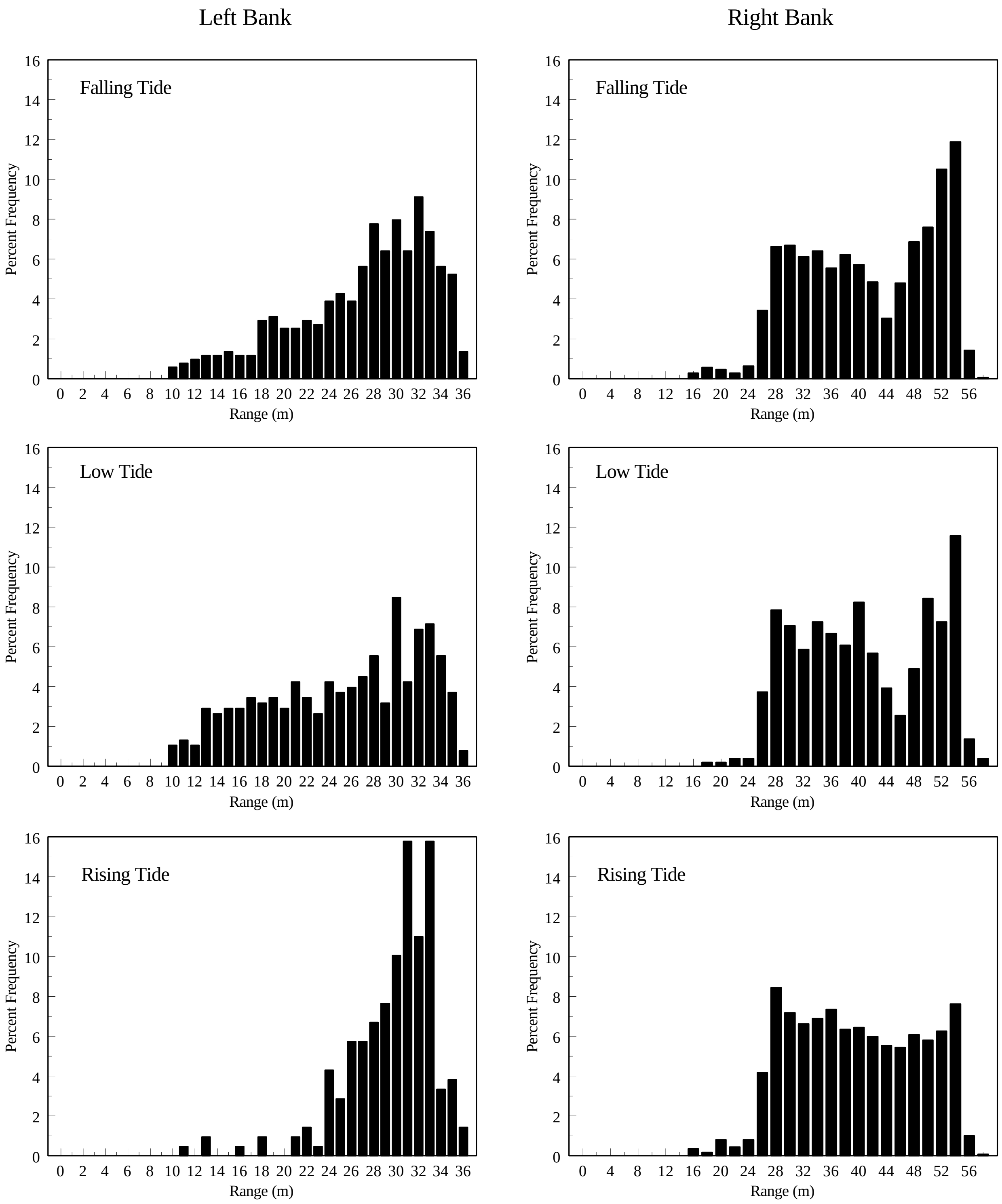


Figure 11.-Range distribution of early-run, upstream-traveling fish during falling, low, and rising tide stages on the left and right banks, Kenai River, 1998.

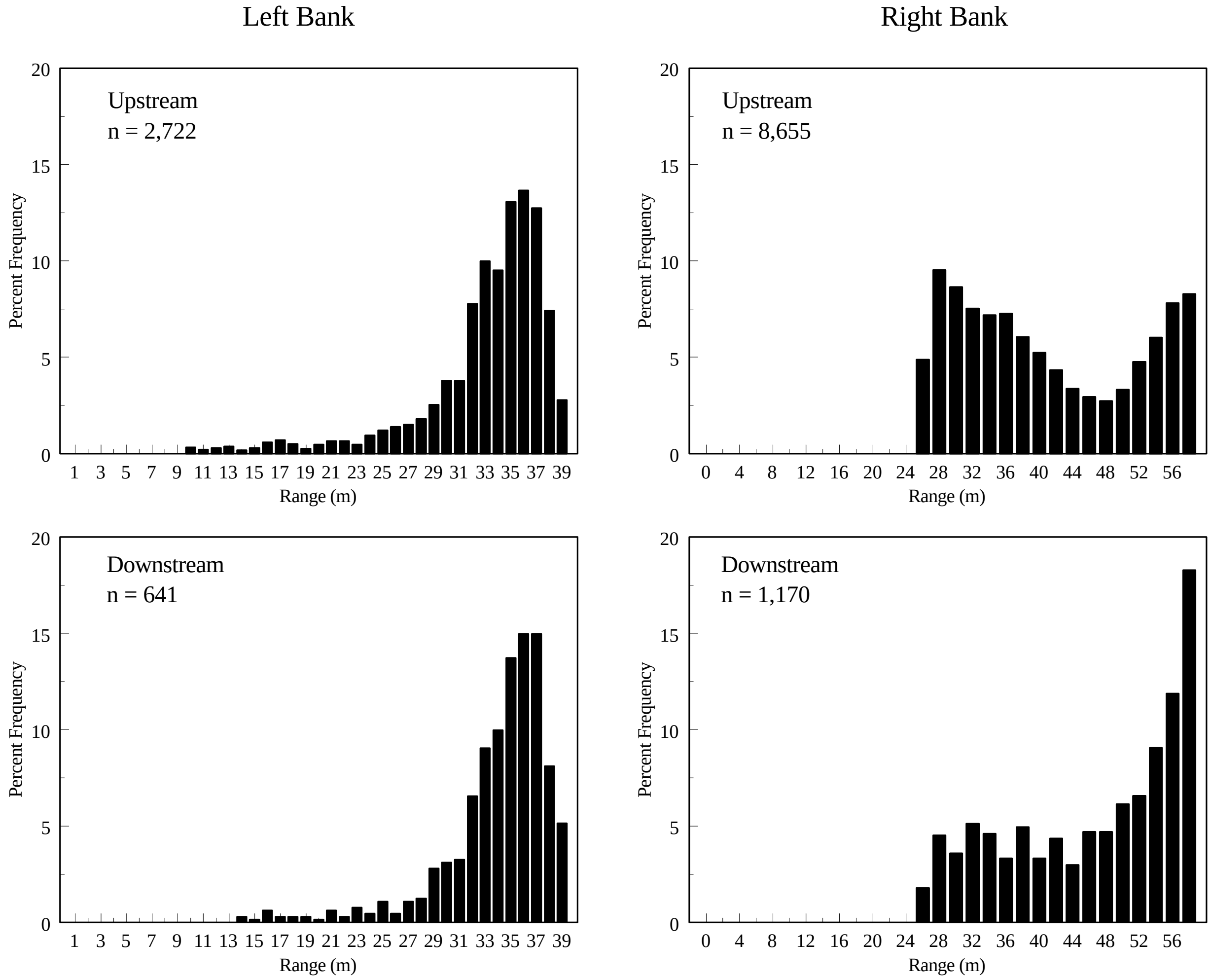


Figure 12.-Range distributions of late-run upstream and downstream fish, on the left and right banks, Kenai River, 1998.

downstream fish (Table 11). On the right bank, mean target strength was again higher (t = -6.32, P << 0.001) and more variable (F = 0.63, P << 0.001) for upstream fish (Table 11), though only by about 1 dB.

During the late run on the left bank, upstream moving fish had on average higher target strength (t = 3.21, P = 0.001) estimates than downstream moving fish, but target strength estimates between these two groups had similar variances (F = 0.94, P = 0.19, Table 11). On the right bank, mean target strength was similar (t = -0.25, P = 0.96) and did not vary among upstream (F = 1.05, P = 0.11) and downstream fish (Table 11).

PASSAGE ESTIMATES

Daily estimates of chinook salmon passage were generated for 7 May-10 August. Sampling was terminated at 2300 on 10 August. A total of 1,523 hours (two banks) of acoustic data were processed during the 96-day season representing 33% of the total available sample time.

Table 8.-Range distribution (5 m increments) for upstream and downstream traveling fish during the 1998 late run (1 July to 10 August).

Range	Upstream	Downstream	Percent of Total Upstream	Percent of Total Downstream	Percent Upstream of Range	Percent Downstream of Range
Left bank						
10 – 14.99	38	2	1.4	0.3	95.0	5.0
15 – 19.99	64	11	2.4	1.7	85.3	14.7
20 – 24.99	88	15	3.2	2.3	85.4	14.6
25 – 29.99	230	43	8.4	6.7	84.2	15.8
30 – 34.99	949	205	34.9	32.0	82.2	17.8
35 – 39.99	1,353	365	49.7	56.9	78.8	21.2
Bank Total	2,722	641	100.0	100.0	80.9	19.1
Right bank						
25 - 29.99	1,996	116	23.1	9.9	94.5	5.5
30 - 34.99	1,625	133	18.8	11.4	92.4	7.6
35 - 39.99	1,258	117	14.5	10.0	91.5	8.5
40 - 44.99	807	118	9.3	10.1	87.2	12.8
45 - 49.99	641	150	7.4	12.8	81.0	19.0
50 - 54.99	1,282	260	14.8	22.2	83.1	16.9
55 – 59.99	1,046	276	12.1	23.6	79.1	20.9
Bank Total	8,655	1,170	100.0	100.0	88.1	11.9

To maintain comparability between recent (1995-1998) 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 that were determined to be traveling upstream.

Total Passage

Total chinook salmon passage from 7 May through 10 August was estimated at 54,334 (SE = 601) fish, 13,951 (SE = 235) during the early run and 40,383 (SE = 553) during the late run (Table 9, Table 10). The daily peak of the early run occurred on 12 June with 50% of the run having passed by 14 June (Figure 16). Run timing for the early run was late, falling within the historic 95% run-timing confidence intervals only during the second half of June (Figure 17). The daily peak of the late run occurred on 18 July, with 50% of the late run having passed by 23 July (Figure 18). Migratory timing for late-run fish also appeared late, falling within normal bounds early in the season, but a weak return during early July caused run timing to fall below the historic 95% run-timing curve for most of July (Figure 17).

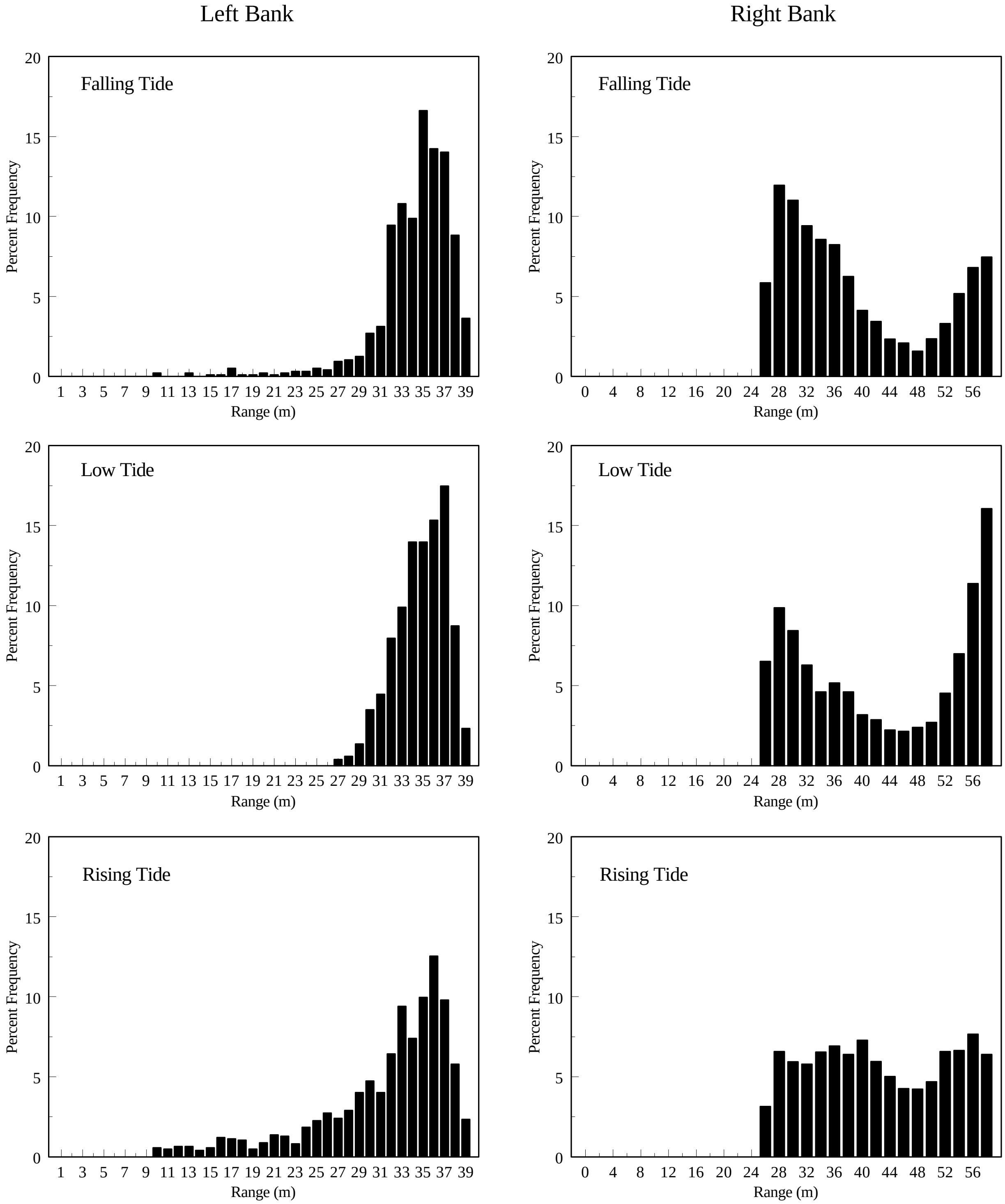


Figure 13.-Range distribution of late-run upstream-traveling fish during falling, low, and rising tide stages on the left and right banks, Kenai River, 1998.

Table 9.-Estimates of 1998 early-run fish passage by direction of travel.

Bank	Estimate of Total Fish Passage	Estimate of Downstream Component	Estimate of Upstream Component
Right Bank	10,276 (206)	544 (34)	9,732 (202)
Left Bank	3,676 (114)	304 (26)	3,371 (110)
Both Banks	13,951 (235)	848 (42)	13,103 (230)

Note: Standard errors are in parentheses.

Table 10.-Estimates of 1998 late-run fish passage by direction of travel.

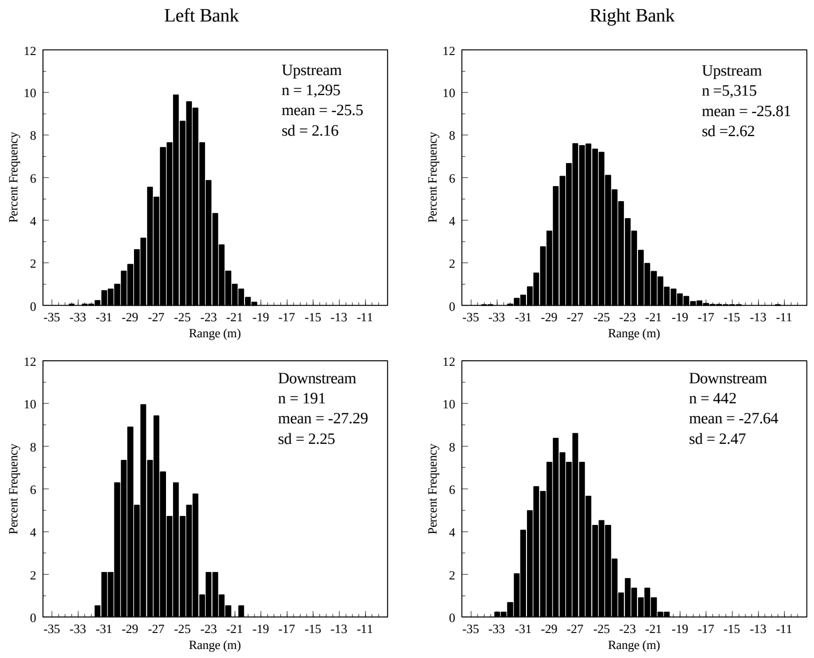
Bank	Estimate of Total Fish Passage	Estimate of Downstream Component	Estimate of Upstream Component
Right Bank	29,513 (501)	3,502 (137)	26,011 (457)
Left Bank	10,870 (235)	2,003 (89)	8,866 (200)
Both Banks	40,383 (553)	5,505 (163)	34,878 (500)

Note: Standard errors are in parentheses.

Table 11.-Mean target strength for upstream and downstream targets by bank during the early (7 May-30 June) and late (1 July-10 August) runs, 1998.

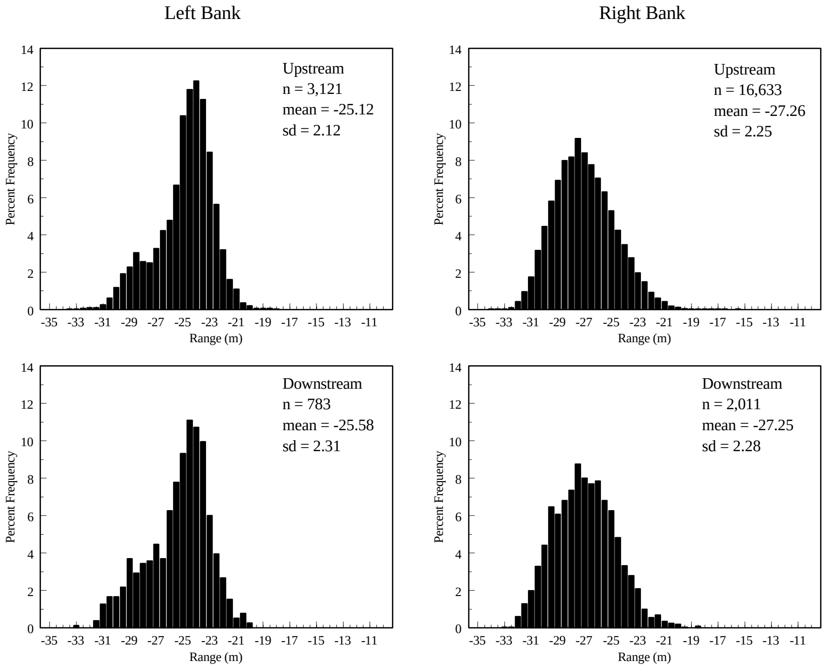
	Upstream			Downstream		
Location	Mean	SD	n	Mean	SD	N
Early Run						
Left Bank	-24.93	1.67	1,102	-25.77	1.63	101
Right Bank	-24.92	2.2	3,361	-25.78	1.75	175
Late Run						
Left Bank	-24.53	1.49	2,722	-24.74	1.53	641
Right Bank	-25.83	1.61	8,655	-25.81	1.57	1,170

Note: Includes only targets meeting all thresholds.



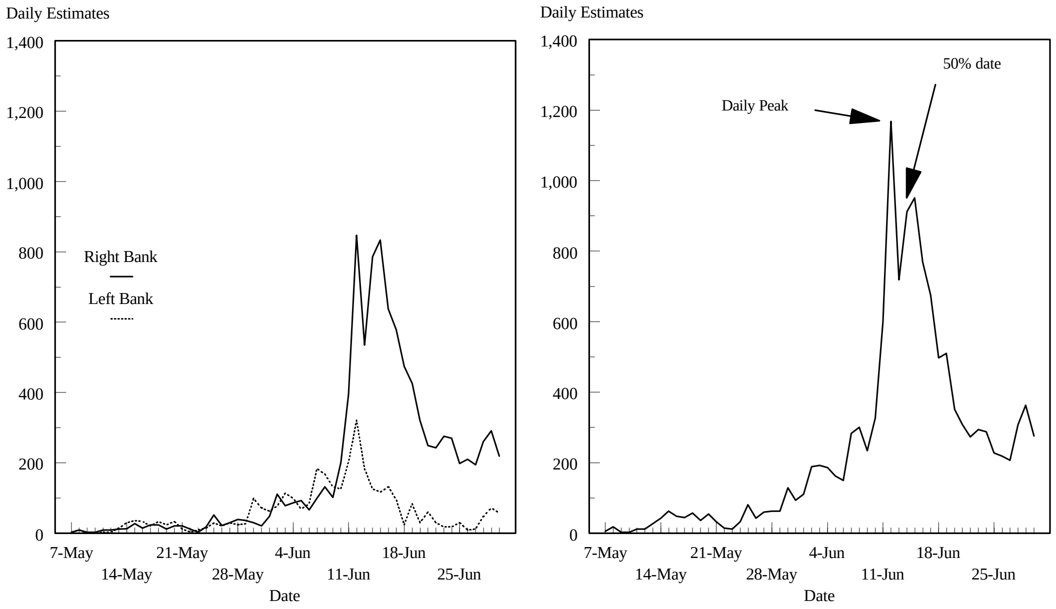
Note: Data have not been filtered by range or target strength criteria.

Figure 14.-Target strength distributions of early-run upstream and downstream fish, on the left and right banks, Kenai River, 1998.



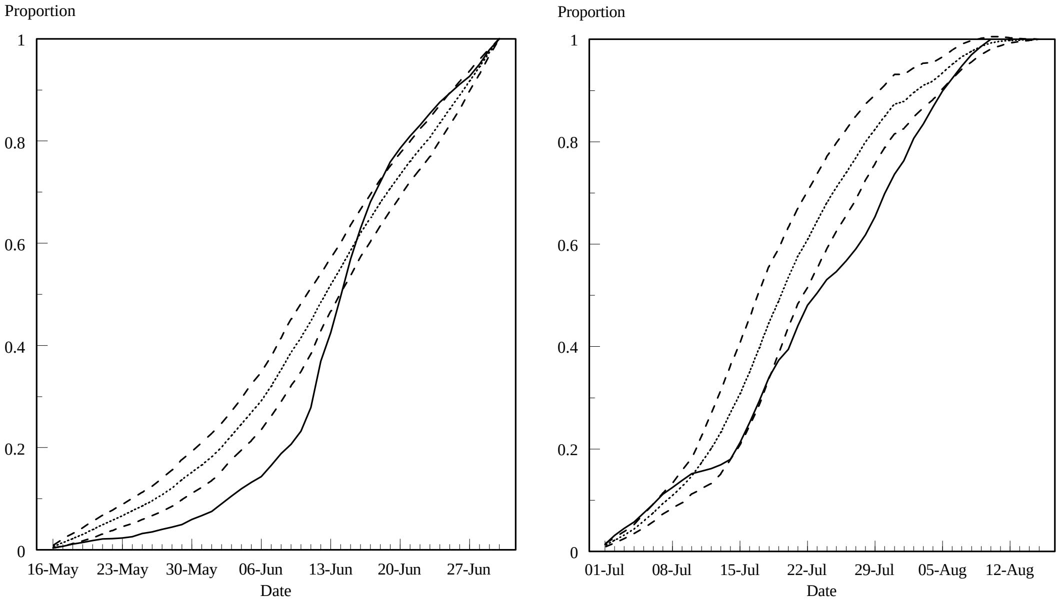
Note: Data have not been filtered by range or target strength criteria.

Figure 15.-Target strength distributions of late-run upstream and downstream fish on the left and right banks, Kenai River, 1998.



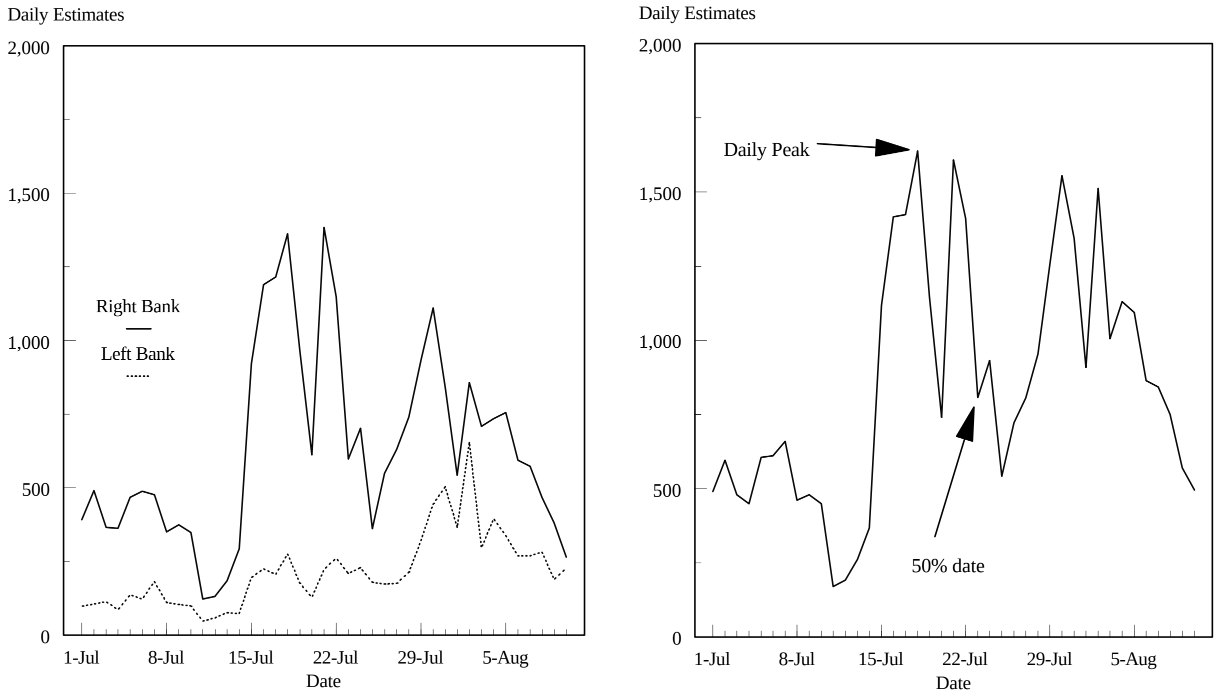
Note: Estimates by bank (left) and total run (right).

Figure 16.-Daily sonar estimates of passage for the early run of chinook salmon returning to the Kenai River, 1998.



Note: Mean migratory-timing curves for the years 1987-1998 (dotted lines), and 95% confidence intervals (dashed lines) are presented for comparison.

Figure 17.-Migratory-timing curves for early (left) and late (right) runs of chinook salmon to the Kenai River, 1998 (solid lines).



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

Figure 18.-Daily sonar estimates of passage for the late run of chinook salmon returning to the Kenai River, 1998.

Upstream Passage

Upstream chinook salmon passage from 7 May through 10 August was estimated at 47,981 (SE = 550) fish, 13,103 (SE = 230) during the early run and 34,878 (SE = 500) during the late run (Table 12, Table 13).

DISCUSSION

EARLY START OF FIELD OPERATIONS

Sonar operations were started on 7 May, 9 days earlier than the conventional startup date of 16 May. Operations were started earlier to address concerns by anglers that we may be missing a significant portion the early run entering the river prior to 16 May. If a large number of fish were being missed on the front end of the run, fishing guides in particular were concerned that we may be closing the fishery unnecessarily in years of low abundance.

Only 187 fish or 1.4 % of the total early run were counted prior to May 16 and only 1,051 fish or 8.0% of the total early run were counted prior to 1 June (Table 12, Appendix F). The chinook fishery was restricted on 5 June despite adding the 9 days of additional escapement to the total early-run estimate. This is a typical pattern in the majority of years in which closures to the early-run chinook fishery occurred. Weak performance of the early run in May is often indicative of a weak run overall (Table 14, Appendix E).

Table 12.-Estimated daily upstream passage of chinook salmon, Kenai River sonar, early run, 1998.

Date	Left Bank	Right Bank	Daily Total	Cumulative Total
7-May	3	3	6	6
8-May	9	9	18	24
9-May	0	3	3	27
10-May	0	3	3	30
11-May	3	9	12	42
12-May	3	9	12	54
13-May	15	12	27	81
14-May	30	13	43	124
15-May	36	27	63	187
16-May	33	15	48	235
17-May	21	24	45	280
18-May	33	24	57	337
19-May	24	12	36	373
20-May	33	21	54	427
21-May	12	21	33	460
22-May	3	12	15	475
23-May	9	3	12	487
24-May	15	18	33	520
25-May	29	52	81	600
26-May	21	22	43	643
27-May	30	30	60	703
28-May	24	39	63	766
29-May	27	36	63	829
30-May	99	30	129	958
31-May	72	21	93	1,051
1-Jun	63	48	111	1,162
2-Jun	78	111	189	1,351
3-Jun	114	78	192	1,543
4-Jun	99	87	186	1,729
5-Jun	69	93	162	1,891
6-Jun	84	66	150	2,041
7-Jun	184	99	283	2,324
8-Jun	168	132	300	2,624
9-Jun	132	102	234	2,858
10-Jun	126	201	327	3,185
11-Jun	204	396	600	3,785
12-Jun	321	847	1,168	4,953
13-Jun	184	535	719	5,672
14-Jun	126	786	912	6,584
15-Jun	117	834	951	7,535
16-Jun	132	638	770	8,305
17-Jun	96	579	675	8,980
18-Jun	24	474	498	9,478
19-Jun	84	426	510	9,988
20-Jun	30	321	351	10,339
21-Jun	60	249	309	10,648
22-Jun	30	243	273	10,921
23-Jun	18	276	294	11,215
24-Jun	18	270	288	11,503
25-Jun	30	198	228	11,731
26-Jun	9	210	219	11,950
27-Jun	12	195	207	12,157
28-Jun	48	260	308	12,464
29-Jun	72	291	363	12,827
30-Jun	57	219	276	13,103
Total	3,371 (25.7%)	9,732 (74.3%)	13,103	

Table 13.-Estimated daily upstream passage of chinook salmon, Kenai River sonar, late run, 1998.

Date	Left Bank	Right Bank	Daily Total	Cumulative Total
1-Jul	99	392	491	491
2-Jul	106	491	597	1,088
3-Jul	114	366	480	1,568
4-Jul	87	363	450	2,018
5-Jul	138	468	606	2,624
6-Jul	123	489	612	3,236
7-Jul	183	477	660	3,896
8-Jul	111	351	462	4,358
9-Jul	105	375	480	4,838
10-Jul	100	349	450	5,287
11-Jul	48	124	171	5,459
12-Jul	60	132	192	5,651
13-Jul	77	185	262	5,912
14-Jul	74	294	368	6,280
15-Jul	196	922	1,118	7,398
16-Jul	226	1,190	1,416	8,814
17-Jul	207	1,216	1,424	10,238
18-Jul	276	1,362	1,638	11,876
19-Jul	177	969	1,146	13,022
20-Jul	129	612	741	13,763
21-Jul	224	1,384	1,608	15,370
22-Jul	262	1,149	1,411	16,781
23-Jul	210	598	808	17,590
24-Jul	230	703	933	18,523
25-Jul	180	362	542	19,065
26-Jul	174	549	723	19,788
27-Jul	176	631	807	20,595
28-Jul	214	740	954	21,549
29-Jul	321	934	1,255	22,803
30-Jul	445	1,111	1,556	24,360
31-Jul	504	840	1,344	25,704
1-Aug	366	543	909	26,613
2-Aug	654	858	1,512	28,125
3-Aug	297	709	1,006	29,130
4-Aug	396	735	1,131	30,261
5-Aug	338	756	1,094	31,355
6-Aug	270	594	864	32,219
7-Aug	270	573	843	33,062
8-Aug	282	468	750	33,812
9-Aug	189	381	570	34,382
10-Aug	230	266	496	34,878
Total	8,867 (25.4%)	26,011 (74.6%)	34,878	

Five of the last 11 early-run chinook fisheries (1990, 1991, 1992, 1997, and 1998) have been restricted to catch-and-release. In most years when the fishery was restricted (1990, 1991, 1992, and 1998), inriver returns from 16 to 31 May averaged less than 10% of the average early-run inriver return (Table 14). During years when there were no restrictions to the early-run chinook fishery, more than 18% (usually more than 20%) of the average run occurred from 16 to 31 May. The one exception occurred in 1997, another restriction year, when 18.6% of the average early inriver return was estimated from 16 to 31 May.

These data suggest that starting up sonar operations prior to 16 May would not provide the additional escapement necessary to prevent fishery closures in most years. Nor is it possible to start counting efforts much earlier than we did in the 1998 season. Starting sonar operations prior to early May is problematic. River ice conditions typically prevent secure deployment of the sonar transducers earlier than 1 May. At least several days are then required for calibration and testing of sonar equipment prior to starting counting operations.

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 cross-section (Figure 2). The increase in the proportion of right-bank oriented fish during June and July may be a response to the increasing discharge levels that occur over the same period. The proportion of the river cross-section 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 levels were also far below average during each of these runs (Burwen and Bosch 1998, Bosch and Burwen 1999).

Table 14.-Proportion of average total early run estimated prior to 1 June 1987-1998.

Year	May Inriver Estimate	% of Average Early Run Inriver Estimate[a]
1987	Not available	Not available
1988	5,574	33.7
1989	3,900	23.5
1990	1,559	9.4
1991	992	6.0
1992	1,368	8.3
1993	2,979	18.0
1994	4,481	27.1
1995	3,499	21.1
1996	3,387	20.4
1997	3,081	18.6
1998[b]	1,052	6.4

[a] Average early run estimate = 16,563.

[b] The 1998 run estimate started 7 May; all other years started 16 May.

In 1998, fish passage was higher on the right bank during both runs (Table 12, Table 13). Approximately 25% of fish were detected on the left bank and 75% on the right bank during both runs. Discharge levels were slightly below average during May, and above average for most of June and July (USGS 1999).

Vertical Distribution

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 2), it is not possible to insonify the entire cross-sectional area of the river that can potentially be used by migrating chinook salmon. Fish position data suggest that most upstream fish are within the insonified zone. When sockeye are not present in large numbers, most fish prefer the offshore, bottom section of the river where beam coverage is maximized. Although there was a tendency for upstream fish to rise off the bottom during the rising tide stage on both banks during the 1998 early run (Figure 7), relatively few fish occupied the upper half of the beam overall. The tendency to rise off the bottom on rising tides during the early run may be related to relatively low discharge levels that occur in the spring. 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).

Because the vast majority of fish travel close to the river bottom (Figure 6, Figure 8), our greatest concern is missing fish passing under the sonar beam. Relatively few fish were detected below the -2.0^{o} beam angle (Figure 6, Figure 8). Even with the decreased ability to detect targets on the edge of the beam, we believe 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 late-run fish on the right bank only appear to be traveling higher in the water column than fish traveling on the left bank (Figure 8). Because sediments are less reflective on the right bank, we are able to aim the sonar beam closer to the river bottom. This shifts the distribution of bottom-oriented fish upward in the sonar beam and likely increases our ability to detect bottom-oriented fish.

Range Distribution

On the left bank, upstream-moving fish were generally channel-oriented. During the early run, a majority passed the sonar between 25 m and 35 m from the transducer (Figure 10). During the late run, a majority of upstream-moving fish passed between 30 m and 38 m (Figure 12).

On the right bank, the range distribution was bimodal with modes near 30 m and 55 m (Figure 10, Figure 12). It should be noted that the right-bank range distribution is artificially truncated at 25 m, the range threshold for filtering nearshore sockeye salmon. During the late run, nearshore fish within the 25 m range threshold are not tracked due to time constraints. The decline in the right-bank distribution at the far range is also an artifact of moving the transducer closer to shore as the water level rises, causing a corresponding increase in the maximum range.

This bimodal range distribution on the right bank is atypical of range distributions measured prior to 1995. Whether it is the result of the 140-year flood in 1995 or a combination of some other environmental factors, an acoustic structure appears during the late run corresponding to the nearshore mode (30 m). Most likely this ridge or structure is exposed as the deep layer of mud that covers the right bank each spring is washed out as the season progresses. We believe this is an area that is more acoustically reflective and most likely a strip of gravel in an otherwise mud-dominated area (rather than a physical structure) because we do not observe any obvious structure in late-run bottom transects. For unknown reasons, fish appear to favor this region for upstream travel. In future years, we recommend that comprehensive bottom transects be conducted after the structure appears to ensure that there is no evidence of an actual physical ridge (and shadowing effects). It would also be instructive to determine whether there is any velocity gradient associated with this section of the river that might be impacting fish behavior.

One question that has been raised is whether the nearshore mode could represent an area of high sockeye salmon passage. We do not believe so for reasons discussed below.

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 *In prep*) 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.

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%, while the downstream component of the late run has been consistently below 5% (Burwen and Bosch 1996, 1998; Bosch and Burwen 1999). While the downstream component of the early run (6.1%) was relatively low by comparison, the downstream component of the 1998 late run (13.6%) was the highest recorded. High levels of downstream activity in late July and August heavily influenced the overall proportion of downstream targets observed during the late run. The late-run downstream component was estimated at only 6.0% before 29 July, but increased to 23.7% thereafter (Table 15). There are several potential explanations for this. First, it was near the end of the entire chinook run, and one could expect a certain number of dead and dying spawned out chinook salmon to be washed downstream. Mainstem spawning in the area could also explain a high level of milling and downstream activity. Finally, 1998 is an on-cycle year for Kenai River pink salmon. Sonar operations have been terminated several days early in past years in response to high levels of milling and spawning activity of pink salmon in the acoustic beam (Burwen and Bosch 1998).

Table 15.-Upstream and downstream proportions of late-run targets in two temporal strata, 1 July to 28 July, and 29 July to 10 August 1998.

Dates	Downstream Chinook	Upstream Chinook	Total	Percent Downstream	Percent Upstream
1 July - 28 July	1,372	21,549	22,921	6.0	94.0
29 July - 10 August	4,133	13,329	17,462	23.7	76.3
Total	5,505	34,878	40,383	13.6	86.4

Target strength differed little between upstream and downstream targets, suggesting that most downstream targets on both banks were correctly classified as fish, especially during the late run (Table 11, Figure 15). Target strength distributions for upstream and downstream fish were statistically different during the early run, but the differences were less than 1 dB (Table 11, Figure 14).

COMPARISON OF SONAR ESTIMATES WITH OTHER INDICES

The Kenai River chinook sonar program has evolved such that we no longer assume the sonar generates inriver abundance estimates of chinook salmon equally well under all conditions. Recent research efforts have focused on identifying conditions when the sonar estimates may not accurately index chinook salmon abundance. Our foremost concern is that the sonar may mistake substantial numbers of sockeye as chinook. Radiotelemetry projects were implemented in 1996 and 1997 to estimate the magnitude of bias introduced during periods of high sockeye passage. Late-run sonar estimates in 1996 and 1997 were both estimated to be 21% higher than the telemetry estimates (Hammarstrom and Hasbrouck 1998, 1999).

Early Run

Several lines of evidence indicate that daily right-bank sonar estimates during the early run (Table 12) may be inflated by sockeye salmon starting on approximately 3 June and continuing through at least 16 June. Sockeye were caught in relatively large numbers by inriver netting crews starting on 3 June and continuing through 16 June (Table 16, Figure 19). Mean daily pulse width (right bank) started decreasing rapidly in early June and did not recover until 16-17 June and continued increasing until 25 June (Figure 20). Mean daily pulse width did not fall substantially again until early August. The right-bank range distribution of early-run targets also started changing on 7 June with a distinct nearshore mode emerging between 0 and 22 m from the transducer (Figure 21). The ratio of left to right bank estimates also dropped precipitously from 8 June to 15 June (Figure 22). The changes in range distribution and left-to-right bank ratio are less conclusive, however, because they also correspond with a dramatic rise in water discharge between 1 June and 12 June (Figure 23).

A clear relationship between inriver net CPUE and sonar estimates (Figure 24) could not be established throughout the early run for several reasons. The goal of the netting crews in May and June was to establish the optimal fishing area for generating standardized CPUE data to be used during the late run. Consequently, netting crews were not consistently fishing the same

Table 16.-Catch by date and species in the Kenai River inriver netting program, early run (15 May–30 June), 1998.

Date	Chinook	Sockeye
15 May	2	0
16 May	2	0
17 May	1	0
18 May	9	0
19 May	3	1
20 May	4	0
21 May		
22 May		
23 May	5	0
24 May	1	0
25 May	1	0
26 May		
27 May		
28 May	10	4
29 May	25	2
30 May	16	5
31 May	15	0
1 June	11	3
2 June	11	5
3 June	10	18
4 June	10	5
5 June		
6 June		
7 June	18	10
8 June	20	11
9 June		
10 June		
11 June	28	8
12 June	8	10
13 June	9	8
14 June	30	17
15 June	24	4
16 June	15	12
17 June		
18 June		
19 June	2	3
20 June	3	5
21 June	4	3
22 June	6	4
23 June	5	2
24 June	1	8
25 June		
26 June		
27 June	14	5
28 June	9	9
29 June	6	1
30 June	9	2
Total	347	165

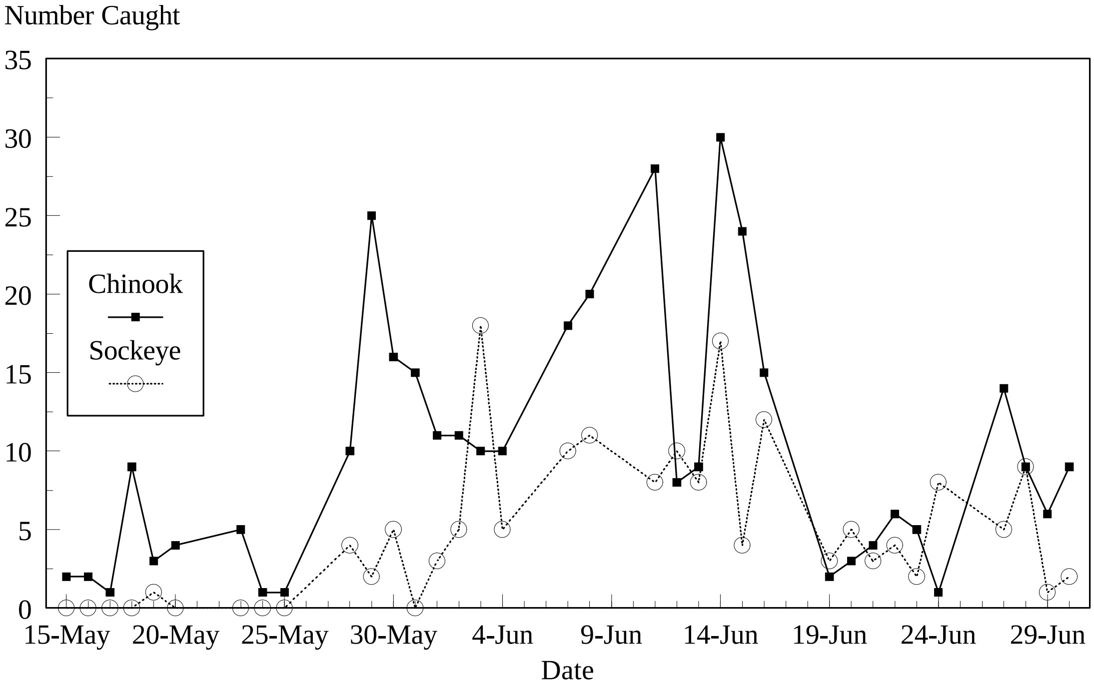


Figure 19.-Daily catch of inriver netting crews, by species, 7 May–30 June 1998.

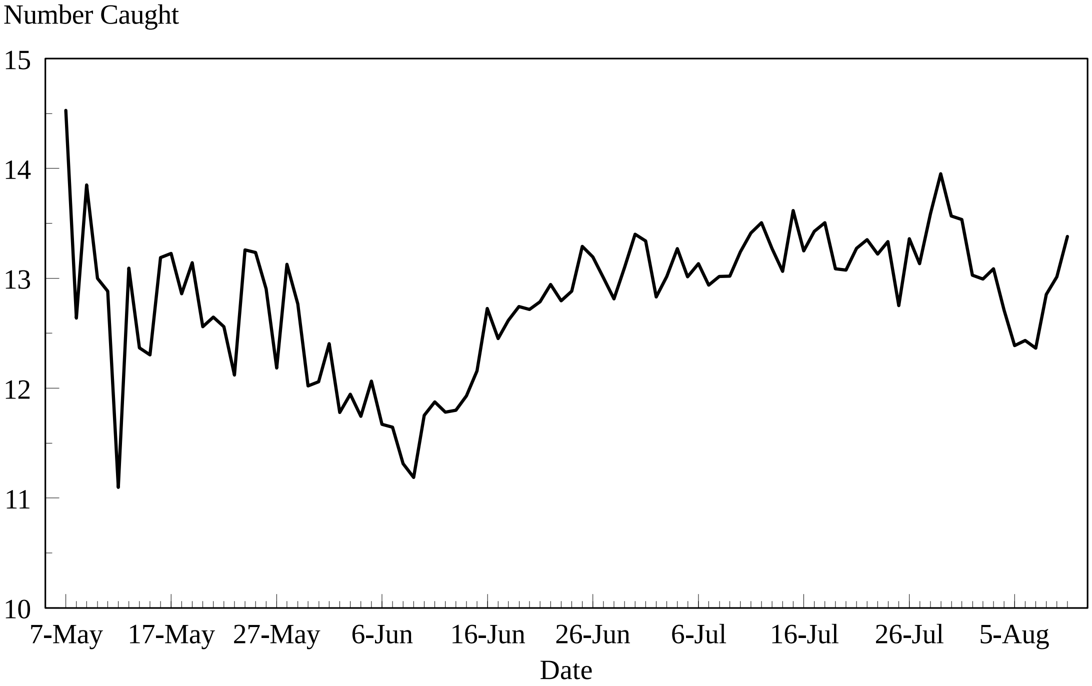


Figure 20.-Daily right-bank mean pulse width (measured at –12 dB down from peak amplitude), 7 May to 10 August 1998.

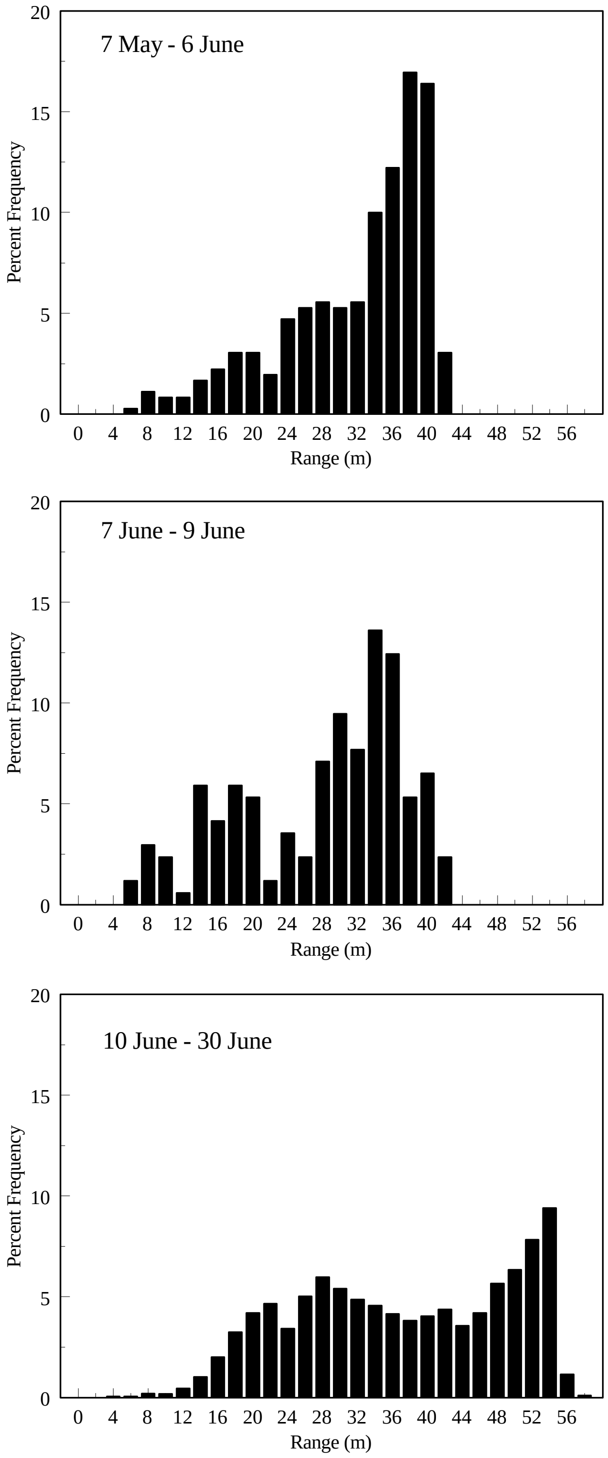


Figure 21.-Right bank range distributions in early June prior to periods of high sockeye abundance, from 7-9 June with sockeye abundance increasing, and from 10-30 June after moving transducer 15 m inshore.

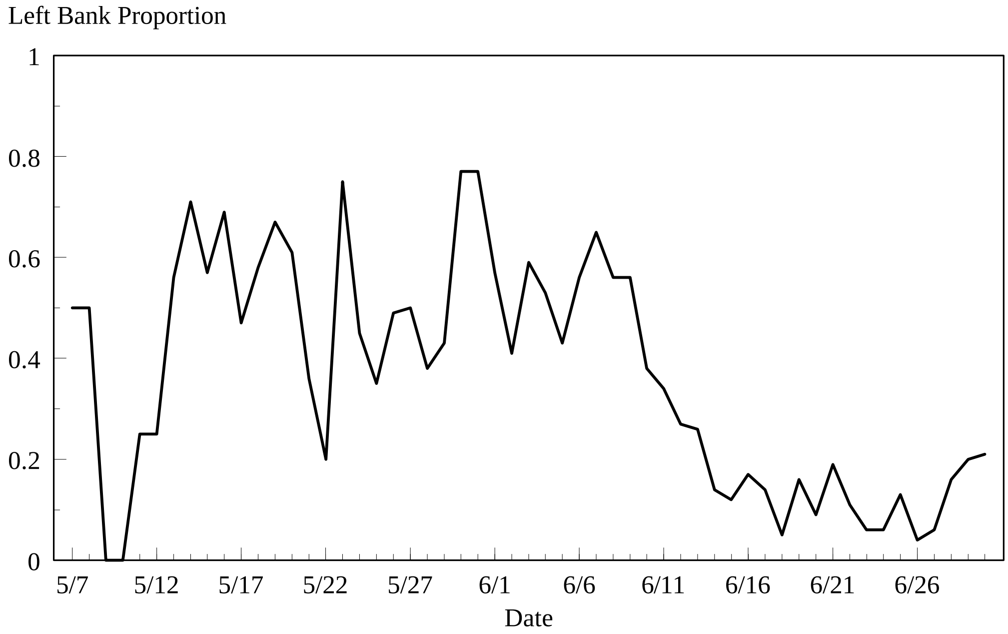


Figure 22.-Left bank proportion of total daily estimate, early run (7 May–30 June), 1998.

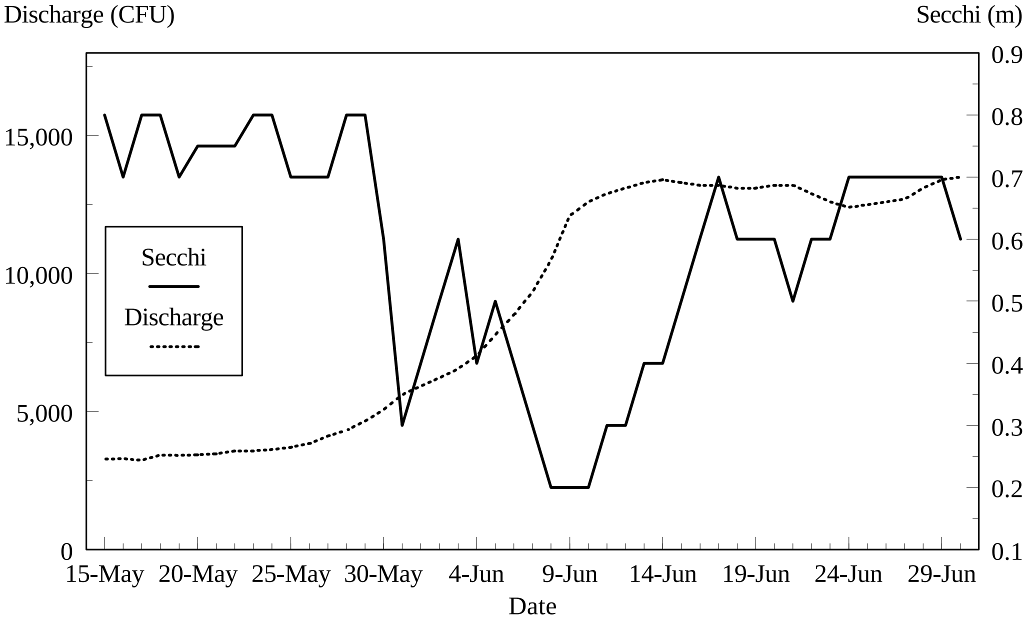


Figure 23.-Daily Secchi depth readings (in front of sonar site) and discharge rates (Soldotna Bridge) for lower Kenai River, early run (7 May–30 June), 1998.

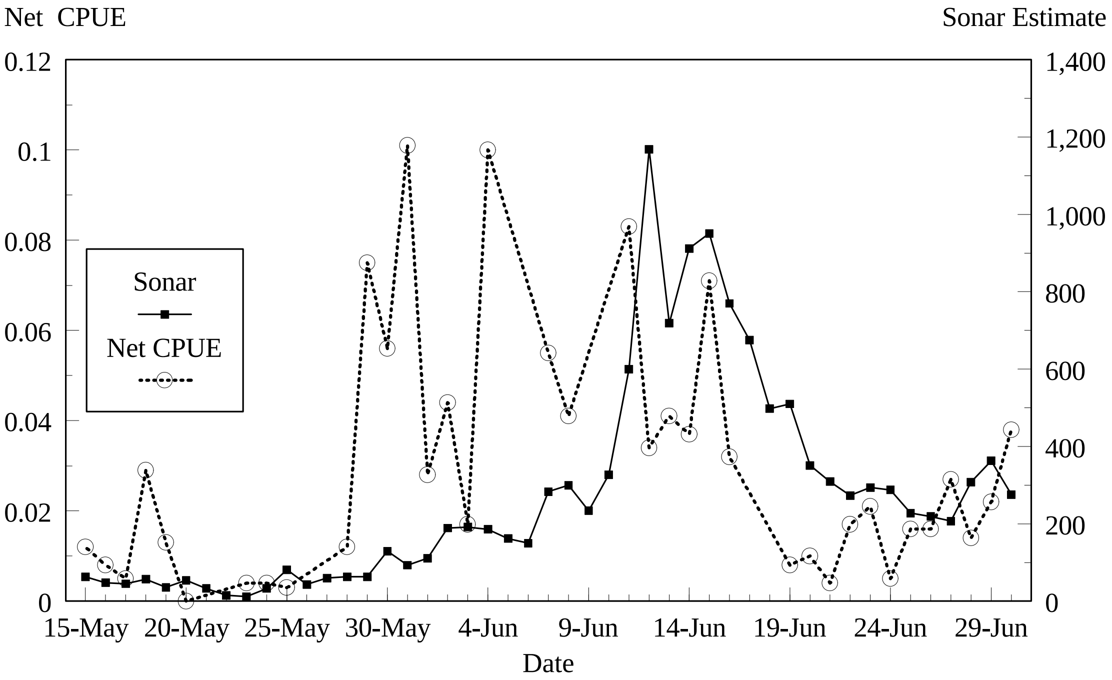


Figure 24.-Daily sonar estimates with inriver net CPUE, early run (7 May–30 June), 1998.

sites nor were they fishing every day as they were in the late run. Additionally, both discharge rates and water clarity were highly variable during the early run (Figure 23) adding additional noise to the CPUE data.

Evidence of high sockeye abundance during the early run caught us by surprise, and we were unable to implement an adjustment based on netting CPUE because of the reasons described above. We did attempt three ad hoc adjustments, none of which were entirely satisfactory. The first, motivated by the change in range distribution coincident with the apparent influx of sockeye salmon, discarded fish within 40 m of the transducer after 9 June (Figure 21). A 40-m range threshold may be defensible because the right bank transducer was moved approximately 15 m closer to shore on 10 June. This adjustment yields an estimate of 9,184 fish for the early run, approximately 30% less than the unadjusted estimate (Table 17, Appendix C1). Of course some chinook salmon would be excluded by a 40-m range threshold also. The estimate would be overly conservative if the number of chinook salmon within 40 m was relatively high.

The second adjustment exploited the relationship between left- and right-bank counts before 3 June to estimate right bank counts from 3 to 30 June. As discussed previously, we believe that the left-bank estimates are rarely inflated by sockeye salmon. The ratio estimate was 6,311 early-run chinook salmon, 52% fewer than unadjusted estimate (Table 17). This estimate is probably conservative because the ratio of right- to left bank counts generally increases with rising water levels. In 1998, water level rose rapidly in early June and did not stabilize until 15 June. The ratio estimate was based on data collected prior to the rise in water level.

Table 17.-Comparison of chinook salmon passage estimates using a 40 m range threshold, using the left bank estimate to expand for the right-bank estimate during the period of high sockeye passage, and using the 21% bias estimated by the radiotelemetry study in 1996 and 1997.

Date	Sonar Both Banks	40 m threshold	Left Bank Expansion	21% Estimated Bias
7 May	6	6	6	5
8 May	18	18	18	14
9 May	3	3	3	2
10 May	3	3	3	2
11 May	12	12	12	10
12 May	12	12	12	10
13 May	27	27	27	21
14 May	43	43	43	34
15 May	63	63	63	50
16 May	48	48	48	38
17 May	45	45	45	36
18 May	57	57	57	45
19 May	36	36	36	29
20 May	54	54	54	43
21 May	33	33	33	26
22 May	15	15	15	12
23 May	12	12	12	10
24 May	33	33	33	26
25 May	81	81	81	64
26 May	43	43	43	34
27 May	60	60	60	48
28 May	63	63	63	50
29 May	63	63	63	50
30 May	129	129	129	102
31 May	93	93	93	74
1 June	111	111	111	88
2 June	189	189	189	150
3 June	192	192	192	152
4 June	186	186	186	148
5 June	162	162	162	129
6 June	150	150	150	119
7 June	283	283	343	225
8 June	300	300	314	238
9 June	234	234	247	186
10 June	327	162	235	260
11 June	600	408	382	476
12 June	1,168	779	601	927
13 June	719	510	344	571
14 June	912	630	236	724
15 June	951	585	219	755
16 June	770	455	247	611
17 June	675	414	180	536
18 June	498	252	45	395
19 June	510	303	157	405
20 June	351	168	56	279
21 June	309	183	112	245
22 June	273	165	56	217
23 June	294	156	34	233
24 June	288	183	34	229
25 June	228	138	56	181
26 June	219	135	17	174
27 June	207	123	22	164
28 June	308	189	90	245
29 June	363	222	135	288
30 June	276	165	107	219
Total	13,103	9,184	6,311	10,405

The third adjustment simply assumed a 21% bias as determined by the radiotelemetry studies conducted in 1996 and 1997. This yields an adjusted estimate of 10,405 early-run chinook salmon (Table 17).

It is our hope that in the future, as we continue to refine and standardize the inriver netting, we will develop a more objective method for identifying and correcting for sockeye inflation.

Late Run

Although the right-bank range distribution for the late run (Figure 25) was atypical of most years when sockeye salmon contamination is not a concern, other indices such as the inriver net CPUE, sport fish CPUE, mean daily pulse width and mean daily target strength do not indicate high levels of inflation of chinook estimates by sockeye salmon.

Unlike the early run, water clarity and discharge remained relatively stable during the late run (Figure 26) leading to greater confidence in inriver net CPUE data. Daily sonar estimates and inriver net CPUE tracked well on all but a few days (Figure 27) and cumulative curves show almost identical run timing (Figure 28). Reasonably good correlation with the sport fishery catch rates was also observed (Figure 29). On the right bank, mean daily pulse width (Figure 20) and left/right bank ratios (Figure 30) remained relatively stable throughout the run despite large influxes of sockeye in late July and early August. There was also no obvious correlation with sockeye sonar estimates lagged 1 day (Figure 31). Although netting crews did pick up sockeye (Table 18, Figure 32), daily catches in the late run were lower than those of the early run and smaller proportional to the chinook catch.

OUTLOOK FOR FUTURE IMPROVEMENTS IN SONAR ACCURACY

Exclusive use of acoustics to precisely discriminate fish species is not possible at this time. We are currently pursuing two options to increase the accuracy of chinook sonar estimates by improving our ability to discriminate larger chinook salmon from other smaller species. First, we are investigating an alternate site 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. Second, we are continuing experiments to develop alternate or additional acoustic parameters to aid in discriminating species.

Exploration for alternate sites began in October 1998 and will continue through 1999. The search will focus on areas below Honeymoon Cove (river mile 13) and above Eagle rock (river mile 12) (Figure 1). This portion of the river is above the limits of extreme tidal influence but still below the majority of mainstem spawning during the late run (Bendock and Alexandersdottir 1992).

We continue to pursue improved techniques for separating chinook and sockeye salmon using acoustic information. Results of a tethered fish study indicated that pulse width may provide higher discriminatory power than target strength for separating sockeye and chinook salmon (Burwen and Fleischman 1998). The feasibility of using pulse width as an additional species discriminator at the Kenai River site is still being investigated. Additional studies exploring the use of multifrequency sonar to discriminate fish species were implemented during the 1998 season and the results of this study will be forthcoming. We are also making significant progress in our ability to correct for threshold and noise-related bias in target strength estimates

(Fleischman and Burwen *In prep*) which will improve the utility of target strength for classifying acoustic targets.

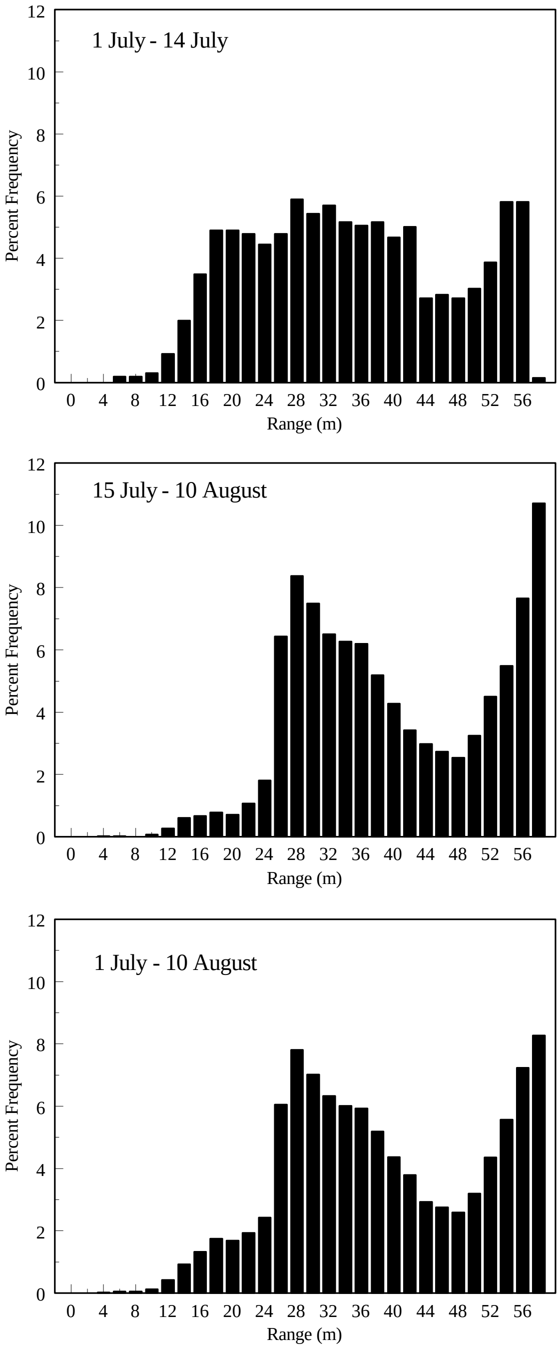


Figure 25.-Right bank range distributions prior to periods of high sockeye abundance (1 July-14 July), periods of high sockeye abundance (15 July to 10 August), and for the entire late run, 1 July to 10 August.

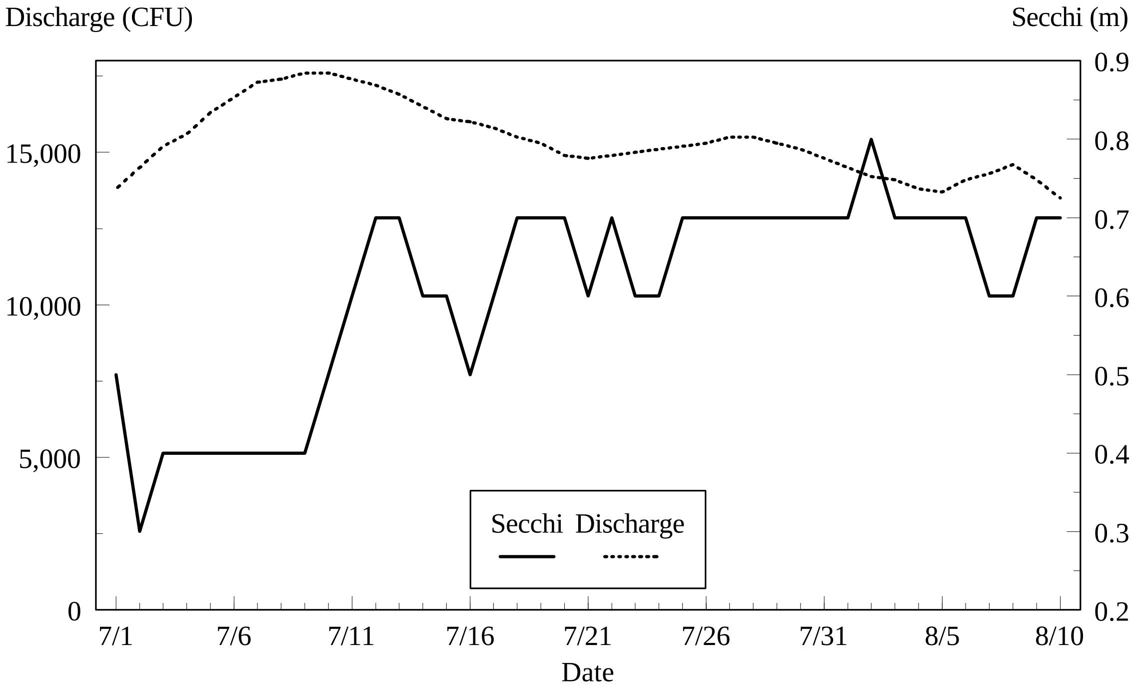


Figure 26.-Daily Secchi depth readings (in front of sonar site) and discharge rates (Soldotna Bridge) for lower Kenai River, late run (1 July–10 August), 1998.

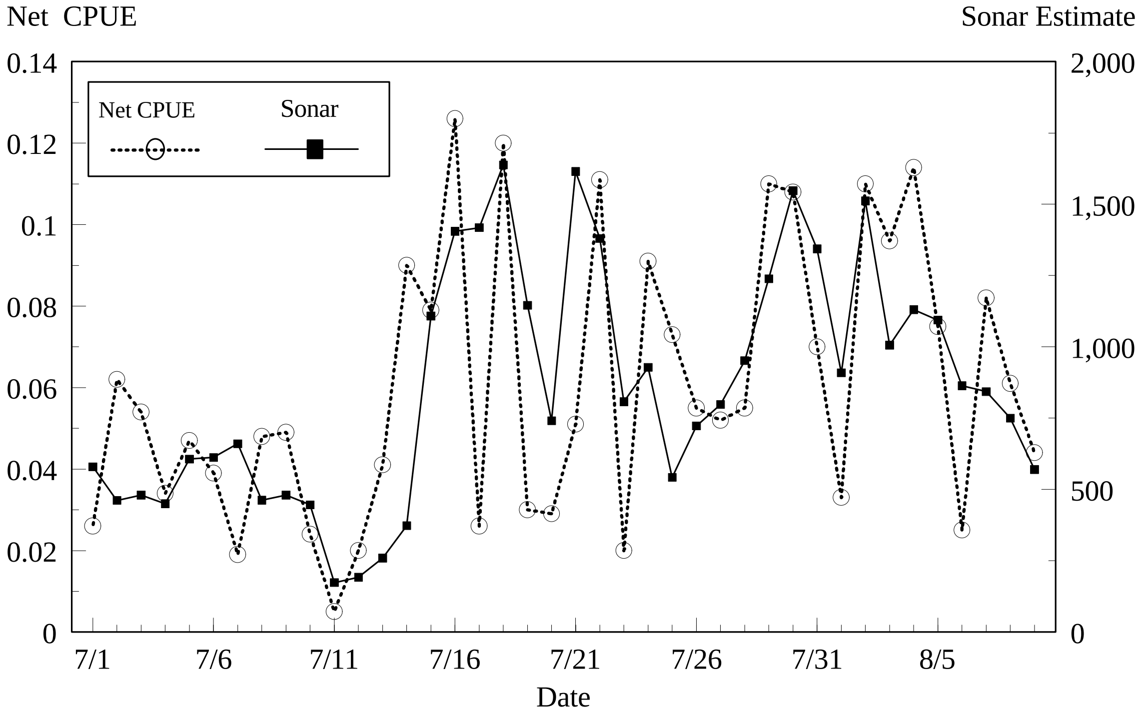


Figure 27.-Daily sonar estimates with inriver net CPUE, late run (1 July–10 August), 1998.

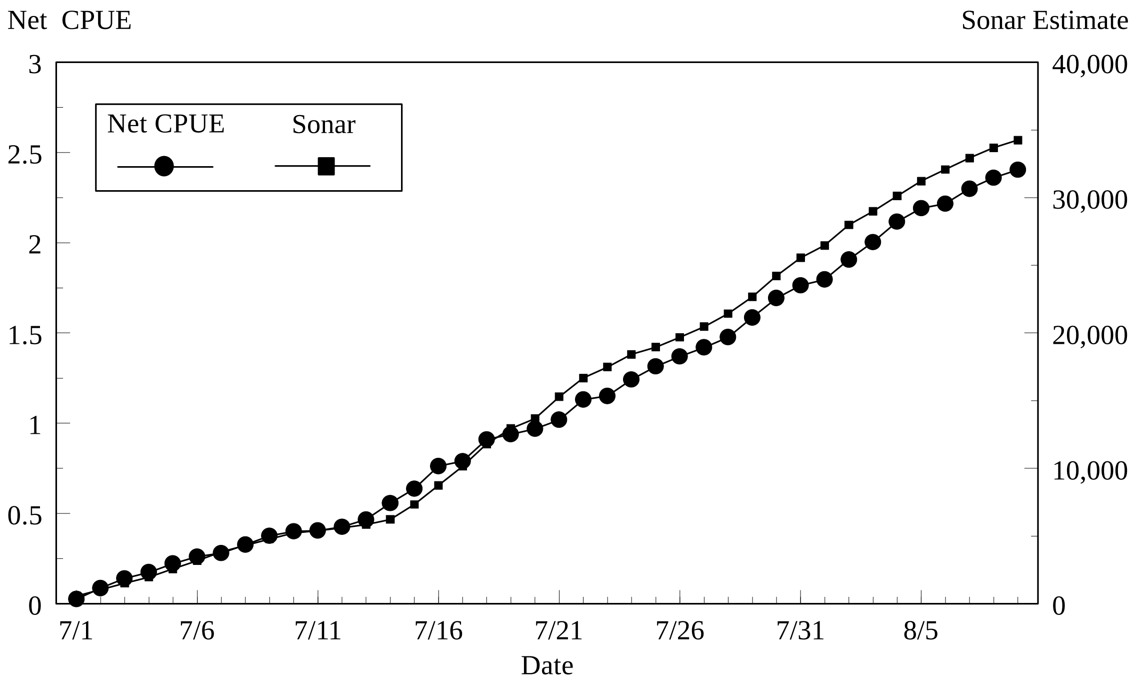


Figure 28.-Cumulative sonar estimates with cumulative inriver net CPUE, late run (1 July–10 August), 1998.

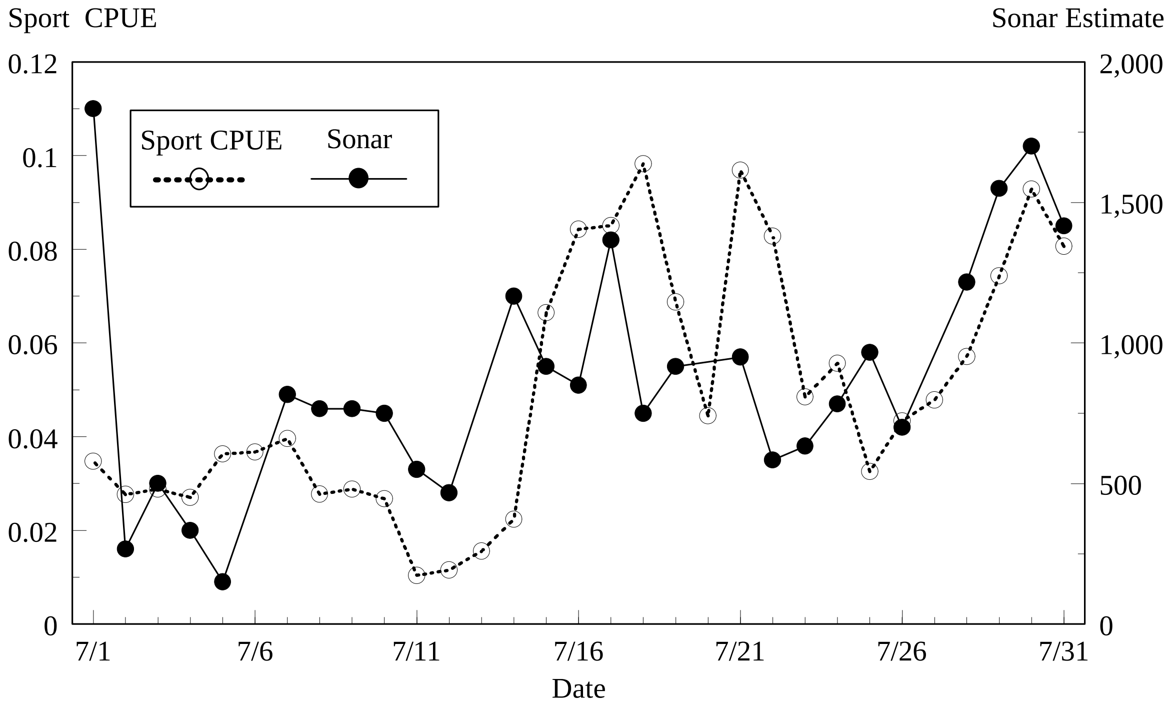


Figure 29.-Daily sonar estimates with sport fish CPUE, late run (1 July–10 August), 1998.

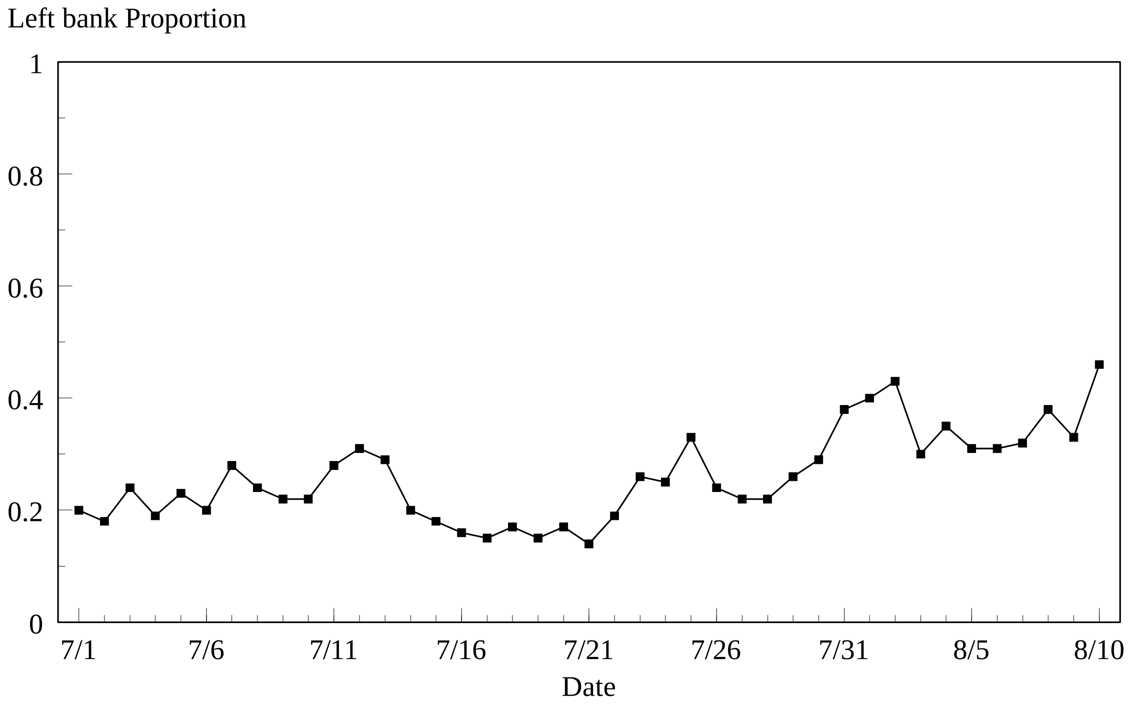


Figure 30.-Left bank proportion of total daily estimate, late run (1 July–10 August), 1998.

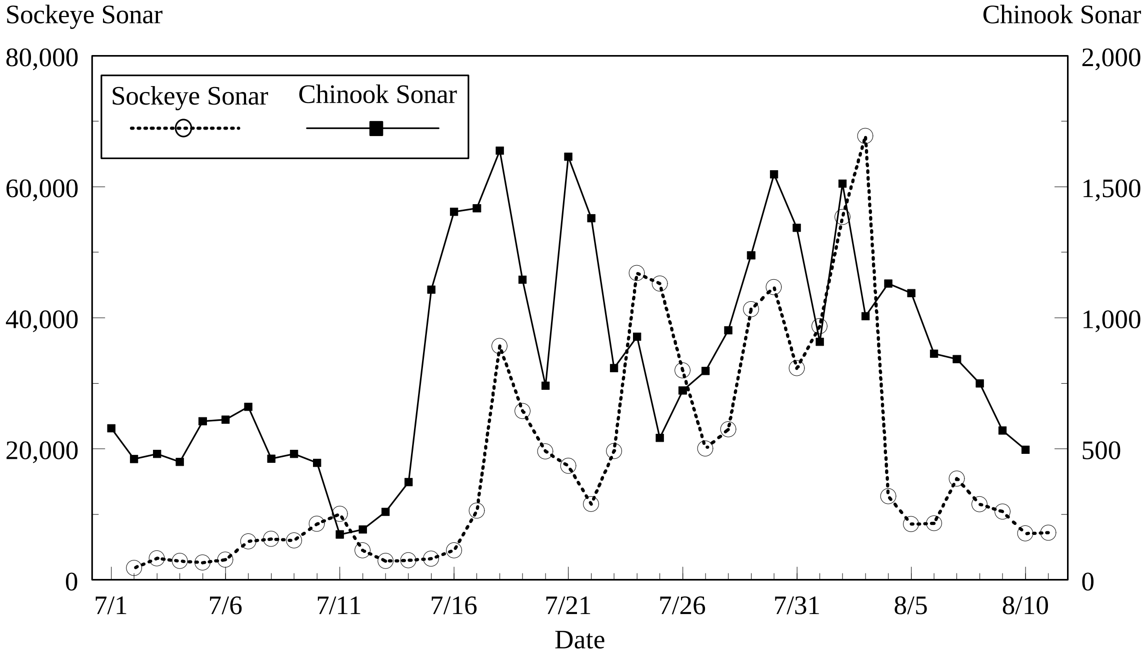


Figure 31.-Daily chinook sonar estimates with river mile 19 sockeye sonar estimates lagged 1 day, late run (1 July–10 August), 1998.

Table 18.-Catch by date and species in the Kenai River inriver netting program, late run (1 July–9 August), 1998

Date	Chinook	Sockeye	Coho	Pinks
1 July	6	6	0	0
2 July	8	3	0	0
3 July	12	4	0	0
4 July	7	5	0	0
5 July	10	10	0	0
6 July	7	3	0	0
7 July	4	5	0	2
8 July	10	6	0	0
9 July	10	7	0	0
10 July	4	1	0	0
11 July	1	1	0	0
12 July	5	1	0	0
13 July	7	2	0	0
14 July	17	1	0	0
15 July	30	9	0	0
16 July	13	12	0	0
17 July	5	14	0	0
18 July	18	5	0	0
19 July	7	7	0	0
20 July	7	7	0	0
21 July	10	7	0	0
22 July	14	15	0	0
23 July	4	6	0	1
24 July	11	3	1	0
25 July	0	0	0	0
26 July	11	0	0	0
27 July	10	6	0	0
28 July	10	5	1	0
29 July	18	6	1	0
30 July	17	1	1	0
31 July	14	6	2	1
1 August	7	13	2	4
2 August	35	2	4	8
3 August	17	0	1	10
4 August	20	0	0	13
5 August	14	1	3	27
6 August	5	3	0	39
7 August	11	1	2	6
8 August	10	3	1	13
9 August	4	0	0	1
10 August	0	0	0	0
Total	430	187	19	125

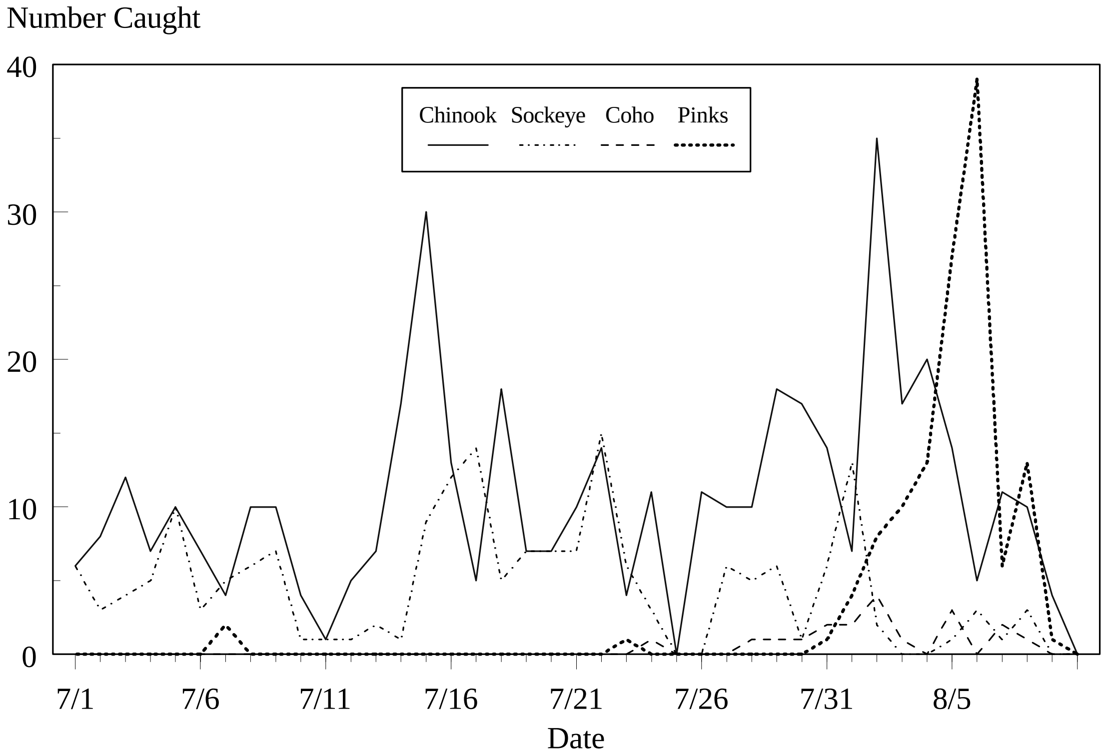


Figure 32.-Daily catch of inriver netting crews by species, 1 July–10 August 1998.

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

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APPENDIX A. TARGET STRENGTH ESTIMATION

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

Target strength, 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

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

* Start Processing at Port 1 -FILE_PARAMETERS-

* 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	220.7900	sl - transducer source level
202	-1	-171.3700	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	60.0000	echogram stop range in meters
211	-1	662.0000	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	75.0000	range plot maximum in meters
217	-1	-2.5000	min_angoff_v - minimum angle off axis vertical
218	-1	2.0000	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	-8.0584	ux - horizontal electrical to mechanical angle ratio
223	-1	-16.0900	uy - vertical electrical to mechanical angle ratio
224	-1	0.0000	ud_coef_a - a coeff. for up-down beam pattern eq.
225	-1	-0.0004	ud_coef_b - b coeff. for up-down beam pattern eq.
226	-1	-2.4845	ud_coef_c - c coeff. for up-down beam pattern eq.
227	-1	0.0167	ud_coef_d - d coeff. for up-down beam pattern eq.
228	-1	-0.1857	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	-0.0002	lr_coef_b - b coeff. for left-rt beam pattern eq.
231	-1	-0.2137	lr_coef_c - c coeff . for left-rt beam pattern eq.
232	-1	0.0005	lr_coef_d - d coeff. for left-rt beam pattern eq.
233	-1	-0.0001	lr_coef_e - ecoeff. for left-rt beam pattern eq.
234	-1	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	55.2000	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	662.0000	th_val[0] - thr. for 1st layer (mV)
402	1	622.0000	th_val[1] - thr. for 2nd layer (mV)
402	2	662.0000	th_val[2] - thr. for 3rd layer (mV)
402	3	662.0000	th_val[3] - thr. for 4th layer (mV)
402	4	662.0000	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-TESTER	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-

* 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	218.29000	sl - transducer source level
202	-1	-172.9700	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	40.0000	echogram stop range in meters
211	-1	413.0000	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	-22.0000	max_dB_off - maximum angle off in dB
222	-1	-8.0200	ux - horizontal electrical to mechanical angle ratio
223	-1	-30.3560	uy - vertical electrical to mechanical angle ratio
224	-1	0.0000	ud_coef_a - a coeff. for up-down beam pattern eq.
225	-1	0.0099	ud_coef_b - b coeff. for up-down beam pattern eq.
226	-1	-2.8163	ud_coef_c - c coeff. for up-down beam pattern eq.
227	-1	-0.1756	ud_coef_d - d coeff. for up-down beam pattern eq.
228	-1	-0.1573	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	-0.2141	lr_coef_c - c coeff . for left-rt beam pattern eq.
232	-1	0.0000	lr_coef_d - d coeff. for left-rt beam pattern eq.
233	-1	-0.0001	lr_coef_e - ecoeff. for left-rt beam pattern eq.
234	-1	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	37.8000	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	15.0000	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	413.0000	th_val[0] - thr. for 1st layer (mV)
402	1	413.0000	th_val[1] - thr. for 2nd layer (mV)
402	2	413.0000	th_val[2] - thr. for 3rd layer (mV)
402	3	413.0000	th_val[3] - thr. for 4th layer (mV)
402	4	413.0000	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-TESTER	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. DAILY PROPORTIONS OF UPSTREAM AND DOWNSTREAM FISH FOR THE 1998 EARLY AND LATE KENAI RIVER CHINOOK SALMON RUNS

Appendix C1.-Daily proportions of upstream and downstream fish for the 1998 Kenai River early chinook run.

Date	Downstream Count	Upstream Count	Daily Total	% Downstream	% Upstream
7 May	0	6	6	0.0	100.0
8 May	6	18	24	25.0	75.0
9 May	3	3	6	50.0	50.0
10 May	3	3	6	50.0	50.0
11 May	0	12	12	0.0	100.0
12 May	9	12	21	42.9	57.1
13 May	3	27	30	10.0	90.0
14 May	6	43	49	12.4	87.6
15 May	3	63	66	4.5	95.5
16 May	6	48	54	11.1	88.9
17 May	6	45	51	11.8	88.2
18 May	15	57	72	20.8	79.2
19 May	9	36	45	20.0	80.0
20 May	9	54	63	14.3	85.7
21 May	6	33	39	15.4	84.6
22 May	0	15	15	0.0	100.0
23 May	3	12	15	20.0	80.0
24 May	3	33	36	8.3	91.7
25 May	10	81	91	10.9	89.1
26 May	12	43	55	21.8	78.2
27 May	3	60	63	4.8	95.2
28 May	9	63	72	12.5	87.5
29 May	12	63	75	16.0	84.0
30 May	18	129	147	12.2	87.8
31 May	6	93	99	6.1	93.9
1 June	18	111	129	14.0	86.0
2 June	12	189	201	6.0	94.0
3 June	9	192	201	4.5	95.5
4 June	6	186	192	3.1	96.9
5 June	12	162	174	6.9	93.1
6 June	18	150	168	10.7	89.3
7 June	39	283	322	12.1	87.9
8 June	39	300	339	11.5	88.5
9 June	24	234	258	9.3	90.7
10 June	59	327	386	15.3	84.7
11 June	39	600	639	6.1	93.9
12 June	32	1,168	1,200	2.7	97.3
13 June	21	719	740	2.9	97.1
14 June	9	912	921	1.0	99.0
15 June	30	951	981	3.1	96.9
16 June	27	770	797	3.4	96.6
17 June	33	675	708	4.7	95.3
18 June	36	498	534	6.7	93.3
19 June	42	510	552	7.6	92.4
20 June	24	351	375	6.4	93.6
21 June	30	309	339	8.8	91.2
22 June	6	273	279	2.2	97.8
23 June	15	294	309	4.9	95.1
24-Jun	27	288	315	8.6	91.4
25-Jun	18	228	246	7.3	92.7
26-Jun	15	219	234	6.4	93.6
27-Jun	9	207	216	4.2	95.8
28-Jun	15	308	323	4.7	95.3
29-Jun	9	363	372	2.4	97.6
30-Jun	15	276	291	5.2	94.8
Total	848	13,103	13,951	6.1	93.9

Appendix C2.-Daily proportions of upstream and downstream fish for the 1998 Kenai River late chinook run.

Date	Downstream Count	Upstream Count	Daily Total	% Downstream	% Upstream
1 July	25	491	516	4.9	95.1
2 July	65	597	662	9.8	90.2
3 July	63	480	543	11.6	88.4
4 July	30	450	480	6.3	93.8
5 July	42	606	648	6.5	93.5
6 July	33	612	645	5.1	94.9
7 July	36	660	696	5.2	94.8
8 July	42	462	504	8.3	91.7
9 July	21	480	501	4.2	95.8
10 July	18	450	468	3.8	96.2
11 July	3	171	174	1.7	98.3
12 July	3	192	195	1.5	98.5
13 July	6	262	268	2.2	97.8
14 July	27	368	395	6.9	93.1
15 July	44	1,118	1,162	3.8	96.2
16 July	31	1,416	1,447	2.1	97.9
17 July	51	1,424	1,475	3.5	96.5
18 July	108	1,638	1,746	6.2	93.8
19 July	108	1,146	1,254	8.6	91.4
20 July	30	741	771	3.9	96.1
21 July	98	1,608	1,706	5.7	94.3
22 July	98	1,411	1,509	6.5	93.5
23 July	60	808	868	6.9	93.1
24 July	79	933	1,012	7.8	92.2
25 July	30	542	572	5.2	94.8
26 July	63	723	786	8.0	92.0
27 July	46	807	852	5.4	94.6
28 July	112	954	1,066	10.5	89.5
29 July	210	1,255	1,465	14.4	85.6
30 July	310	1,556	1,867	16.6	83.4
31 July	438	1,344	1,782	24.6	75.4
1 August	297	909	1,206	24.6	75.4
2 August	390	1,512	1,902	20.5	79.5
3 August	312	1,006	1,318	23.7	76.3
4 August	318	1,131	1,449	21.9	78.1
5 August	259	1,094	1,353	19.1	80.9
6 August	225	864	1,089	20.7	79.3
7 August	276	843	1,119	24.7	75.3
8 August	339	750	1,089	31.1	68.9
9 August	438	570	1,008	43.5	56.5
10 August	321	496	816	39.3	60.7
Total	5,505	34,878	40,383	13.6	86.4

APPENDIX D. AVERAGE VERTICAL ANGLE BY TIDE STAGE, RUN, BANK, AND FISH ORIENTATION (UPSTREAM OR DOWNSTREAM) FOR THE 1998 KENAI RIVER CHINOOK SALMON RUNS

Appendix D1.-Average vertical angle by tide stage and orientation for the 1998 early Kenai River chinook run.

Tide Stage / Fish Orientation	Average Vertical Angle	Standard Deviation	Sample Size
1998 Early Run, Left Bank			
Falling			
Downstream	-0.51	0.91	57
Upstream	-1.24	0.65	515
Tide Stage Total	-0.87	1.11	572
Low			
Downstream	-0.73	0.94	26
Upstream	-1.43	0.39	209
Tide Stage Total	-1.08	1.02	235
Rising			
Downstream	-0.74	0.83	18
Upstream	-0.37	0.99	378
Tide Stage Total	-0.56	1.29	396
Left Bank Total	-0.84	1.99	1,203
1998 Early Run, Right Bank			
Falling			
Downstream	-0.27	0.71	85
Upstream	-0.84	0.57	1,750
Tide Stage Total	-0.55	0.91	1,835
Low			
Downstream	-0.29	0.79	52
Upstream	-0.98	0.53	510
Tide Stage Total	-0.63	0.95	562
Rising			
Downstream	-0.30	0.68	38
Upstream	-0.49	0.67	1,101
Tide Stage Total	-0.40	0.96	1,139
Right Bank Total	-0.53	1.63	3,536

Appendix D2.-Average vertical angle by tide stage and orientation for the 1998 late Kenai River chinook run.

Tide Stage / Fish Orientation	Average Vertical Angle	Standard Deviation	Sample Size
<u>1998 Late Run, Left Bank</u>			
Falling			
Downstream	-1.10	0.62	202
Upstream	-1.33	0.49	962
Tide Stage Total	-1.22	0.78	1,164
Low			
Downstream	-1.19	0.60	153
Upstream	-1.42	0.33	515
Tide Stage Total	-1.30	0.69	668
Rising			
Downstream	-1.08	0.70	286
Upstream	-0.93	0.83	1,245
Tide Stage Total	-1.00	1.08	1,531
Left Bank Total	-1.17	1.51	3,363
<u>1998 Late Run, Right Bank</u>			
Falling			
Downstream	-0.53	0.55	428
Upstream	-0.44	0.50	3,991
Tide Stage Total	-0.48	0.74	4,419
Low			
Downstream	-0.72	0.48	260
Upstream	-0.62	0.49	1,257
Tide Stage Total	-0.67	0.68	1,517
Rising			
Downstream	-0.68	0.52	482
Upstream	-0.4	0.58	3,407
Tide Stage Total	-0.54	0.78	3,889
Right Bank Total	-0.56	1.27	9,825

APPENDIX E. HISTORIC OPERATION DATES AND INRIVER RETURN ESTIMATES.

Appendix E1.-Kenai River early-run chinook: dates of operation, inriver return estimates, and standard error of the estimate.

Year	Dates of Operation	Upstream Estimate[b]	Downstream Estimate[b]	Total Estimate	SE (Estimate)
1987	4 June – 20 June[a]				
1988	16 May - 30 June			20,880	461
1989	16 May - 30 June			17,992	356
1990	16 May - 30 June			10,768	242
1991	16 May - 30 June			10,939	269
1992	16 May - 30 June			10,087	255
1993	16 May - 30 June			19,669	386
1994	16 May - 30 June			18,403	288
1995	16 May - 30 June			21,884	396
1996	16 May - 30 June	21,983	1,522	23,505	376
1997	16 May - 30 June	13,370	1,593	14,963	236
1998	7 May - 30 June	13,103	848	13,103[c]	230

[a] Operation still in research mode.

[b] Prior to 1996 we were unable to estimate upstream and downstream components.

[c] Only upstream moving fish reported.

Appendix E2.-Kenai River late-run chinook: dates of operation, inriver return estimate, and standard error of the estimate.

Year	Dates of Operation	Upstream Estimate[a]	Downstream Estimate[a]	Total Estimate	SE (Estimate)
1987	1 July - 10 Aug			48,123	NA
1988	1 July - 11 Aug			52,008	1,018
1989	1 July - 7 Aug			29,035	693
1990	1 July - 15 Aug			33,474	746
1991	1 July - 8 Aug			34,614	901
1992	1 July - 10 Aug			30,314	685
1993	1 July - 10 Aug			49,674	1,338
1994	1 July - 7 Aug			53,281	1,101
1995	1 July - 9 Aug			44,336	970
1996	1 July - 31 July	51,844	2,090	53,934	1,053
1997	1 July - 3 Aug	52,745	2,138	54,883	914
1998	1 July - 10 Aug	34,878	5,505	34,878[b]	500

[a] Prior to 1996 we were unable to estimate upstream and downstream components.

[b] Only upstream moving fish reported.

APPENDIX F. HISTORIC ESTIMATES OF INRIVER RETURN BY YEAR AND DATE (1987–1998).

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

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

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 F2.-Kenai River late-run chinook salmon sonar estimates of inriver return, by year and date.

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

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

[a] Upstream fish only reported.