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Estimates of Chinook Salmon Abundance in the Kenai River Using Split-Beam Sonar, 1996

by

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and

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February 1998

Alaska Department of Fish and Game | Division of Sport Fish

Symbols and Abbreviations

The following symbols and abbreviations, and others approved for the Système International d'Unités (SI), are used in Division of Sport Fish Fishery Manuscripts, Fishery Data Series Reports, Fishery Management Reports, and Special Publications without definition. All others must be defined in the text at first mention, as well as in the titles or footnotes of tables and in figures or figure captions.

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-31 July) 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. We estimated the net upstream migration of chinook salmon from 16 May through 31 July 1996 to be 70,216. This estimate is comprised of 20,461 early-run and 49,755 late-run fish.

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 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 chinook salmon are also harvested by the Upper Cook Inlet commercial sockeye fishery and subsistence and personal use fisheries 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 (ADF&G 1990).

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 early and late runs of chinook salmon have returned at levels that have not required management restrictions.

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 more 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. 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. *In prep)* 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. Results of the tethered-fish experiment also suggested that there are other acoustic parameters, such as pulse width, that may assist in species discrimination when used in conjunction with target strength in a multivariate discriminant function analysis.

To address concerns raised by these studies, a new mark-recapture study based on radio-tagged fish was initiated during the late run in 1996 (Hammarstrom and Hasbrouck *In prep*.) and will continue through the late run of 1997. This study is designed to provide an independent and accurate estimate of inriver chinook abundance during the late run when the potential for misclassifying sockeye is greatest. Use of radiotelemetry technology will avoid certain biases introduced in previous mark-recapture estimates. Additionally, we continue efforts to improve current methods of species separation through research using tethered and free-swimming fish of known size and/or species to further explore the potential for discriminating size groups of fish using a combination of acoustic parameters (Burwen and Fleischman *In prep*).

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 1996 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 11 years despite a 100-year flood event during September 1995 (Joe Dorava, United States Geological Survey [USGS], Anchorage, personal communication). The slope from both banks is gradual and uniform, which allows a large proportion

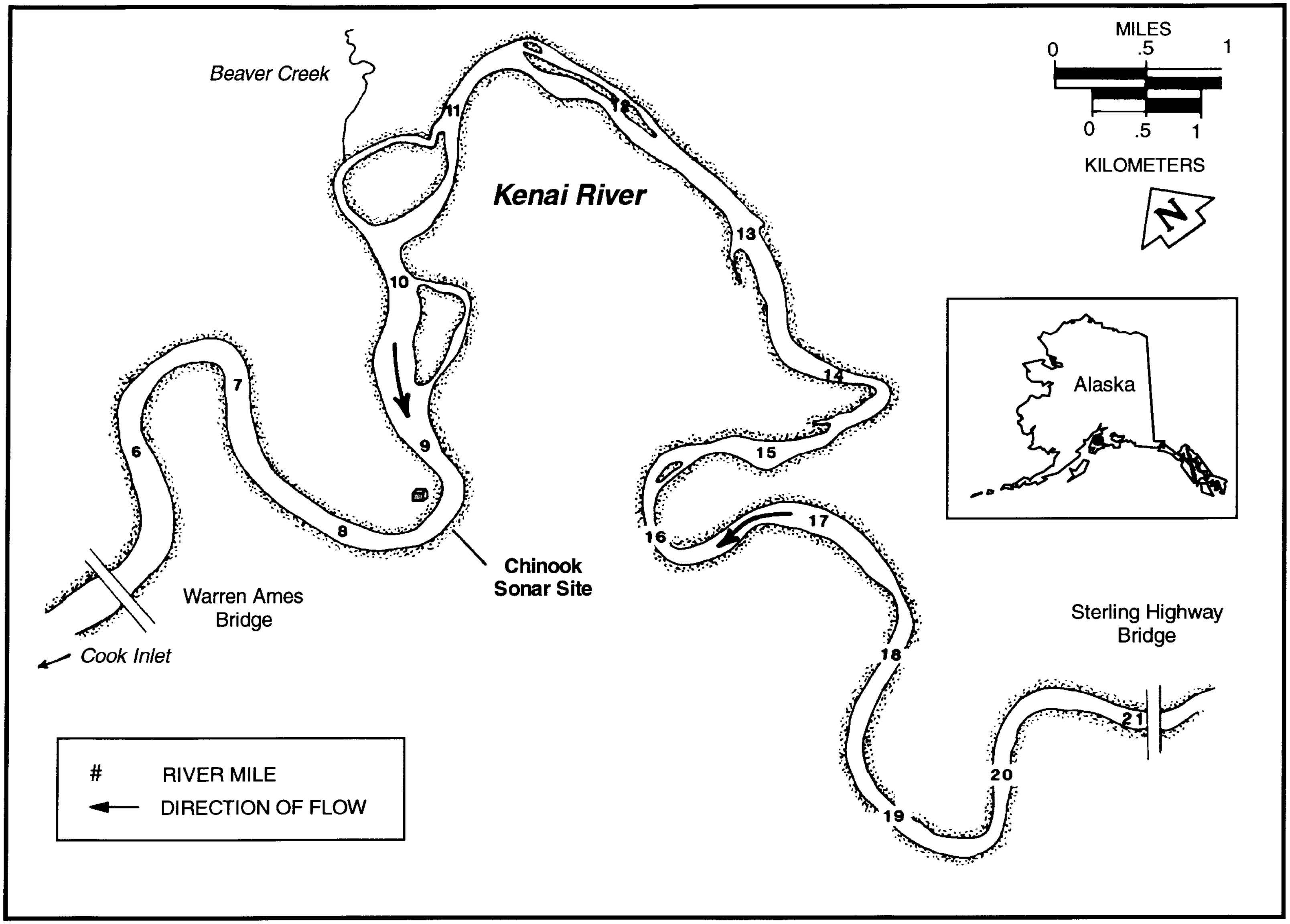

Figure 1.-Map of lower Kenai River showing location of the 1996 sonar site.

Table 1.-Principal components of the split-beam sonar system used in 1996.

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	Simrad Model CF-100 color video monitor
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

of the water column to be insonified without acoustic shadowing effects. On the right bank, the bottom is composed primarily of mud, providing an acoustically absorptive rather than reflective surface. This absorptive property improves the signal-to-noise ratio when the beam is aimed along the river bottom. The left bank bottom gradient is steeper and consists of more acoustically reflective small rounded cobble and gravel.

The sonar site is located below the lowest suspected spawning sites of chinook salmon yet far enough from the mouth that most of the fish counted are probably committed to the Kenai River (Alexandersdottir and Marsh 1990), reducing the incidence of chinook salmon loitering in the sonar beam or returning downstream. Initially, almost all sport fishing occurred upstream of this site. In recent years, however, fishing has rapidly increased in front of and below the sonar site.

ACOUSTIC SAMPLING

The sonar system operated from 16 May through 31 July 1996. 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

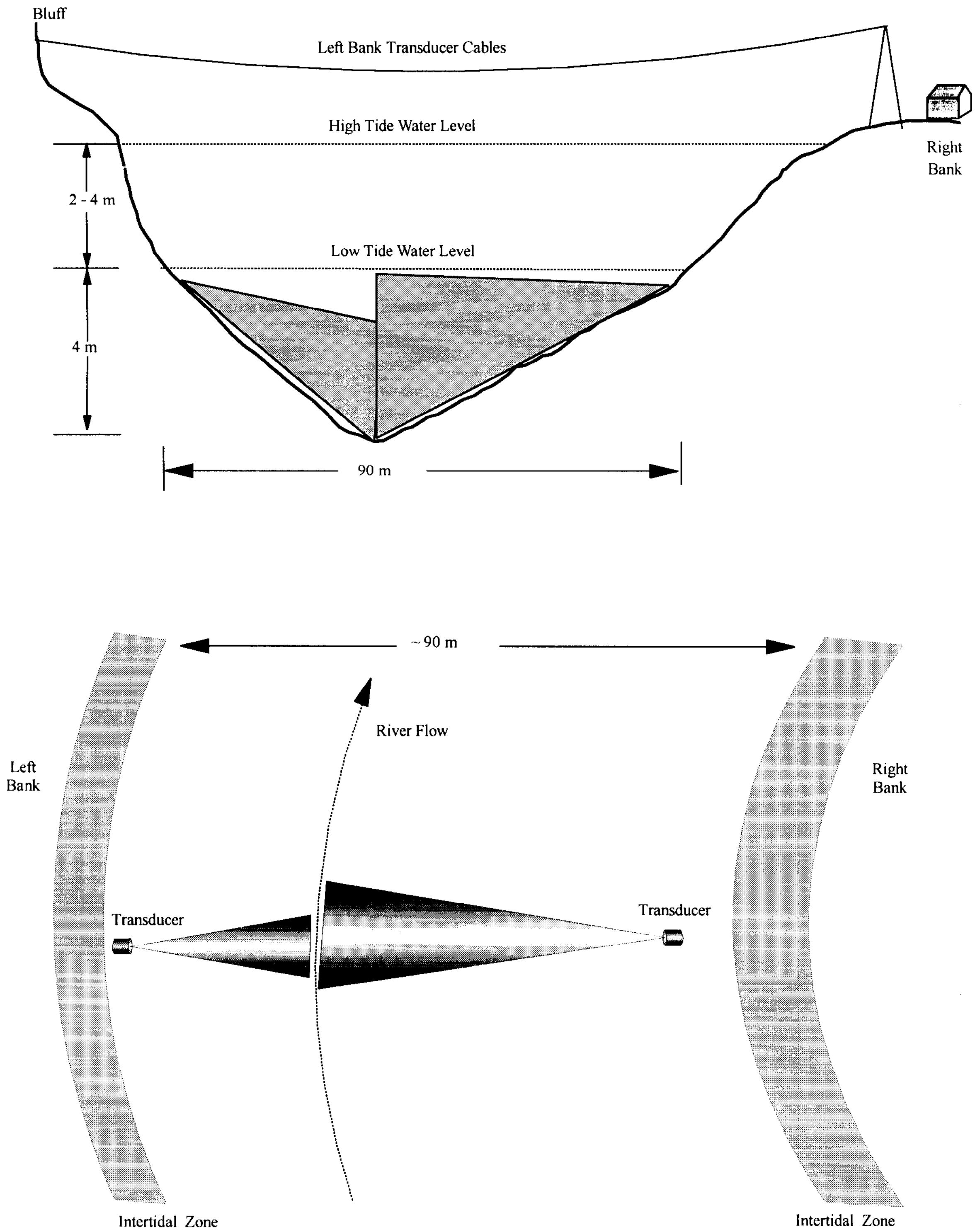

Figure 2.-Aerial and cross-sectional views of sonar site showing insonified portions of the Kenai River, 1996.

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. From 16 May to 31 July 1996 water level, at low tide, rose approximately 1 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 75 m at the lowest water conditions to 85 m at high water.

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

Both systems were professionally calibrated by Hydroacoustic Technology, Inc. (HTI)[1] in Seattle. Target strength measurements were also obtained from a 38.1 mm tungsten carbide sphere (Foote and MacLennan 1984) at the calibration facility. At the sonar site, we measured the same standard sphere *in situ* by suspending it from monofilament line in the acoustic beam. For each bank, we performed such *in situ* calibration verifications during early, mid, and late season to measure any drift in performance. These calibration checks were often conducted near high-slack tide when ambient noise levels were low and the position of the target was stable due to minimal current. For each calibration verification, we recorded the maximum background noise level and voltage threshold in addition to the data collected automatically by the on-board 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 echo sounder settings are listed in Table 2 with a more complete summary in Appendix B1 and Appendix B2. Most echo sounder settings were identical for each bank and remained consistent throughout the sample period. High power and low gain settings were used to maximize SNR. The transmitted pulse width was set relatively low to maximize resolution of individual fish, and SNR. The ping rate on each bank was increased this year to the maximum allowable rate for the ranges covered.

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

Table 2.-1996 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	65m
Maximum Left Bank Range	45m
Ping Rate Right Bank	11 pings/sec
Ping Rate Left Bank	16 pings/sec

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 B); it also recorded the start time, date and number of pings processed for each sample.

Echoes less than 2.0 m range from each transducer were excluded due to the transducer near-field effect (MacLennan and Simmonds 1992). Minimum vertical and horizontal off-axis values were used to prevent consideration of unreliable data from transducer side lobes. The minimum pulse width criterion prevents narrow band noise from being mistaken for valid echoes. The maximum pulse width criterion excludes potential multiple targets when estimating target strength.

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

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

The sum channel voltage from the Model 240 DES was also output to a dot matrix printer using a 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©.

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Figure 3.-Schematic diagram of 1996 split-beam sonar system configuration and data flow.

Table 3.-Echo acceptance criteria for digital echo processing, 1996.

Bank	pulse width (ms) at -6 dB	Vertical angle off-axis (°)	Horizontal angle off-axis(°)	Threshold mV (dB)	Range (m)
Right	0.15 to 0.30	-2.0 to 2.0	-5.0 to 5.0	> 672 (-35 dB)	>2.0
Left	0.15 to 0.30	-2.0 to 2.0	-5.0 to 5.0	> 411 (-35 dB)	>2.0

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

Downstream targets (and occasionally upstream targets during a strong flooding 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 1996, obvious debris-like targets were excluded during the tracking procedure and the remainder of downstream targets were retained to adjust the total estimate of fish passage. Separate summary files were generated for targets classified as debris (i.e. *.DEC and *.DFS files).

Except for debris, only targets comprised of 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 31 July) 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:

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

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 calculated 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 1996 to ensure comparability of passage estimates with those of past years, while continuing to investigate other means of discriminating between fish sizes (Burwen et al. *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 (*O. nerka*), pink (*O. gorbuscha*), and coho (*O. kisutch*) salmon. Fish within 10 m (16 May-31 July) on the left bank were deleted as were right bank fish within 15 m (16 May through 9 July) and 25 m (10 July through 31 July).

Passage Estimates and Run Timing

To maintain comparability between recent (1995-1996) 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, net upstream passage, takes the direction of travel for each fish into consideration by subtracting the total number of downstream fish from the total number of upstream fish. Estimates of fish passage were generated daily and were available to fishery managers by noon the following day. Passage estimates were checked for errors and variance estimates were calculated postseason.

An estimate of total 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:

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

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:

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

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:

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

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.

RESULTS

System Calibration

During system calibration at the HTI calibration facility, the target strength of a standard sphere was measured at -38.2 dB and -37.9 dB with the right and left bank systems, respectively (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 -40.0 dB to -37.6 dB on the right bank and from -39.9 to -38.7 on the left bank (Table 4).

Target Tracking

A total of 36,726 fish were manually tracked, 9,424 during the early run (16 May-30 June) and 27,302 during the late run (1 July-31 July). After filtering for range and target strength criteria, the proportion of upstream fish was 93.6% for the early run and 96.1% for the late run (Table 5, Table 6, Figure 4). The proportions of downstream fish during the early and late runs were 6.4% and 3.9%, respectively, with most downstream activity taking place on the right bank during the early run.

The number of acquired echoes per fish varied by run, bank, and direction of travel. During the early run, upstream fish averaged 39 (SD = 29) and 40 (SD = 32) echoes per fish on the left and right banks, respectively. Downstream fish averaged 46 echoes (SD = 41) on the left bank and 50 echoes (SD = 41) on the right bank. During the late run the number of echoes per fish increased substantially on the right bank. Upstream fish averaged 41 (SD =32) echoes on the left bank and 77 (SD=49) echoes on the right bank. Downstream fish averaged 55 (SD=60) echoes on the left bank and 79 (SD=81) 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 (54.2%) and late (49.6%) runs (Table 5, Table 6, Figure 5). The highest proportion of downstream fish occurred during the rising tide during the early run (46%) and during the falling tide during the late run (50%).

SPATIAL DISTRIBUTION

Fish were bottom-oriented during both runs, although vertical distribution did vary somewhat by direction of travel, tide stage, and season. During the early run, 89% of the upstream fish on the left bank (Figure 6) and 67% on the right bank (Figure 7) were below the acoustic axis. Downstream fish were less bottom-oriented. Fifty-nine percent of downstream fish on the left bank (Figure 6) and 54% on the right bank (Figure 7) were below the acoustic axis. Upstream fish on the left bank (mean = -1.18^o, SD = 0.72, n = 4,523) were on average significantly lower ($P \ll 0.001$) in the water column than downstream fish (mean = -0.38 ^{o}, SD = 1.01, n = 225). On the right bank, upstream fish (mean = -0.53 ^{o}, SD = 0.84) were also significantly lower in the water column ($P \ll 0.001$) than downstream fish (mean = -0.22 ^{o}, SD = 0.82, n = 283). There was a tendency for early-run upstream fish on both banks to rise off the bottom during the rising tide phase (Figure 8, Figure 9).

Table 4.-Results of 1996 *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]	6-May	-38.2	1.04	797	6	N/A[e]	
Kenai River	14-May	-40.0	1.49	1864	13	50	150
Kenai River	12-June	-38.5	3.88	2,931	15	20	75
Kenai River	10-July	-37.6	4.44	2,116	25	200-225	250
Kenai River	23-July	-37.63	6.1	1,677	19	200	250
			Left Bank				
HTI[a]	6-May	-37.9	0.38	797	6	N/A[e]	
Kenai River	14-May	-39.9	1.59	1220	16	35	100
Kenai River	6-June	-38.8	3.58	1,899	20	20	65
Kenai River	10-July	-38.7	1.57	3,316	14	15	250

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

Table 5.-Estimates of chinook salmon passage by tide stage and direction of travel for the 1996 early run (16 May to 30 June).

1996 Early Run[a]	Total # of Fish	Rising	Falling	Low
Upstream	**21,893**	**3,057**	**11,873**	**6,963**
Row %	100.0%	14.0%	54.2%	31.8%

Column %	93.6%	81.6%	96.5%	94.8%
Downstream	**1,503**	**690**	**432**	**381**
Row %	100.0%	45.9%	28.7%	25.3%
Column %	6.4%	18.4%	3.5%	5.2%

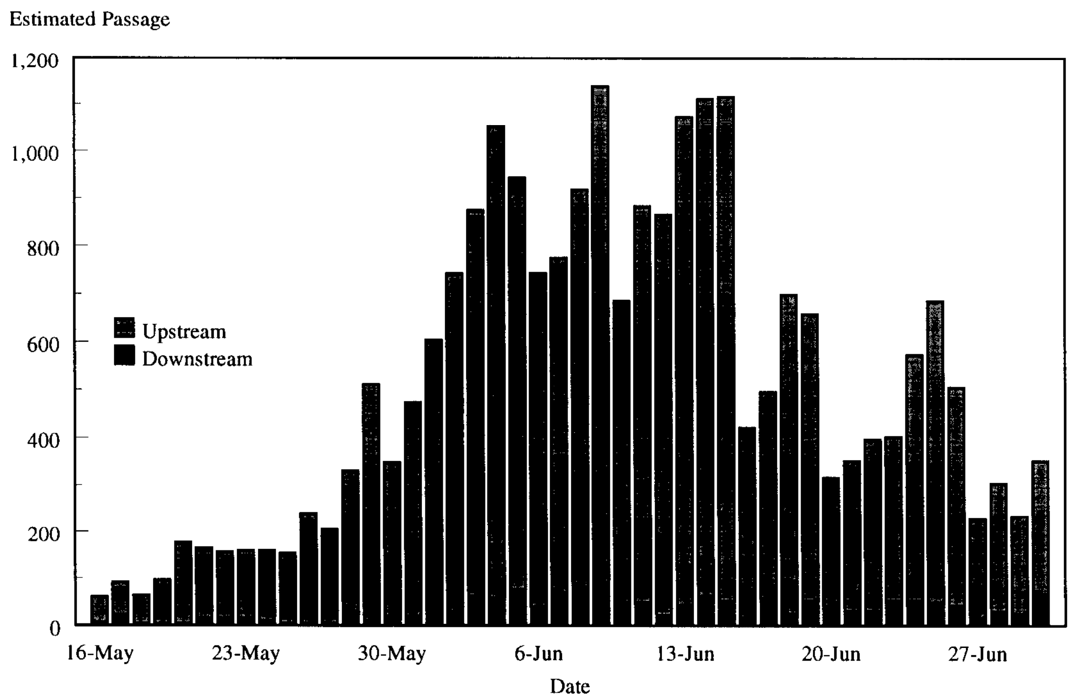
Test for Independence: Chi-square = 1,089, df = 2, P<<<0.0001

[a] The tide stage entry pattern could not be determined for 109 fish.

Table 6.-Estimates of chinook salmon passage by tide stage and direction of travel for the 1996 late run (1 July to 31 July).

1996 Late Run	Total # of Fish	Rising	Falling	Low
Upstream	**51,845**	**14,999**	**25,716**	**11,130**
Row %	100.0%	28.9%	49.6%	21.5%
Column %	96.1%	96.3%	96.5%	95.1%
Downstream	**2,090**	**569**	**944**	**577**
Row %	100.0%	27.2%	45.2%	27.6%
Column %	3.9%	3.7%	3.5%	4.9%

Test for Independence: Chi-square = 45, df = 2, P <<<0.001



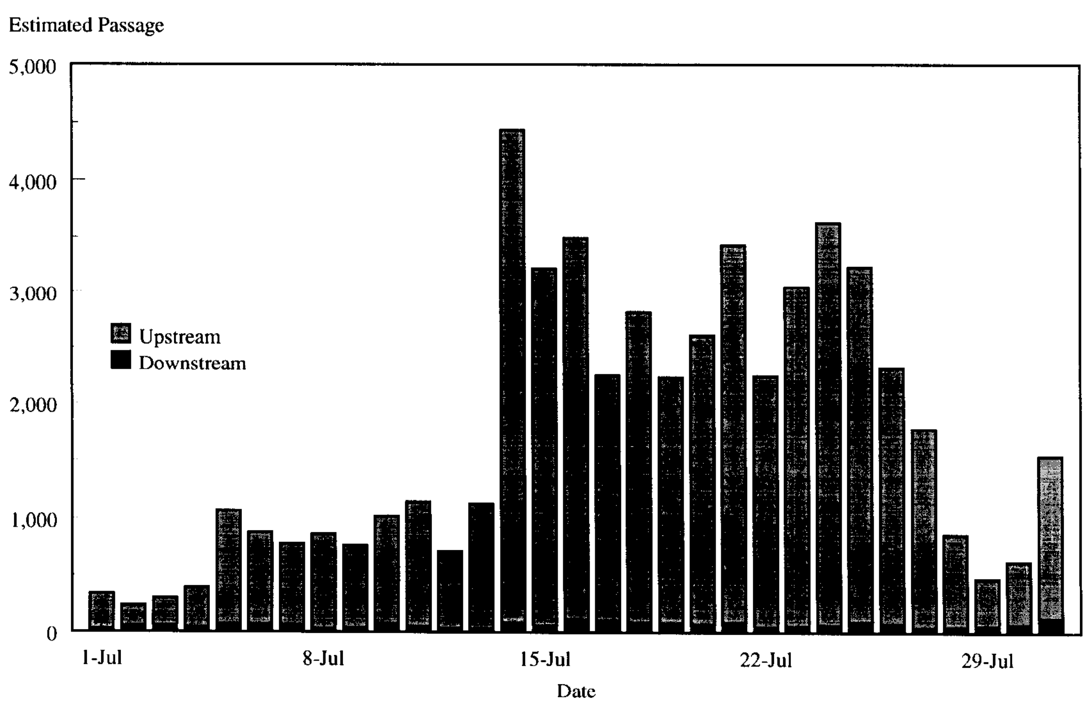


Figure 4.-Upstream and downstream components of the early (top) and late (bottom) runs of chinook salmon to the Kenai River, 1996.

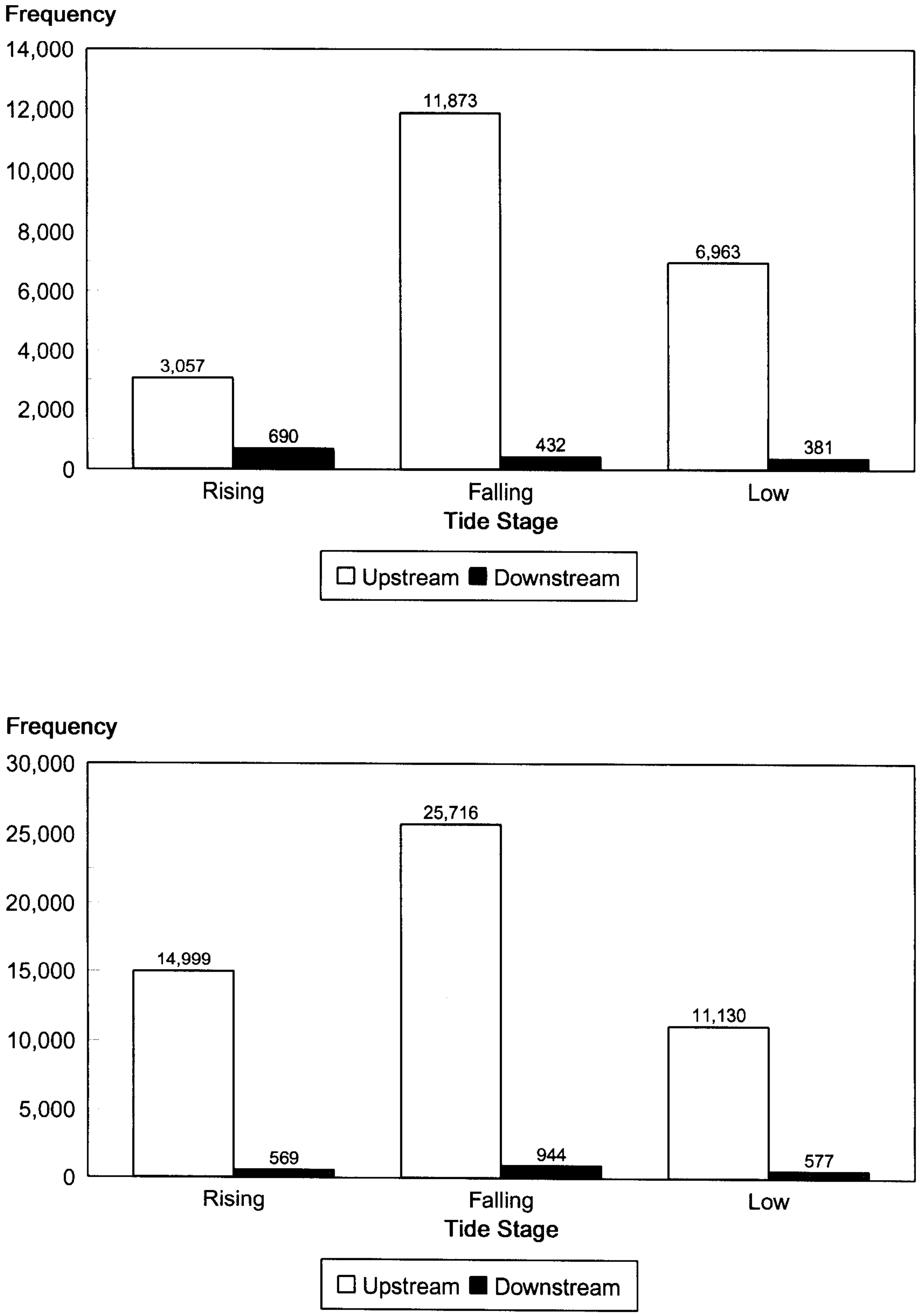


Figure 5.-Distribution of upstream and downstream fish by tide stage during the early run (top) and late run (bottom).

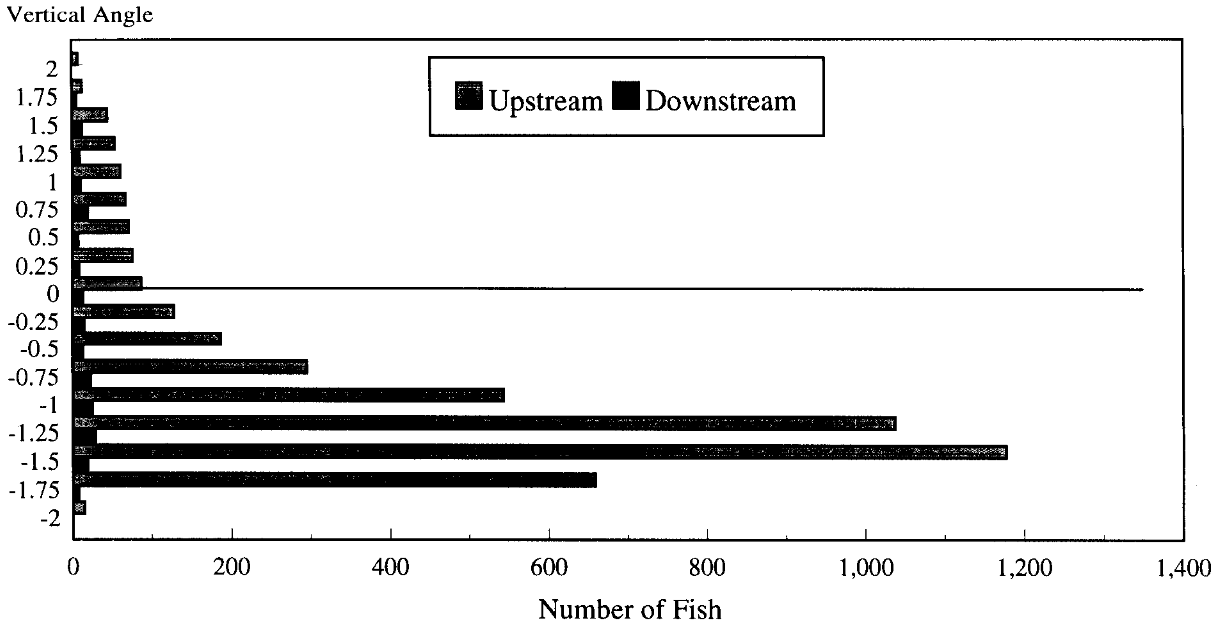


Figure 6.-Vertical distributions of early-run upstream and downstream fish, on the left bank, Kenai River, 1996.

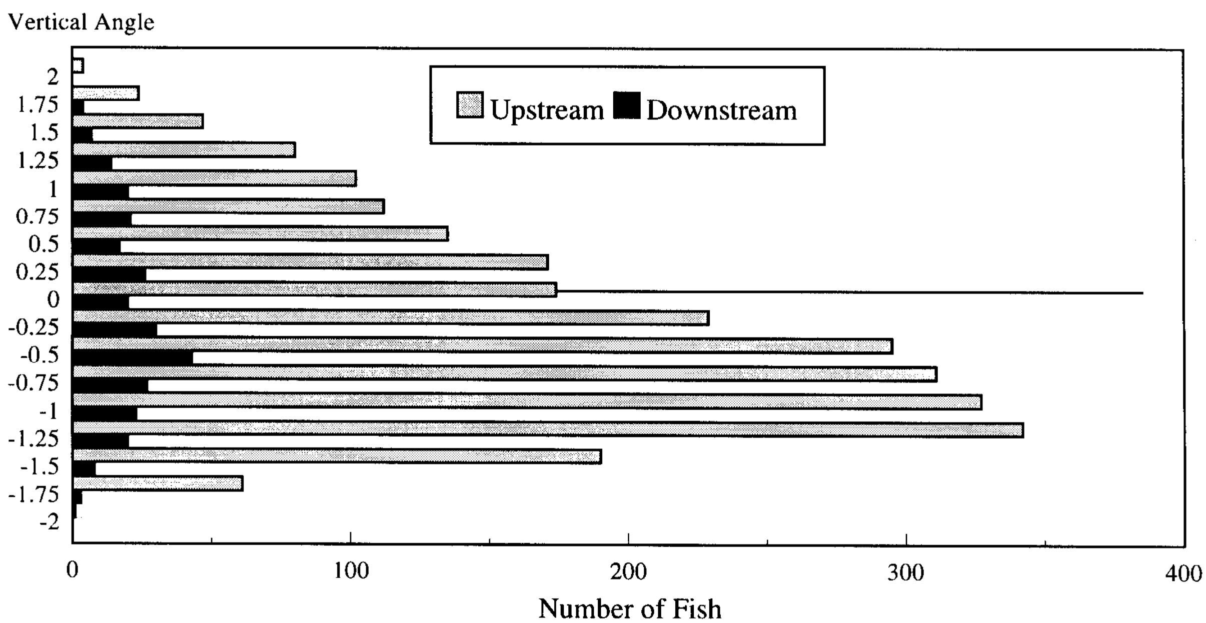


Figure 7.-Vertical distributions of early-run upstream and downstream fish, on the right bank, Kenai River, 1996.

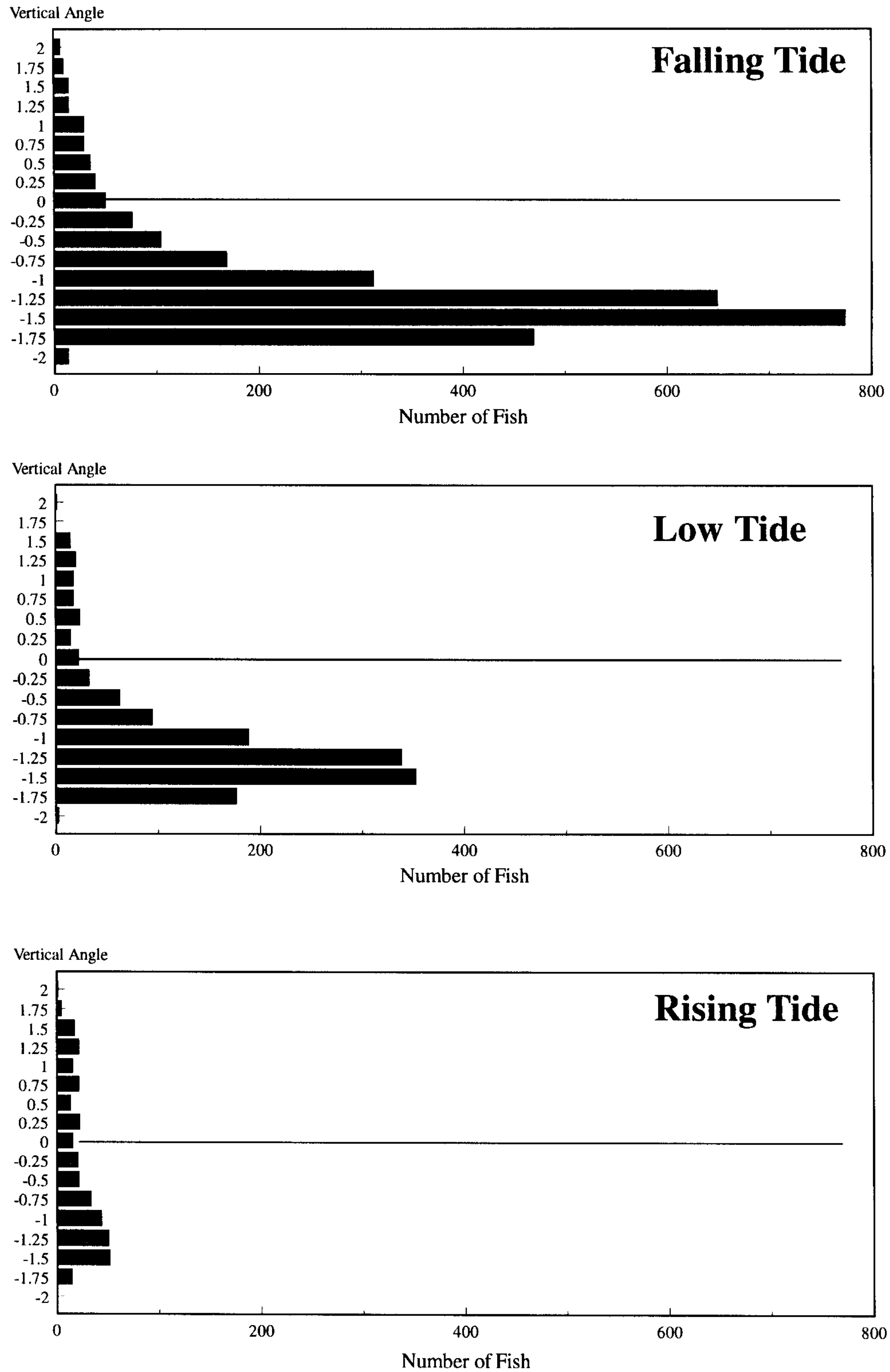


Figure 8.-Vertical distribution of early-run, upstream-traveling fish during falling (top), low (middle), and rising (bottom) tide stages on the left bank, Kenai River, 1996.

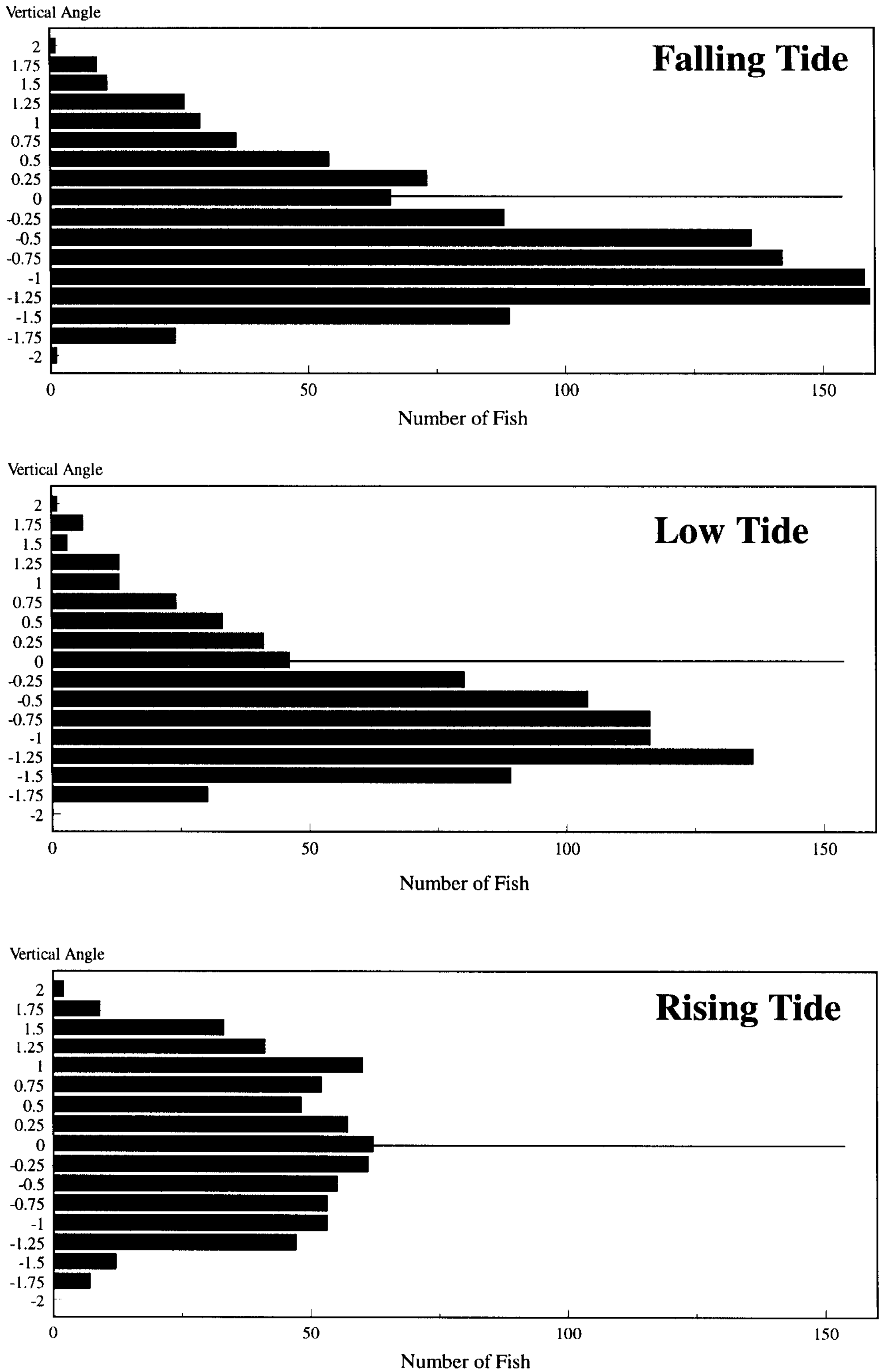


Figure 9.-Vertical distribution of early-run, upstream-traveling fish during falling (top), low (middle), and rising (bottom) tide stages on the right bank, Kenai River, 1996.

Late-run fish showed an even stronger tendency to travel along the river bottom (Figure 10, Figure 11). Ninety-five percent of upstream fish on the left bank and 78% of upstream fish on right bank were below the acoustic axis. Seventy-seven percent of downstream fish on both left and right banks were below the acoustic axis. Upstream fish on the left bank (mean = -1.23 ^{o}, SD = 0.57, n = 6,538) traveled, on average, significantly lower ($P << 0.001$) in the water column than downstream fish (mean = -0.61 ^{o}, SD = 0.78, n = 238). On the right bank, mean vertical angle did not differ ($P = 0.82$) between upstream fish (mean = -0.34, SE = 0.53, n = 10,238) and downstream fish (mean = -0.35 ^{o}, SD = 0.60, n = 458). Fish on both banks retained a strong bottom orientation during all tide phases (Figure 12, Figure 13).

During the early run, fish on both banks were channel-oriented. There was no significant difference between upstream and downstream range distributions for either the left (Anderson-Darling, $P = 0.062$) or right ($P = 0.488$) banks (Table 7, Figure 14, Figure 15). Range distributions on both banks also remained relatively unchanged throughout the falling, low, and rising tide phases (Figure 16, Figure 17).

During the late run, upstream fish were more evenly distributed across the offshore ranges and 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 18, Figure 19). Left bank range distributions remained relatively unchanged throughout the falling, low and rising tide phases (Figure 20). The right-bank range distribution during the falling tide appeared bimodal compared to the more uniform distributions during the low and rising tide phases (Figure 21).

The left bank produced higher passage estimates than the right bank during the early run but lower passage estimates during the late run. During the early run, 61.3% of fish passed on the left bank compared with 38.7% on the right bank (Table 9). During the late run, 38.1% of fish passed on the left bank compared with 61.9% on the right bank (Table 10).

TARGET STRENGTH

Target strength distributions varied considerably by bank, direction of travel, and run. Mean target strength estimates for upstream fish on the left bank averaged 4 dB to 5 dB higher than right bank estimates for early and late runs (Table 11, Figure 22, Figure 23). Mean target strength of upstream and downstream fish on both banks was larger during the early run (Table 11).

During the early run on the left bank, mean target strength was higher ($t = 17.54$, $P << 0.001$) and less variable ($F = 2.31$, $P << 0.001$) among upstream fish than downstream fish (Table 11, Figure 22). On the right bank, mean target strength was again higher ($t = 8.6$, $P << 0.001$) for upstream fish, though only by 1 dB, and variances were equal ($F = 0.40$, $P > 0.05$) (Table 11, Figure 22).

During the late run on the left bank, mean target strength was higher ($t = 15.49$, $P << 0.01$) and less variable ($F = 2.42$, $P << 0.001$) among upstream fish than downstream fish (Table 11, Figure 23). On the right bank, mean target strength was equal ($t = -0.58$, $P = 0.56$) among upstream and downstream fish but less variable ($F = 1.25$, $P << 0.001$) for upstream fish (Table 11, Figure 23).

PASSAGE ESTIMATES

Daily estimates of chinook salmon passage were generated for 16 May-31 July. Sampling was terminated at midnight 31 July, approximately 1 week earlier than in previous years. After 31 July, pink salmon spawning in the insonified area affected the ability of the sonar to identify unique targets. A total of

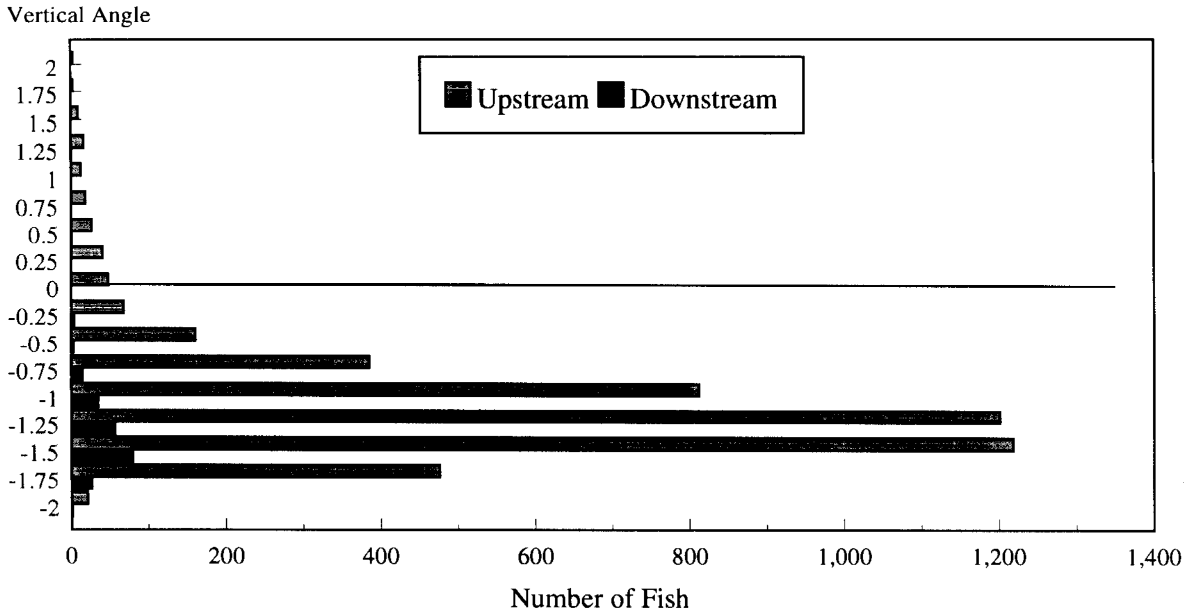


Figure 10.-Vertical distributions of late-run upstream- and downstream-traveling fish, on the left bank, Kenai River, 1996.

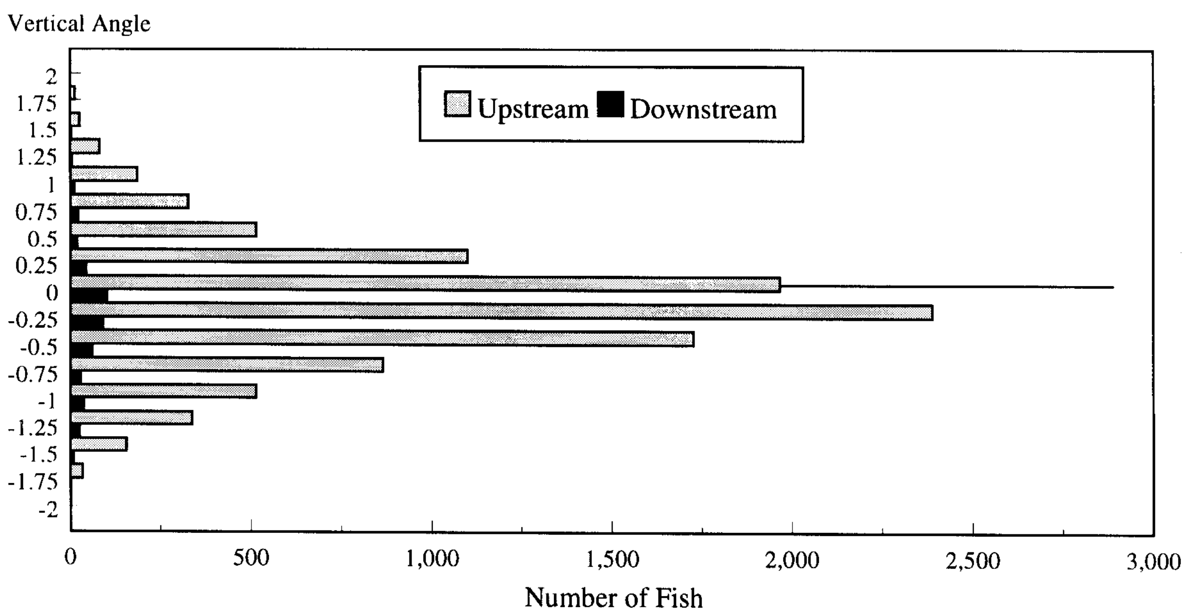


Figure 11.-Vertical distributions of late-run upstream- and downstream-traveling fish, on the right bank, Kenai River, 1996.

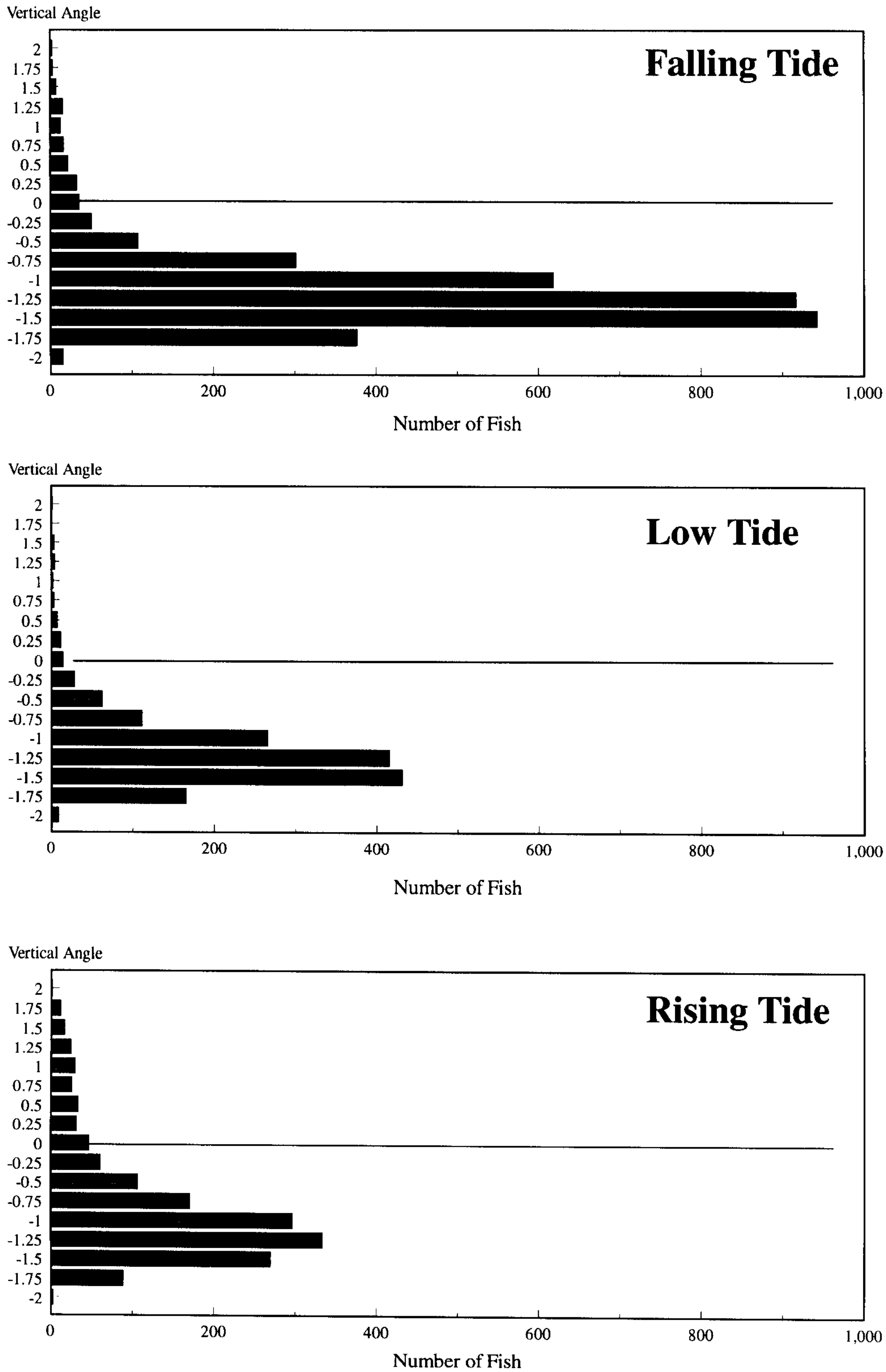


Figure 12.-Vertical distribution of late-run upstream-traveling fish during falling (top), low (middle), and rising (bottom) tide stages on the left bank, Kenai River, 1996.

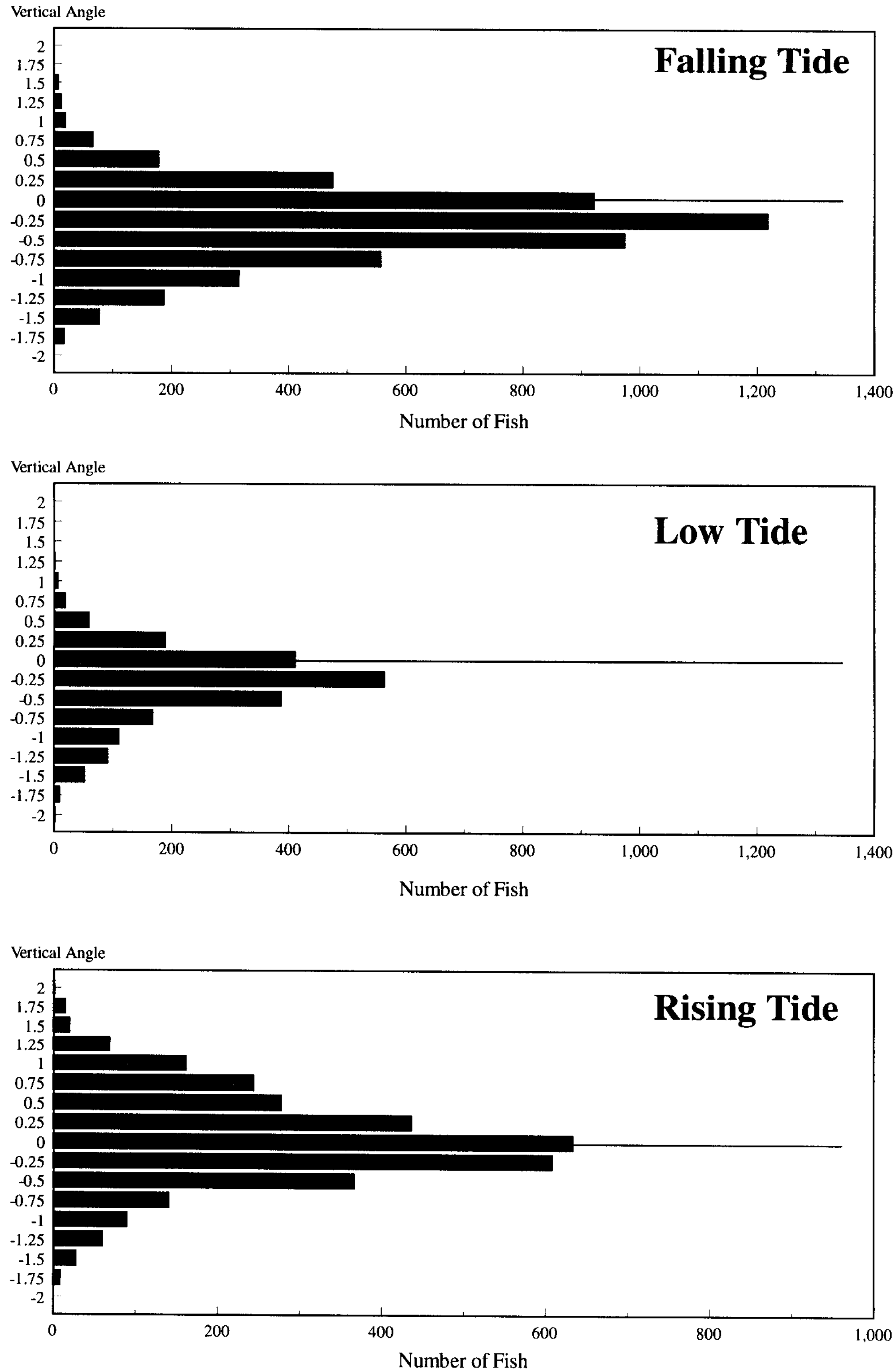


Figure 13.-Vertical distribution of late-run upstream-traveling fish during falling (top), low (middle), and rising (bottom) tide stages on the right bank, Kenai River, 1996.

Table 7.-Range distribution (5 m increments) for upstream- and downstream-traveling fish during the 1996 early run (16 May to 30 June).

Range	Up-stream	Down-stream	Percent of Total Upstream	Percent of Total Downstream	Percent Upstream of Range	Percent Downstream of Range
Left Bank						
10 - 14.99	924	45	20.4%	20.1%	95.4%	4.6%
15 - 19.99	2,406	110	53.2%	49.1%	95.6%	4.4%
20 - 24.99	1,193	69	26.4%	30.8%	94.5%	5.5%
Bank Total	4,523	224	100.0%	100.0%	95.3%	4.7%
Right Bank						
15 - 19.99	158	22	6.1%	7.8%	87.8%	12.2%
20 - 24.99	255	22	9.8%	7.8%	92.1%	7.9%
25 - 29.99	295	27	11.3%	9.5%	91.6%	8.4%
30 - 34.99	399	40	15.3%	14.1%	90.9%	9.1%
35 - 39.99	578	66	22.2%	23.3%	89.8%	10.2%
40 - 44.99	765	82	29.4%	29.0%	90.3%	9.7%
45 - 49.99	155	24	6.0%	8.5%	86.6%	13.4%
Bank Total	2,605	283	100.0%	100.0%	90.2%	9.8%

1,216 hours (two banks) of acoustic data were processed during the 77-day season representing 33% of the total available sample time.

Total Passage

Total chinook salmon passage from 16 May through 31 July was estimated at 77,439 (SE = 1,118) fish, 23,505 (SE = 376) during the early run and 53,934 (SE = 1,053) during the late run (Table 12, Table 13). The daily peak of the early run occurred on 9 June with 50% of the run having passed by 10 June (Figure 24). A strong return in late June pushed the 1996 curve above the historic 95% run-timing confidence intervals for the last half of the early run (Figure 25). The daily peak of the late run occurred on 14 July, with 50% of the late run having passed by 19 July (Figure 26). Migratory timing for late-run fish started within normal bounds early in the season, but a particularly strong return starting in mid July pushed the 1996 curve above the historic 95% confidence intervals for the last week in July (Figure 25).

Net Upstream Passage

Downstream migrants comprised an estimated 1,522 fish or 6.5% of the total early-run passage estimate (Table 9). After adjusting for downstream migrants, the net upstream passage estimate for the early run was 20,461 chinook salmon. The estimate of downstream-migrating fish during the late run was 2,090 fish or 3.9% of the total late-run passage estimate (Table 10). The net upstream passage estimate for the late run was 49,755 chinook salmon.

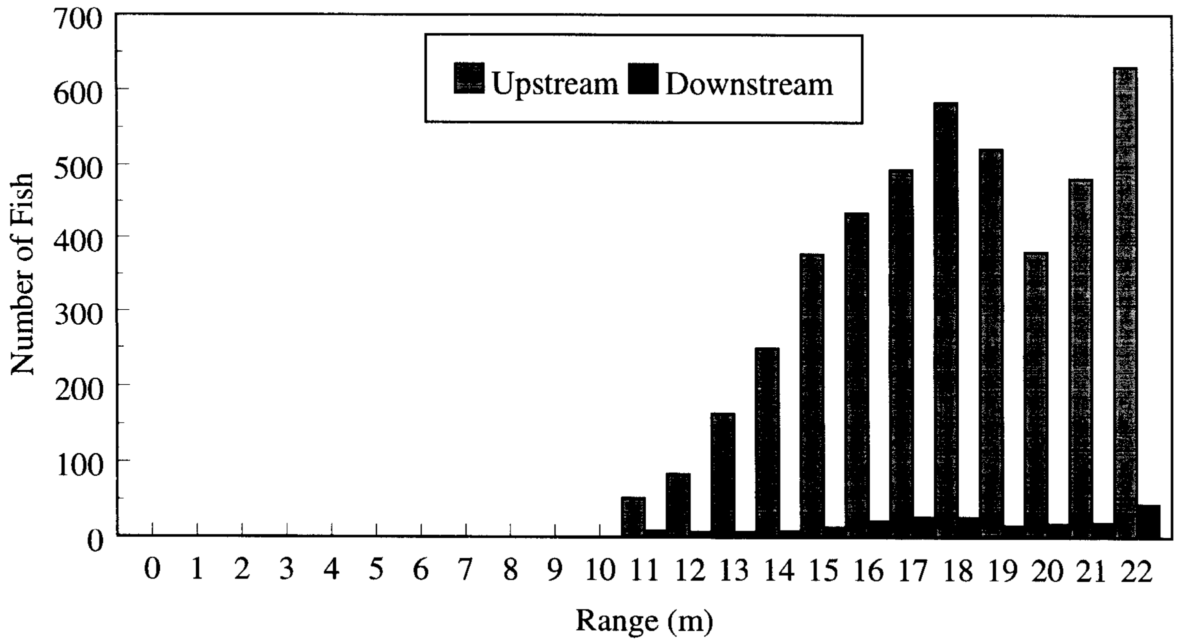


Figure 14.-Range distributions of early-run upstream (n = 4,523) and downstream (n = 219) fish, on the left bank, Kenai River, 1996.

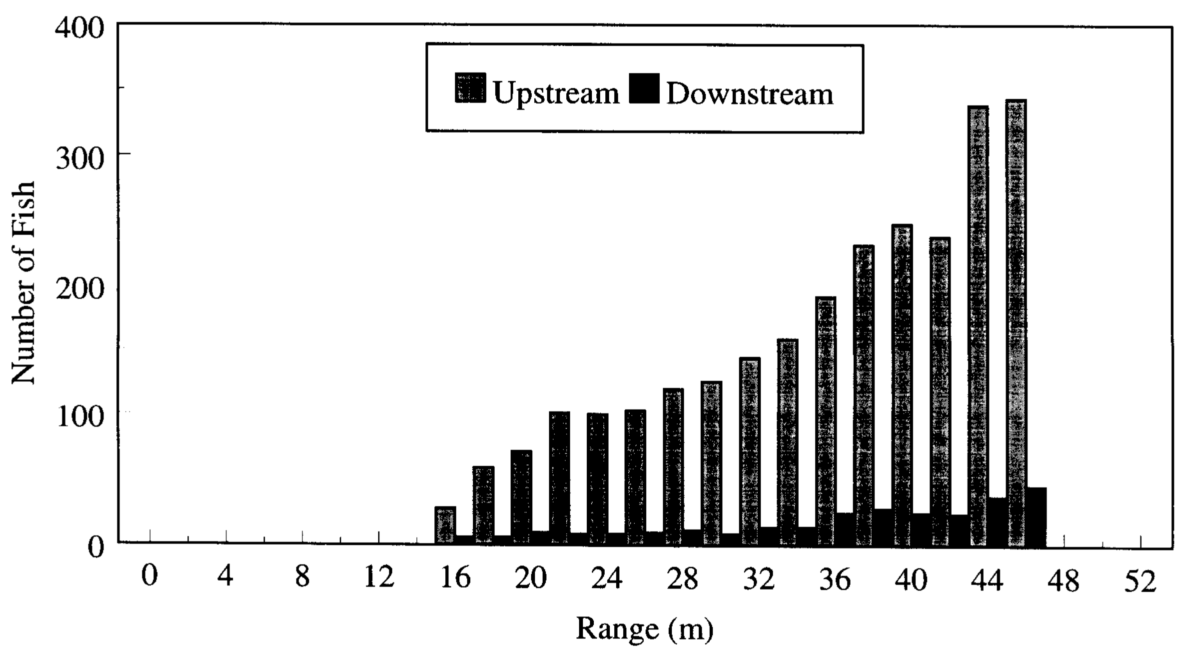


Figure 15.-Range distributions of early-run upstream (n = 2,605) and downstream (n = 283) fish, on the right bank, Kenai River, 1996.

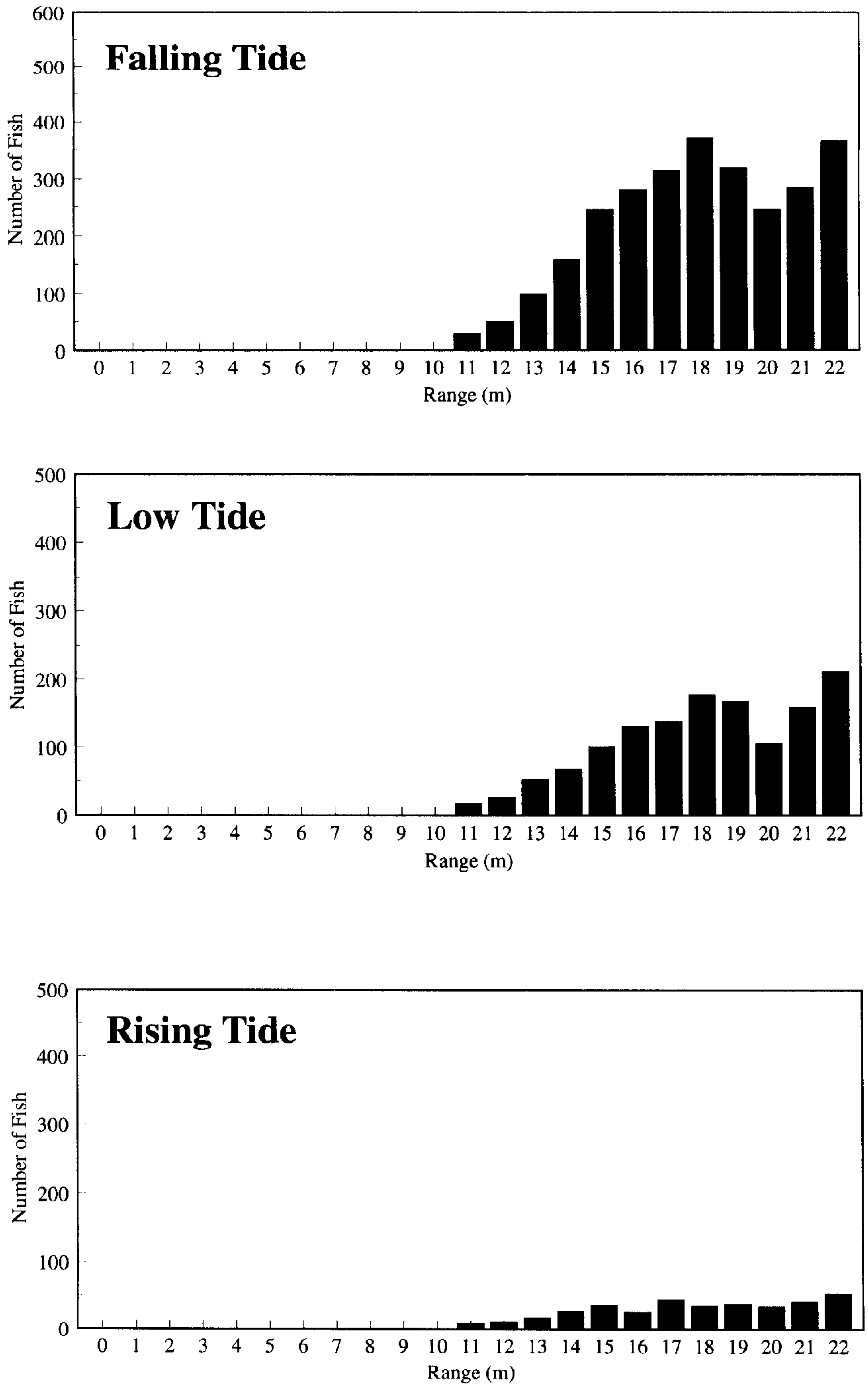


Figure 16.-Range distribution of early-run, upstream-traveling fish during falling (top), low (middle), and rising (bottom) tide stages on the left bank, Kenai River, 1996.

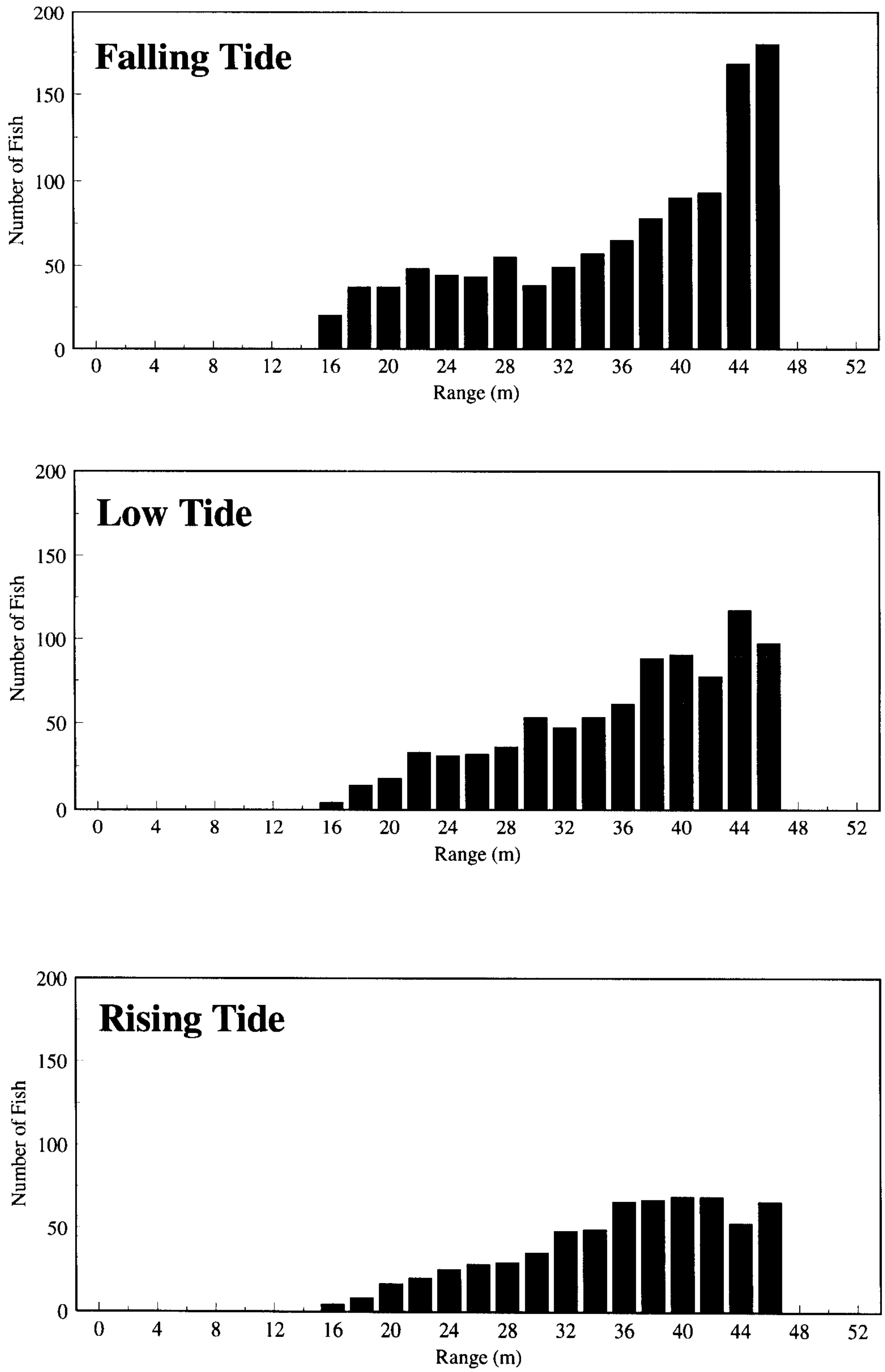


Figure 17.-Range distribution of early-run, upstream-traveling fish during falling (top), low (middle), and rising (bottom) tide stages on the right bank, Kenai River, 1996.

Table 8.-Range distribution (5 m increments) for upstream- and downstream-traveling fish during the 1996 late run (1 July to 31 July).

Range	Up-stream	Down-stream	Percent of Total Upstream	Percent of Total Downstream	Percent Upstream of Range	Percent Downstream of Range
Left bank						
10 – 14.99	1,311	34	20.1%	14.3%	97.5%	2.5%
15 – 19.99	3,626	104	55.5%	43.7%	97.2%	2.8%
20 – 24.99	1,601	100	24.5%	42.0%	94.1%	5.9%
Bank Total	6,538	238	100.0%	100.0%	96.5%	3.5%
Right bank						
15 - 19.99	48	7	0.5%	1.5%	87.3%	12.7%
20 - 24.99	86	11	0.8%	2.4%	88.7%	11.3%
25 - 29.99	2,194	56	21.4%	12.2%	97.5%	2.5%
30 - 34.99	2,091	50	20.4%	10.9%	97.7%	2.3%
35 - 39.99	1,632	74	15.9%	16.2%	95.7%	4.3%
40 - 44.99	1,948	101	19.0%	22.1%	95.1%	4.9%
45 - 49.99	1,776	115	17.3%	25.1%	93.9%	6.1%
50 - 54.99	463	44	4.5%	9.6%	91.3%	8.7%
Bank Total	10,238	458	100.0%	100.0%	95.7%	4.3%

DISCUSSION

Bank Preference

More fish were detected on the left bank than on the right bank during the early run for the first time since the project became operational (Eggers et al. 1995, Burwen and Bosch 1995a, Burwen and Bosch 1995b, Burwen and Bosch 1996). Typically, more than 70% of all fish are detected on the right bank during the early run, and over 80% during the late run. During the 1996 early run, 61% of all fish (filtered for range and target strength) were detected on the left bank. During the late run, the right bank passed a higher number of fish than the left bank, but the proportion of 72% was lower than any other previous year. There were two environmental events in 1996 that may have contributed to deviations from typical migratory behavior patterns. First, 1996 was the first season following a 100-year flood event that took place during September 1995. Although the bottom topography at the sonar site remained relatively unchanged, there may have been changes in the river channel downstream that could alter prior migration routes. The change in bank preference may also be attributed to lower than average discharge rates recorded on the Kenai River. The mean discharge rate was 2,393 cubic feet per second below

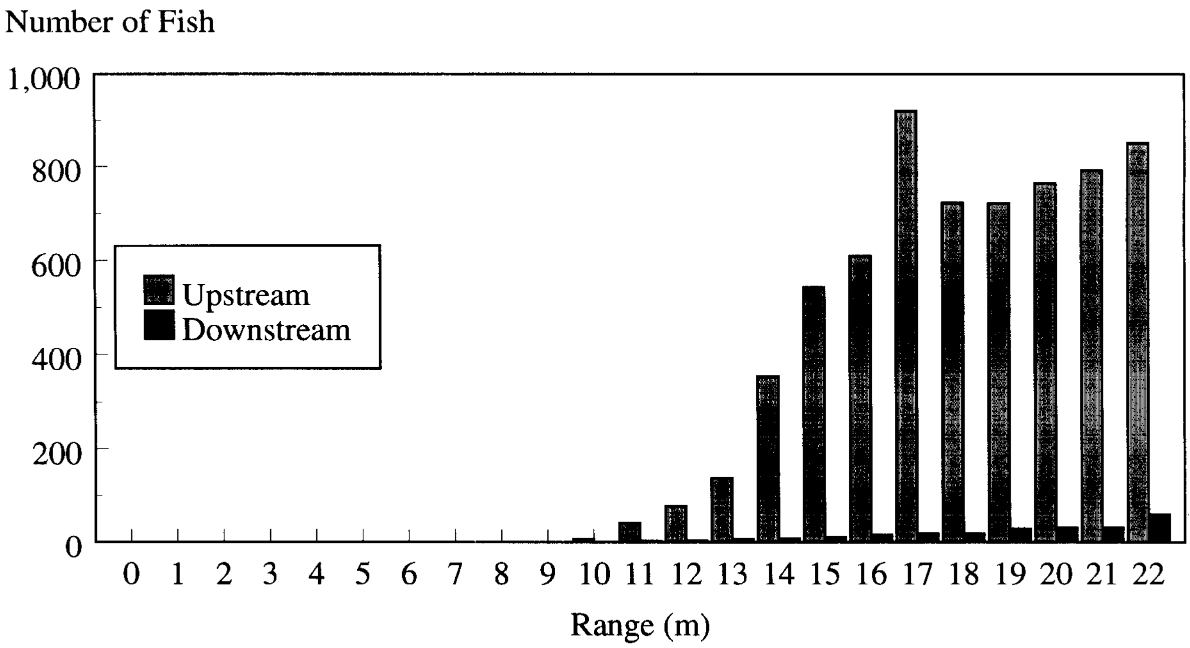


Figure 18.-Range distribution of late-run upstream (n = 6,538) and downstream (n = 238) fish, on the left bank, Kenai River, 1996.

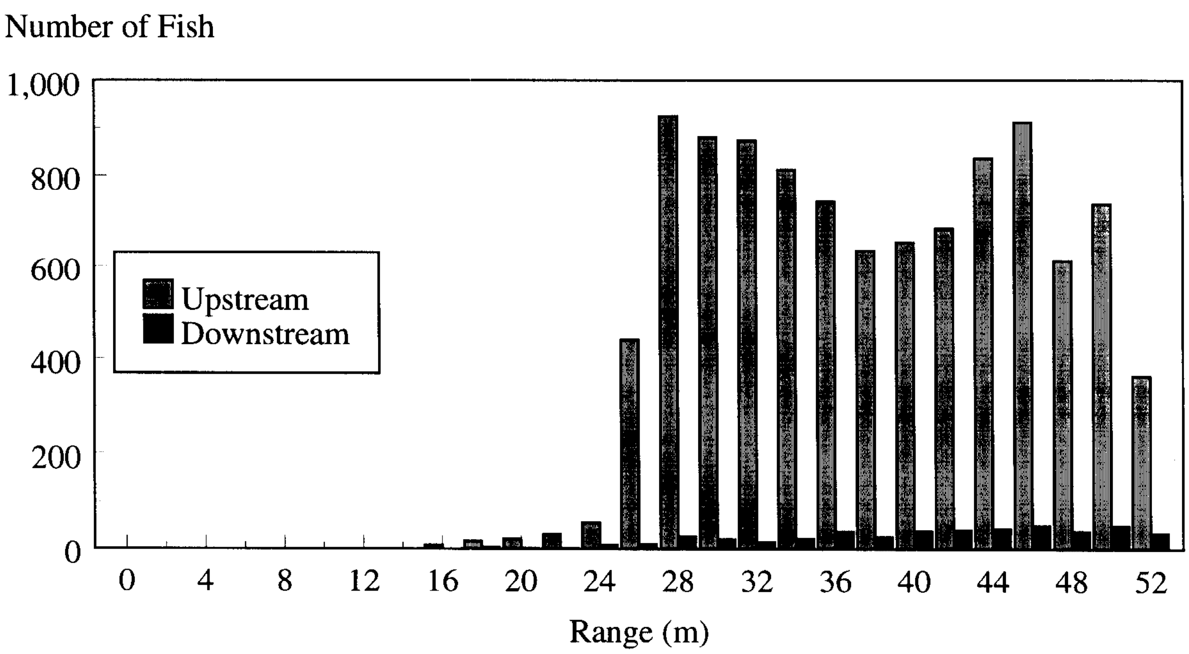


Figure 19.-Range distribution of late-run upstream (n = 10,238) and downstream (n = 458) fish, on the right bank, Kenai River, 1996.

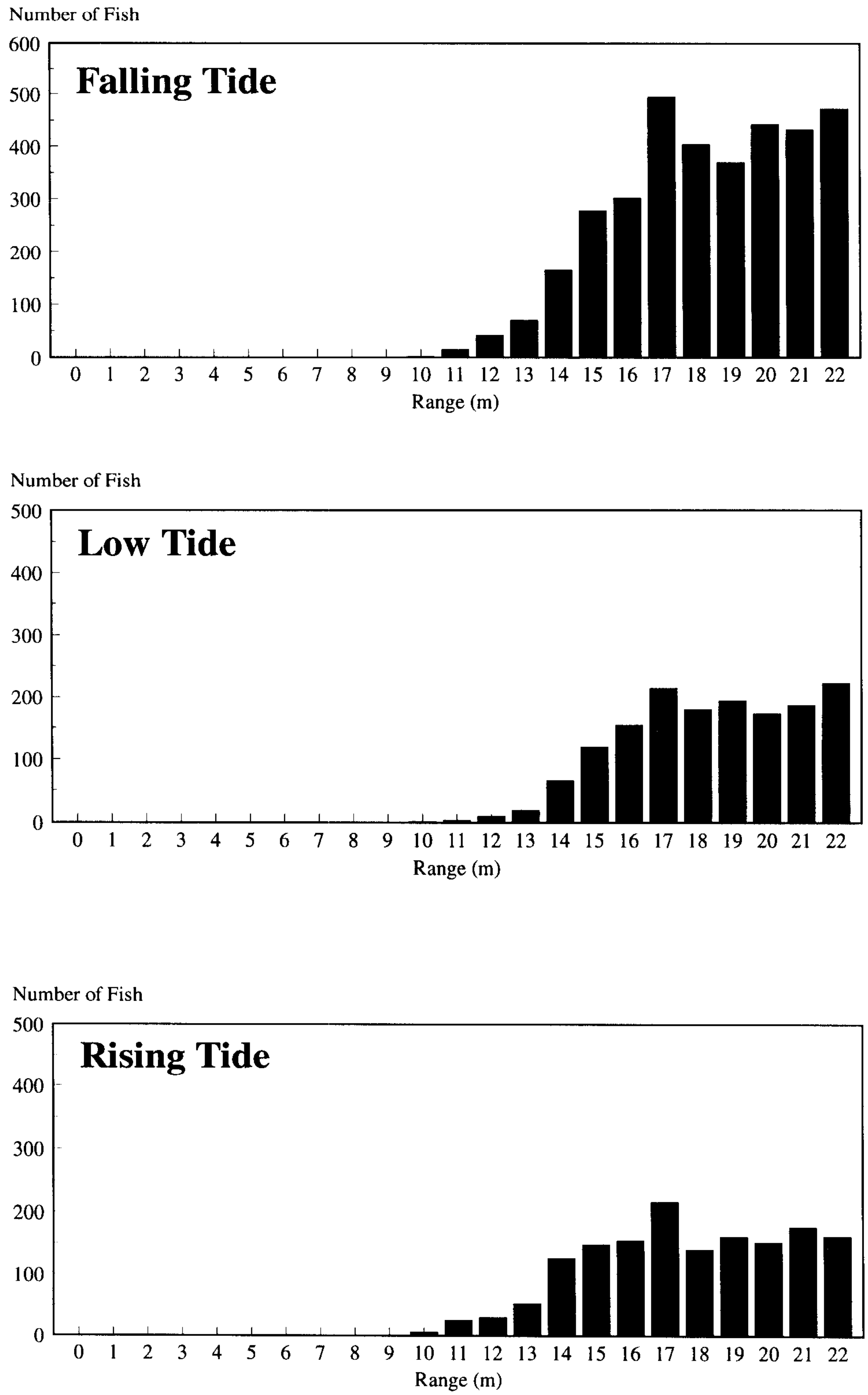


Figure 20.-Range distribution of late-run upstream-traveling fish during falling (top), low (middle), and rising (bottom) tide stages on the left bank, Kenai River, 1996.

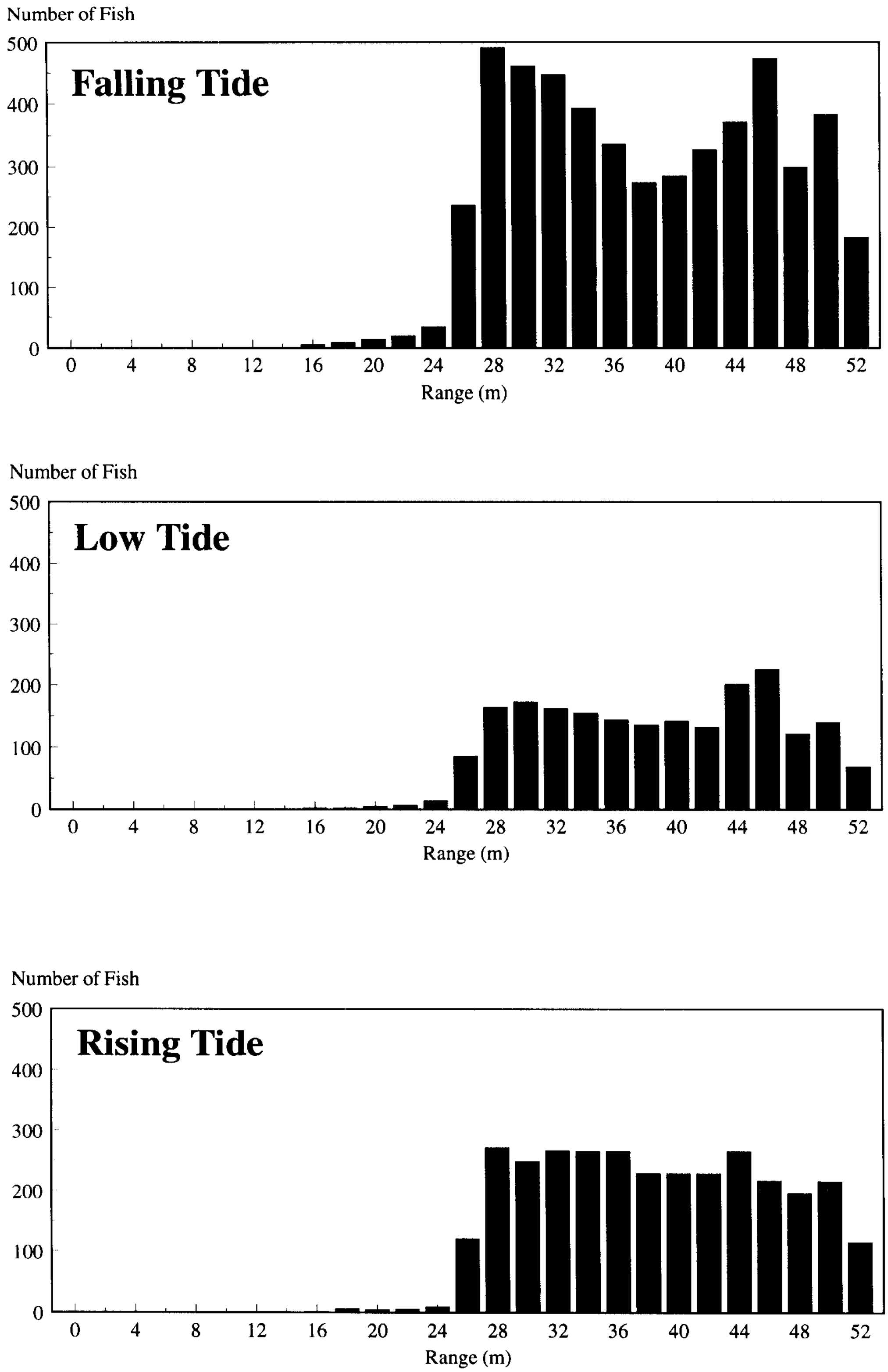


Figure 21.-Range distribution of late-run upstream-traveling fish during falling (top), low (middle), and rising (bottom) tide stages on the right bank, Kenai River, 1996.

Table 9.-Estimates of 1996 early-run fish passage by direction of travel. Variance estimates are in parenthesis.

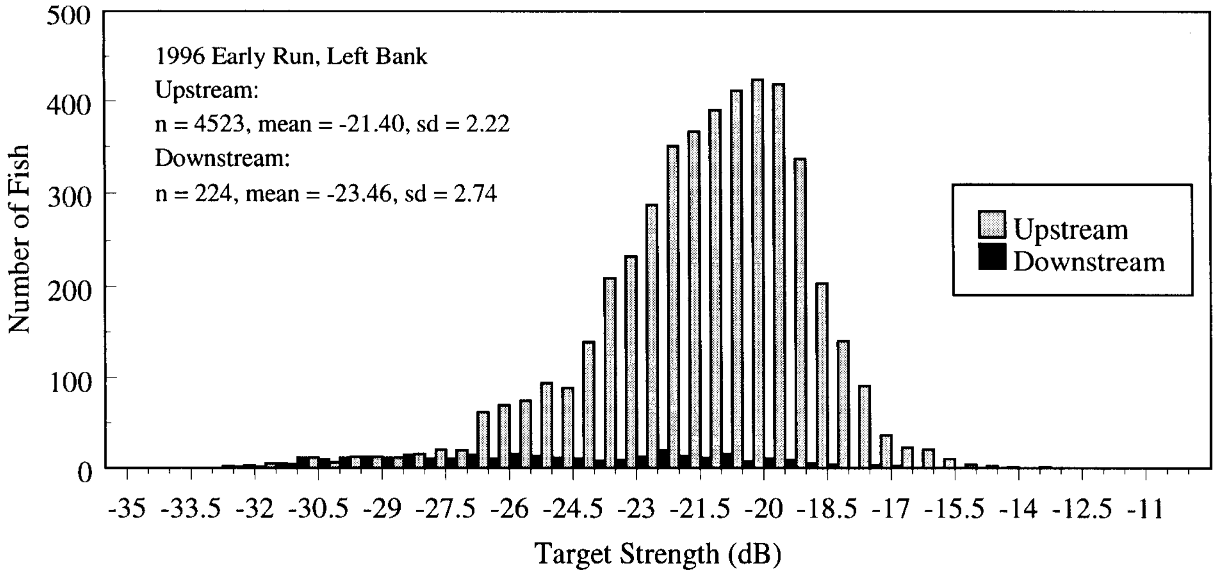
	Estimate of Total Fish Passage	Estimate of Downstream Component	Estimate of Upstream Component	Passage Adjusted For Downstream Component
Right Bank	9,092 (65,755)	850	8,242 (66,518)	7,392
Left Bank	14,413 (75,702)	672	13,741 (75,205)	13,069
Both Banks	23,505 (141,457)	1,522	21,983 (141,727)	20,461

Table 10.-Estimates of 1996 late-run fish passage by direction of travel. Variance estimates are in parenthesis.

	Estimate of Total Fish Passage	Estimate of Downstream Component	Estimate of Upstream Component	Passage Adjusted For Downstream Component
Right Bank	33,383 (909,819)	1,378	32,005 (878,836)	30,627
Left Bank	20,551 (200,168)	712	19,840 (195,700)	19,128
Both Banks	53,934 (1,109,987)	2,090	51,845 (1,074,536)	49,755

Table 11.-Mean target strength for upstream and downstream targets by bank during the early (16 May-30 June) and late (1 July-31 July) runs, 1996.

	Upstream			Downstream		
Early Run	mean	SD	n	mean	SD	n
Left Bank	-21.56	2.48	4,609	-25.33	3.77	316
Right Bank	-25.55	2.25	3,027	-26.59	2.23	384
Late Run						
Left Bank	-22.65	2.29	7,278	-25.46	3.56	398
Right Bank	-27.24	2.16	18,684	-27.29	2.42	1,005



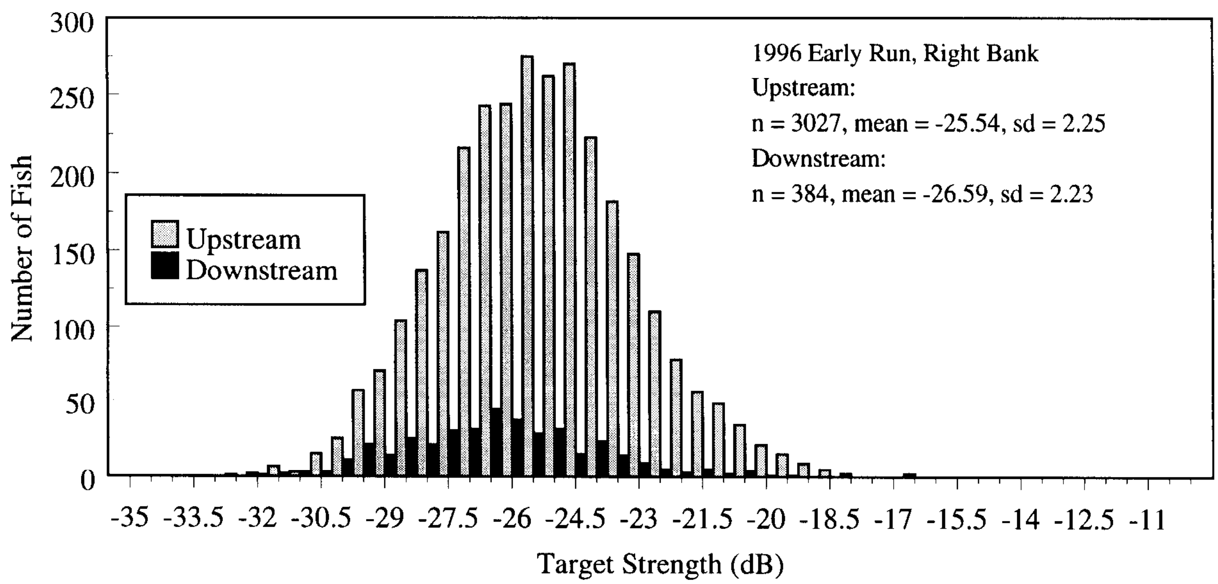
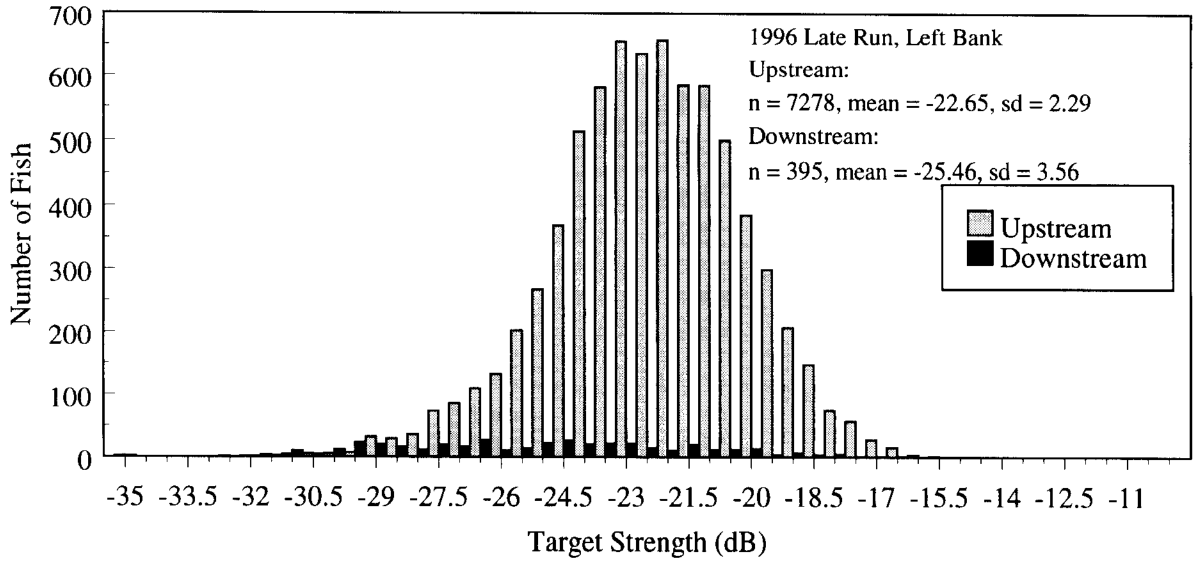


Figure 22.-Early-run target strength distributions for upstream and downstream fish on the left (top) and right (bottom) banks.



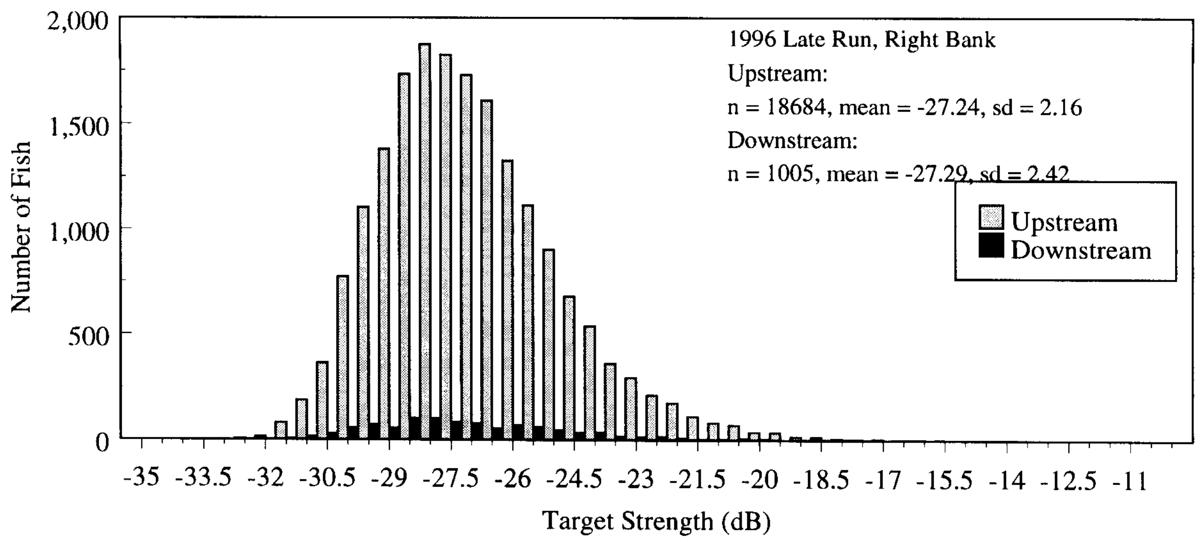


Figure 23.-Late-run target strength distributions for upstream and downstream fish on the left (top) and right (bottom) banks.

Table 12.-Estimated daily chinook salmon passage, Kenai River Sonar, early run, 1996.

Date	Left Bank	Right Bank	Daily Total	Cumulative Total
16-May	45	15	60	60
17-May	57	34	91	151
18-May	18	45	63	214
19-May	60	36	96	310
20-May	102	75	177	487
21-May	75	90	165	652
22-May	54	102	156	808
23-May	57	102	159	967
24-May	57	102	159	1,126
25-May	66	87	153	1,279
26-May	87	153	240	1,519
27-May	117	87	204	1,723
28-May	231	99	330	2,053
29-May	291	221	512	2,565
30-May	165	183	348	2,913
31-May	219	255	474	3,387
1-Jun	333	270	603	3,990
2-Jun	409	332	741	4,730
3-Jun	645	228	873	5,603
4-Jun	600	451	1,051	6,654
5-Jun	559	384	943	7,597
6-Jun	444	297	741	8,338
7-Jun	420	353	773	9,110
8-Jun	605	313	918	10,028
9-Jun	648	492	1,140	11,168
10-Jun	402	282	684	11,852
11-Jun	549	333	882	12,734
12-Jun	609	255	864	13,598
13-Jun	804	267	1,071	14,669
14-Jun	796	315	1,111	15,780
15-Jun	741	375	1,116	16,896
16-Jun	261	159	420	17,316
17-Jun	351	144	495	17,811
18-Jun	504	193	697	18,508
19-Jun	471	186	657	19,165
20-Jun	225	90	315	19,480
21-Jun	225	126	351	19,831
22-Jun	243	153	396	20,227
23-Jun	188	213	401	20,628
24-Jun	354	219	573	21,201
25-Jun	414	270	684	21,885
26-Jun	306	198	504	22,389
27-Jun	99	129	228	22,617
28-Jun	162	141	303	22,920
29-Jun	144	90	234	23,154
30-Jun	201	150	351	23,505

Table 13.-Estimated daily chinook salmon passage, Kenai River Sonar, late run, 1996.

Date	Left Bank	Right Bank	Daily Total	Cumulative Total
1-Jul	169	172	341	341
2-Jul	60	180	240	581
3-Jul	96	207	303	884
4-Jul	129	264	393	1,277
5-Jul	317	750	1,067	2,343
6-Jul	357	522	879	3,222
7-Jul	303	477	780	4,002
8-Jul	348	519	867	4,869
9-Jul	207	561	768	5,637
10-Jul	400	623	1,023	6,660
11-Jul	339	807	1,146	7,806
12-Jul	222	492	714	8,520
13-Jul	390	738	1,128	9,648
14-Jul	1,101	3,336	4,437	14,085
15-Jul	840	2,382	3,222	17,308
16-Jul	1,143	2,351	3,494	20,802
17-Jul	960	1,293	2,253	23,054
18-Jul	1,065	1,755	2,820	25,874
19-Jul	846	1,390	2,236	28,110
20-Jul	1,176	1,433	2,609	30,719
21-Jul	1,303	2,132	3,435	34,155
22-Jul	753	1,497	2,250	36,405
23-Jul	1,350	1,700	3,050	39,455
24-Jul	1,686	1,948	3,634	43,089
25-Jul	1,377	1,863	3,240	46,329
26-Jul	987	1,332	2,319	48,648
27-Jul	702	1,080	1,782	50,430
28-Jul	444	417	861	51,291
29-Jul	204	270	474	51,765
30-Jul	342	279	621	52,386
31-Jul	936	612	1,548	53,934

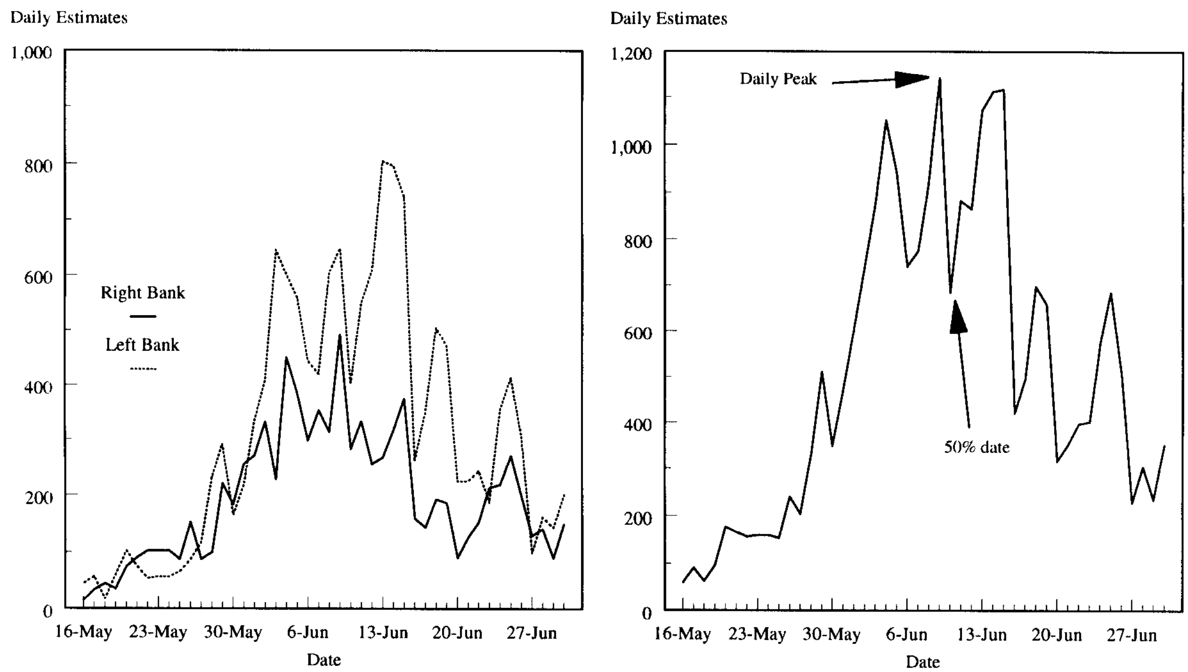


Figure 24.-Daily sonar estimates of passage for the early run of chinook salmon returning to the Kenai River, 1996. Estimates by bank (left) and total run (right).

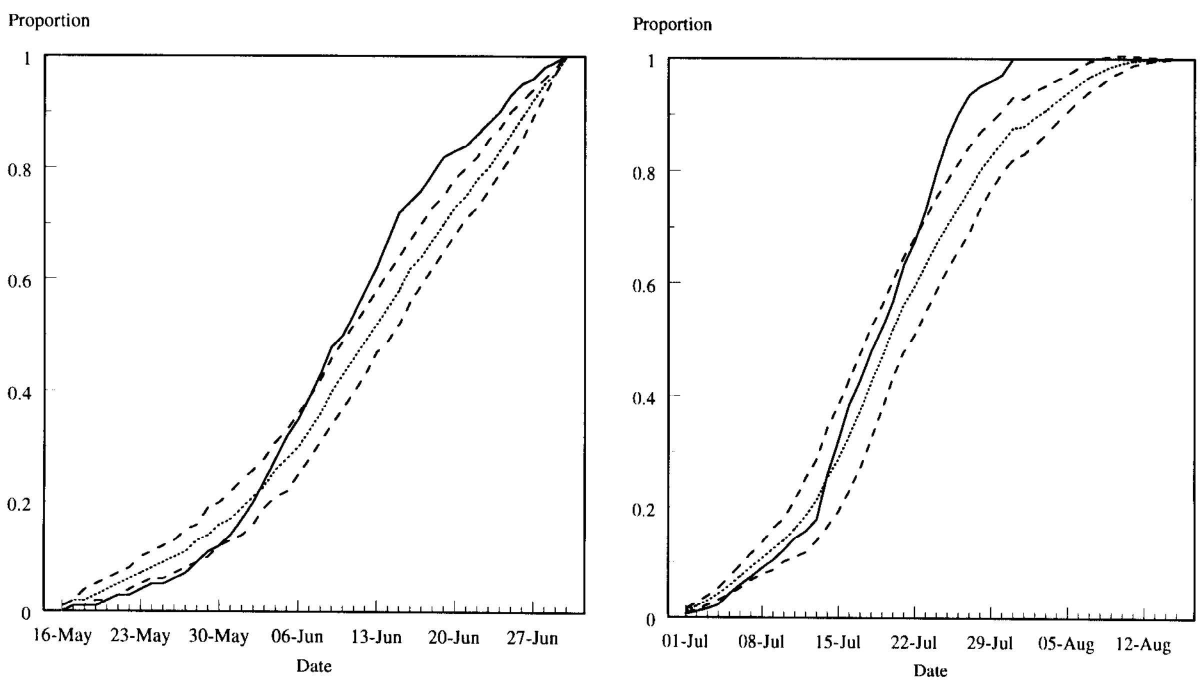


Figure 25.-Migratory-timing curves for early (left) and late (right) runs of chinook salmon to the Kenai River, 1996 (solid lines). Mean migratory-timing curves for the years 1987-1995 (dotted lines), and 95% confidence intervals (dashed lines) are presented for comparison.

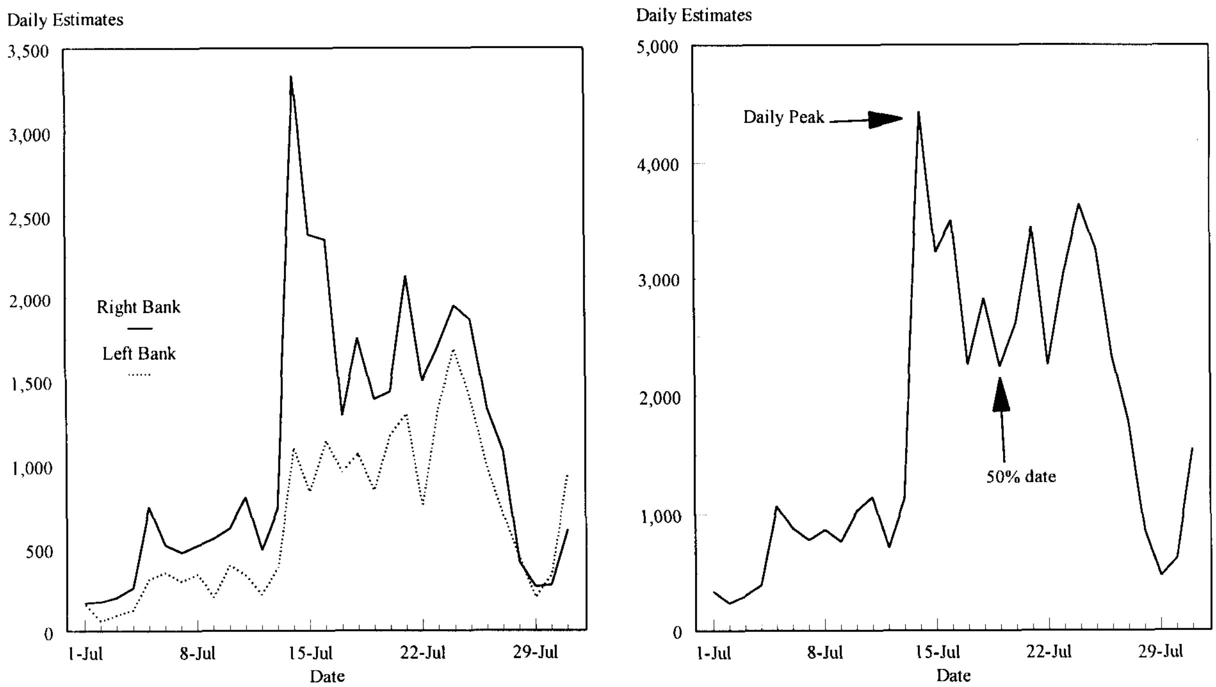


Figure 26.-Daily sonar estimates of passage for the late run of chinook salmon returning to the Kenai River, 1996. Estimates by bank (left) and total run (right).

the average mean discharge for June and 2,110 cubic feet per second lower than the average mean July discharge rates for water years 1965-1995 (USGS 1996). These lower discharge rates translate into slower water velocities in the main channel of the river. Migrating fish may have taken advantage of this and passed the sonar site in the deeper water of the main channel located near the left bank (Figure 2).

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. The 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, the majority of 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 of the early run (Figure 8, Figure 9), relatively few fish occupied the upper edge of the beam. Consequently, it does not appear that significant numbers of fish are swimming above the beam. The tendency to rise off the bottom during the rising tide may be related to low discharge levels in 1996 since this pattern is inconsistent with vertical distributions during the 1996 late run (Figure 12, Figure 13) and with data collected in previous years where fish maintained a strong bottom orientation during all three tide stages (Eggers et al. 1995, Burwen et al. 1995).

Range Distribution

The range distribution of upstream-moving chinook on the left bank was similar between runs. These fish were generally channel-oriented, with a majority passing the sonar between 15 m and 20 m. A drop in the left bank distribution between 19 m and 21 m suggests the presence of a sound shadow which may have limited target detection (Figure 14, Figure 18) in this area. Finding an optimal aim on the left bank is typically more difficult than on the right bank due to the reflective cobble and less uniform bottom topography.

On the right bank, range distributions of upstream fish differed between runs. The range distribution during the early run was similar to the left bank where fish where generally channel-oriented (Figure 15). However, during the late run, the range distribution was more bimodal with a nearshore peak in the 26-28 m range and a second peak in the 44-46 m range (Figure 19). A potential explanation for this late-run distribution is discussed later. It should be noted that the right-bank range distribution is artificially truncated at 25 m 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, increasing the maximum range a few meters each time.

Target Strength

Differences in mean target strength between banks can most likely be explained by the effects of threshold-induced bias (Ehrenberg and Torkelson 1996, Wiemer and Ehrenberg 1975) rather than actual differences in fish size. 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 a more acoustically-reflective gravel compared to the acoustically-lossy 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.

Direction of Travel and Debris

The 1996 passage estimates are the first such estimates of Kenai River chinook salmon adjusted for downstream migrants. For the 1996 estimate of net upstream migration, we assumed that all downstream targets retained after initial filtering were valid fish targets (i.e. no debris was included). The downstream component of both runs was fairly small at 6.5% and 3.9% for the early and late runs, respectively. Consequently, early- and late-run estimates of net upstream passage were approximately 13% and 8% lower than the total passage estimates.

The primary concern with respect to both identifying and integrating downstream targets into estimates of fish passage centers around the accuracy with which we can correctly classify downstream targets as either fish or debris. A target moving actively upstream against current is clearly a fish. However, some downstream-moving targets may be debris that meet threshold criteria for valid fish targets (i.e., target strength, range and pulse width criteria).

Mean target strength distributions of upstream and downstream targets suggest that most downstream targets on the right bank were correctly classified as fish whereas on the left bank, some debris may have been incorrectly classified as downstream-traveling fish. Target strength distributions for upstream and downstream fish on the right bank were similar for both early and late runs (Table 11,

Figure 22, Figure 23). The downstream target strength distributions were unimodal and corresponded to the modes of the upstream target strength distributions. This indicates little contamination by debris in classifying downstream targets on the right bank. However, fish moving downstream on the left bank during both runs were, on average, considerably smaller than fish moving upstream on the left bank. The mean target strength estimates for upstream fish, for both runs, were 2 to 3 dB larger than the mean target strength estimates of downstream fish (Figure 22, Figure 23). These differences in mean target strength estimates may reflect some contamination by debris. Alternatively, left bank downstream fish may be more affected by threshold-induced bias than right bank downstream fish. On the left bank, the average vertical position of downstream fish was two to three times closer to the acoustic axis than that of upstream-moving fish, thus reducing the effects of threshold-induced bias and causing them to appear smaller (Figure 6, Figure 10).

Misclassifying downstream targets as debris or fish may have a potentially large impact on passage estimates. We have elected to use a conservative approach by interpreting all downstream targets as fish. Several other approaches have been used for applying direction-of-travel information to estimates of fish passage. Many ADF&G sonar projects do not adjust passage estimates for downstream-moving fish because this information is not or has not been available and the downstream component is believed to be relatively small (Burwen et al. 1995). Other projects (Fleischman et al. 1995, Daum and Osborne 1996) simply do not include downstream-moving fish in passage estimates (this is the equivalent of subtracting one fish for each downstream fish from the total count of fish). This method assumes that all downstream-moving targets are debris since, if a downstream target is actually a fish, two fish should be subtracted from the total count of targets.

Species Classification

We continue to evaluate the ability of the current configuration to segregate sockeye and chinook salmon. Several lines of evidence suggest that our chinook salmon passage estimates include some sockeye salmon. In a study of tethered chinook and sockeye salmon, Burwen et al. (1995) found that target strength was too variable to provide complete separation of sockeye and chinook salmon. In a concurrent netting study, sockeye salmon were found in the middle insonified portion of the river beyond current range thresholds.

Results of a 1996 radiotelemetry study (Hammarstrom and Hasbrouck *In prep*) showed that sonar estimates may be biased high during periods of high sockeye salmon abundance. During the time period from 1 July to 31 July, the sonar estimate of 49,755 (SE = 1,037) chinook salmon was 26% higher than the estimate obtained from the radiotelemetry study of 39,356 (SE = 3,535). These estimates were further broken down into estimates for two time periods, (1) from 1 July to 13 July, when approximately 25,000 sockeye salmon entered the river, and (2) from 14 July to 31 July, when approximately 600,000 sockeye salmon entered the river. The estimates differed by only 1% during the first period whereas the radiotelemetry study estimated 8,246 chinook salmon (SE = 1,511) compared to 8,318 chinook salmon (SE = 255) estimated by the sonar. However, during the second period, the estimates differed by 13% with the inriver return estimated at 36,596 (SE = 3,491) chinook salmon by the radio-tag study and 41,437 (SE = 1,011) by the sonar.

During 1996, changes in range distribution on the right bank were correlated with sockeye salmon abundance. During the early run, when relatively few (<250,000) sockeye salmon were present, fish were channel oriented (Figure 15). During the late run, when a large (>500,000) run of sockeye salmon occurs, fish were more evenly distributed (Figure 19). Range distribution also differed between the first half of July when few late-run sockeye were present and the second half of July when late-run sockeye were abundant. Fish were channel-oriented during 1-13 July (Figure 27), but were more evenly distributed across all ranges during 14-31 July (Figure 28). Left-bank range distributions did not show the same trends. It is likely that the right bank, with its slower water velocities and gradual slope, is favored by sockeye salmon. The higher velocities on the left bank may also force sockeye salmon closer to shore where they would be missed by a relatively small beam or pass behind the left-bank transducer.

We continue to pursue improved techniques for separating chinook and sockeye salmon using acoustic information. Results of the tethered fish study indicated that pulse width may provide higher discriminatory power than target strength for separating sockeye and chinook salmon. The feasibility of using pulse width as an additional species discriminator at the Kenai River site is being investigated (Burwen and Fleischman *In prep*).

ACKNOWLEDGMENTS

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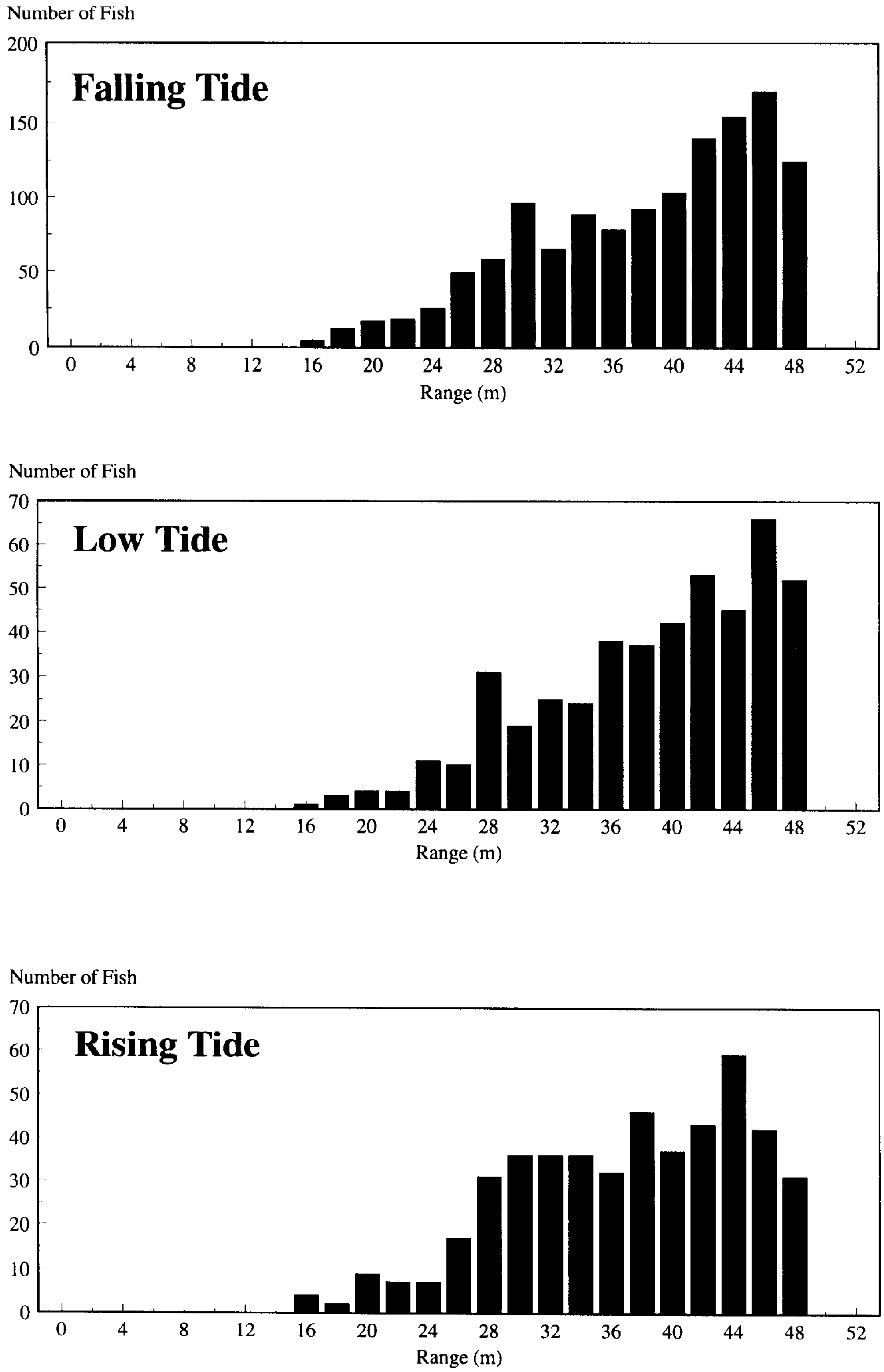

Figure 27.-Range distribution of late-run upstream-traveling fish from 1-13 July during falling (top), low (middle), and rising (bottom) tide stages on the right bank, Kenai River, 1996.

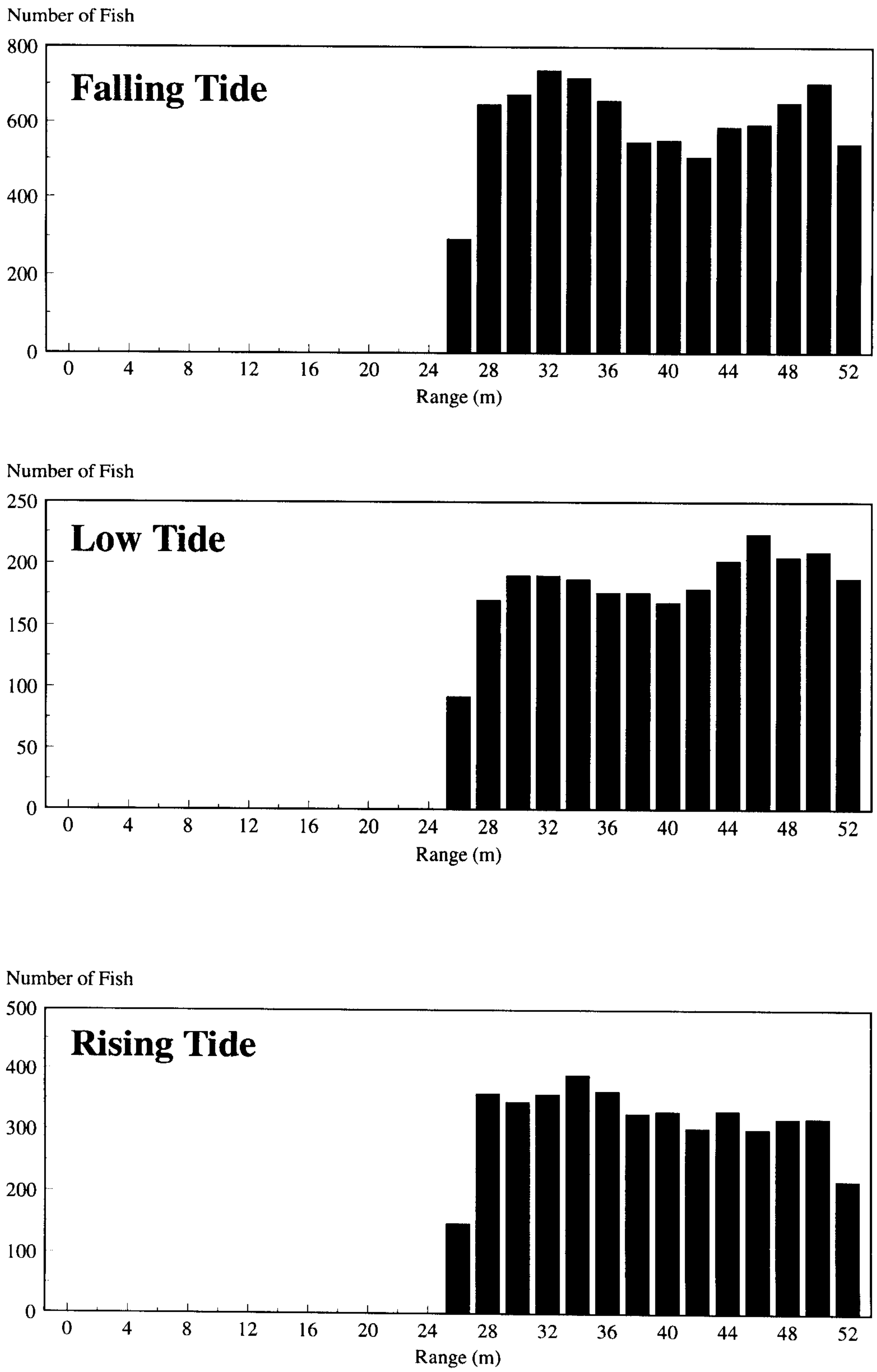

Figure 28.-Range distribution of late-run upstream-traveling fish from 14-31 July during falling (top), low (middle), and rising (bottom) tide stages on the right bank, Kenai River, 1996.

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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 m), θ degrees from the maximum response axis (MRA) in one plane and ϕ degrees from the MRA in the other plane is estimated as:

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

where:

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

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

Appendix B1.-Criteria used for the collection of echoes for the right bank transducer.

* Start Processing at Port 1 -FILE_PARAMETERS- Wed Aug 09 06:00:00 1996

* 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	5	max_tbp - maximum time between pings in pings
106	-1	7	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	220.4900	sl - transducer source level
202	-1	-170.9500	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	47.0000	echogram stop range in meters
211	-1	672.0000	echogram threshold in millivolts
212	-1	13.2000	print width in inches
213	-1	-40.0000	ts plot minimum target strength in dB
214	-1	-10.0000	ts plot maximum target strength in dB

-continued-

215	-1	0.0000	range plot minimum in meters
216	-1	60.0000	range plot maximum in meters
217	-1	-2.0000	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	-7.8000	ux - horizontal electrical to mechanical angle ratio
223	-1	-16.3283	uy - vertical electrical to mechanical angle ratio
224	-1	0.0000	ud_coef_a - a coeff. for up-down beam pattern eq.
225	-1	-0.0010	ud_coef_b - b coeff. for up-down beam pattern eq.
226	-1	-2.6482	ud_coef_c - c coeff. for up-down beam pattern eq.
227	-1	0.0276	ud_coef_d - d coeff. for up-down beam pattern eq.
228	-1	-0.1467	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	-0.2014	lr_coef_c - c coeff . for left-rt beam pattern eq.
232	-1	-0.0003	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	5.0000	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	40.2000	bottom - bottom depth in meters
239	-1	0.0000	init_slope - initial slope for tracking in m/ping
240	-1	0.0000	exp_cont - exponent for expanding tracking window
241	-1	0.3500	max_ch_rng - maximum change in range in m/ping
242	-1	0.1000	pw_criteia->min_pw_6-min -6 dB pulse width
243	-1	0.4000	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	-18.0000	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	0.0000	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)
300	0	0	
300	1	16256	
300	2	0	
300	3	16544	
300	4	0	
300	5	16800	
401	0	5.0000	th_layer[0] - bottom of first threshold layer (m)
401	1	25.0000	th_layer[1] - bottom of second threshold layer (m)
401	2	50.0000	th_layer[2] - bottom of third threshold layer (m)
401	3	60.0000	th_layer[3] - bottom of forth threshold layer (m)
401	4	100.0000	th_layer[4] - bottom of fifth threshold layer (m)
402	0	672.0000	th_val[0] - thr. for 1st layer (mV)
402	1	672.0000	th_val[1] - thr. for 2nd layer (mV)
402	2	672.0000	th_val[2] - thr. for 3rd layer (mV)
402	3	672.0000	th_val[3] - thr. for 4th layer (mV)
402	4	9999.0000	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	305785	Echo sounder serial number
603	-1	HTISB-2.8X10	Transducer type
604	-1	306733	Transducer serial number
605	-1	Spd-3	Echogram paper speed
606	-1	9_pin	Echogram resolution
607	-1	Board_External	Trigger option
608	-1	Left_to_Right-->	River flow direction
609	-1	All_Fish	Fish included in 3d plot
610	-1	OFF	Echogram enable flag
611	-1	C:\SBDATA\K	Drive and first letter to send files

Appendix B2.-Criteria used for the collection of echoes for the left bank transducer.

* Start Processing at Port 2 -FILE_PARAMETERS- Wed Aug 09 06:00:00 1996

* 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	5	max_tbp - maximum time between pings in pings
106	-1	10	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	218.31000	sl - transducer source level
202	-1	-173.0300	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	25.0000	echogram stop range in meters
211	-1	411.0000	echogram threshold in millivolts
212	-1	13.2000	print width in inches
213	-1	-60.0000	ts plot minimum target strength in dB
214	-1	-30.0000	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	-2.0000	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	-22.0000	max_dB_off - maximum angle off in dB
222	-1	-7.7942	ux - horizontal electrical to mechanical angle ratio
223	-1	-28.9652	uy - vertical electrical to mechanical angle ratio
224	-1	0.0000	ud_coef_a - a coeff. for up-down beam pattern eq.
225	-1	-0.0013	ud_coef_b - b coeff. for up-down beam pattern eq.
226	-1	-2.5944	ud_coef_c - c coeff. for up-down beam pattern eq.
227	-1	-0.0379	ud_coef_d - d coeff. for up-down beam pattern eq.
228	-1	-0.1352	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	-0.2052	lr_coef_c - c coeff . for left-rt beam pattern eq.
232	-1	-0.0002	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	5.0000	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	22.3000	bottom - bottom depth in meters
239	-1	0.0000	init_slope - initial slope for tracking in m/ping
240	-1	0.0000	exp_cont - exponent for expanding tracking window
241	-1	0.3500	max_ch_rng - maximum change in range in m/ping
242	-1	0.1500	pw_criteria->min_pw_6-min -6 dB pulse width
243	-1	0.3000	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	0.0000	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	0.0000	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	50.0000	th_layer[2] - bottom of third threshold layer (m)
401	3	100.0000	th_layer[3] - bottom of forth threshold layer (m)
402	0	411.0000	th_val[0] - thr. for 1st layer (mV)
402	1	411.0000	th_val[1] - thr. for 2nd layer (mV)
402	2	411.0000	th_val[2] - thr. for 3rd layer (mV)
402	3	411.0000	th_val[3] - thr. for 4th layer (mV)
402	4	411.0000	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	305785	Echo sounder serial number
603	-1	HTISB-2.8X10	Transducer type
604	-1	306738	Transducer serial number
605	-1	Spd-3	Echogram paper speed
606	-1	9_pin	Echogram resolution
607	-1	Board_External	Trigger option
608	-1	Right_to_Left-->	River flow direction
609	-1	All_Fish	Fish included in 3d plot
610	-1	OFF	Echogram enable flag
611	-1	C:\SBDATA\K	Drive and first letter to send files

APPENDIX C. DAILY PROPORTIONS OF UPSTREAM AND DOWNSTREAM FISH FOR THE 1996 EARLY AND LATE KENAI RIVER CHINOOK RUNS.

Appendix C1.-Daily proportions of upstream and downstream fish for the 1996 Kenai River early chinook run.

Date	Downstream Count	Upstream Count	Daily Total	Percent Downstream	Percent Upstream
16-May	6	54	60	10.0%	90.0%
17-May	22	69	91	24.2%	75.8%
18-May	3	60	63	4.8%	95.2%
19-May	0	96	96	0.0%	100.0%
20-May	3	174	177	1.7%	98.3%
21-May	15	150	165	9.1%	90.9%
22-May	15	141	156	9.6%	90.4%
23-May	15	144	159	9.4%	90.6%
24-May	9	150	159	5.7%	94.3%
25-May	3	150	153	2.0%	98.0%
26-May	3	237	240	1.3%	98.8%
27-May	0	204	204	0.0%	100.0%
28-May	0	330	330	0.0%	100.0%
29-May	6	506	512	1.2%	98.8%
30-May	18	330	348	5.2%	94.8%
31-May	18	456	474	3.8%	96.2%
1-Jun	42	561	603	7.0%	93.0%
2-Jun	30	711	741	4.1%	95.9%
3-Jun	60	813	873	6.9%	93.1%
4-Jun	57	994	1,051	5.4%	94.6%
5-Jun	75	868	943	8.0%	92.0%
6-Jun	39	702	741	5.3%	94.7%
7-Jun	69	704	773	8.9%	91.1%
8-Jun	81	837	918	8.8%	91.2%
9-Jun	90	1,050	1,140	7.9%	92.1%
10-Jun	48	636	684	7.0%	93.0%
11-Jun	48	834	882	5.4%	94.6%
12-Jun	21	843	864	2.4%	97.6%
13-Jun	42	1,029	1,071	3.9%	96.1%
14-Jun	60	1,051	1,111	5.4%	94.6%
15-Jun	51	1,065	1,116	4.6%	95.4%
16-Jun	15	405	420	3.6%	96.4%
17-Jun	54	441	495	10.9%	89.1%
18-Jun	24	673	697	3.4%	96.6%
19-Jun	51	606	657	7.8%	92.2%
20-Jun	42	273	315	13.3%	86.7%
21-Jun	30	321	351	8.5%	91.5%
22-Jun	30	366	396	7.6%	92.4%
23-Jun	51	350	401	12.7%	87.3%
24-Jun	51	522	573	8.9%	91.1%
25-Jun	48	636	684	7.0%	93.0%
26-Jun	42	462	504	8.3%	91.7%
27-Jun	15	213	228	6.6%	93.4%
28-Jun	30	273	303	9.9%	90.1%
29-Jun	24	210	234	10.3%	89.7%
30-Jun	66	285	351	18.8%	81.2%
Total	1,522	21,983	23,505	6.5%	93.5%

Appendix C2.-Daily proportions of upstream and downstream fish for the 1996 Kenai River late chinook run.

Date	Downstream Count	Upstream Count	Daily Total	Percent Downstream	Percent Upstream
1-Jul	30	311	341	8.8%	91.2%
2-Jul	54	186	240	22.5%	77.5%
3-Jul	60	243	303	19.8%	80.2%
4-Jul	48	345	393	12.2%	87.8%
5-Jul	71	996	1,067	6.6%	93.4%
6-Jul	72	807	879	8.2%	91.8%
7-Jul	66	714	780	8.5%	91.5%
8-Jul	36	831	867	4.2%	95.8%
9-Jul	42	726	768	5.5%	94.5%
10-Jul	76	947	1,023	7.4%	92.6%
11-Jul	54	1,092	1,146	4.7%	95.3%
12-Jul	36	678	714	5.0%	95.0%
13-Jul	21	1,107	1,128	1.9%	98.1%
14-Jul	87	4,350	4,437	2.0%	98.0%
15-Jul	60	3,162	3,222	1.9%	98.1%
16-Jul	118	3,377	3,494	3.4%	96.6%
17-Jul	108	2,145	2,253	4.8%	95.2%
18-Jul	87	2,733	2,820	3.1%	96.9%
19-Jul	84	2,152	2,236	3.8%	96.2%
20-Jul	74	2,536	2,609	2.8%	97.2%
21-Jul	88	3,348	3,435	2.5%	97.5%
22-Jul	51	2,199	2,250	2.3%	97.7%
23-Jul	60	2,990	3,050	2.0%	98.0%
24-Jul	69	3,565	3,634	1.9%	98.1%
25-Jul	99	3,141	3,240	3.1%	96.9%
26-Jul	81	2,238	2,319	3.5%	96.5%
27-Jul	42	1,740	1,782	2.4%	97.6%
28-Jul	51	810	861	5.9%	94.1%
29-Jul	57	417	474	12.0%	88.0%
30-Jul	75	546	621	12.1%	87.9%
31-Jul	135	1,413	1,548	8.7%	91.3%
Total	2,090	51,845	53,934	3.9%	96.1%

APPENDIX D. AVERAGE VERTICAL ANGLE BY TIDE STAGE, RUN, BANK, AND FISH ORIENTATION (UPSTREAM OR DOWNSTREAM) FOR THE 1996 KENAI RIVER CHINOOK RUNS.

Appendix D1.-Average vertical angle by tide stage and orientation for the 1996 early Kenai River chinook run.

1996 Early Run, Left Bank

Tide Stage/Fish Orientation	Average Vertical Angle	Standard Deviation	Sample Size
Falling			
Downstream	-0.69	0.91	63
Upstream	-1.26	0.66	2,791
Tide Stage Total	-1.25	0.67	2,854
Low			
Downstream	-0.35	1.07	51
Upstream	-1.20	0.69	1,371
Tide Stage Total	-1.17	0.72	1,422
Rising			
Downstream	-0.21	0.99	110
Upstream	-0.52	1.00	361
Tide Stage Total	-0.45	1.01	471
Left Bank Total	-1.15	0.76	4,747

1996 Early Run, Right Bank

Tide Stage/Fish Orientation	Average Vertical Angle	Standard Deviation	Sample Size
Falling			
Downstream	-0.12	0.82	82
Upstream	-0.64	0.78	1,102
Tide Stage Total	-0.60	0.80	1,184
Low			
Downstream	-0.47	0.80	78
Upstream	-0.76	0.73	851
Tide Stage Total	-0.74	0.74	929
Rising			
Downstream	-0.13	0.81	123
Upstream	-0.07	0.87	652
Tide Stage Total	-0.08	0.86	775
Right Bank Total	-0.50	0.84	2,888

Appendix D2.-Average vertical angle by tide stage and orientation for the 1996 late Kenai River chinook run.

1996 Late Run, Left Bank

Tide Stage/Fish Orientation	Average Vertical Angle	Standard Deviation	Sample Size
Falling			
Downstream	-0.63	0.79	113
Upstream	-1.30	0.50	3,468
Tide Stage Total	-1.28	0.52	3,581
Low			
Downstream	-0.65	0.74	66
Upstream	-1.32	0.46	1,530
Tide Stage Total	-1.30	0.49	1,596
Rising			
Downstream	-0.52	0.82	59
Upstream	-0.99	0.74	1,540
Tide Stage Total	-0.97	0.75	1,599
Left Bank Total	-1.21	0.59	6,776

1996 Late Run, Right Bank

Tide Stage/Fish Orientation	Average Vertical Angle	Standard Deviation	Sample Size
Falling			
Downstream	-0.38	0.56	199
Upstream	-0.44	0.47	5,024
Tide Stage Total	-0.44	0.47	5,223
Low			
Downstream	-0.42	0.52	132
Upstream	-0.46	0.46	2,065
Tide Stage Total	-0.46	0.46	2,197
Rising			
Downstream	-0.21	0.71	127
Upstream	-0.10	0.58	3,149
Tide Stage Total	-0.10	0.58	3,276
Right Bank Total	-0.34	0.53	10,696