Fishery Data Series No. 99-03

# Estimates of Chinook Salmon Abundance in the Kenai River Using Split-Beam Sonar, 1997

by

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and

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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, $\chi^2$, 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 |

*FISHERY DATA SERIES NO. 99-03*

# ESTIMATES OF CHINOOK SALMON ABUNDANCE IN THE KENAI RIVER USING SPLIT-BEAM SONAR, 1997

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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 (before July 1) and late (after June 30) 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 3 August 1997 to be 62,383. This estimate is comprised of 11,776 early-run and 50,607 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 *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 of allocative conflicts. Chinook salmon are also harvested by the Upper Cook Inlet commercial sockeye salmon *O. nerka* 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 (before July 1) and late-run (after June 30) 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 draws 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, only the early run, during 1997, 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 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 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 effects of 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. 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 1998) and continued through the late run of 1997 (Hammarstrom and Hasbrouck *In prep*). This study was 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 radio telemetry technology avoided 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 1998).

The primary goal of this ongoing project is to provide daily and seasonal estimates of chinook salmon passage into the lower Kenai River. These estimates, used in conjunction with other run information, facilitate inseason management of the fishery. Additionally, the estimates contribute to a database used for long-term assessment of the Kenai River chinook salmon population.

# 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 1997 sonar site was located 14 km from the mouth of the Kenai River (Figure 1). This

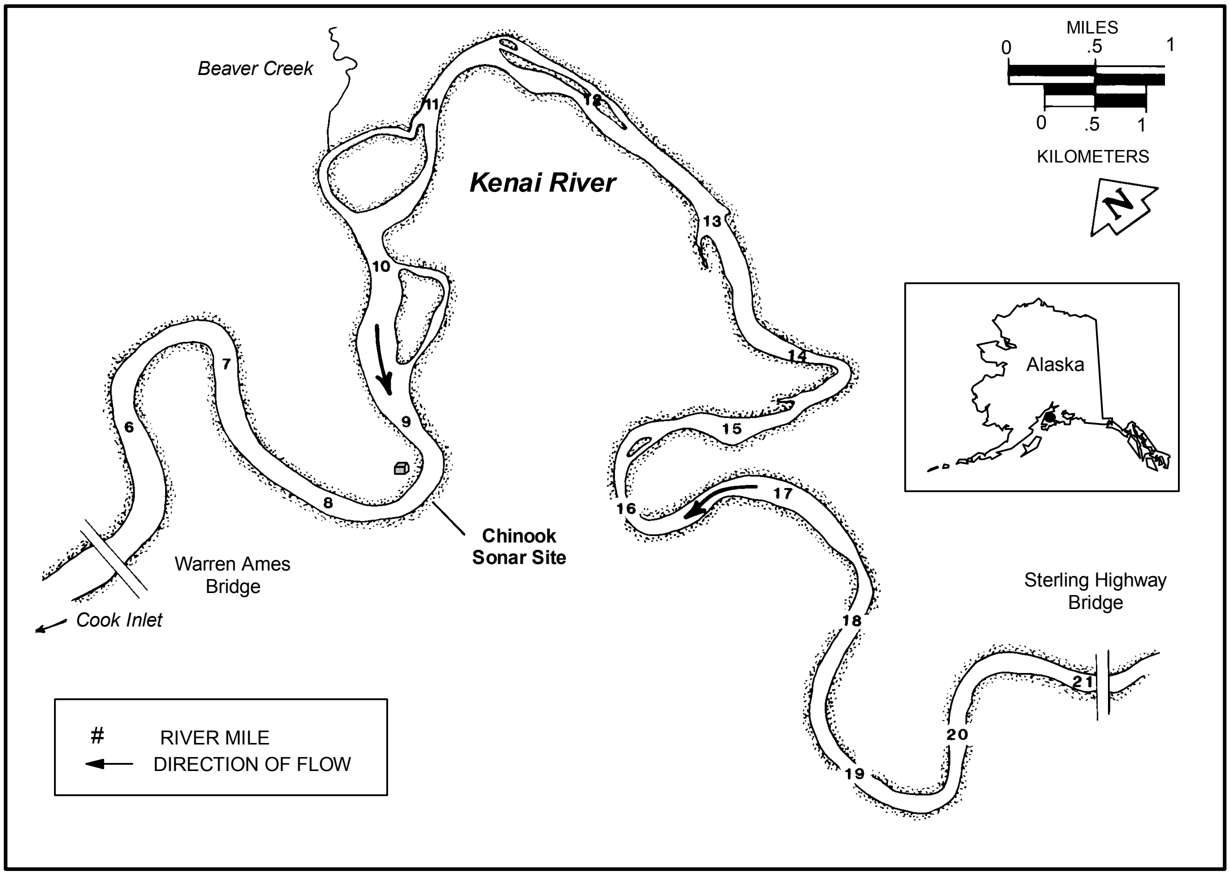



**Figure 1.-Map of lower Kenai River showing location of the 1997 sonar site.**

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 13 years despite a 100-year flood event during September 1995 (USGS 1996; Joe Dorava, United States Geological Survey [USGS], Anchorage, personal communication). The slope from both banks is gradual and uniform, which allows a large proportion of the water column to be insonified without acoustic shadowing effects. On the right bank, the bottom is composed primarily of mud, providing an acoustically absorptive 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, mostly during the late run.

## ACOUSTIC SAMPLING

The sonar system operated from 16 May through 3 August 1997. 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. From 16 May to 3 August 1997 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 62 m at the lowest water conditions to 86 m at high water.

**Table 1.-Principal components of the split-beam sonar system used in 1997.**

| 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:<br>Left Bank: nominal beam widths: $2.9^{o}$x$10.2^{o}$<br>Right Bank: nominal beam widths: $2.8^{o}$X$10^{o}$ |
| 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 |

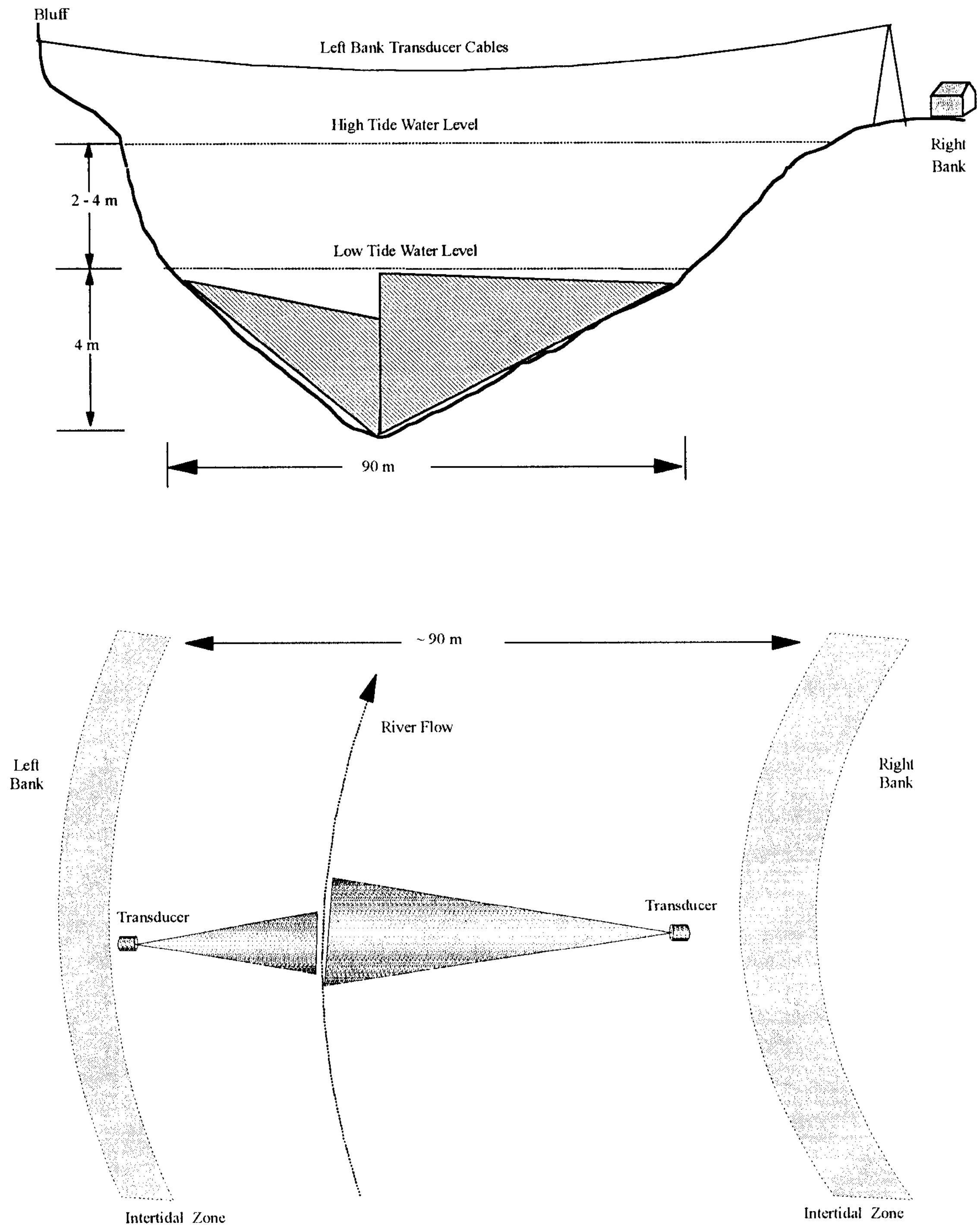



**Figure 2.-Aerial and cross-sectional views of sonar site showing insonified portions of the Kenai River, 1997.**

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 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 transducers 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.

**Table 2.-1997 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 |

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

## 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 echoes 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. Typically these values are set such that echoes located outside of the nominal beam width are ignored. Pulse width filters used in past years (Burwen and Bosch 1998) were removed in 1997 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.

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©. 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.

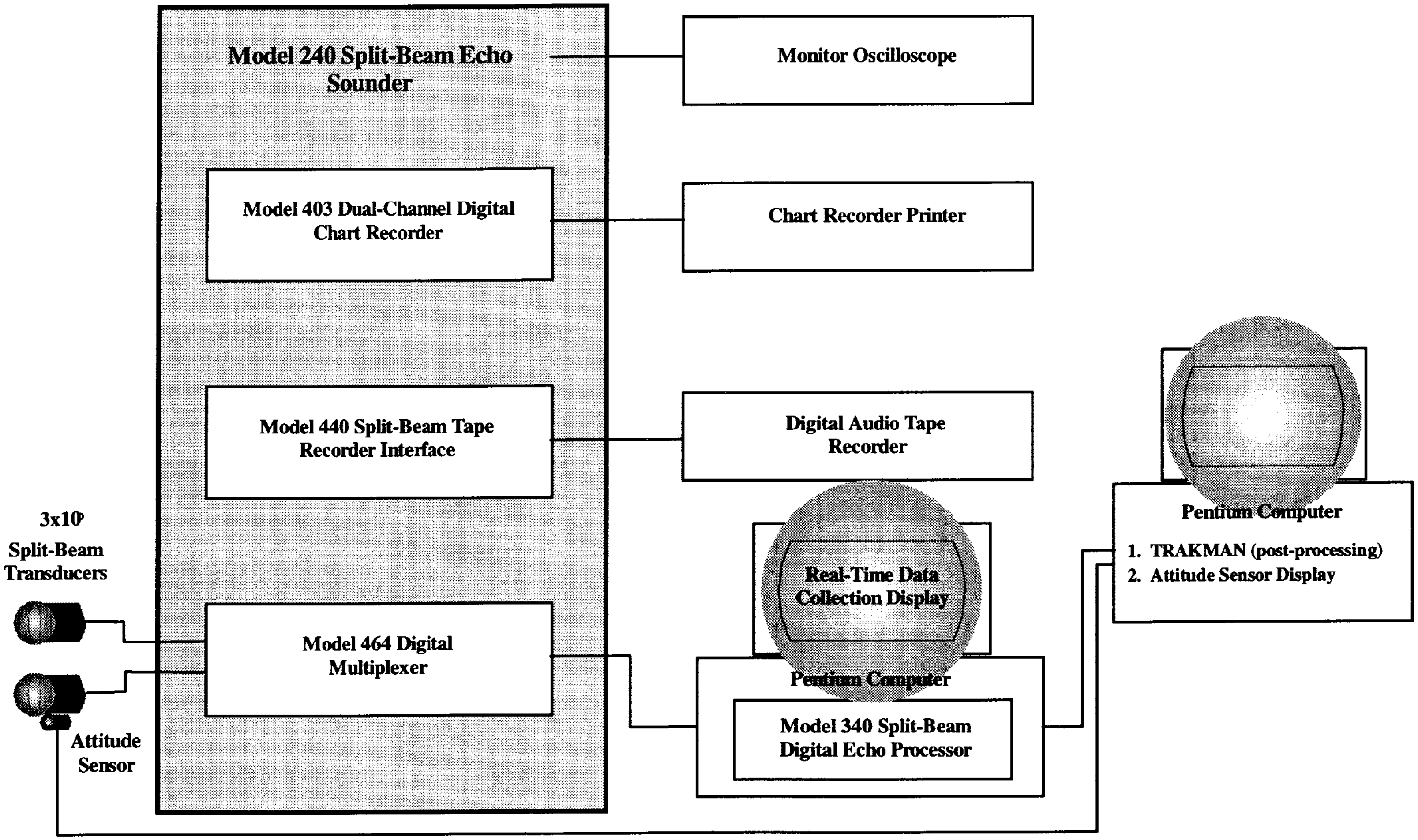



Figure 3.-Schematic diagram of 1997 split-beam sonar system configuration and data flow.

**Table 3.-Echo acceptance criteria for digital echo processing, 1997.**

| Bank | pulse width (ms) at -6 dB | Vertical angle off-axis (°) | Horizontal angle off-axis(°) | Threshold mV (dB) | Range (m) |
|---|---|---|---|---|---|
| Right | | | | | |
| 16 May to 2 July | 0.0 to 2.0 | -2.0 to 2.0 | -5.0 to 5.0 | > 762 (-35 dB) | >2.0 |
| 3-July to 3 Aug | 0.0 to 2.0 | -2.5 to 2.5 | -5.0 to 5.0 | >762 (-35 dB) | >2.0 |
| Left | | | | | |
| 16 May to 2 July | 0.0 to 2.0 | -2.0 to 2.0 | -5.0 to 5.0 | > 456 (-35 dB ) | >2.0 |
| 3-July to 3 Aug | 0.0 to 2.0 | -2.5 to 2.5 | -5.0 to 5.0 | > 456 (-35 dB ) | >2.0 |

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 1997, obvious debris-like downstream targets were excluded from consideration as valid fish targets 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 tracked 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 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:

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

where:

$\theta_y$ = 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 1997 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).

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 (16 May-3 August) on the left bank were deleted as were right-bank fish within 25 m (16 May through 3 August).

### Passage Estimates and Run Timing

To maintain comparability between recent (1995-1997) 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:

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

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

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

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

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

where:

$N_H$ = total number of hours during the run, and

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

$\phi_{bj}$ = 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 38.1 mm tungsten carbide standard sphere was measured at -39.2 dB and -38.5 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 -40.1 dB to -38.8 dB on the right bank and from -40.0 to -38.3 on the left bank (Table 4).

**Table 4.-Results of 1997 *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] | 8-May | -39.23 | 0.62 | 524 | 5.6 | N/A[c] | N/A |
| Kenai River | 12-May | -38.78 | 1.73 | 3,881 | 12.7 | 150 | 244 |
| Kenai River | 25-June | -39.7 | 1.84 | 2,772 | 10.3 | 80 | 244 |
| Kenai River | 30-July | -40.12 | 1.22 | 2,045 | 10.7 | 80 | 244 |
| | | | | **Left Bank** | | | |
| HTI[a] | 8-May | -38.49 | 0.54 | 925 | 5.7 | N/A[c] | N/A |
| Kenai River | 12-May | -38.29 | 1.41 | 3,456 | 13.8 | [b] | 144 |
| Kenai River | 25-June | -39.74 | 1.35 | 4,578 | 12.1 | <100 | 144 |
| Kenai River | 30-July | -39.9 | 1.27 | 3,986 | 10.5 | 60 | 144 |

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

[b] Background noise was not measured for the left bank on 12 May.

[c] Measurements conducted under controlled environment and measurements not available or not recorded.

## TARGET TRACKING

A total of 69,844 fish was manually tracked, 14,963 during the early run (16 May-30 June) and 54,881 during the late run (1 July-3 August). After filtering for range and target strength criteria, the proportion of upstream fish was 89.4% for the early run and 96.1% for the late run (Table 5, Table 6, Figure 4). Conversely, the proportions of downstream fish during the early and late runs were 10.6% 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 45 (SD = 39) and 38 (SD = 32) echoes per fish on the left and right banks, respectively. Downstream fish averaged 55 echoes (SD = 63) on the left bank and 51 echoes (SD = 47) on the right bank. During the late run the number of echoes per fish increased substantially for upstream moving fish on the right bank. Upstream fish averaged 41 (SD = 34) echoes on the left bank and 65 (SD = 40) echoes on the right bank. Downstream fish averaged 53 (SD = 54) echoes on the left bank and 58 (SD = 55) 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 (50.6%) and late (40.7%) runs (Table 5, Table 6, Figure 5). The highest proportion of downstream fish also occurred during the falling tide for both the early (38.2%) and late (45.5%) runs.

## 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, 87% of the upstream fish on the left bank (Figure 6) and 85% on the right bank (Figure 7) were below the acoustic axis. Downstream fish were less bottom-oriented. Seventy-two percent of downstream fish on the left bank (Figure 6) and 57% on the right bank (Figure 7) were below the acoustic axis. Upstream fish on the left bank (mean = -1.09$^o$, SD = 0.74, n = 2,043) were on average significantly lower ($P \ll 0.001$) in the water column than downstream fish (mean = -0.70 $^o$, SD = 0.86, n = 215). On the right bank, upstream fish (mean = -0.95 $^o$, SD = 0.70, n = 2,305) were also significantly lower in the water column ($P \ll 0.001$) than downstream fish (mean = -0.35 $^o$, SD = 0.86, n = 316). 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).

Late-run fish showed an even stronger tendency to travel along the river bottom (Figure 10, Figure 11). Ninety-three percent of upstream fish on the left bank and 83% of upstream fish on the right bank were below the acoustic axis. Eighty-seven percent of downstream fish on the left bank and 73% of downstream fish on the right bank were below the acoustic axis. Upstream fish on the left bank (mean = -1.36 $^o$, SD = 0.64, n = 3,138) traveled, on average, significantly lower ($P \ll 0.001$) in the water column than downstream fish (mean = -1.14 $^o$, SD = 0.78, n = 228). On the right bank, mean vertical angle also differed ($P \ll 0.001$) between upstream fish (mean = -0.62$^o$, SE = 0.46, n = 15,629) and downstream fish (mean = -0.47 $^o$, SD = 0.54, n = 522). 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 (Figure 14, Figure 15). There was significant difference between upstream and downstream range distributions for both the left (Anderson-Darling, P = 0.005) and right ($P <<< 0.05$) banks (Table 7,

**Table 5.-Estimates of chinook salmon passage by tide stage and direction of travel for the 1997 early run (16 May to 30 June).**

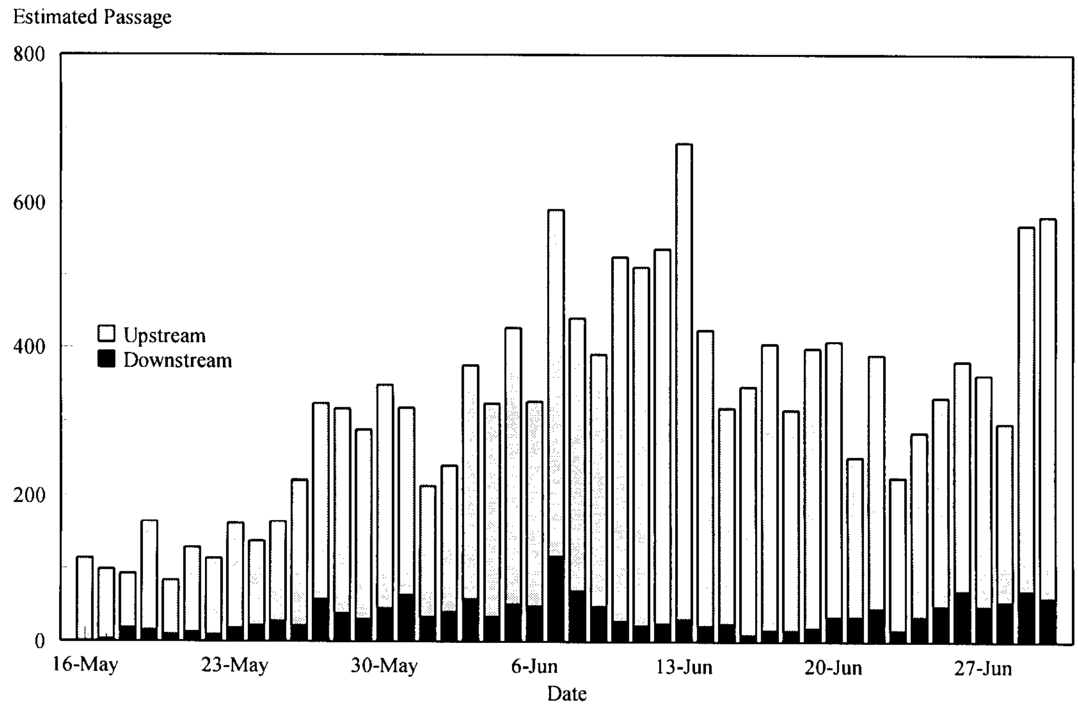
| 1997 Early Run | Total # of Fish | Rising | Falling | Low |
|---|---|---|---|---|
| Upstream | 13,370 | 2,982 | 6,768 | 3,620 |
| Row % | 100.0% | 22.3% | 50.6% | 27.1% |
| Column % | 89.4% | 83.4% | 91.8% | 90.2% |
| | | | | |
| Downstream | 1,593 | 592 | 608 | 393 |
| Row % | 100.0% | 37.2% | 38.2% | 24.7% |
| Column % | 10.6% | 16.6% | 8.2% | 9.8% |

Test for Independence: Chi-square = 179.43, df = 2, P<<<0.0001

**Table 6.-Estimates of chinook salmon passage by tide stage and direction of travel for the 1997 late run (1 July to 3 August).**

| 1997 Late Run | Total # of Fish | Rising | Falling | Low |
|---|---|---|---|---|
| Upstream | 52,743 | 19,898 | 21,464 | 11,381 |
| Row % | 100.0% | 37.7% | 40.7% | 21.6% |
| Column % | 96.1% | 96.8% | 95.7% | 95.7% |
| | | | | |
| Downstream | 2,138 | 652 | 973 | 513 |
| Row % | 100.0% | 30.5% | 45.5% | 24.0% |
| Column % | 3.9% | 3.2% | 4.3% | 4.3% |

Test for Independence: Chi-square = 45.8, df = 2, P <<<0.001



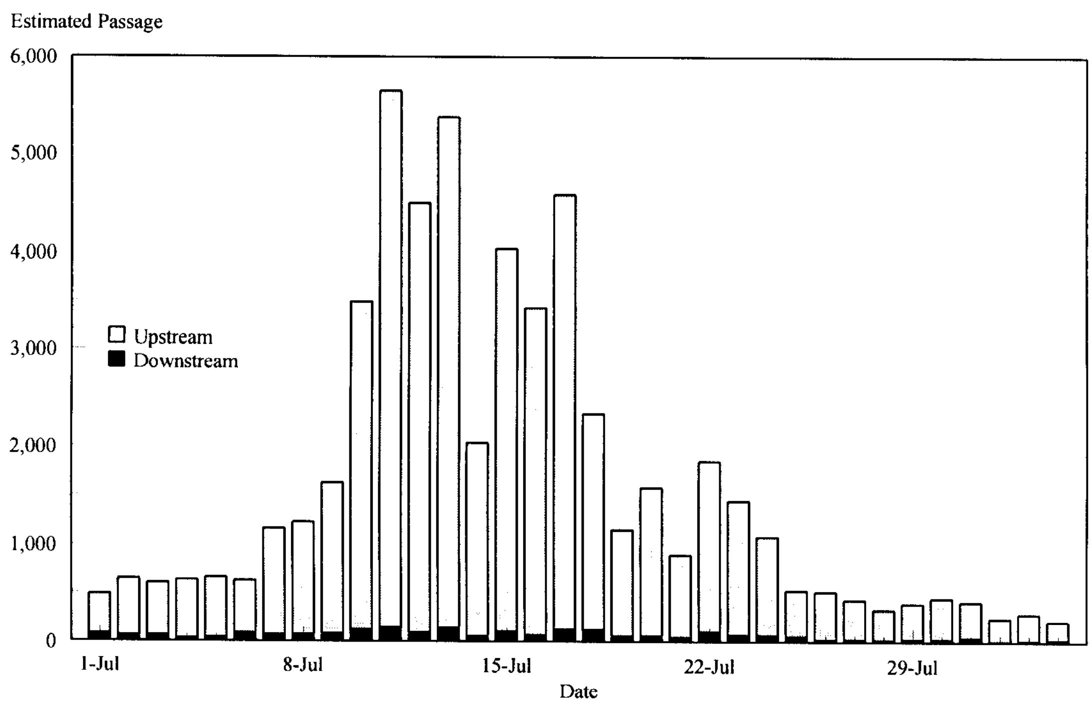




**Figure 4.-Upstream and downstream components of the early (top) and late (bottom) runs of chinook salmon to the Kenai River, 1997.**

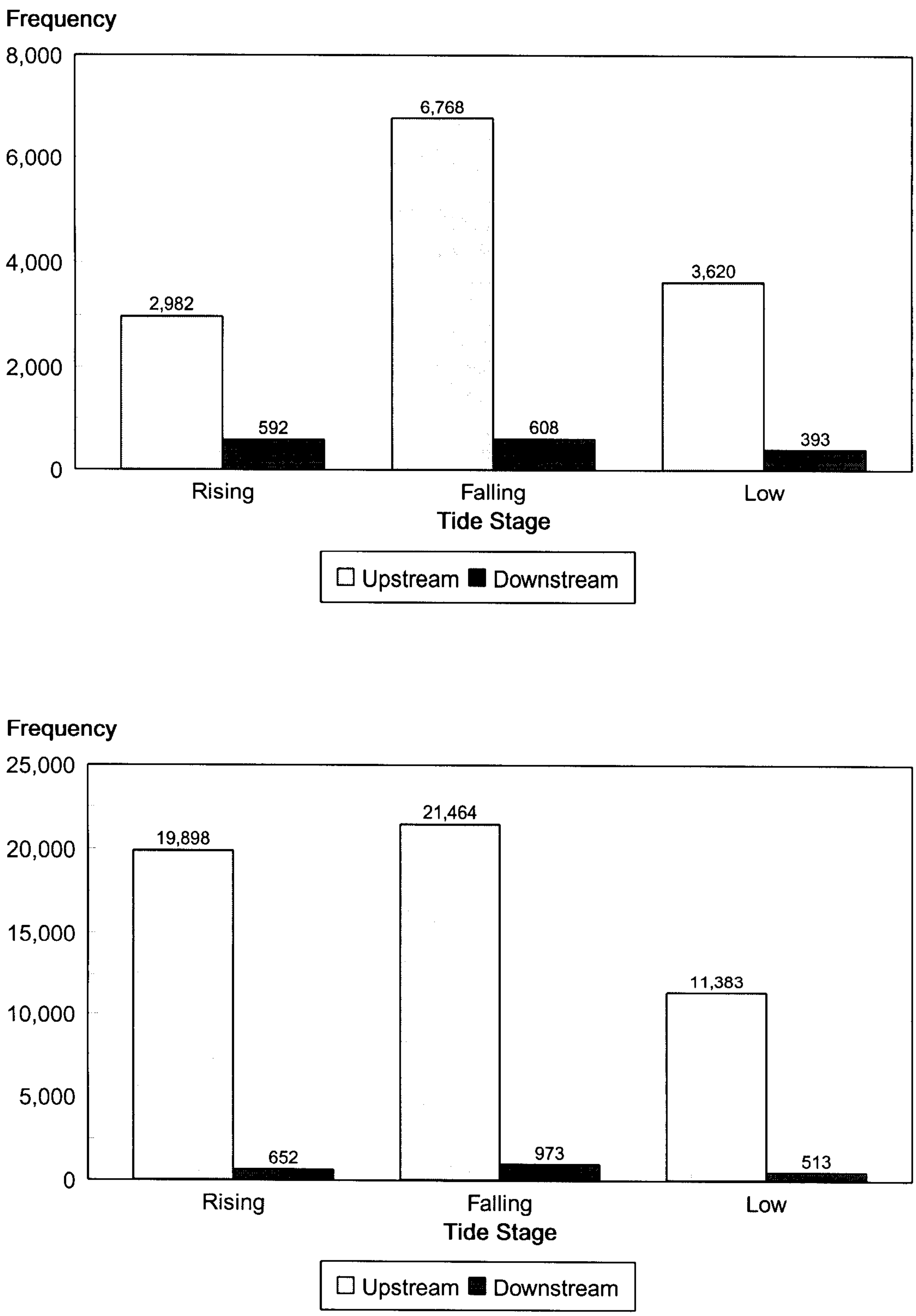



**Figure 5.-Distribution of upstream and downstream fish by tide stage during the early run (top) and late run (bottom).**

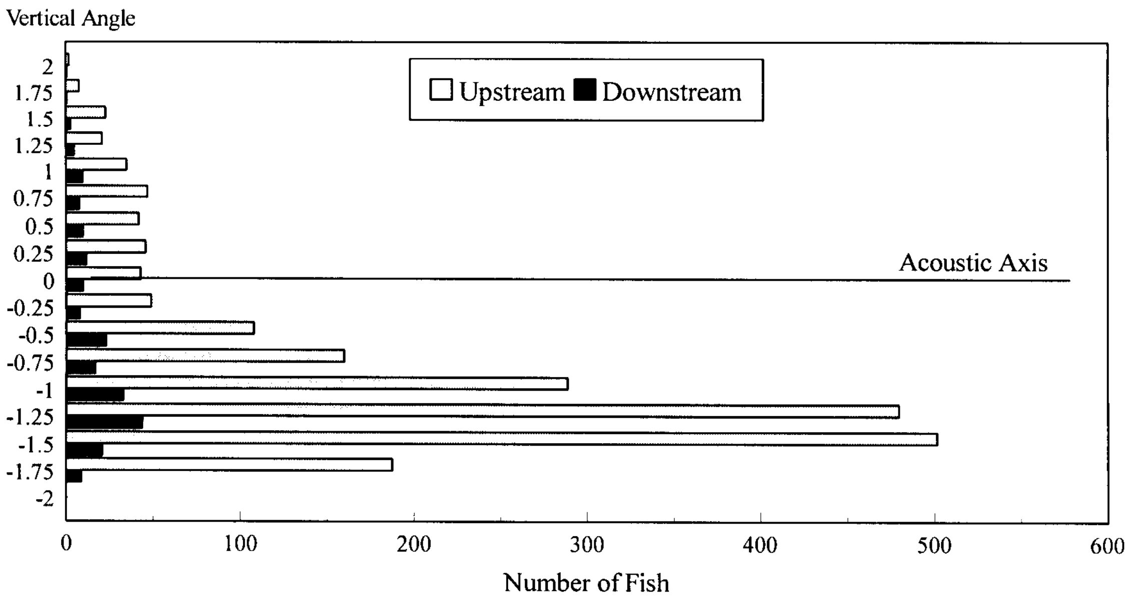



**Figure 6.-Vertical distributions of early-run upstream and downstream fish, on the left bank, Kenai River, 1997.**

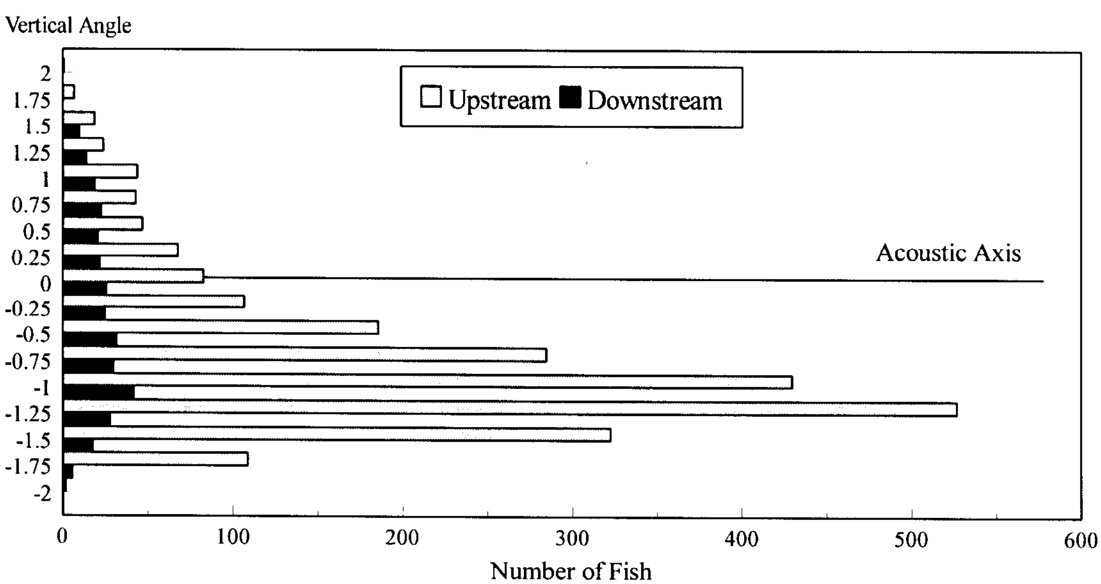



**Figure 7.-Vertical distributions of early-run upstream and downstream fish, on the right bank, Kenai River, 1997.**

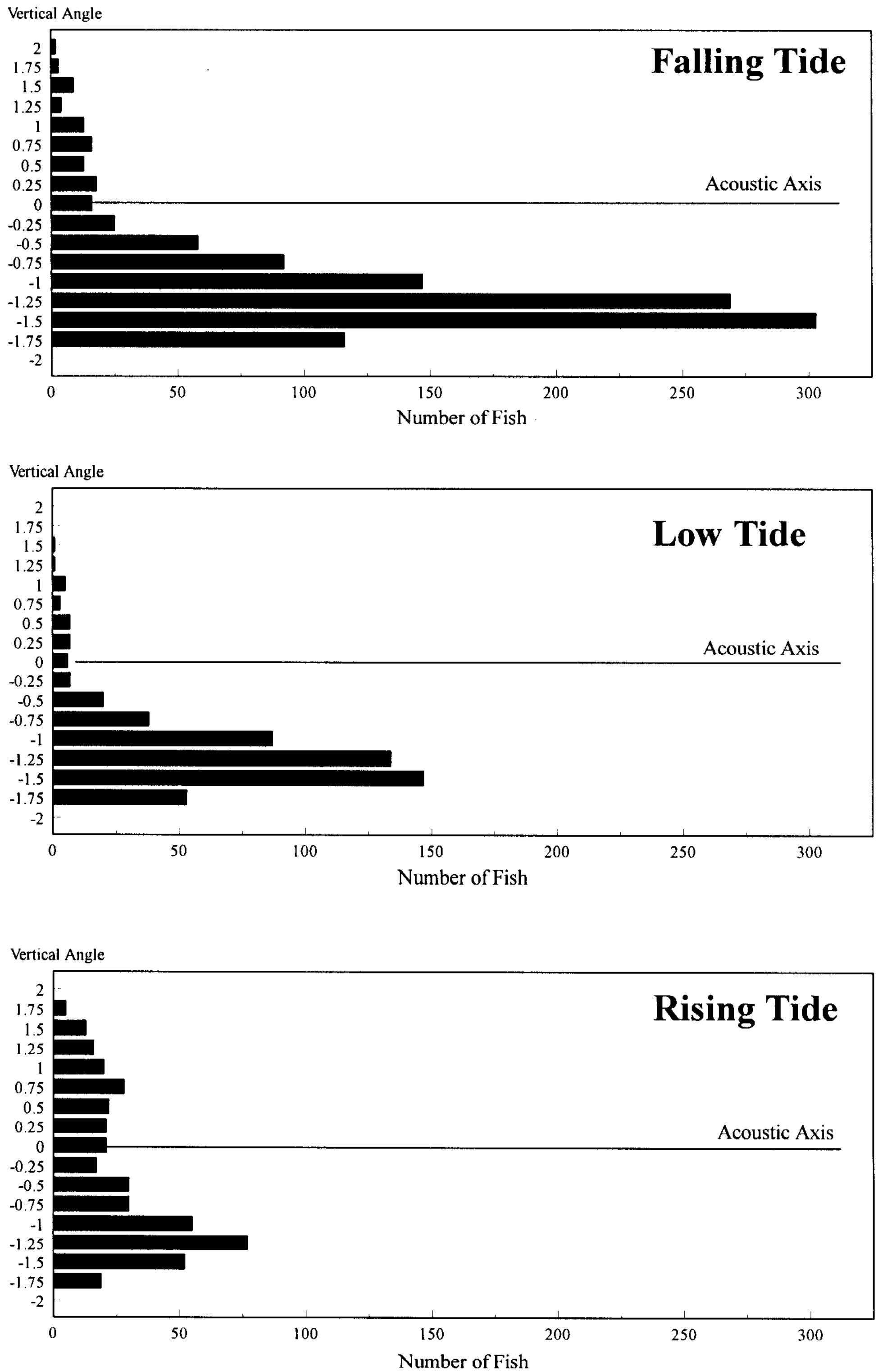



**Figure 8.-Vertical distribution of early-run, upstream-traveling fish during falling (top), low (middle), and rising (bottom) tide stages on the left bank, Kenai River, 1997.**

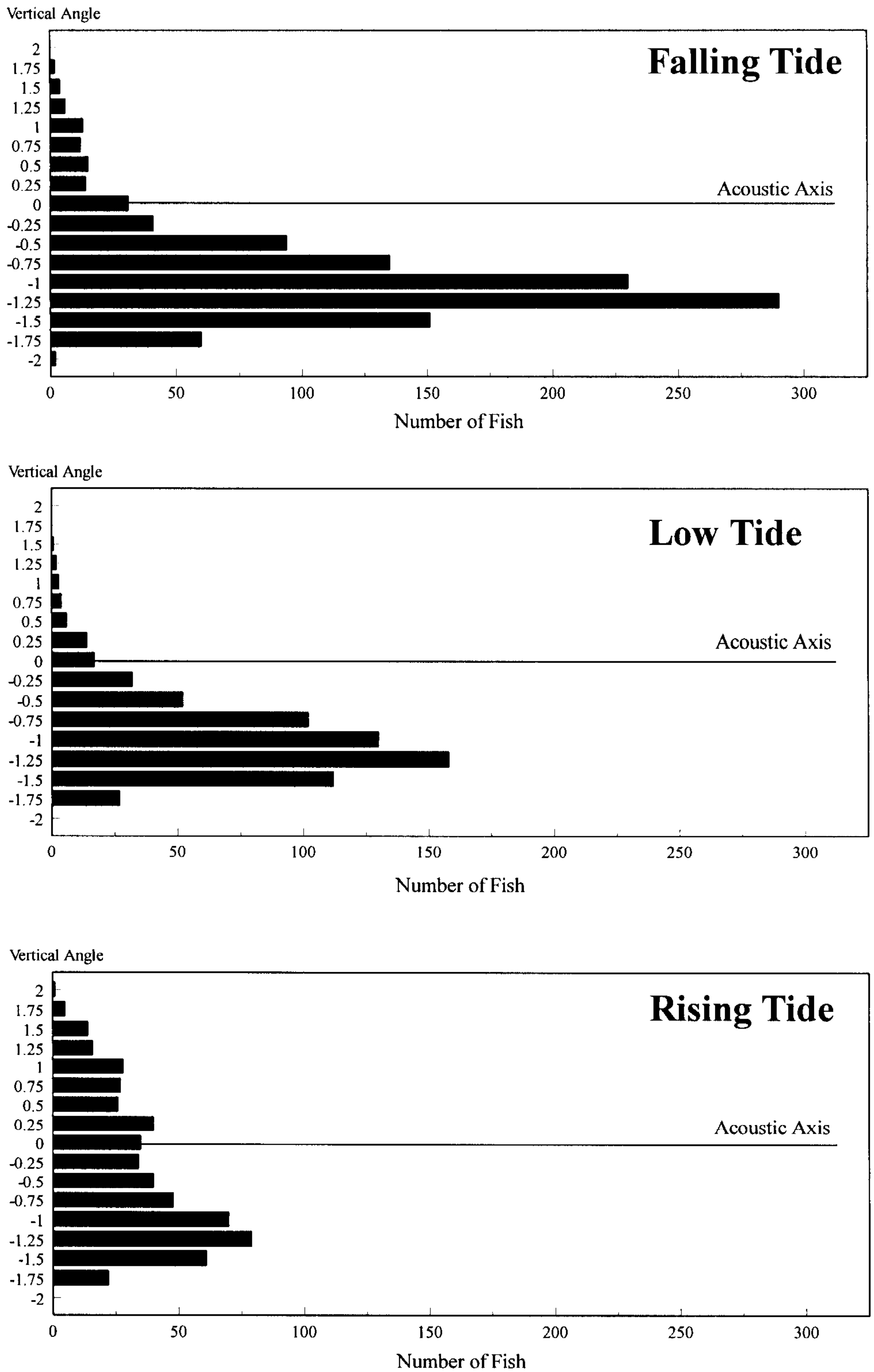



**Figure 9.-Vertical distribution of early-run, upstream-traveling fish during falling (top), low (middle), and rising (bottom) tide stages on the right bank, Kenai River, 1997.**

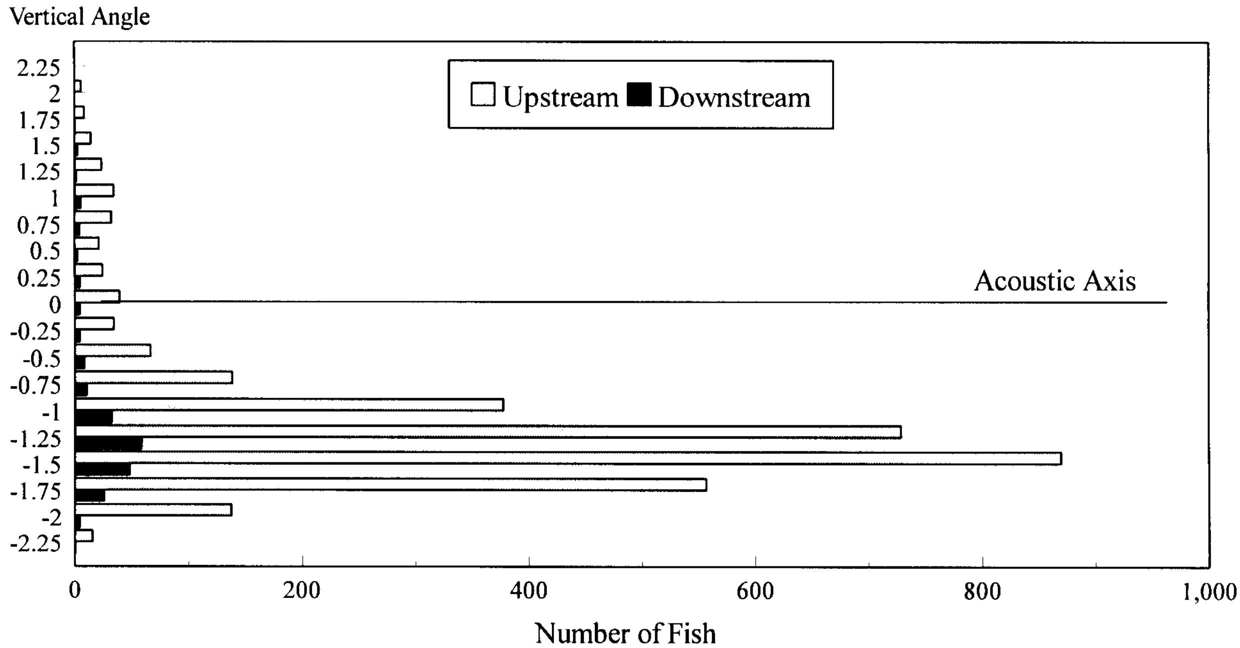



**Figure 10.-Vertical distributions of late-run upstream- and downstream-traveling fish, on the left bank, Kenai River, 1997.**

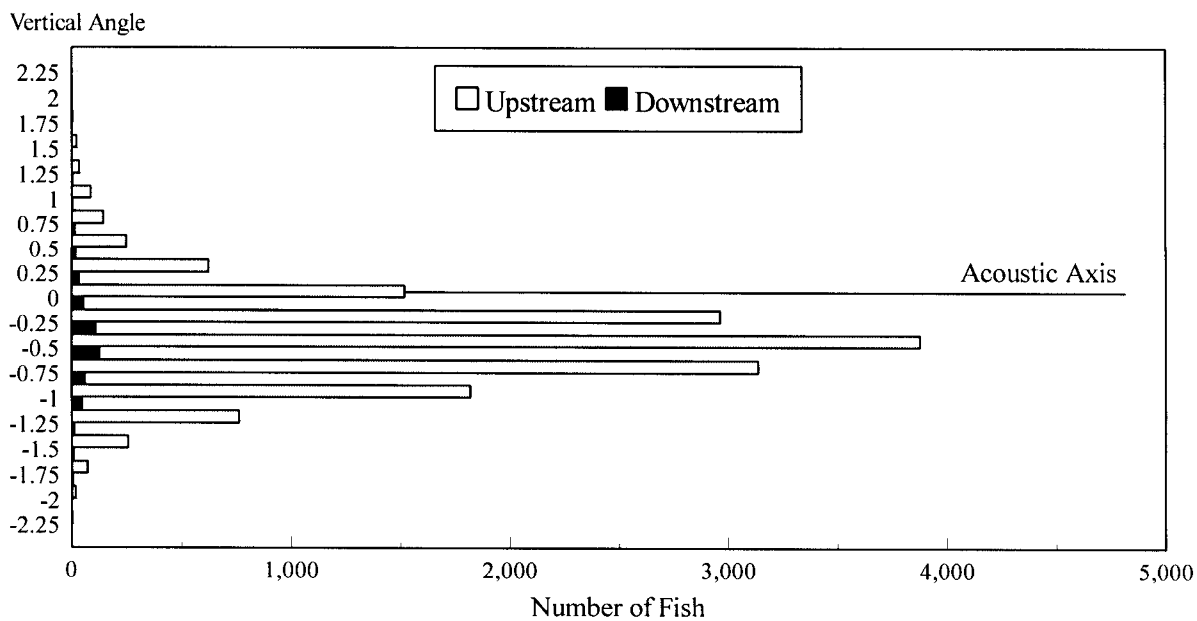



**Figure 11.-Vertical distributions of late-run upstream- and downstream-traveling fish, on the right bank, Kenai River, 1997.**

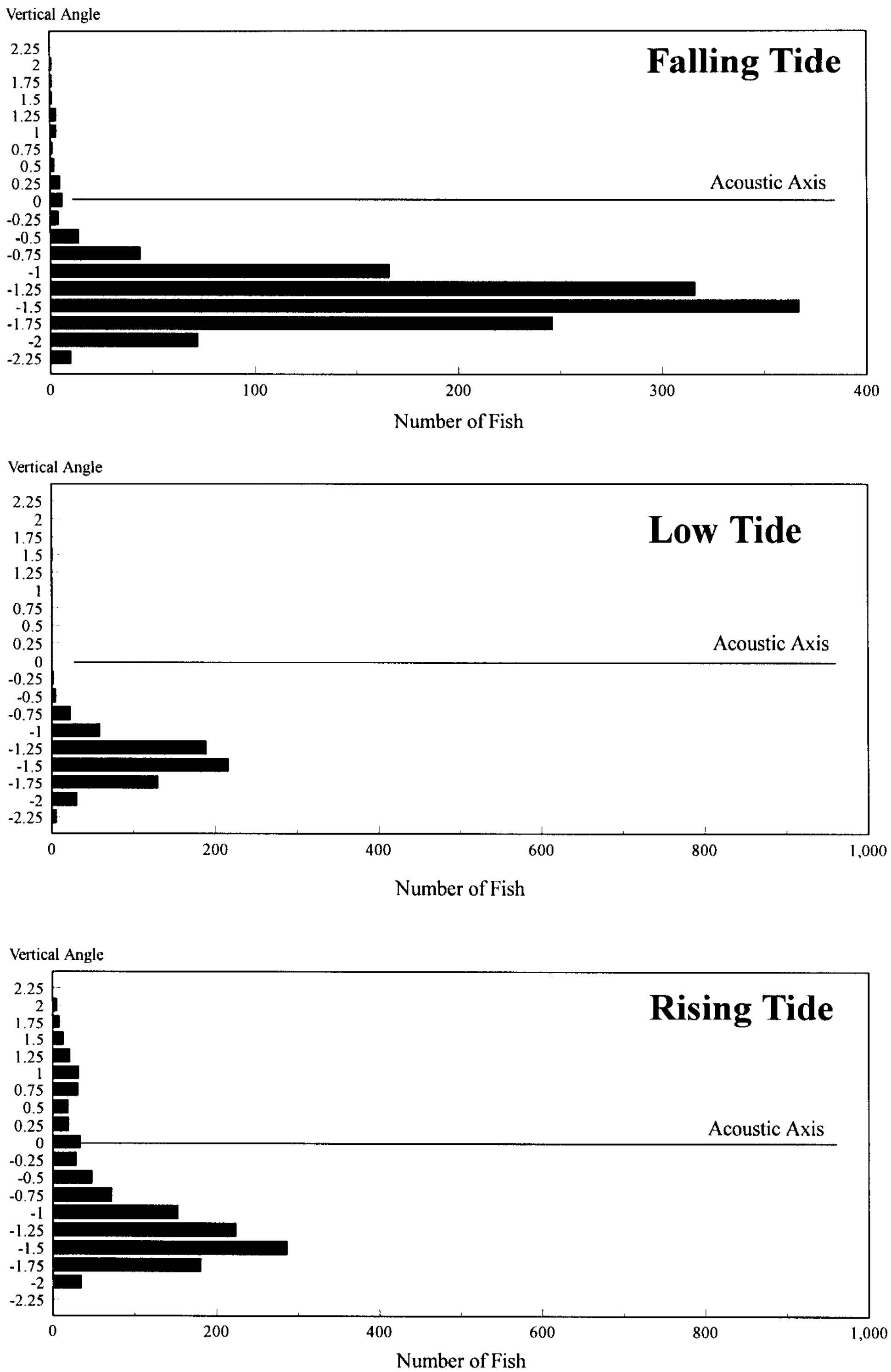



**Figure 12.-Vertical distribution of late-run upstream-traveling fish during falling (top), low (middle), and rising (bottom) tide stages on the left bank, Kenai River, 1997.**

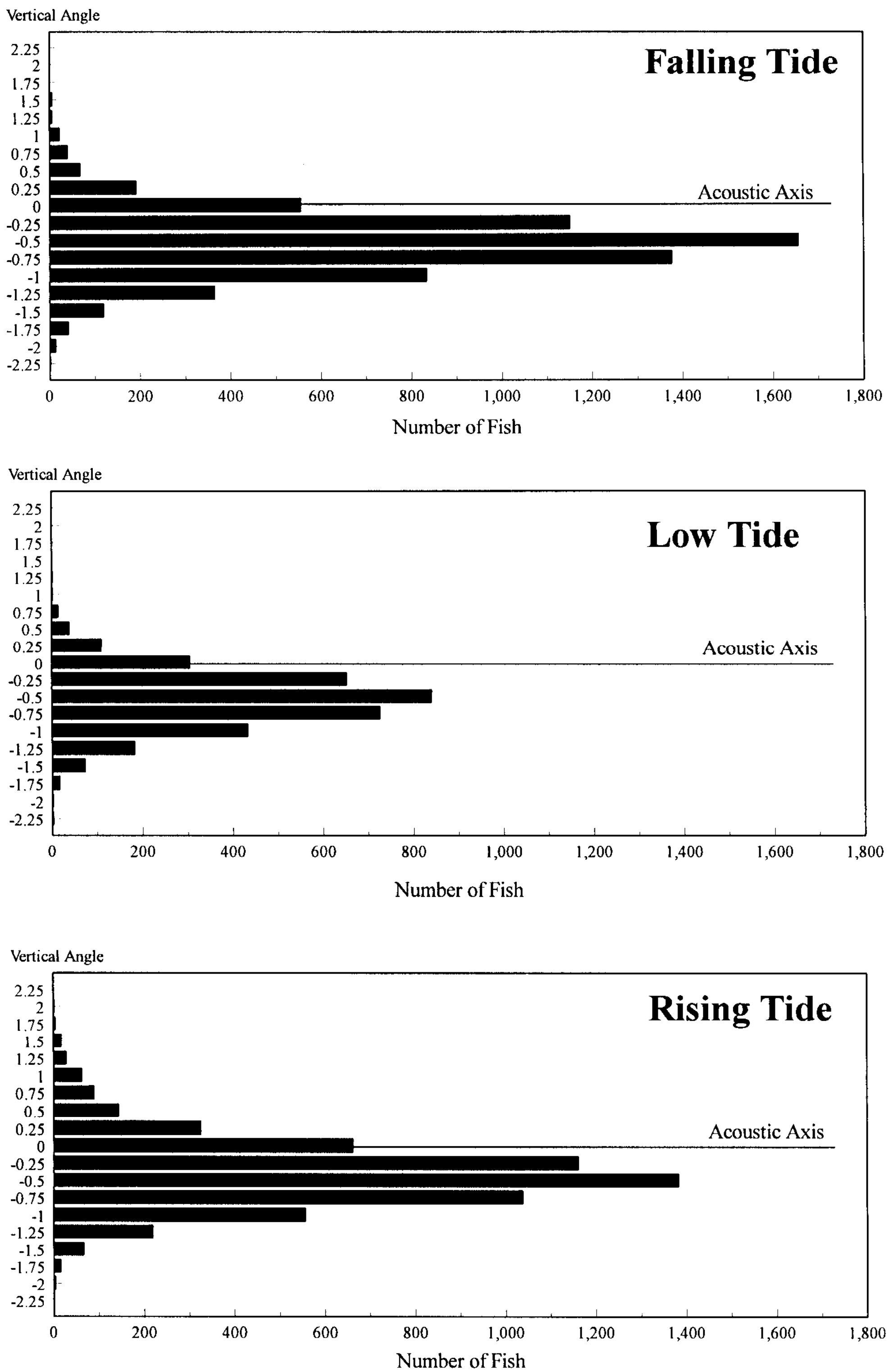



**Figure 13.-Vertical distribution of late-run upstream-traveling fish during falling (top), low (middle), and rising (bottom) tide stages on the right bank, Kenai River, 1997.**

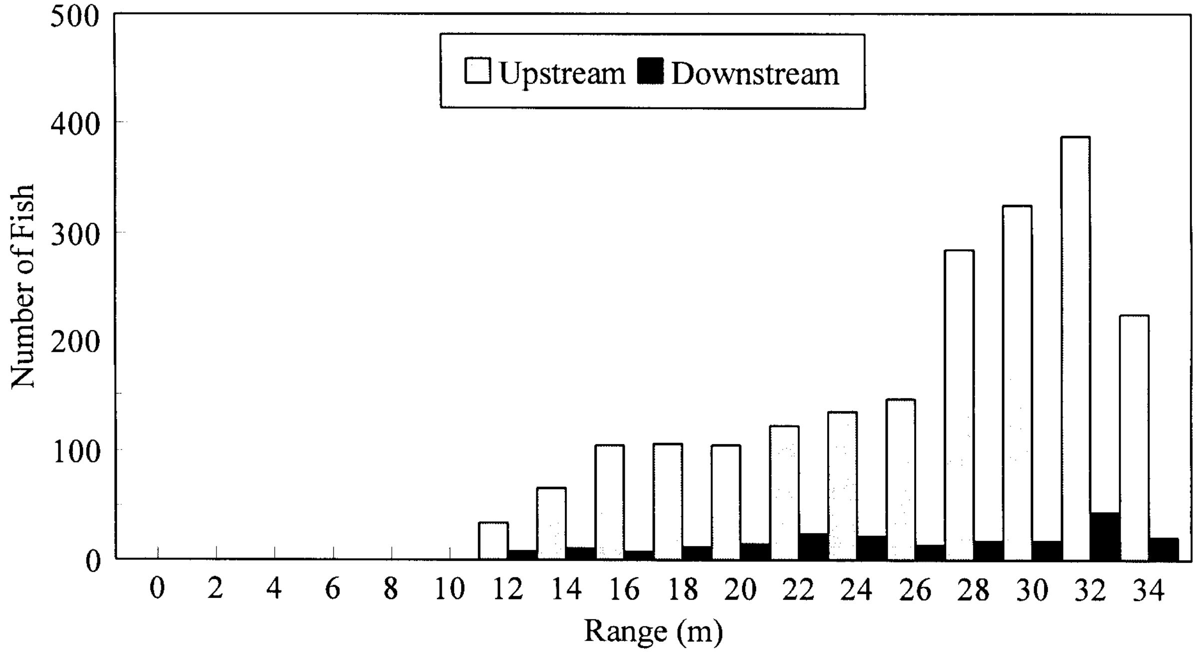



**Figure 14.-Range distributions of early-run upstream (n = 4,523) and downstream (n = 219) fish, on the left bank, Kenai River, 1997.**

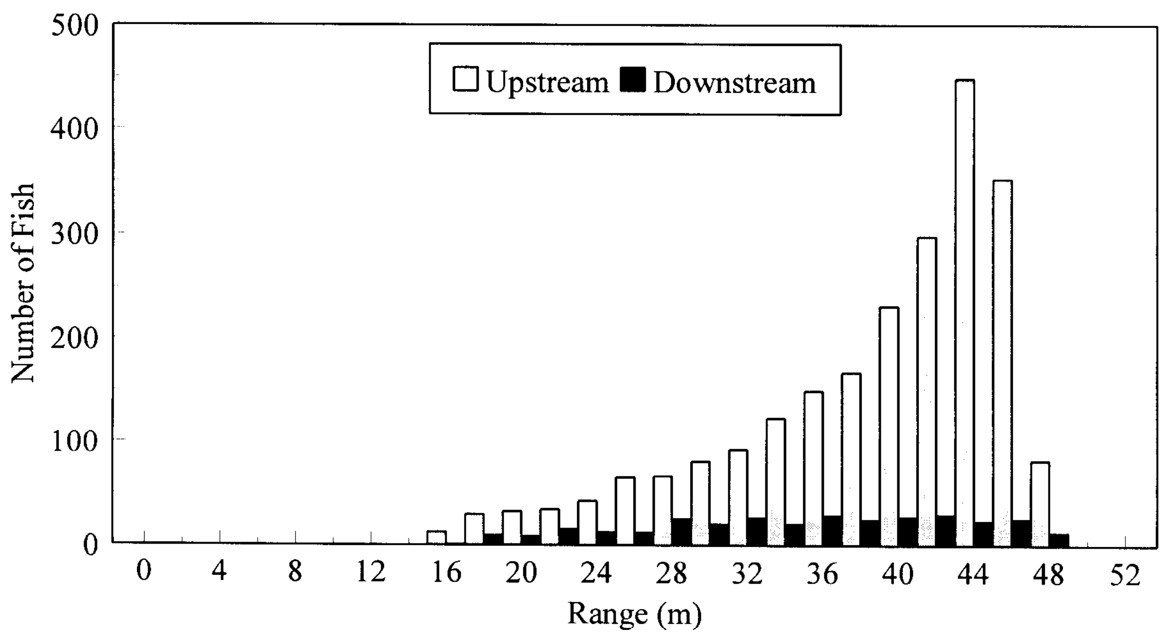



**Figure 15.-Range distributions of early-run upstream (n = 2,605) and downstream (n = 283) fish, on the right bank, Kenai River, 1997.**

**Table 7.-Range distribution (5 m increments) for upstream and downstream traveling fish during the 1997 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 | 144 | 22 | 7.0% | 10.2% | 86.7% | 13.3% |
| 15 - 19.99 | 265 | 32 | 13.0% | 14.9% | 89.2% | 10.8% |
| 20 - 24.99 | 310 | 51 | 15.2% | 23.7% | 85.9% | 14.1% |
| 25 - 29.99 | 702 | 41 | 34.4% | 19.1% | 94.5% | 5.5% |
| 30 – 34.99 | 622 | 69 | 30.4% | 32.1% | 90.0% | 10.0% |
| Bank Total | 2,043 | 215 | 100.0% | 100.0% | 90.5% | 9.5% |
| **Right Bank** | | | | | | |
| 15 - 19.99 | 73 | 17 | 3.2% | 5.4% | 81.1% | 18.9% |
| 20 - 24.99 | 100 | 36 | 4.3% | 11.4% | 73.5% | 26.5% |
| 25 - 29.99 | 186 | 53 | 8.1% | 16.7% | 77.8% | 22.2% |
| 30 - 34.99 | 280 | 52 | 12.1% | 16.4% | 84.3% | 15.7% |
| 35 - 39.99 | 481 | 67 | 20.8% | 21.1% | 87.8% | 12.2% |
| 40 - 44.99 | 948 | 66 | 41.1% | 20.8% | 93.5% | 6.5% |
| 45 - 49.99 | 240 | 26 | 10.4% | 8.2% | 90.2% | 9.8% |
| Bank Total | 2,308 | 317 | 100.0% | 100.0% | 87.9% | 12.1% |

Figure 14, Figure 15). Range distributions on both banks also remained relatively unchanged throughout the falling and low tide phases. Fish were least channel-oriented during the rising tide on both banks (Figure 16, Figure 17).

During the late run, upstream fish were still channel-oriented on the left bank but were more evenly distributed across the offshore ranges on the right bank (Figure 18, Figure 19). Upstream moving fish differed significantly from the more channel-oriented downstream fish on both left (Anderson-Darling, $P = 0.003$) 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). Right-bank range distribution during the falling and low tides appeared bimodal compared to the more unimodal distribution during the rising tide phase (Figure 21).

The left bank produced slightly lower passage estimates than the right bank during the early run but significantly lower passage estimates during the late run (Tables 9, 10, 11, and 12). During the early run, 46.8% of fish passed on the left bank compared with 53.2% on the right bank (Table 9, total passage). During the late run, 17.6% of fish passed on the left

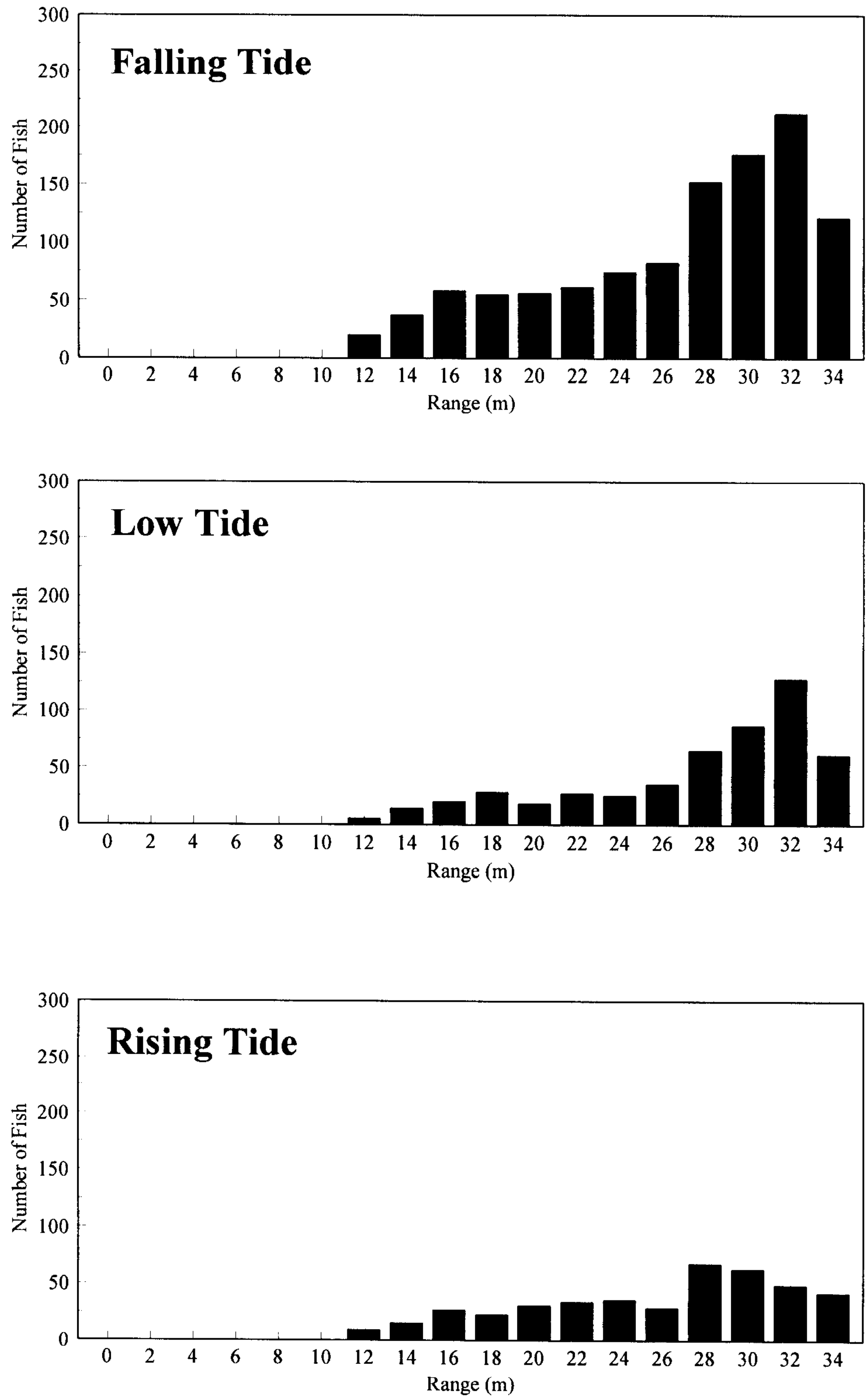



**Figure 16.-Range distribution of early-run, upstream-traveling fish during falling (top), low (middle), and rising (bottom) tide stages on the left bank, Kenai River, 1997.**

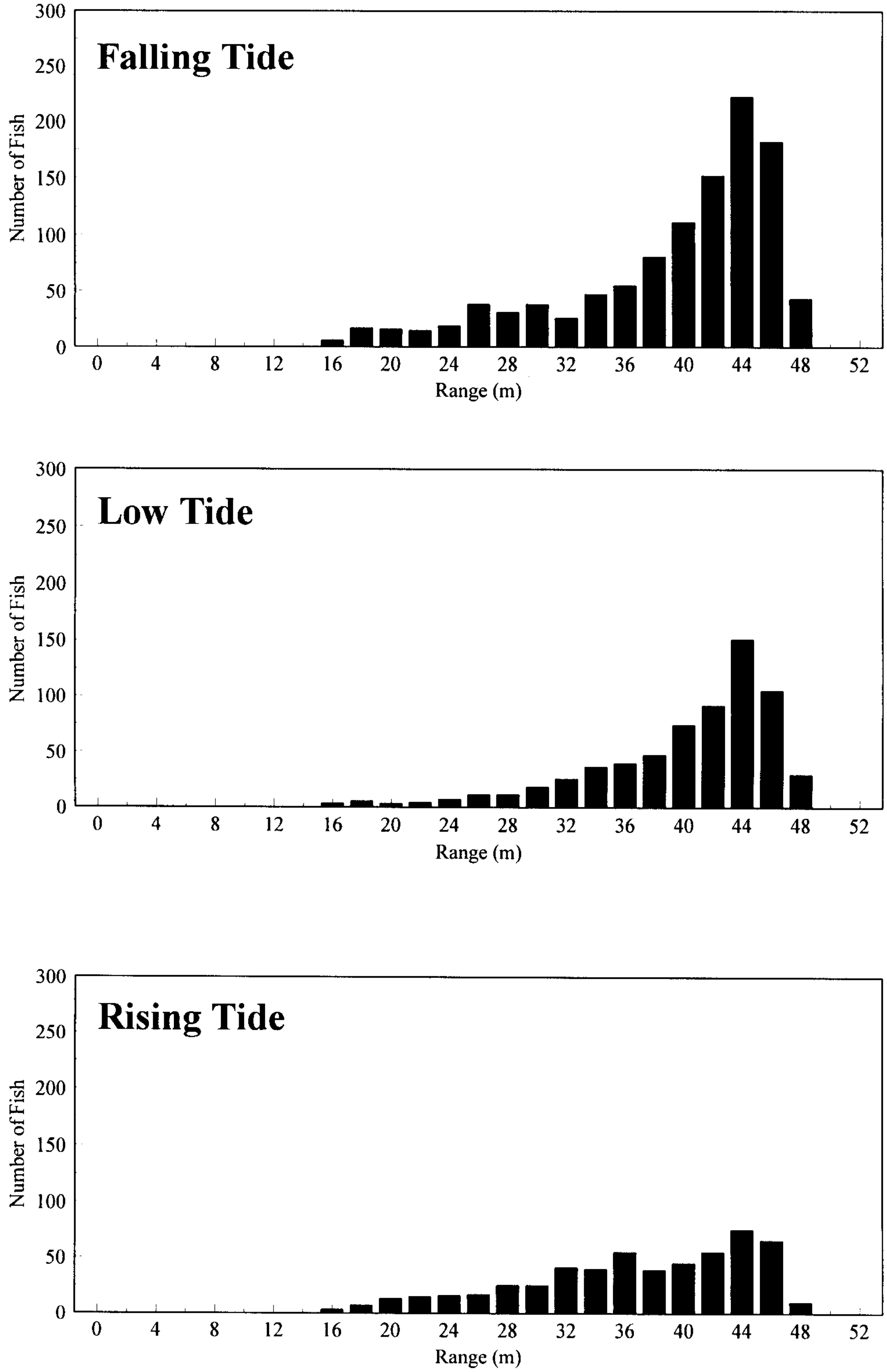



**Figure 17.-Range distribution of early-run, upstream-traveling fish during falling (top), low (middle), and rising (bottom) tide stages on the right bank, Kenai River, 1997.**

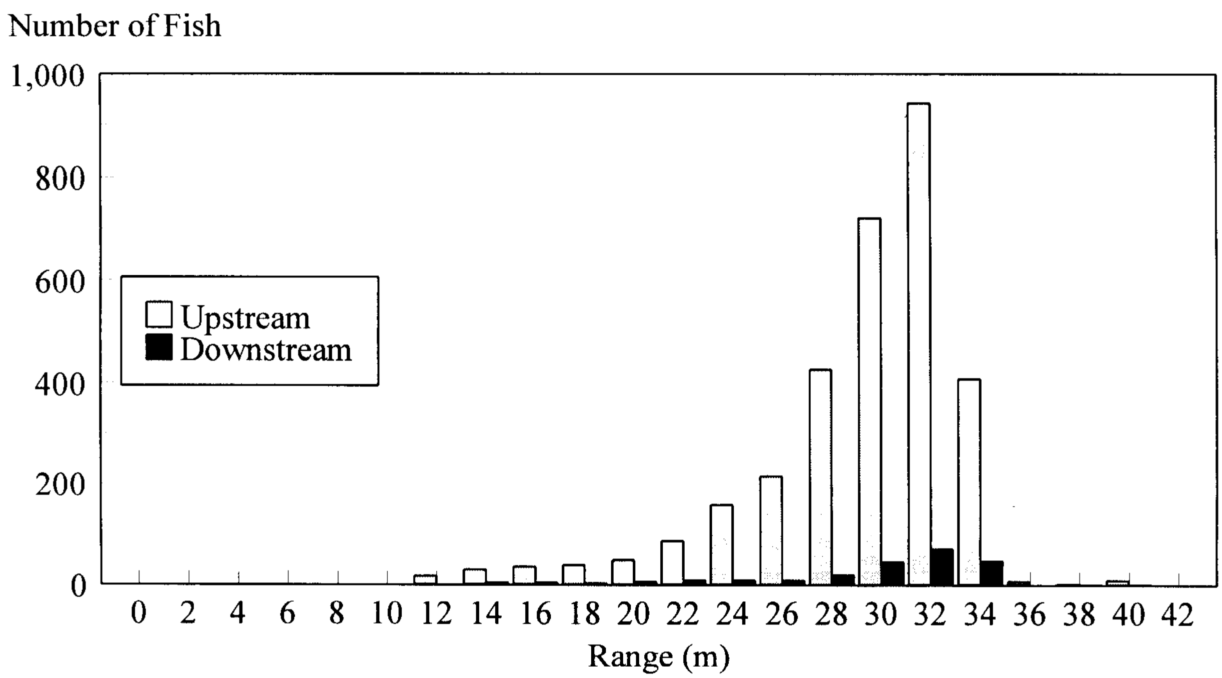



**Figure 18.-Range distributions of late-run upstream (n = 3,138) and downstream (n = 228) fish, on the left bank, Kenai River, 1997.**

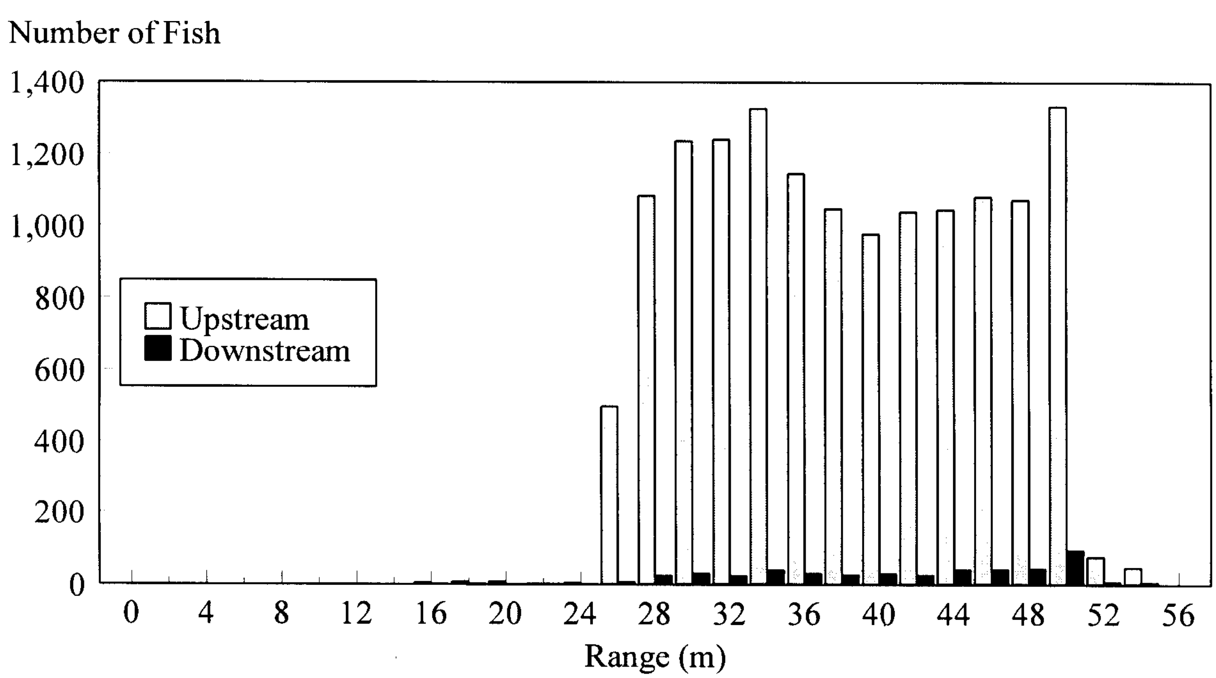



**Figure 19.-Range distributions of late-run upstream (n = 14,284) and downstream (n = 477) fish, on the right bank, Kenai River, 1997.**

**Table 8.-Range distribution (5 m increments) for upstream and downstream traveling fish during the 1997 late run (1 July to 3 August).**

| 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 | 59 | 8 | 1.9% | 3.5% | 88.1% | 11.9% |
| 15 – 19.99 | 108 | 10 | 3.4% | 4.4% | 91.5% | 8.5% |
| 20 – 24.99 | 327 | 23 | 10.4% | 10.1% | 93.4% | 6.6% |
| 25 – 29.99 | 1,276 | 69 | 40.7% | 30.3% | 94.9% | 5.1% |
| 30 – 34.99 | 1,355 | 116 | 43.2% | 50.9% | 92.1% | 7.9% |
| 35 – 39.99 | 13 | 2 | 0.4% | 0.9% | 86.7% | 13.3% |
| Bank Total | 3,138 | 228 | 100.0% | 100.0% | 93.2% | 6.8% |
| **Right Bank** | | | | | | |
| 15 - 19.99 | 20 | 3 | 0.1% | 0.6% | 87.0% | 13.0% |
| 20 - 24.99 | 13 | 3 | 0.1% | 0.6% | 81.3% | 18.8% |
| 25 - 29.99 | 2,812 | 61 | 19.7% | 12.8% | 97.9% | 2.1% |
| 30 - 34.99 | 3,164 | 78 | 22.2% | 16.4% | 97.6% | 2.4% |
| 35 - 39.99 | 2,578 | 74 | 18.0% | 15.5% | 97.2% | 2.8% |
| 40 - 44.99 | 2,631 | 85 | 18.4% | 17.8% | 96.9% | 3.1% |
| 45 - 49.99 | 2,943 | 161 | 20.6% | 33.8% | 94.8% | 5.2% |
| 50 - 54.99 | 123 | 12 | 0.9% | 2.5% | 91.1% | 8.9% |
| Bank Total | | | 100.0% | 100.0% | 96.8% | 3.2% |

bank compared with 82.4% on the right bank (Table 10) total passage.

## TARGET STRENGTH

Target strength distributions varied by bank, direction of travel, and run. Mean target strength estimates for upstream fish on the left bank averaged about 1 dB higher than right bank estimates for early and late runs (Table 13, Figure 22, Figure 23). Mean target strength of upstream and downstream fish varied the most between banks during the late run (Figure 23).

During the early run on the left bank, mean target strength was higher ($t = -10.00$, $P << 0.001$) and less variable ($F = 1.57$, $P << 0.001$) among upstream fish than downstream fish (Table 13, Figure 22). On the right bank, mean target strength was again higher ($t = -11.56$, $P << 0.001$) for upstream fish, though only by about 1 dB, and upstream fish were more variable ($F = 1.16$, $P = 0.01$) (Table 13, Figure 22).

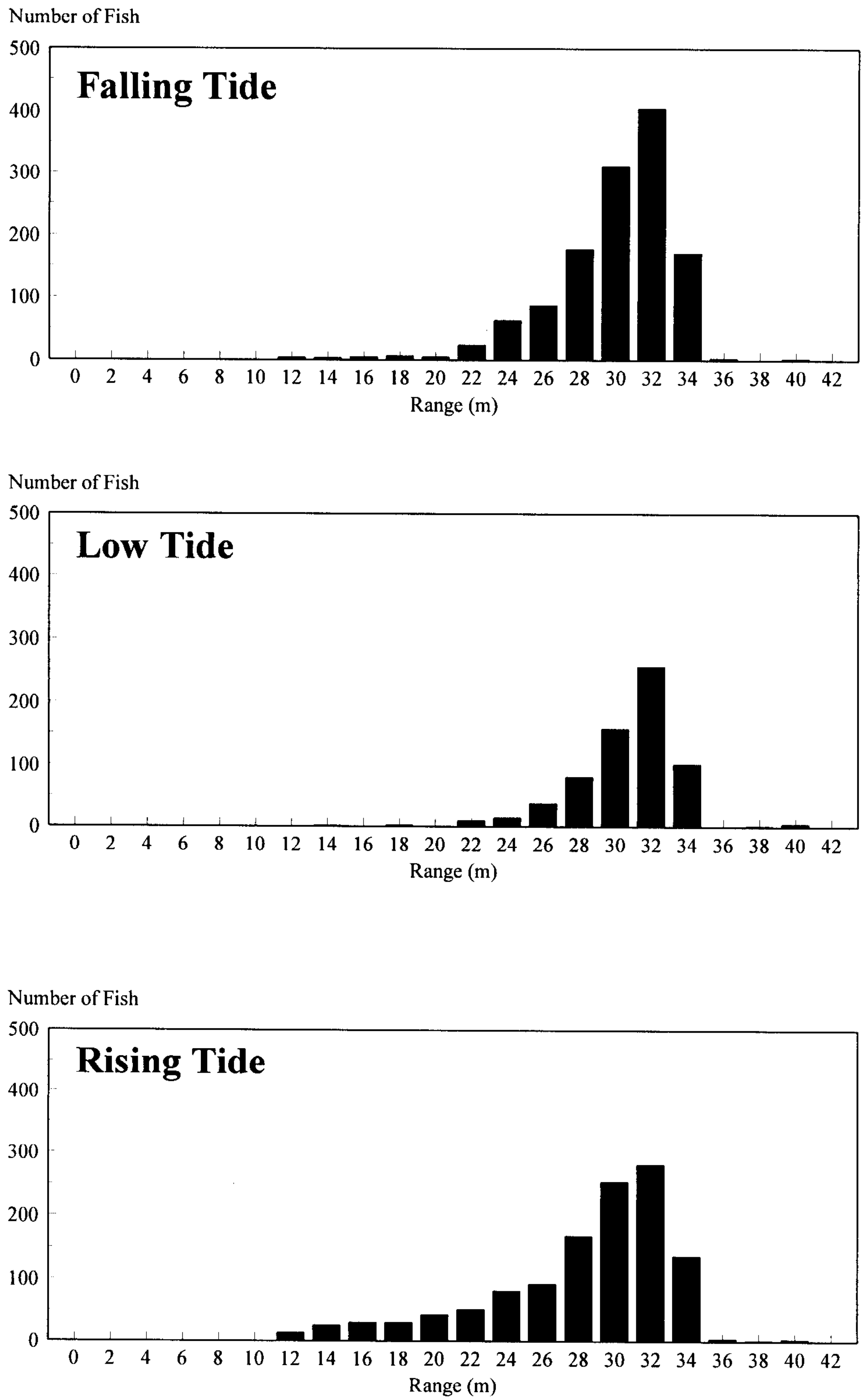



**Figure 20.-Range distribution of late-run upstream-traveling fish during falling (top), low (middle), and rising (bottom) tide stages on the left bank, Kenai River, 1997.**

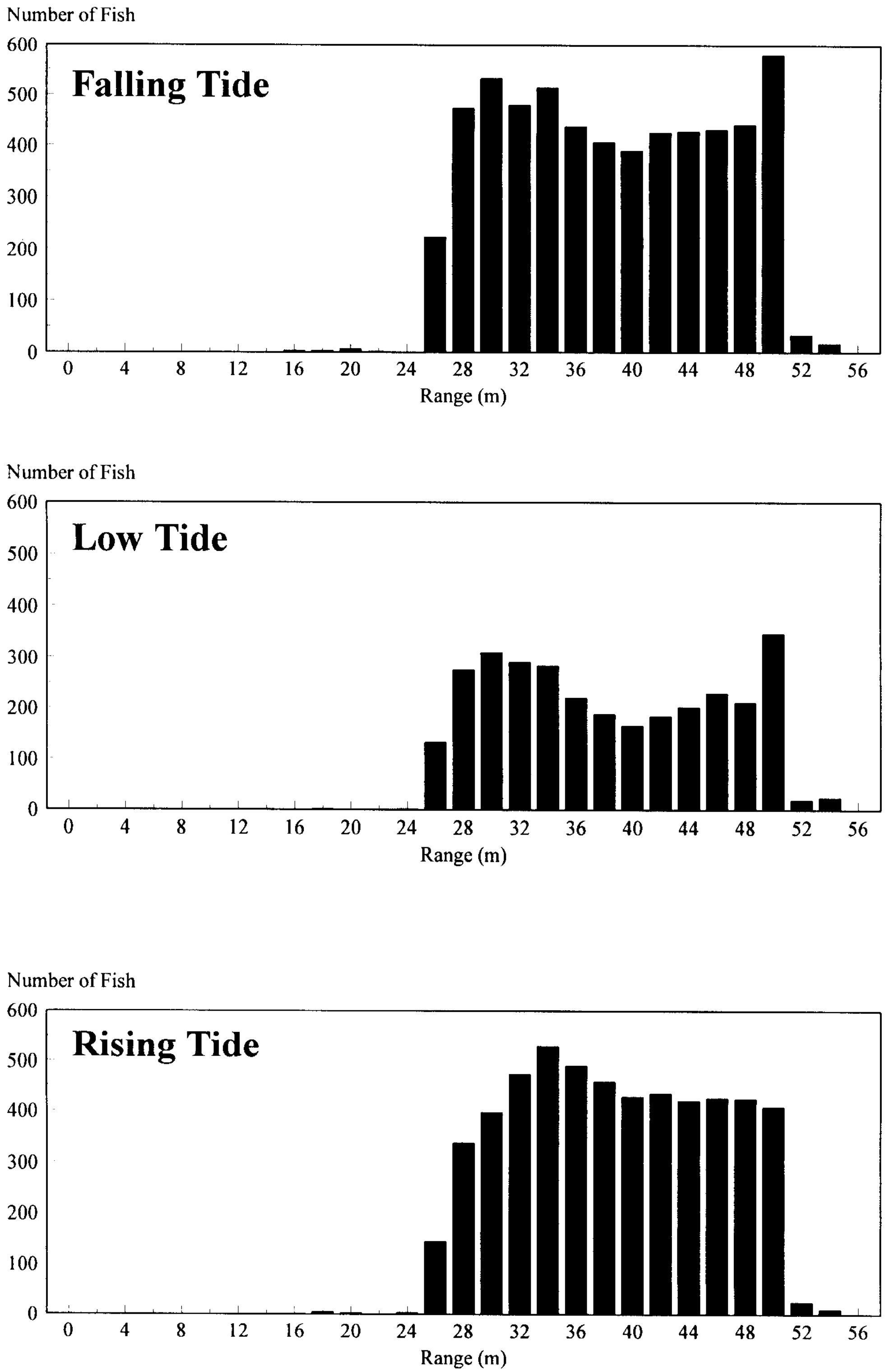



**Figure 21.-Range distribution of late-run upstream-traveling fish during falling (top), low (middle), and rising (bottom) tide stages on the right bank, Kenai River, 1997.**

**Table 9.-Estimates of 1997 early-run fish passage by direction of travel.**

| | Estimate of Total Fish Passage | | Estimate of Downstream Component | | Estimate of Upstream Component | | Passage Adjusted For Downstream Component | |
|---|---|---|---|---|---|---|---|---|
| Right Bank | 7,963 | (176) | 946 | (49) | 7,016 | (164) | 6,070 | (167) |
| Left Bank | 7,001 | (158) | 647 | (39) | 6,353 | (152) | 5,706 | (155) |
| Both Banks | 14,963 | (236) | 1,593 | (62) | 13,370 | (224) | 11,776 | (228) |

Note: Standard error estimates are in parenthesis.

**Table 10.-Estimates of 1997 late-run fish passage by direction of travel.**

| | Estimate of Total Fish Passage | | Estimate of Downstream Component | | Estimate of Upstream Component | | Passage Adjusted For Downstream Component | |
|---|---|---|---|---|---|---|---|---|
| Right Bank | 45,207 | (866) | 1,443 | (63) | 43,764 | (857) | 42,321 | (853) |
| Left Bank | 9,676 | (213) | 695 | (42) | 8,981 | (207) | 8,286 | (209) |
| Both Banks | 54,881 | (892) | 2,138 | (76) | 52,745 | (882) | 50,607 | (879) |

Note: Standard error estimates are in parenthesis.

During the late run on the left bank, mean target strength was higher ($t = -8.51$, $P << 0.01$) and less variable ($F = 1.19$, $P = 0.01$) among upstream fish than downstream fish (Table 13, Figure 23). On the right bank, mean target strength was higher ($t = -8.84$, $P << 0.05$) and less variable among upstream ($F = 1.28$, $P << 0.05$) than downstream fish (Table 13, Figure 23).

## PASSAGE ESTIMATES

Daily estimates of chinook salmon passage were generated for 16 May-3 August. Sampling was terminated at midnight 3 August, approximately 1 week earlier than in previous years. By 3 August, 8 consecutive days with daily estimates of passage below 1% of the total estimated chinook passage had occurred. A total of 1,282 hours (two banks) of acoustic data were processed during the 80-day season representing 33% of the total available sample time.

### Total Passage

Total chinook salmon passage from 16 May through 3 August was estimated at 69,844 (SE = 944) fish, 14,963 (SE =236) during the early run and 54,881 (SE =914) during the late run (Table 11, Table 12). The daily peak of the early run occurred on 13 June with 50% of the run having passed by 11 June (Figure 24). Run timing for the early run was average and within the historic 95% run-timing confidence intervals for the entire early run (Figure 25). The daily peak of the late run occurred on 11 July, with 50% of the late run having passed by 14 July (Figure 26). Migratory timing for late-run fish was early,

**Table 11.-Estimated daily chinook salmon passage, Kenai River sonar, early run, 1997.**

| Date | Left Bank | Right Bank | Daily Total | Cumulative Total |
|---|---|---|---|---|
| 16-May | 24 | 90 | 114 | 114 |
| 17-May | 36 | 63 | 99 | 213 |
| 18-May | 33 | 60 | 93 | 306 |
| 19-May | 66 | 99 | 165 | 471 |
| 20-May | 36 | 48 | 84 | 555 |
| 21-May | 39 | 90 | 129 | 684 |
| 22-May | 69 | 45 | 114 | 798 |
| 23-May | 51 | 111 | 162 | 960 |
| 24-May | 60 | 78 | 138 | 1,098 |
| 25-May | 69 | 96 | 165 | 1,263 |
| 26-May | 60 | 160 | 220 | 1,483 |
| 27-May | 133 | 192 | 325 | 1,808 |
| 28-May | 211 | 106 | 317 | 2,125 |
| 29-May | 240 | 48 | 288 | 2,413 |
| 30-May | 215 | 135 | 350 | 2,763 |
| 31-May | 183 | 135 | 318 | 3,081 |
| 1-Jun | 108 | 105 | 213 | 3,294 |
| 2-Jun | 144 | 97 | 241 | 3,535 |
| 3-Jun | 177 | 199 | 376 | 3,911 |
| 4-Jun | 162 | 162 | 324 | 4,235 |
| 5-Jun | 176 | 251 | 427 | 4,662 |
| 6-Jun | 159 | 168 | 327 | 4,989 |
| 7-Jun | 237 | 354 | 591 | 5,580 |
| 8-Jun | 129 | 312 | 441 | 6,021 |
| 9-Jun | 177 | 214 | 391 | 6,412 |
| 10-Jun | 249 | 278 | 527 | 6,939 |
| 11-Jun | 258 | 254 | 512 | 7,451 |
| 12-Jun | 219 | 318 | 537 | 7,988 |
| 13-Jun | 291 | 390 | 681 | 8,669 |
| 14-Jun | 171 | 253 | 424 | 9,092 |
| 15-Jun | 138 | 180 | 318 | 9,410 |
| 16-Jun | 153 | 195 | 348 | 9,758 |
| 17-Jun | 189 | 216 | 405 | 10,163 |
| 18-Jun | 159 | 156 | 315 | 10,478 |
| 19-Jun | 174 | 225 | 399 | 10,877 |
| 20-Jun | 198 | 210 | 408 | 11,285 |
| 21-Jun | 117 | 135 | 252 | 11,537 |
| 22-Jun | 186 | 204 | 390 | 11,928 |
| 23-Jun | 105 | 120 | 225 | 12,153 |
| 24-Jun | 126 | 159 | 285 | 12,438 |
| 25-Jun | 194 | 138 | 332 | 12,770 |
| 26-Jun | 198 | 183 | 381 | 13,151 |
| 27-Jun | 204 | 159 | 363 | 13,514 |
| 28-Jun | 123 | 174 | 297 | 13,811 |
| 29-Jun | 246 | 324 | 570 | 14,381 |
| 30-Jun | 309 | 273 | 582 | 14,963 |
| **Total** | **7,001 (47%)** | **7,962 (53%)** | **14,963** | |

**{PRIVATE }Table 12.-Estimated daily chinook salmon passage, Kenai River sonar, late run, 1997.**

| Date | Left Bank | Right Bank | Daily Total | Cumulative Total |
|---|---|---|---|---|
| 1-Jul | 243 | 243 | 486 | 486 |
| 2-Jul | 282 | 360 | 642 | 1,128 |
| 3-Jul | 204 | 396 | 600 | 1,728 |
| 4-Jul | 207 | 426 | 633 | 2,361 |
| 5-Jul | 244 | 412 | 657 | 3,018 |
| 6-Jul | 264 | 363 | 627 | 3,645 |
| 7-Jul | 339 | 819 | 1,158 | 4,803 |
| 8-Jul | 228 | 993 | 1,221 | 6,025 |
| 9-Jul | 222 | 1,396 | 1,618 | 7,643 |
| 10-Jul | 459 | 3,027 | 3,486 | 11,129 |
| 11-Jul | 357 | 5,252 | 5,649 | 16,778 |
| 12-Jul | 402 | 4,095 | 4,497 | 21,275 |
| 13-Jul | 801 | 4,572 | 5,373 | 26,648 |
| 14-Jul | 324 | 1,707 | 2,031 | 28,679 |
| 15-Jul | 486 | 3,556 | 4,042 | 32,721 |
| 16-Jul | 513 | 2,907 | 3,420 | 36,141 |
| 17-Jul | 603 | 3,981 | 4,584 | 40,725 |
| 18-Jul | 510 | 1,824 | 2,334 | 43,059 |
| 19-Jul | 390 | 756 | 1,146 | 44,205 |
| 20-Jul | 339 | 1,239 | 1,578 | 45,783 |
| 21-Jul | 216 | 678 | 894 | 46,677 |
| 22-Jul | 285 | 1,555 | 1,840 | 48,517 |
| 23-Jul | 339 | 1,102 | 1,441 | 49,958 |
| 24-Jul | 297 | 783 | 1,080 | 51,038 |
| 25-Jul | 253 | 279 | 532 | 51,570 |
| 26-Jul | 210 | 309 | 519 | 52,089 |
| 27-Jul | 144 | 294 | 438 | 52,527 |
| 28-Jul | 78 | 255 | 333 | 52,860 |
| 29-Jul | 101 | 300 | 401 | 53,260 |
| 30-Jul | 138 | 312 | 450 | 53,710 |
| 31-Jul | 93 | 327 | 420 | 54,130 |
| 1-Aug | 34 | 213 | 247 | 54,377 |
| 2-Aug | 36 | 255 | 291 | 54,668 |
| 3-Aug | 33 | 180 | 213 | 54,881 |
| **Total** | **9,675 (18%)** | **45,207 (82%)** | **54,881** | |

**Table 13.-Mean target strength for upstream and downstream targets by bank during the early (16 May-30 June) and late (1 July-3 August) runs, 1997 (currently uses only targets meeting target, strength, and range thresholds).**

| | Upstream | | | Downstream | | |
|---|---|---|---|---|---|---|
| Bank | mean | SD | n | mean | SD | n |
| **Early Run** | | | | | | |
| Left Bank | -25.24 | 1.43 | 2,042 | -25.68 | 1.62 | 215 |
| Right Bank | -25.31 | 1.82 | 2,308 | -26.04 | 1.61 | 317 |
| **Late Run** | | | | | | |
| Left Bank | -24.58 | 1.66 | 3,138 | -25.08 | 1.61 | 228 |
| Right Bank | -25.99 | 1.53 | 14,284 | -26.07 | 1.56 | 477 |

starting within normal bounds early in the season, but a particularly strong return starting in early July pushed the 1997 curve above the historic 95% confidence intervals for most of July (Figure 25).

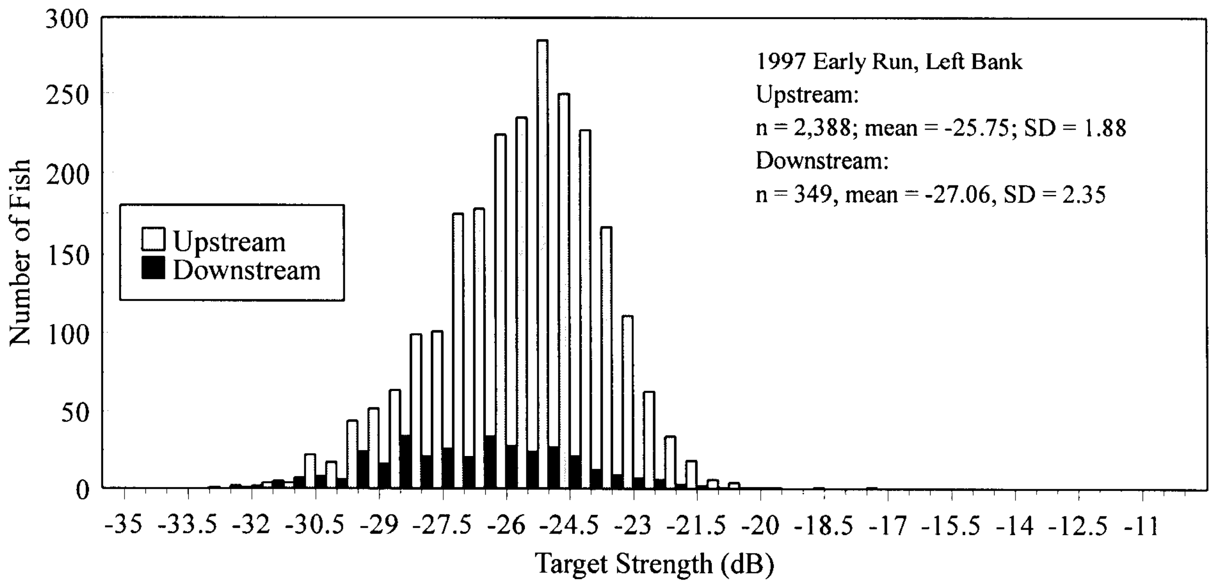
### Net Upstream Passage

Downstream migrants comprised an estimated 1,593 fish or 10.6% of the total early-run passage estimate (Table 9, Appendix C1). After adjusting for downstream migrants, the net upstream passage estimate for the early run was 11,776 (SE = 229) chinook salmon. The estimate of downstream-migrating fish during the late run was 2,138 fish or 3.9% of the total late run passage estimate (Table 10, Appendix C2). The net upstream passage estimate for the late run was 50,607 (SE = 879) chinook salmon.

## DISCUSSION

### Bank Preference

Historically, the right bank has been heavily favored by migrating fish during both the early and late runs with the proportion of fish traveling up the right bank increasing as the season progresses. During the 1997 early run, however, approximately equal proportions of fish were detected on each bank, 47% on the left bank and 53% on the right bank (Table 11). This atypical pattern was also observed during the early run of 1996. Two possible explanations exist for the observed changes in bank preference. First, the 1996 season followed a 100-year flood event in September 1995 (Burwen and Bosch 1998). Although no notable changes occurred in the bottom topography at the sonar site itself following the flood, changes downstream from the site may have occurred leading to changes in migrational patterns of fish at the site. The change in bank preference during the early run also may be attributed to lower than average daily discharge rates recorded on the Kenai River during May and June (Figure 27), as we suspected during the 1996 run. 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).



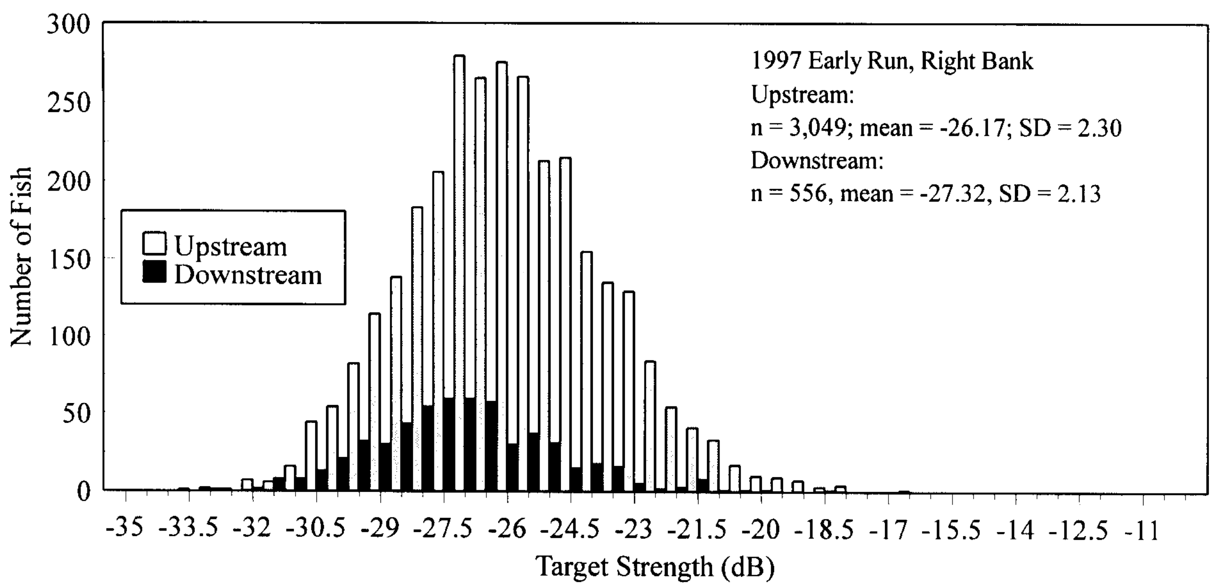
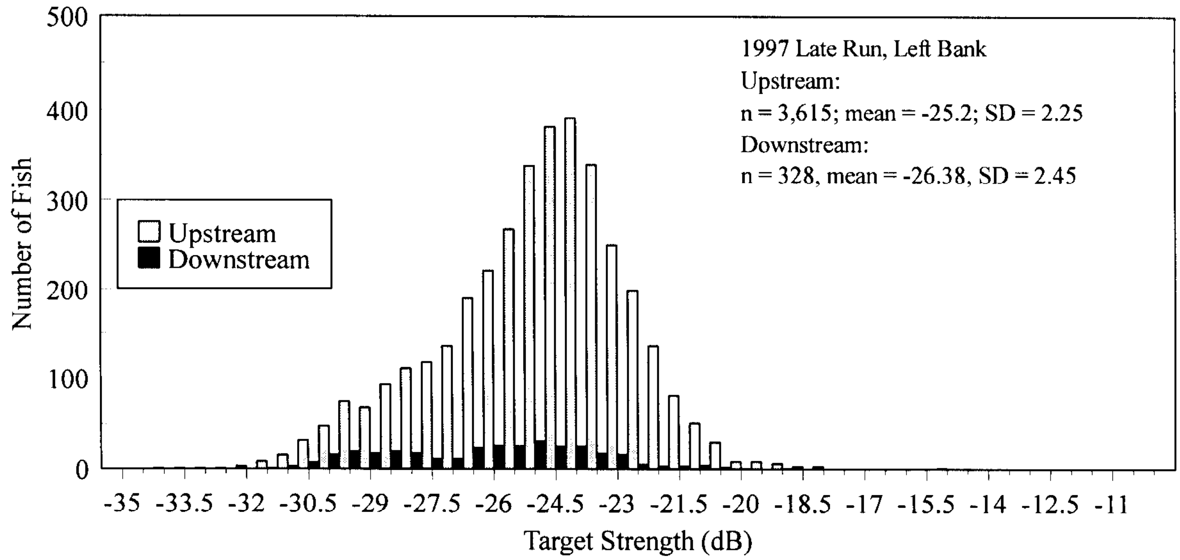




**Figure 22.-Early run target strength distributions for upstream and downstream fish on the left (top) and right (bottom) banks.**



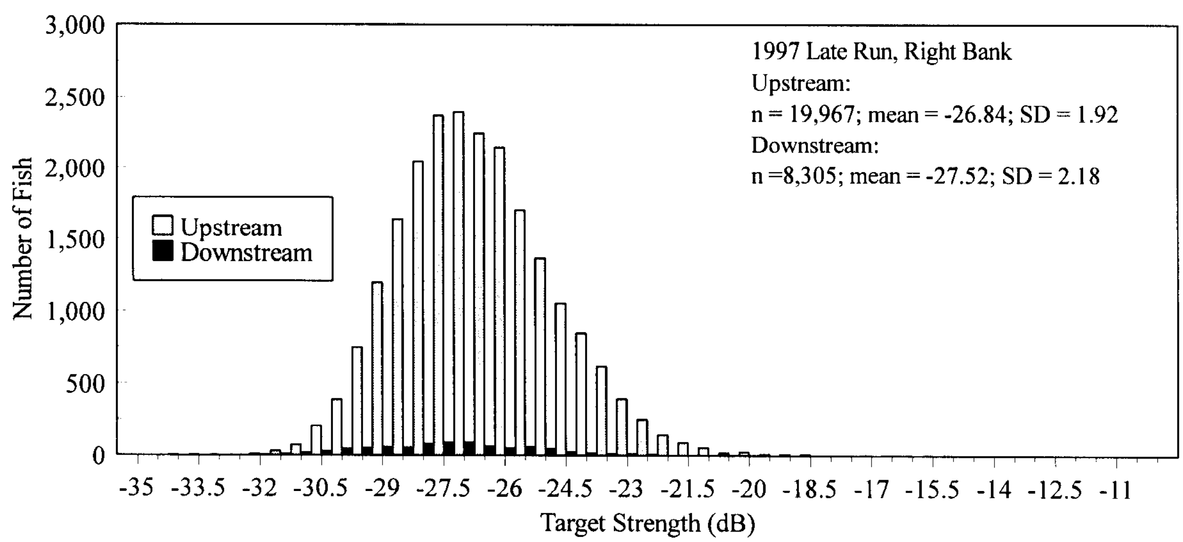




**Figure 23.-Late run target strength distributions for upstream and downstream fish on the left (top) and right (bottom) banks.**

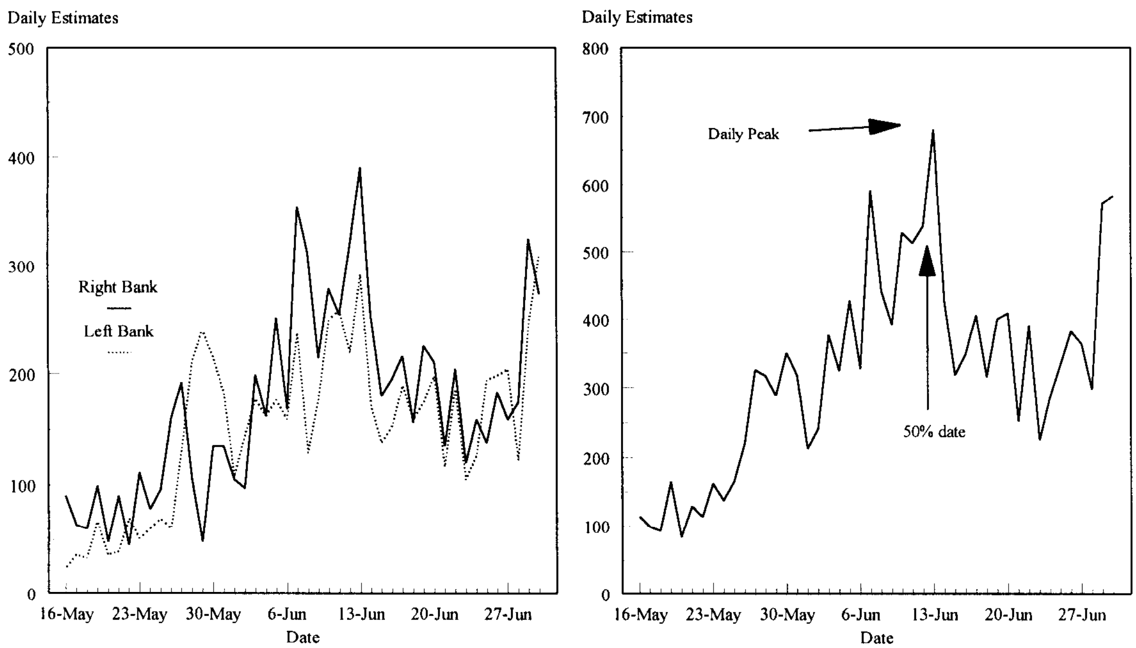



**Figure 24.-Daily sonar estimates of passage for the early run of chinook salmon returning to the Kenai River, 1997. Estimates by bank (left) and total run (right).**

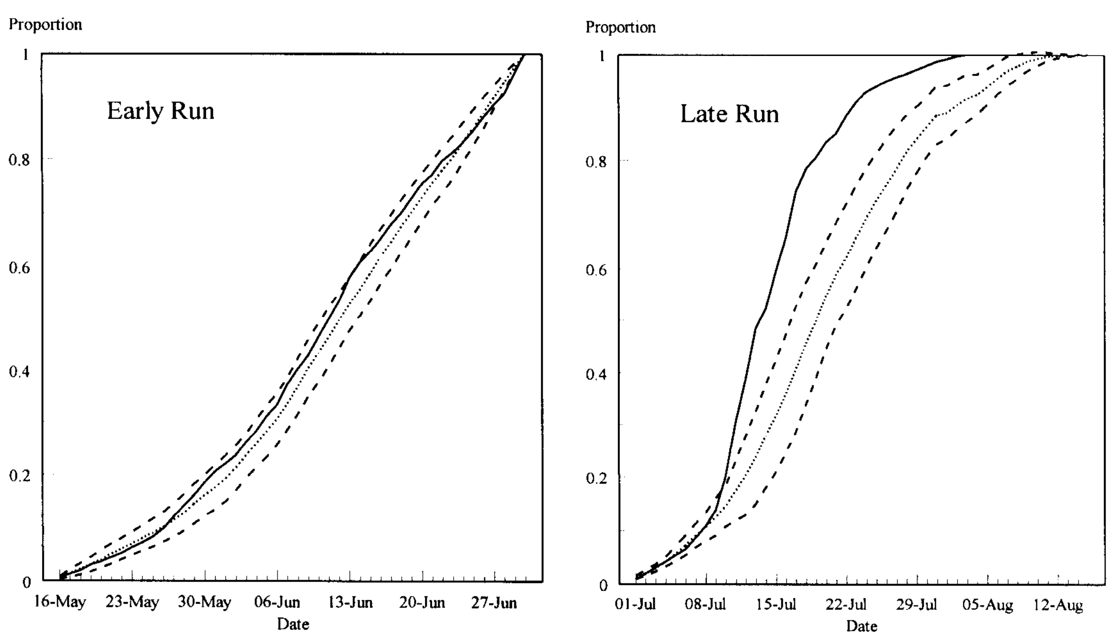
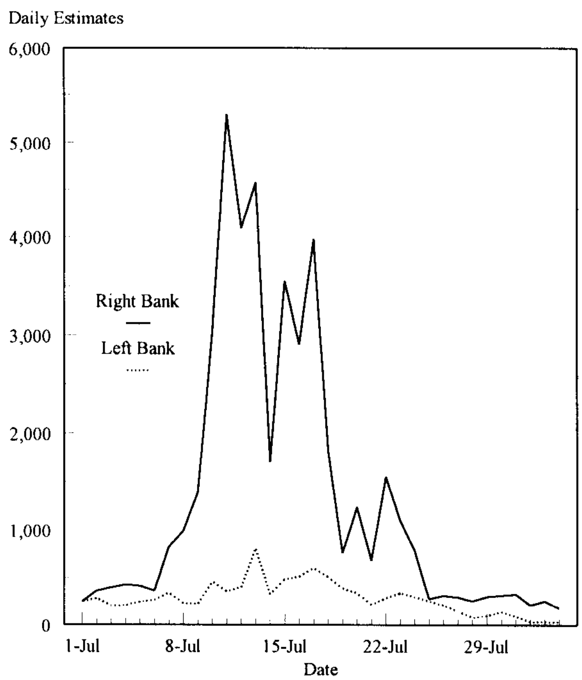



**Figure 25.-Migratory-timing curves for early (left) and late (right) runs of chinook salmon to the Kenai River, 1997 (solid lines). Mean migratory-timing curves for the years 1987-1995 (dotted lines), and 95% confidence intervals (dashed lines) are presented for comparison.**



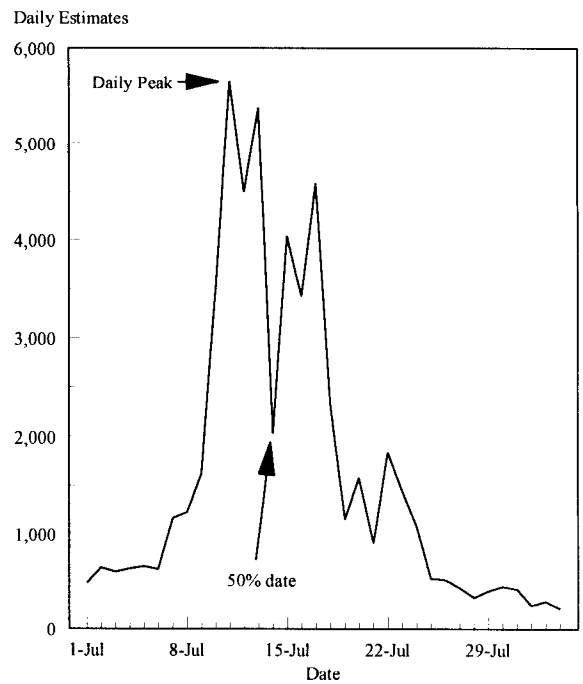




**Figure 26.-Daily sonar estimates of passage for the late run of chinook salmon returning to the Kenai River, 1997. Estimates by bank (left) and total run (right).**

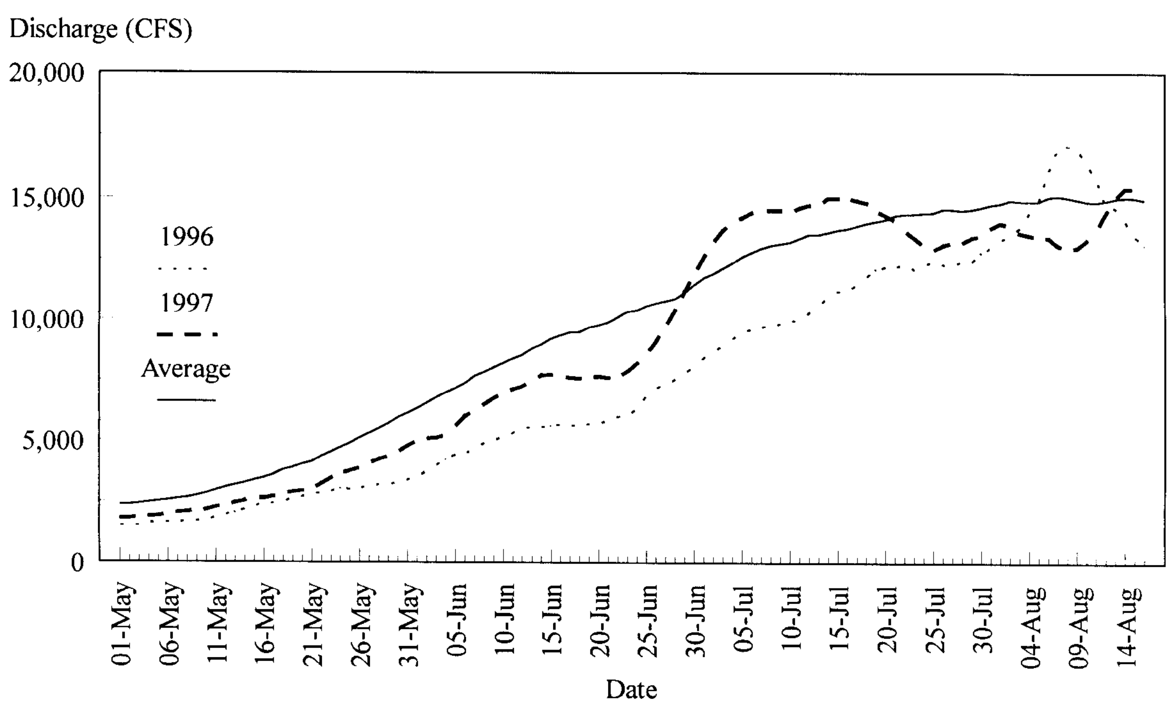



**Figure 27.-Kenai River discharge (CFS), 10-year average compared with 1996 and 1997.**

During the late run, fish passage returned to more typical migration patterns with 82.4% passing the right bank and 17.6% passing on the left bank. Several factors may have contributed to, or were coincidental to the movement of more fish to the shallower right bank of the river. Starting 29 June, the daily discharge rates increased to levels above the 10-year average and stayed above this average until 21 July. Also, sometime during the early morning on 7 July, a fairly large portion of the left bank sloughed off into the river approximately 75 m to 100 m downstream of the left bank transducer. The section of bank appeared to be at least 20 to 30 m wide though it was difficult to determine how far into the river it extended. It consisted of dirt, rocks, large alders and a dead moose. Fish detection on the right bank also increased when sockeye salmon immigration increased dramatically, starting about 10 July.

## 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 (Appendices D1 and D2). 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 a great majority of all upstream fish are within the insonified zone. When sockeye are not present in large numbers, most of the 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 early run (Figure 8, Figure 9), relatively few fish occupied the upper half of the beam overall.

The tendency to rise off the bottom during the rising tides during the early run may be related to low discharge levels such as those that occurred in 1996 when the same pattern occurred (Burwen and Bosch 1998). This is supported by the fact that fish did not tend to rise from the bottom during the late runs of 1996 or 1997 after discharge rates had substantially increased (Figure 12, Figure 13). 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).

## Range Distribution

The range distribution of upstream-moving chinook salmon on the left bank was similar between runs. These fish were generally channel-oriented, with a majority passing the sonar between 25 m and 35 m.

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 were generally channel oriented (Figure 14, Figure 15). However, during the late run, the range distribution was more bimodal with a nearshore peak near the 30 m range and a second peak near the 50 m range (Figure 19). This distribution is atypical of most distributions observed in prior years and 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 assumed to be sockeye salmon or other smaller fish and 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 (Weimer and Ehrenberg 1975; Ehrenberg and Torkelson 1996) 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-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.

## Direction of Travel and Debris

Prior to the switch to split-beam sonar in 1995, direction of travel for each acoustic target could not be determined. Consequently, earlier chinook salmon passage estimates have included an unknown number of fish traveling downstream. However, three independent studies had indicated that the proportion of downstream migrants was relatively small (Eggers et al. 1995, Burwen et al. 1998). With the advent of split-beam sonar, we now had the option of adjusting sonar estimates for the positive bias that results from classifying all targets as upstream migrants. 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). Incorrectly classifying downstream debris as a valid fish target would lead to a negative bias in the resulting estimates.

In 1996, after a season of using split-beam sonar and developing methods to isolate downstream traces that were most likely fish, we elected to generate an estimate referred to as the net upstream passage. The 1997 passage estimates are the second such estimates of Kenai River chinook salmon adjusted for downstream migrants (Burwen and Bosch 1998). For the 1997 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 10.6% and 3.9% for the early and late runs, respectively. Consequently, early- and late-run estimates of net upstream passage were approximately 20% and 8% lower than the total passage estimates.

The mean target strength distributions of upstream and downstream targets suggest that most downstream targets on both banks were correctly classified as fish. Target strength distributions for upstream and downstream fish on the right bank, while statistically different, appear similar for both early and late runs (Table 13, Figure 22, Figure 23). The differences are most likely due to large sample size and the high power of the Anderson-Darling test. The downstream target strength distributions were unimodal and corresponded well to modes of the upstream target strength distributions. This suggests little contamination by debris in classifying downstream targets on the right bank. Because downstream fish are generally distributed higher in the sonar beam than actively swimming upstream fish (Figure 6, Figure 7, Figure 10, Figure 11), the effects of threshold induced bias could explain the fact that downstream fish average 1 dB smaller than upstream fish.

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. (1998) 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.

During 1997, changes in range distribution on the right bank were correlated with sockeye salmon abundance. During the early run, when relatively few (<100,000) 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 early 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 1-9 July (Figure 28), but were more evenly distributed across all ranges during 10 July-3 August (Figure 29). 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 1998). Additional studies exploring the use of multifrequency sonar to discriminate fish species will also be implemented during the 1998 season.

## Independent Estimates of Abundance

Results of a 2-year radio telemetry study (Hammarstrom and Hasbrouck *In prep*) showed that sonar estimates may be biased high during periods of high sockeye abundance. In 1996, 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 telemetry study of 39,356 (SE = 3,535). In 1997, for the same time period, the sonar estimate of 49,933 (SE = 876) chinook

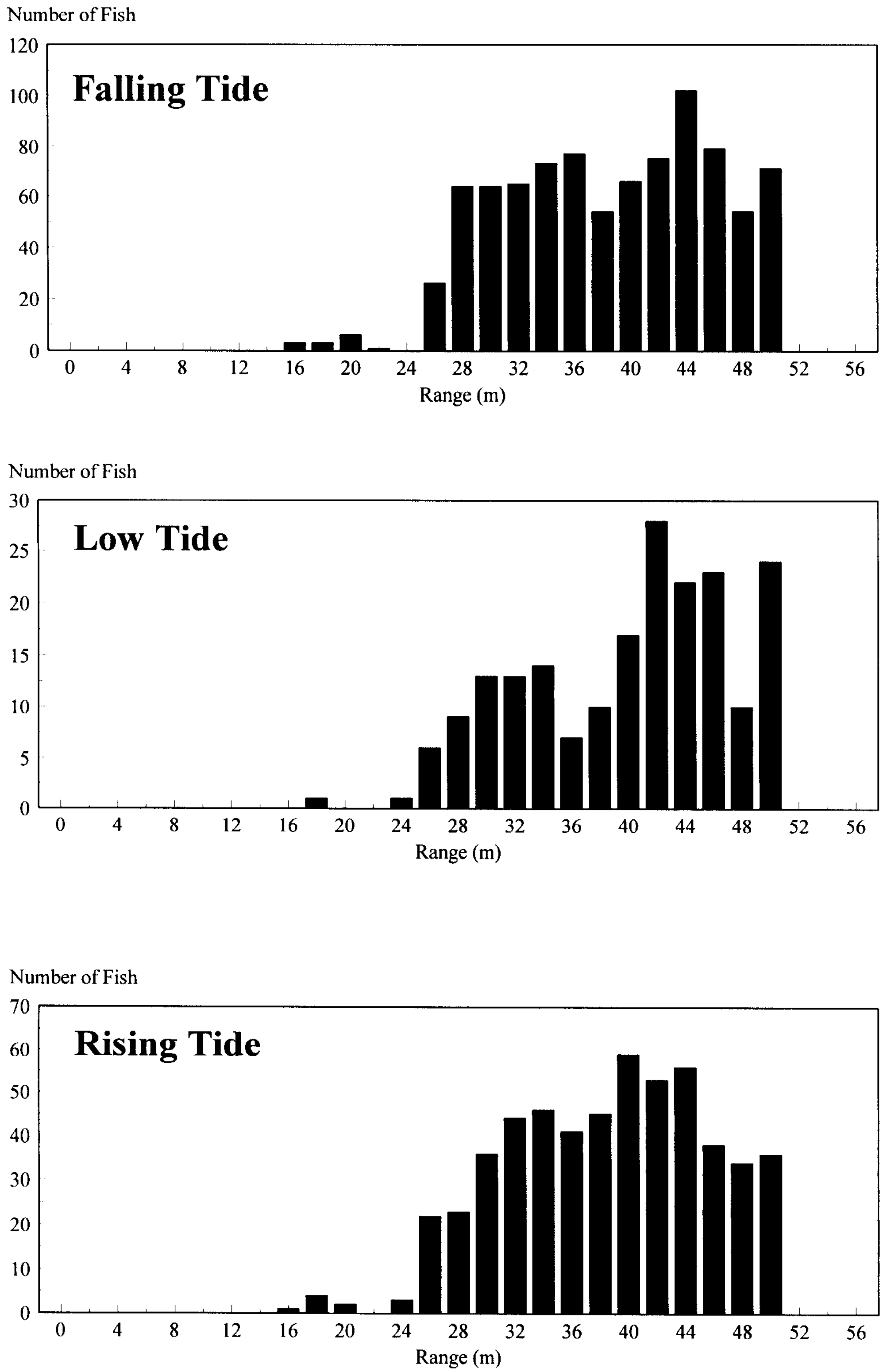
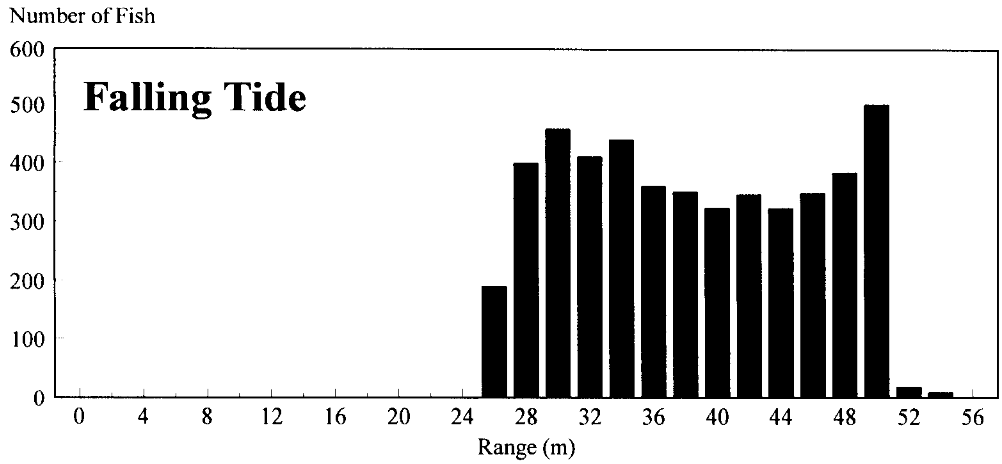
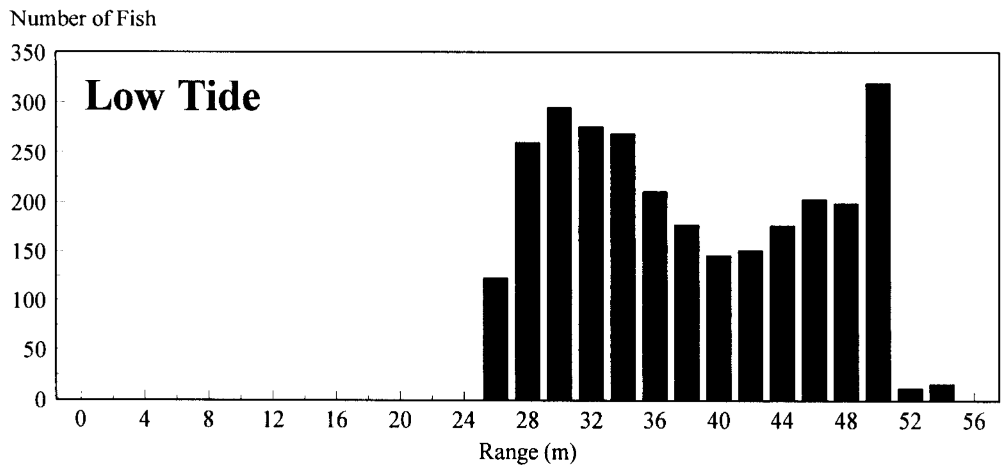



**Figure 28.-Range distribution of late-run upstream-traveling fish from 1-9 July during falling (top), low (middle), and rising (bottom), tide stages on the right bank, Kenai River, 1997.**



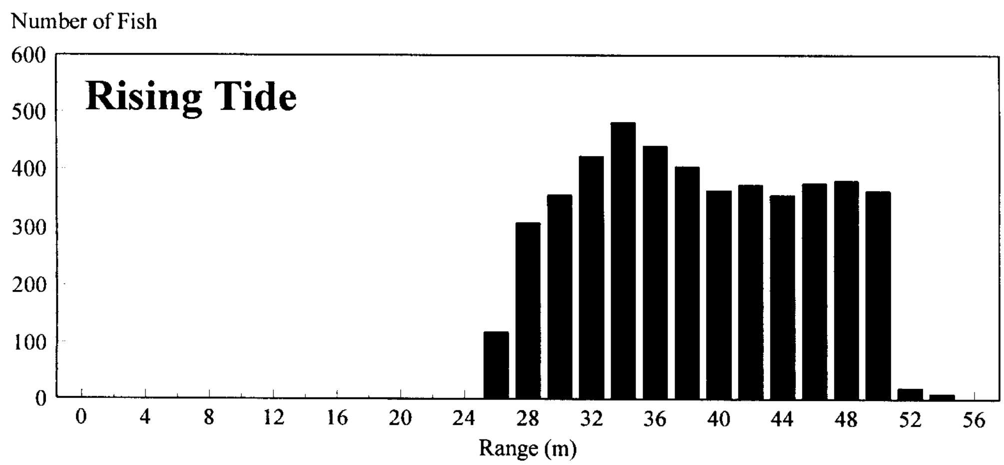




**Figure 29.-Range distribution of late-run upstream-traveling fish from 10-31 July during falling (top), low (middle), and rising (bottom), tide stages on the right bank, Kenai River, 1997.**

salmon was 28% higher than the 39,080 (SE = 4,207) fish estimated by the telemetry study.

The 1996 estimates were further divided into two time strata corresponding to periods of low and high sockeye abundance: (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 where the radio tag 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. The 1997 telemetry estimate could not be stratified due to the distribution of radio tags in the fishery and management restrictions imposed on the fishery (Hammarstrom and Hasbrouck *In prep*).

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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 because it is negligible in fresh water at 200 kHz (0.01 dB/m).

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 July 09 02:00:00 1997

* 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 | 220.7900 | sl - transducer source level |
| 202 | -1 | -170.1600 | 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 | 52.0000 | echogram stop range in meters |
| 211 | -1 | 762.0000 | 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 | 2.5000 | max_angoff_v - maximum angle off axis vertical |
| 219 | -1 | -5.0000 | min_angoff_h - minimum angle off axis horiz. |
| 220 | -1 | 5.0000 | max_angoff_ h - maximum angle off axis horiz. |
| 221 | -1 | -24.0000 | max_dB_off - maximum angle off in dB |
| 222 | -1 | -7.8000 | 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 | -0.0066 | ud_coef_b - b coeff. for up-down beam pattern eq. |
| 226 | -1 | -2.7241 | ud_coef_c - c coeff. for up-down beam pattern eq. |
| 227 | -1 | -0.1137 | ud_coef_d - d coeff. for up-down beam pattern eq. |
| 228 | -1 | -0.1773 | 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 | -0.2186 | lr_coef_c - c coeff . for left-rt beam pattern eq. |
| 232 | -1 | -0.0004 | lr_coef_d - d coeff. for left-rt beam pattern eq. |
| 233 | -1 | -0.0001 | lr_coef_e - ecoeff. for left-rt beam pattern eq. |
| 234 | -1 | 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 | 49.9000 | 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 | 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 | 75.0000 | th_layer[4] - bottom of fifth threshold layer (m) |
| 402 | 0 | 762.0000 | th_val[0] - thr. for 1st layer (mV) |
| 402 | 1 | 7622.0000 | th_val[1] - thr. for 2nd layer (mV) |
| 402 | 2 | 762.0000 | th_val[2] - thr. for 3rd layer (mV) |
| 402 | 3 | 762.0000 | th_val[3] - thr. for 4th layer (mV) |
| 402 | 4 | 762.0000 | 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 July 09 02:00:00 1997

* 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 | 217.99000 | sl - transducer source level |
| 202 | -1 | -171.8100 | 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 | 37.0000 | echogram stop range in meters |
| 211 | -1 | 456.0000 | 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 | -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 | -0.0220 | ud_coef_b - b coeff. for up-down beam pattern eq. |
| 226 | -1 | -2.6052 | ud_coef_c - c coeff. for up-down beam pattern eq. |
| 227 | -1 | -0.2520 | ud_coef_d - d coeff. for up-down beam pattern eq. |
| 228 | -1 | -0.2035 | 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 | -0.2169 | 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 | -0.0002 | lr_coef_e - ecoeff. for left-rt beam pattern eq. |
| 234 | -1 | 100.0000 | maximum fish velocity in meters per second |
| 235 | -1 | 10.0000 | thd_up_time - minutes between 3d plot updates |
| 236 | -1 | 0.5000 | maxpw - pulse width search window size |
| 237 | -1 | 2.0000 | cltop - start of processing in meters |
| 238 | -1 | 33.0000 | 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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## Appendix B2.-Page 3 of 3.

| | | | |
|---|---|---|---|
| 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 | 20.0000 | 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 | 456.0000 | th_val[0] - thr. for 1st layer (mV) |
| 402 | 1 | 456.0000 | th_val[1] - thr. for 2nd layer (mV) |
| 402 | 2 | 456.0000 | th_val[2] - thr. for 3rd layer (mV) |
| 402 | 3 | 456.0000 | th_val[3] - thr. for 4th layer (mV) |
| 402 | 4 | 456.0000 | 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 1997 EARLY AND LATE KENAI RIVER CHINOOK RUNS

**Appendix C1.-Daily proportions of upstream and downstream fish for the 1997 Kenai River early chinook run.**

| Date | Downstream Count | Upstream Count | Daily Total | Percent Downstream | Percent Upstream |
|---|---|---|---|---|---|
| 16-May | 0 | 114 | 114 | 0.0% | 100.0% |
| 17-May | 3 | 96 | 99 | 3.0% | 97.0% |
| 18-May | 18 | 75 | 93 | 19.4% | 80.6% |
| 19-May | 15 | 150 | 165 | 9.1% | 90.9% |
| 20-May | 9 | 75 | 84 | 10.7% | 89.3% |
| 21-May | 12 | 117 | 129 | 9.3% | 90.7% |
| 22-May | 9 | 105 | 114 | 7.9% | 92.1% |
| 23-May | 18 | 144 | 162 | 11.1% | 88.9% |
| 24-May | 21 | 117 | 138 | 15.2% | 84.8% |
| 25-May | 27 | 138 | 165 | 16.4% | 83.6% |
| 26-May | 21 | 200 | 220 | 9.3% | 90.7% |
| 27-May | 57 | 267 | 325 | 17.7% | 82.3% |
| 28-May | 38 | 279 | 317 | 11.9% | 88.1% |
| 29-May | 30 | 258 | 288 | 10.4% | 89.6% |
| 30-May | 45 | 305 | 350 | 12.9% | 87.1% |
| 31-May | 63 | 255 | 318 | 19.8% | 80.2% |
| 1-Jun | 33 | 180 | 213 | 15.5% | 84.5% |
| 2-Jun | 40 | 201 | 241 | 16.5% | 83.5% |
| 3-Jun | 58 | 318 | 376 | 15.5% | 84.5% |
| 4-Jun | 33 | 291 | 324 | 10.2% | 89.8% |
| 5-Jun | 51 | 376 | 427 | 11.9% | 88.1% |
| 6-Jun | 48 | 279 | 327 | 14.7% | 85.3% |
| 7-Jun | 117 | 474 | 591 | 19.8% | 80.2% |
| 8-Jun | 69 | 372 | 441 | 15.6% | 84.4% |
| 9-Jun | 48 | 343 | 391 | 12.2% | 87.8% |
| 10-Jun | 27 | 500 | 527 | 5.1% | 94.9% |
| 11-Jun | 21 | 491 | 512 | 4.1% | 95.9% |
| 12-Jun | 24 | 513 | 537 | 4.5% | 95.5% |
| 13-Jun | 30 | 651 | 681 | 4.4% | 95.6% |
| 14-Jun | 21 | 403 | 424 | 5.0% | 95.0% |
| 15-Jun | 24 | 294 | 318 | 7.5% | 92.5% |
| 16-Jun | 9 | 339 | 348 | 2.6% | 97.4% |
| 17-Jun | 15 | 390 | 405 | 3.7% | 96.% |
| 18-Jun | 15 | 300 | 315 | 4.8% | 95.2% |
| 19-Jun | 18 | 381 | 399 | 4.5% | 95.5% |
| 20-Jun | 33 | 375 | 408 | 8.1% | 91.9% |
| 21-Jun | 33 | 219 | 252 | 13.1% | 86.9% |
| 22-Jun | 45 | 345 | 390 | 11.5% | 88.5% |
| 23-Jun | 15 | 210 | 225 | 6.7% | 93.3% |
| 24-Jun | 33 | 252 | 285 | 11.6% | 88.4% |
| 25-Jun | 48 | 284 | 332 | 14.4% | 85.6% |
| 26-Jun | 69 | 312 | 381 | 18.1% | 81.9% |
| 27-Jun | 48 | 315 | 363 | 13.2% | 86.8% |
| 28-Jun | 54 | 243 | 297 | 18.2% | 81.8% |
| 29-Jun | 69 | 501 | 570 | 12.1% | 87.9% |
| 30-Jun | 60 | 522 | 582 | 10.3% | 89.7% |
| Total | 1,593 | 13,370 | 14,963 | 10.6% | 89.4% |

**Appendix C2.-Daily proportions of upstream and downstream fish for the 1997 Kenai River late chinook run.**

| Date | Downstream Count | Upstream Count | Daily Total | Percent Downstream | Percent Upstream |
|---|---|---|---|---|---|
| 1-Jul | 78 | 408 | 486 | 16.0% | 84.0% |
| 2-Jul | 57 | 585 | 642 | 8.9% | 91.1% |
| 3-Jul | 57 | 543 | 600 | 9.5% | 90.5% |
| 4-Jul | 27 | 606 | 633 | 4.3% | 95.7% |
| 5-Jul | 36 | 621 | 657 | 5.5% | 94.5% |
| 6-Jul | 81 | 546 | 627 | 12.9% | 87.1% |
| 7-Jul | 60 | 1,098 | 1,158 | 5.2% | 94.8% |
| 8-Jul | 66 | 1,155 | 1,221 | 5.4% | 94.6% |
| 9-Jul | 74 | 1,545 | 1,618 | 4.6% | 95.4% |
| 10-Jul | 123 | 3,363 | 3,486 | 3.5% | 96.5% |
| 11-Jul | 143 | 5,506 | 5,649 | 2.5% | 97.5% |
| 12-Jul | 90 | 4,407 | 4,497 | 2.0% | 98.0% |
| 13-Jul | 135 | 5,238 | 5,373 | 2.5% | 97.5% |
| 14-Jul | 51 | 1,980 | 2,031 | 2.5% | 97.5% |
| 15-Jul | 99 | 3,943 | 4,042 | 2.4% | 97.6% |
| 16-Jul | 66 | 3,354 | 3,420 | 1.9% | 98.1% |
| 17-Jul | 126 | 4,458 | 4,584 | 2.7% | 97.3% |
| 18-Jul | 120 | 2,214 | 2,334 | 5.1% | 94.9% |
| 19-Jul | 54 | 1,092 | 1,146 | 4.7% | 95.3% |
| 20-Jul | 54 | 1,524 | 1,578 | 3.4% | 96.6% |
| 21-Jul | 45 | 849 | 894 | 5.0% | 95.0% |
| 22-Jul | 102 | 1,738 | 1,840 | 5.5% | 94.5% |
| 23-Jul | 69 | 1,372 | 1,441 | 4.8% | 95.2% |
| 24-Jul | 69 | 1,011 | 1,080 | 6.4% | 93.6% |
| 25-Jul | 54 | 478 | 532 | 10.2% | 90.0% |
| 26-Jul | 18 | 501 | 519 | 3.5% | 96.5% |
| 27-Jul | 27 | 411 | 438 | 6.2% | 93.8% |
| 28-Jul | 18 | 315 | 333 | 5.4% | 94.6% |
| 29-Jul | 31 | 370 | 401 | 7.7% | 92.3% |
| 30-Jul | 27 | 423 | 450 | 6.0% | 94.0% |
| 31-Jul | 42 | 378 | 420 | 10.0% | 90.0% |
| 1-Aug | 6 | 241 | 247 | 2.4% | 97.9% |
| 2-Aug | 12 | 279 | 291 | 4.1% | 95.9% |
| 3-Aug | 21 | 192 | 213 | 9.9% | 90.1% |
| Total | 2,138 | 52,745 | 54,881 | 3.9% | 96.1% |

# APPENDIX D. AVERAGE VERTICAL ANGLE BY TIDE STAGE, RUN, BANK, AND FISH ORIENTATION (UPSTREAM OR DOWNSTREAM) FOR THE 1997 KENAI RIVER CHINOOK RUNS

**Appendix D1.-Average vertical angle by tide stage and orientation for the 1997 early Kenai River chinook run.**

| Tide Stage/Fish Orientation | Average Vertical Angle | Standard Deviation | Sample Size |
|---|---|---|---|
| **1997 Early Run, Left Bank** | | | |
| 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 |
| **1997 Early Run, Right Bank** | | | |
| 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 1997 late Kenai River chinook run.**

| Tide Stage/Fish Orientation | Average Vertical Angle | Standard Deviation | Sample Size |
|---|---|---|---|
| | **1997 Late Run, Left Bank** | | |
| 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 |
| | **1997 Late Run, Right Bank** | | |
| 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 |