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# Estimates of Chinook Salmon Abundance in the Kenai River Using Split-Beam Sonar, 2002

by

James D. Miller,

Debby L. Burwen,

and

Steve J. Fleischman

December 2004

Alaska Department of Fish and Game Divisions of Sport Fish and Commercial Fisheries

# Symbols and Abbreviations

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**Weights and measures (metric)**

| | |
|---|---|
| centimeter | cm |
| deciliter | dL |
| gram | g |
| hectare | ha |
| kilogram | kg |
| kilometer | km |
| liter | L |
| meter | m |
| milliliter | mL |
| millimeter | mm |

**Weights and measures (English)**

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

**Time and temperature**

| | |
|---|---|
| day | d |
| degrees Celsius | °C |
| degrees Fahrenheit | °F |
| degrees kelvin | K |
| hour | h |
| minute | min |
| second | s |

**Physics and chemistry**

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

**General**

| | |
|---|---|
| Alaska Administrative Code | AAC |
| all commonly accepted abbreviations | e.g., Mr., Mrs., AM, PM, etc. |
| all commonly accepted professional titles | e.g., Dr., Ph.D., R.N., etc. |
| at | @ |
| compass directions: | |
| east | E |
| north | N |
| south | S |
| west | W |
| copyright | © |
| corporate suffixes: | |
| Company | Co. |
| Corporation | Corp. |
| Incorporated | Inc. |
| Limited | Ltd. |
| District of Columbia | D.C. |
| et alii (and others) | et al. |
| et cetera (and so forth) | etc. |
| exempli gratia (for example) | e.g. |
| Federal Information Code | FIC |
| id est (that is) | i.e. |
| latitude or longitude | lat. or long. |
| monetary symbols (U.S.) | $, ¢ |
| months (tables and figures): first three letters | Jan,...,Dec |
| registered trademark | ® |
| trademark | ™ |
| United States (adjective) | U.S. |
| United States of America (noun) | USA |
| U.S.C. | United States Code |
| U.S. state | use two-letter abbreviations (e.g., AK, WA) |

**Measures (fisheries)**

| | |
|---|---|
| fork length | FL |
| mideye-to-fork | MEF |
| mideye-to-tail-fork | METF |
| standard length | SL |
| total length | TL |

**Mathematics, statistics**

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

*FISHERY DATA SERIES NO. 04-29*

# ESTIMATES OF CHINOOK SALMON ABUNDANCE IN THE KENAI RIVER USING SPLIT-BEAM SONAR, 2002

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James D. Miller,
Debby L. Burwen,
*Division of Sport Fish, Anchorage*
and
Steve J. Fleischman
*Division of Sport Fish, Research and Technical Services, Anchorage*



Alaska Department of Fish and Game
Division of Sport Fish, Research and Technical Services
333 Raspberry Road, Anchorage, Alaska 99518-1599

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*James D. Miller, Debby L. Burwen,*
*Alaska Department of Fish and Game, Division of Sport Fish*
*333 Raspberry Road, Anchorage, Alaska 99518-1599, USA*
*and*
*Steve J. Fleischman*
*Alaska Department of Fish and Game, Division of Sport Fish, Research and Technical Services*
*333 Raspberry Road, Anchorage, Alaska 99518-1599, USA*

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# ABSTRACT

The passage of Chinook salmon *Oncorhynchus tshawytscha* in the Kenai River in 2002 was estimated using side-looking split-beam sonar technology. Early (16 May-30 June) and late (1 July-10 August) runs of Kenai River Chinook salmon have been monitored acoustically since 1987. A 200 kHz split-beam sonar system has been used since 1995 to estimate numbers of adult Chinook salmon migrating into the Kenai River. From 1987 to 1994, a 420 kHz dual-beam sonar was used to generate similar estimates. In 2002, the sonar project only operated through 5 August due to budgetary constraints. Total upstream Chinook salmon passage from 16 May through 5 August was an estimated 46,110 (SE = 535) fish; 7,162 (SE = 169) fish during the early run and 38,948 (SE = 508) fish during the late run. Total late-run passage extrapolated through 10 August was an estimated 41,807 (SE = 1,353) fish. The variability associated with these estimates reflects only sampling error and not other sources of uncertainty including target detectability, species composition, direction of travel, and target tracking. The peak daily passage of the early run occurred on 9 June with 50% of the run having passed by 15 June. The daily peak of the late run occurred on 3 July, with 50% of the late run having passed by 16 July, based on estimated passage through 10 August.

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

# INTRODUCTION

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

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

Sonar estimates of inriver run provide the basis for estimating spawning escapement and implementing management plans that regulate harvest in competing sport and commercial fisheries for this stock. Implementation of these management plans has been contentious and attracts much public scrutiny. Restrictions on the sport fishery were imposed in each year from 1989 through 1992 to ensure spawning escapement goals were met. Since 1993, the 1997, 1998, 2000 and 2002 early runs, and the 1998 late run required a restriction of the sport fishery to meet escapement goals.

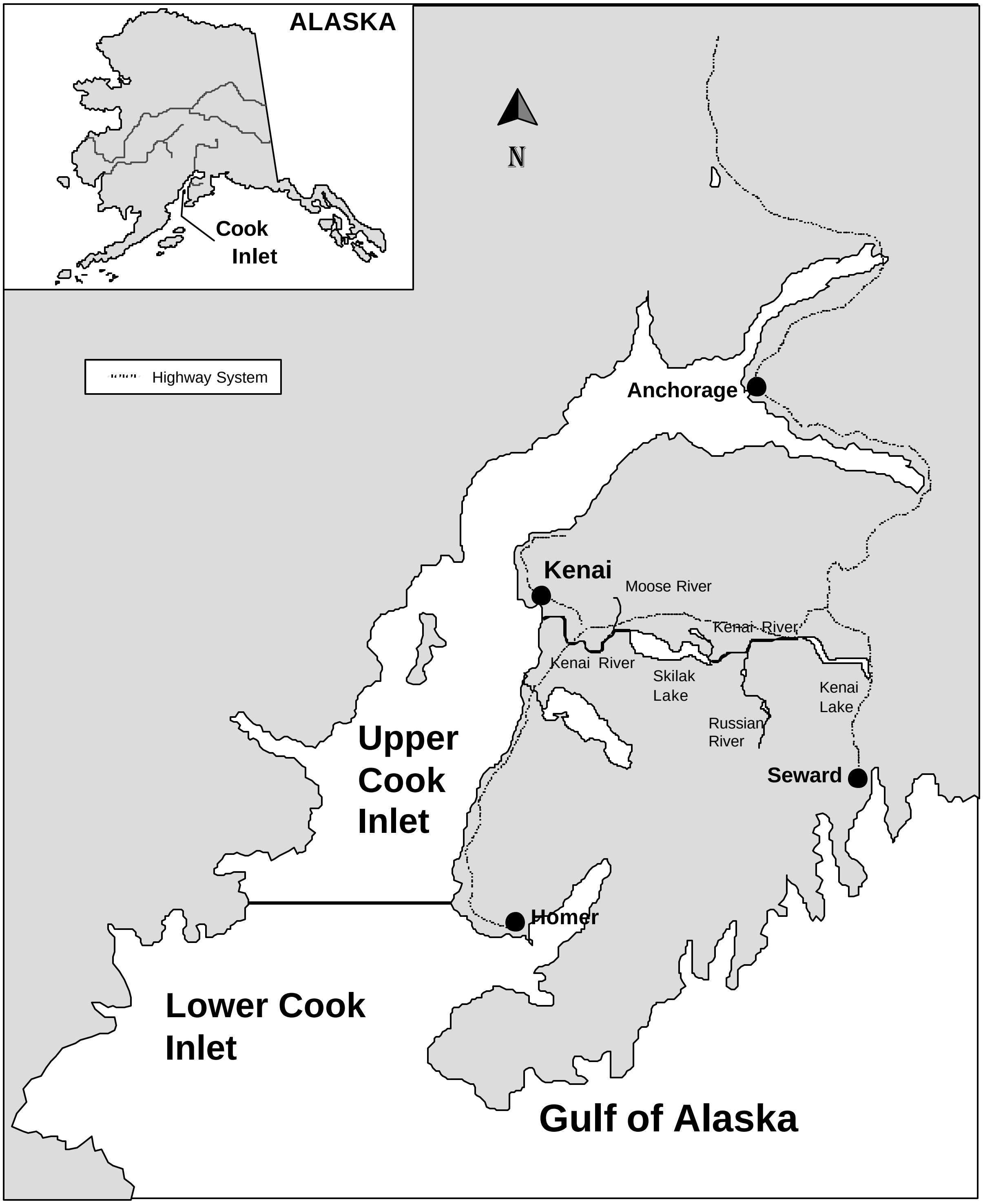



**Figure 1**.-Cook Inlet showing location of the Kenai River.

The first estimates of Chinook salmon abundance were generated for the 1984 late run with a mark-recapture project using drift gillnets (Hammarstrom et al. 1985). The mark-recapture project produced estimates 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 appeared to be biased high, particularly during the late run (Bernard and Hansen 1992).

In order to obtain timely and accurate estimates of Chinook salmon passage, the department initiated studies to determine whether an acoustic assessment program could be developed to provide daily estimates of Chinook salmon into the Kenai River (Eggers et al. 1995). Acoustic assessment of Chinook salmon in the Kenai River is complicated by the presence of more abundant sockeye salmon, which migrate concurrently with Chinook salmon. From 1987-2002, sockeye salmon *O. nerka* escapement estimates generated by the river mile-19 sockeye sonar project ranged from 625,000 to 1,600,000 (Westerman and Willette 2003) while late-run Chinook salmon escapement estimates generated by the Chinook sonar project have ranged from 29,000 to 55,000. Dual-beam sonar was initially chosen for the Chinook sonar project because of its ability to estimate acoustic size (target strength), which was to serve as the discriminatory variable to systematically identify and count only large Chinook salmon. Due to the considerable size difference between Kenai River Chinook salmon and other species of fish present in the river, it was postulated that dual-beam sonar could be used to distinguish the larger Chinook salmon from smaller fish (primarily sockeye) and estimate their numbers returning to the river.

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

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

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

To address these concerns, radiotelemetry projects were implemented in 1996 and 1997 to estimate the magnitude of bias introduced during periods of high sockeye passage estimates (Hammarstrom and Hasbrouck 1998, 1999). These studies were designed to provide an independent and accurate estimate of inriver Chinook abundance during the late run when the potential to misclassify sockeye is greatest. Although the precision was similar, the use of radio-telemetry technology avoided certain biases introduced in previous mark-recapture estimates. Sonar estimates of late-run Chinook abundance were 26% and 28% greater than the telemetry estimates for 1996 and 1997, respectively.

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

Subsequent analysis of 3 years (1998-2000) of standardized CPUE data suggested the netting data were better suited for species apportionment than for abundance estimation (Reimer et al. 2002). In 2001, the inriver netting project continued to produce daily CPUE estimates, but for the first time Chinook abundance was experimentally estimated using a combination of Chinook catch proportions from the netting program and unfiltered passage estimates from the sonar program (Miller et al. 2003). Net-apportioned estimates of Chinook passage tracked well with conventional sonar passage estimates during the 2001 early run, but were substantially higher than the sonar estimates during the 2001 late run. The apparent under-representation of sockeye salmon in the gillnet catches during the 2001 late run led to changes in the netting program for the 2002 season that included using multiple mesh sizes (Reimer 2003).

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

Improved techniques for separating Chinook and sockeye salmon using acoustic information are also being pursued. Studies with tethered and free-swimming fish indicate that a variable based on echo envelope length may provide higher discriminatory power than target strength for separating sockeye and Chinook salmon (Burwen and Fleischman 1998, Burwen et al. 2003). In addition, a new experimental imaging sonar was tested on the Kenai River in 2002 to delineate its range limitations and to determine the feasibility of using it to measure fish size (Burwen and Fleischman *In prep*).

## PROJECT OBJECTIVES

Objectives for 2002 were to generate daily and seasonal estimates of early-run (16 May-30 June) and late-run (1 July-5 August) Chinook salmon passage into the Kenai River using a split-beam sonar system.

In past years, the Kenai River Chinook sonar project was operated through 10 August. In 2002, budget constraints caused operations to cease on 5 August. Extrapolation was used to estimate late-run Chinook passage through 10 August.

# METHODS

## STUDY AREA

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

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

## SITE DESCRIPTION

The 2002 sonar site was located 14 km (8.5 mi) from the mouth of the Kenai River (Figure 2). This site has been used since 1985 and was selected for its acoustic characteristics and its location relative to the sport fishery and known spawning habitat of Chinook salmon.

The river bottom in this area has remained stable for the past 17 years despite a 140-year flood during September 1995 (Bosch and Burwen 1999). The slope from both banks has remained gradual and uniform, which allows a large proportion of the water column to be insonified without acoustic shadowing effects. On the right bank, the bottom is composed primarily of mud, providing an acoustically absorptive rather than reflective surface. This absorptive property improves the signal-to-noise ratio when the beam is aimed along the river bottom. The left-bank bottom gradient is steeper and consists of more acoustically reflective small rounded cobble and gravel.

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

## ACOUSTIC SAMPLING

A Hydroacoustic Technology Inc. (HTI) split-beam sonar system was operated from 16 May through 5 August, 2002. Components of the system are listed in Table 1 and further described in HTI manuals (HTI 1996, 1997). A brief explanation of the theory of split-beam sonar and its use in estimating target strength can be found in Appendix A1. A more detailed explanation can be found in Ehrenberg (1983).

### Sonar System Configuration

Sampling on both banks was controlled by electronics housed in a tent located on the right bank of the river. Communication cables led to transducers and their aiming devices on both banks. Cables leading to the left-bank equipment were suspended above the river at a height that would not impede boat traffic (Figure 3). Steel tripods were used to deploy the transducers offshore. One elliptical, split-beam transducer was mounted on each tripod. At the start of the season the transducer tripods were placed on each bank in a position close to shore but still submerged at low tide. During 16 May to 5 August, water level at low tide rose approximately 1.4 m. Rising water level throughout the season and heavy debris accumulation on the gear resulted in occasional relocation of transducer tripods. Total range insonified by both (right and left) sonar beams ranged from a low of approximately 58 m on 2-5 August to a high of 85 m on 28 May (Figure 4).

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

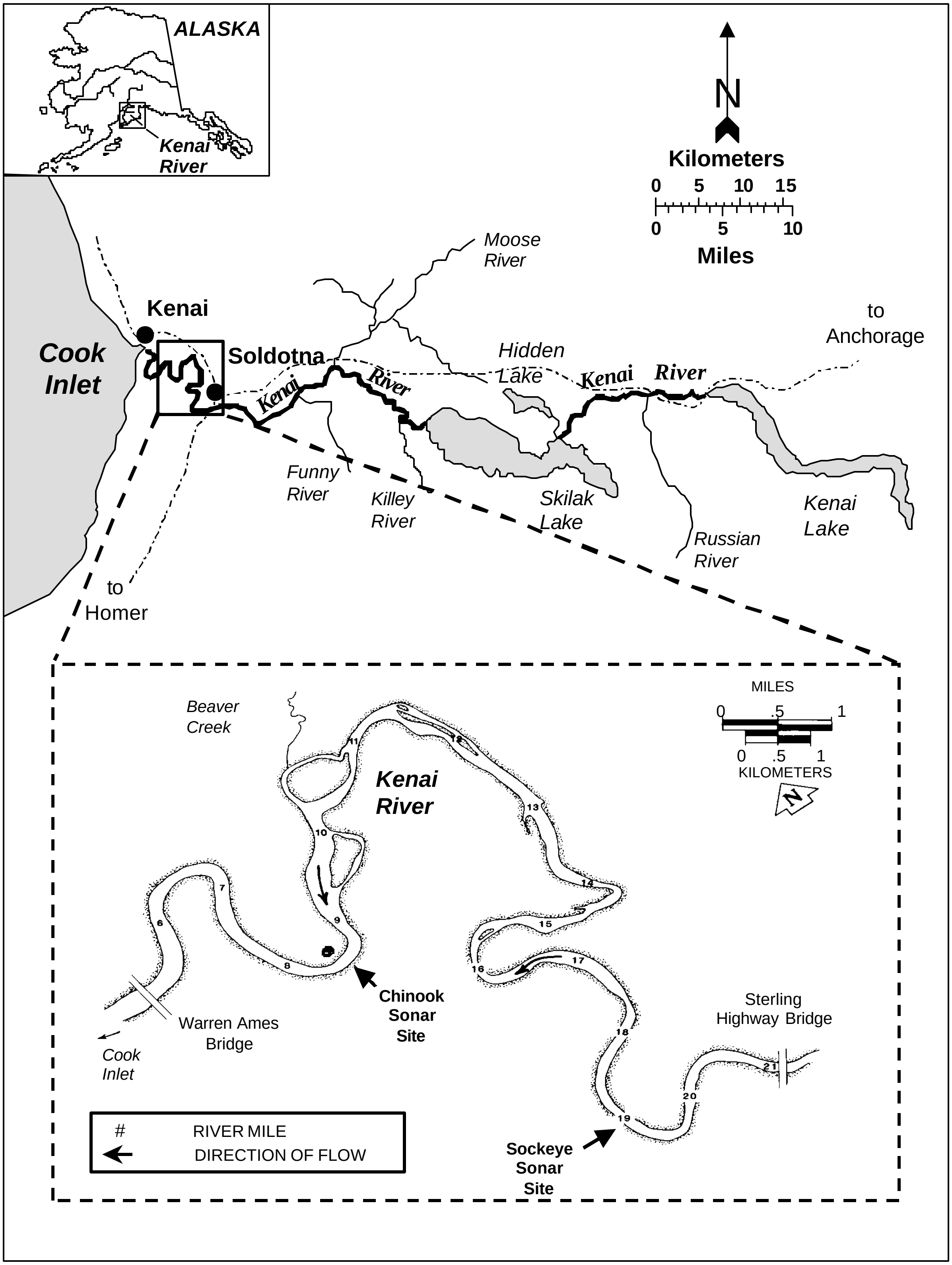



**Figure 2**.-Kenai River showing location of Chinook salmon sonar site, 2002.

**Table 1**.-Main components of the split-beam sonar system used in 2002.

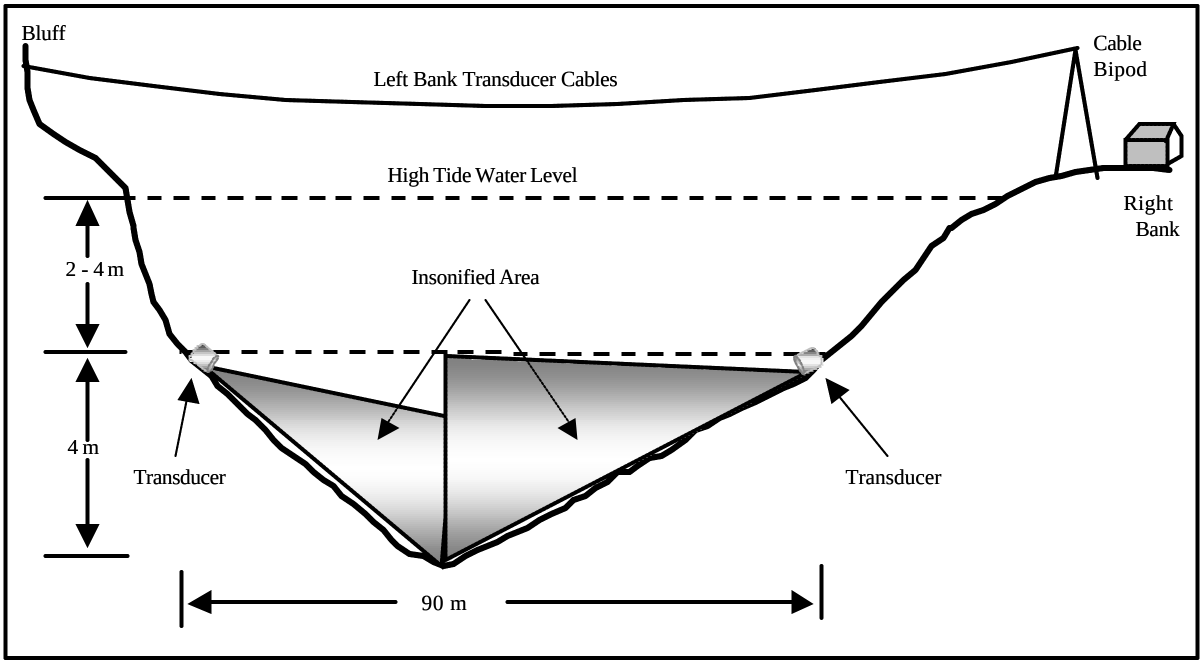
| System Component | Description |
|---|---|
| Sounder | Hydroacoustic Technology Inc. (HTI) Model 244 Split-Beam Echo sounder operating at 200 kHz |
| Signal Processor | HTI Model 340 Digital Echo Processor based in a Dell XPS T450 personal computer |
| Transducers | (2) HTI Split-Beam transducers:<br>Left Bank: nominal beam widths: 2.9°x10.2°<br>Right Bank: nominal beam widths: 2.8°x10.0° |
| Chart Recorder | HTI model 403 digital dual-channel chart recorder |
| Oscilloscope | Nicolet model 310 digital storage oscilloscope |
| Video Display | Hydroacoustic Assessments HARP-HC |
| Remote Pan and Tilt Aiming Controller | Remote Ocean Systems Model PTC-1 Pan and Tilt Controller |
| Remote Pan and Tilt Aiming Unit | Remote Ocean Systems Model PT-25 Remote Pan and Tilt Unit |
| Heading and Angular Measurement Device | JASCO Research Ltd. Uwinstru Underwater Measurement Device. |

insonifying fish from a lateral aspect. The range encompassed by each transducer was determined by the river bottom contour and the transducer tripod placement. Transducer tripods were placed in such a manner as to maximize counting range in an attempt to fully insonify the cross section of the river between the right- and left-bank transducers.

### Bottom Mapping and Beam Coverage

A detailed profile of the river bottom and the area encompassed by the sonar beams was produced prior to acoustic sampling. Depth readings from a Lowrance X-16 were paired with range measurements from a fixed target on shore using a Bushnell Laser Ranger (±1 m accuracy). Prior to 2001, placement of transducer tripods directly across the river from each other provided optimal sonar beam aim and coverage. River bottom profiles collected in 2001 prompted the relocation of the left-bank transducer 35 m downstream from the deployment location used in past years. The new deployment location improved overall quality of the sonar aim, but resulted in a reduced coverage range and an apparent mid river gap in coverage that varied from 2 m to 7 m in size (Miller et al. 2003). The 2001 daily passage estimates were expanded postseason to account for the incomplete spatial coverage. River bottom profiles collected in 2002 again suggested deployment of the left-bank transducer in the same location as that used in 2001. However, the resulting transducer aim, when combined with the right-bank coverage, resulted in an apparent overlap in sonar coverage between the two banks. Appendix B provides a possible explanation for the overlap in coverage and explains why no adjustments were made to the daily sonar passage estimates in 2002.

A detailed visualization of how well the water column above the bottom substrate was insonified by the acoustic beam was generated using detailed bottom profile information combined with



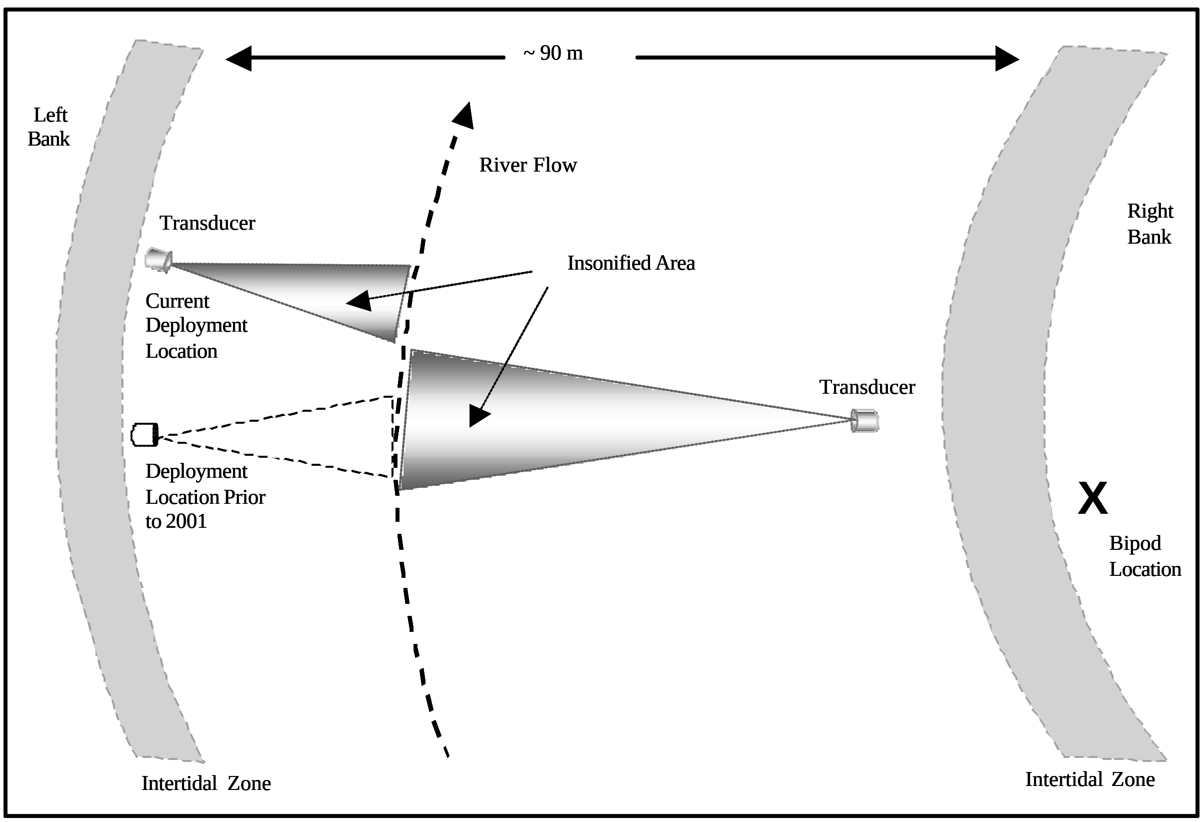




**Figure 3**.-Cross-sectional (top) and aerial (bottom) views of sonar site showing insonified portions of the Kenai River, 2002.

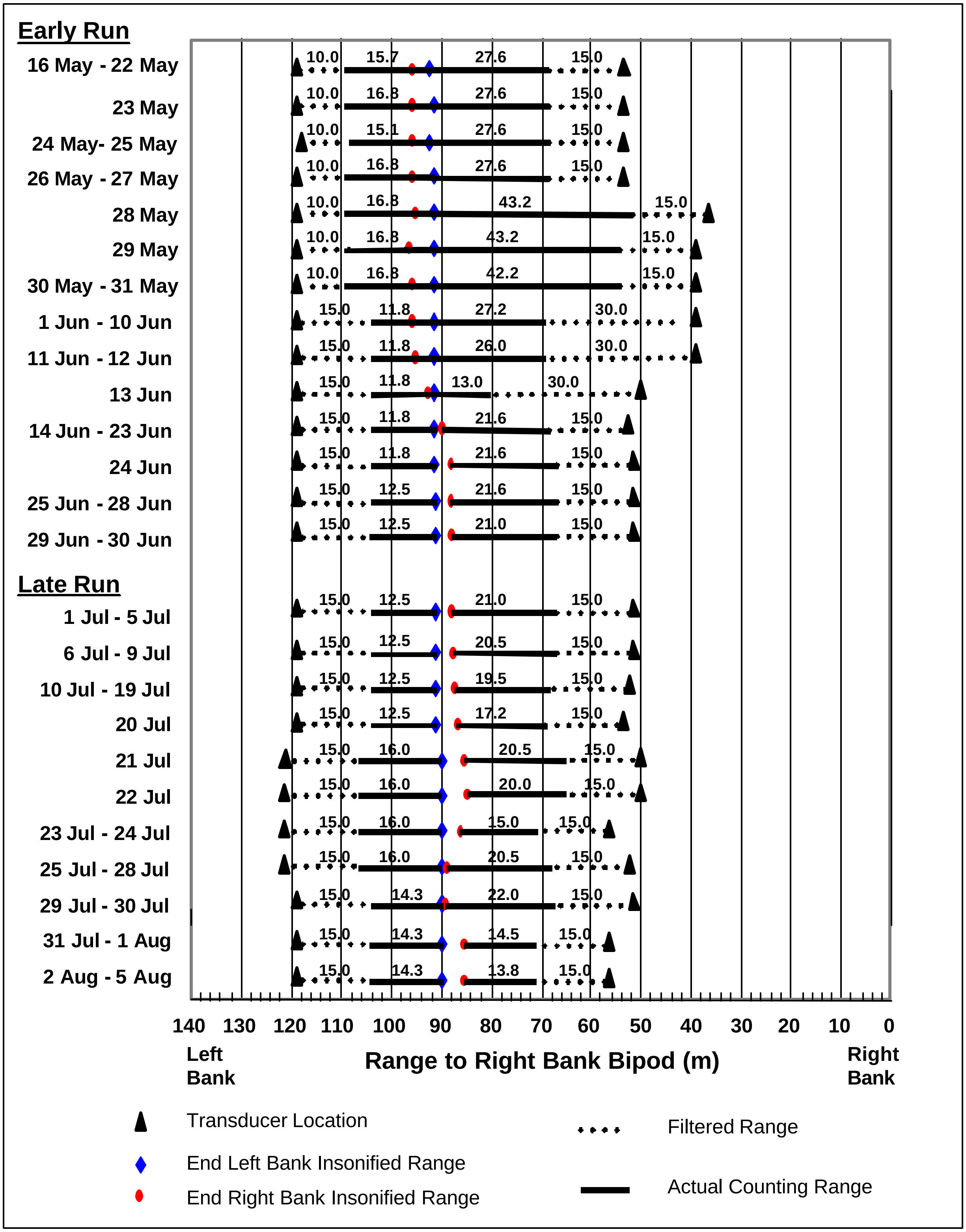



**Figure 4**.-Daily right- and left-bank transducer locations and counting ranges relative to bipod tower located on the right bank, Kenai River, 2002.

information from attitude sensors mounted on the transducers (Figure 5). The attitude sensor is a more reliable indicator of the transducer position than the rotator digital readout, thus information from the attitude sensor provided a more accurate representation of beam aim and coverage than did the rotator output.

Each time the transducer was moved throughout the season, new measurements of the transducer height above the bottom substrate and its position relative to a fixed shore location were updated in an EXCEL worksheet so that beam coverage at the new location could be evaluated.

### System Calibration

HTI performed reciprocity calibrations with a naval standard transducer on 18 October 2001. Calibration results were verified at the calibration facility with a 38.1-mm tungsten carbide sphere (Foote and MacLennan 1984). Further verification was obtained *in situ* by measuring the same standard sphere on 14 May, 20 June, and 1 August 2002. 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).

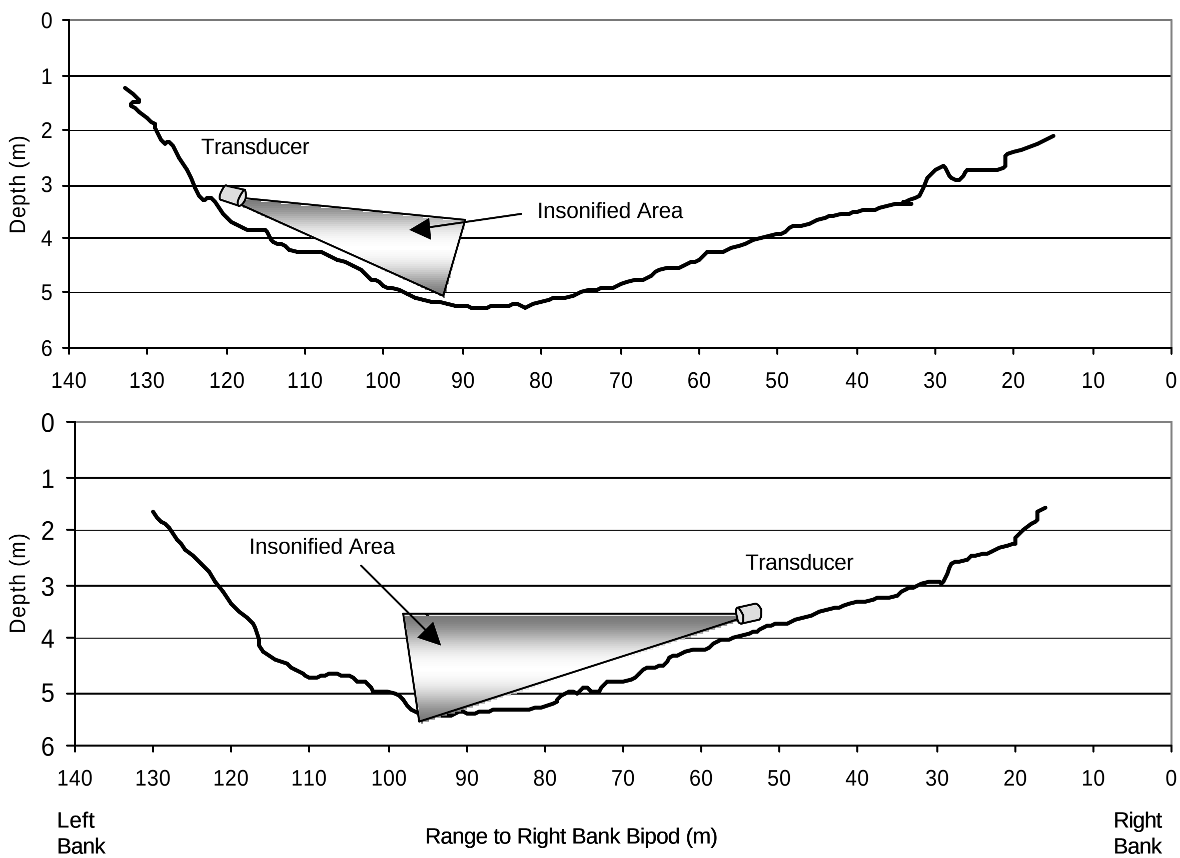



**Figure 5.**-Left- and right-bank bottom profiles at the Kenai River Chinook sonar site with approximate transducer locations and sonar beam coverage for 16 May 2002.

## Sampling Procedure

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

A test of this sample design conducted in 1999 found no significant difference between hourly estimates of Chinook salmon passage obtained using full 1-hour counts and estimates obtained using expanded 20-min counts (Miller et al. 2002).

## Echo Sounder Settings

Relevant echo sounder settings are listed in Table 2 with a more complete summary in Appendix C1 and Appendix C2. Most echo sounder settings were identical for each bank and remained consistent throughout the sampling 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.

**Table 2**.-HTI model 244 digital echo sounder settings used in 2002.

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

## Data Acquisition

The digital echo sounder (DES) sent data from each returned echo to the digital echo processor (DEP, Figure 6). The DEP performed the initial filtering of returned echoes based on user-selected criteria (Table 3, Appendices C1 and C2); it also recorded the start time, date and number of pings processed for each sample.

Echoes in the transducer near field (≤ 2.0 m) were excluded (MacLennan and Simmonds 1992), as were echoes which exceeded maximum vertical and horizontal angles off-axis. The angle filters were used to prevent consideration of unreliable data from transducer side lobes.

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

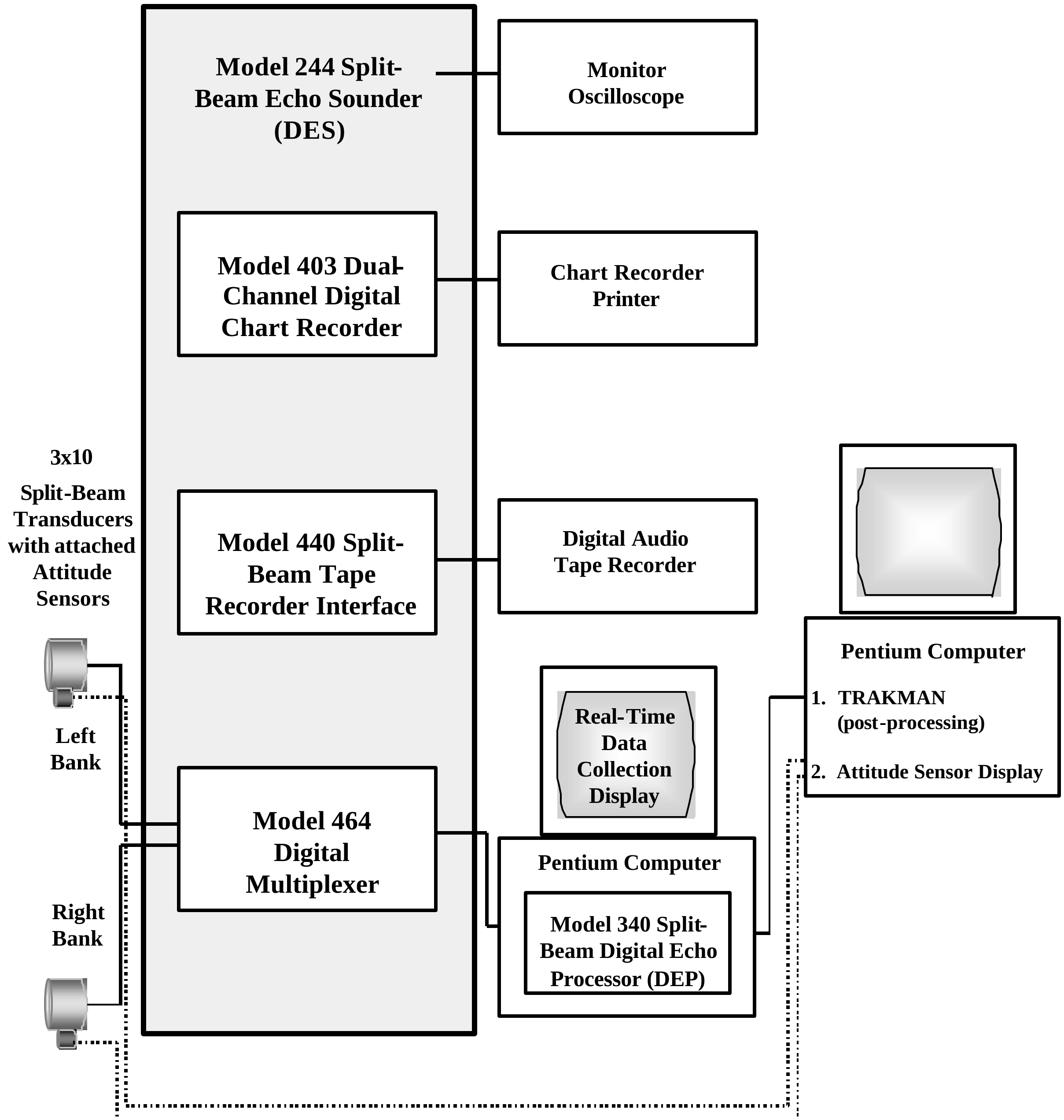



**Figure 6**.-Schematic of 2002 split-beam sonar system configuration and data flow.

distinguish echoes originating from valid fish targets. The amount of background noise is determined largely by the dimensions of the sonar beam in relation to the depth of the river. Since the water level at the sonar site is strongly influenced by tidal stage (vertical fluctuations of more than 4 m), the amount of background noise fluctuates periodically, with lowest noise levels during high tide and the highest levels during falling and low tides. Voltage thresholds corresponding to a -35 dB target on-axis were selected for each bank as the lowest threshold that would exclude background noise at low tide when noise was at a maximum.

**Table 3**.-Echo acceptance criteria for digital echo processing, 2002.

| Bank | pulse width[a] (ms) at -6 dB | Vertical angle off-axis (°) | Horizontal angle off-axis(°) | Threshold mV (dB) | Range (m) |
|---|---|---|---|---|---|
| Right | | | | | |
| 16-May to 5-Aug | 0.04 to 10.0 | -2.5 to 2.5 | -5.0 to 5.0 | 708 (-35 dB) | 2.0 |
| Left | | | | | |
| 16- May to 5- Aug | 0.04 to 10.0 | -2.5 to 2.5 | -5.0 to 5.0 | 420 (-35 dB ) | 2.0 |

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

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 244 DES was also output to a dot matrix printer using an HTI Model 403 Digital Chart Recorder, to a Nicolet 310[1] digital storage oscilloscope and to a Harp HC2 color chart monitor. Chart recorder output was filtered only by a voltage threshold, which was set equal to the DEP threshold. The chart recorder ran concurrently with the echo sounder and produced real-time echograms for each sample. The echograms were used for data backup and transducer aiming, and to aid in manual target tracking. Voltage output to the oscilloscope and color monitor was not filtered. Monitoring the unfiltered color echogram ensured that subthreshold targets were not being unintentionally filtered. Advanced features on the digital oscilloscope aided in performing field calibrations with a standard target and in monitoring the background noise level relative to the voltage threshold level.

## FISH TRACKING AND ECHO COUNTING

A diagram illustrating inseason data flow can be found in Appendix D1. Echoes in the *.RAW files were manually grouped (tracked) into fish using HTI proprietary software called TRAKMAN. This program produces an electronic chart recording for all valid echoes collected during a 20-min sample on the computer monitor. Selected segments of the chart can be enlarged and echoes viewed on a Cartesian grid. Echoes following a sequential progression through the beam were selected by the user and classified into fish traces. TRAKMAN then produced three output files. The first file contained each echo that was tracked in a valid target (*.MEC file) and included the following data for each echo: estimated X (left-right), Y (up-down), and Z (distance from the transducer) coordinates in meters, where the transducer face is the origin of the coordinate system; pulse widths measured at -6 dB, -12 dB, and -18 dB

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

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 estimated by calculating the simple linear regression of X-axis position (distance up- or down-river from the beam axis) on ping number, for echoes with absolute X-axis angle less than 5 degrees. On the right bank, a target was classified as upstream-bound if the slope of the regression was negative, or downstream-bound if the slope was positive. On the left bank the criteria are reversed.

Downstream targets (and occasionally upstream targets during a strong flood tide) were further classified as fish or debris primarily by looking at the angle of passage and degree of movement in the Z-axis (range from transducer) as the target transited the acoustic beam. For debris, the angle of passage through the beam is constant with little change in the range as it passes through the beam. Consequently, debris resembles a line drawn on the echogram with a straight edge. A fish typically leaves a meandering trace that reflects some level of active movement as it passes through the acoustic beam. Obvious debris-like downstream targets were excluded from consideration as valid fish targets during the tracking procedure and the remainder of downstream targets was retained to adjust the total estimate of fish passage. Separate summary files were generated for tracked targets classified as debris (i.e. *.DEC and *.DFS files). Except for debris, only targets comprising echoes displaying fish-like behavior were tracked. Echoes from structure, boat wake and sport fishing tackle were ignored.

## DATA ANALYSES

### Tidal and Temporal Distribution

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

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

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

where:

$z_a$ = adjusted range (in meters),

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

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

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

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

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

where:

$\theta_y$ = vertical angle-off-axis midpoint (degrees),

$y_s$ = starting vertical coordinate (in meters), and

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

## Target Strength Distribution

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

## Species Discrimination

Tracked fish were filtered using criteria intended to minimize the number of sockeye salmon counted. Two parameters have been used historically on this project to separate large Chinook salmon from smaller species: target strength and distance from the transducer (range). Although studies have questioned the ability of these filters to exclude sufficient numbers of sockeye salmon (Eggers 1994; Burwen et al. 1995), we continued their use in 2002 to ensure comparability of passage estimates with those of past years, while continuing to investigate other means of discriminating between fish sizes (see Discussion).

Tracked fish with mean target strength less than -28 dB were assumed to be species other than Chinook salmon and excluded from further analysis. The majority of fish within the nearshore area were assumed to be smaller species such as sockeye, pink *O. gorbuscha*, and coho *O. kisutch* salmon, so all targets within a particular threshold range were filtered out regardless of target strength. Several range thresholds were applied on the right and left bank, all associated with either moving the transducer tripods closer to shore and increasing the range to maintain mid-channel coverage, or with extending the range thresholds during periods of high sockeye salmon passage to avoid misclassifying offshore-distributed sockeye as Chinook. Early-run range thresholds were 10 m (16 May–31 May ) and 15 m (1 June-30 June) on the left bank and 15 m (16 May-31 May and 14 June-30 June) and 30 m (1 June-13 June) on the right bank (Figure 4). A 15-meter range threshold was used throughout the late run (1 July-5 August) on both the right and left bank (Figure 4).

Targets observed passing the sonar site in pairs or small groups were assumed to be sockeye salmon. During periods of high sockeye salmon passage, size and range filters failed to remove many of these targets. For this reason, hourly samples containing substantial numbers of paired or grouped targets at far range (beyond the range thresholds) were considered unreliable and were excluded from calculation of the Chinook passage estimate (Appendix E1).

### Passage Estimates

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

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

where the mean hourly passage past bank k during day i was:

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

where $n_{ik}$ was the number of hours during which passage was estimated (or imputed) on bank k for day i. When the sonar was functional on bank k during hour j of day i, then hourly Chinook salmon passage was estimated as follows:

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

where:

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

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

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

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

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

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

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

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

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

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

$$\hat{Y} = \sum_i \hat{y}_i \text{, and} \tag{9}$$

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

Late-run passage through 10 August ($\hat{Y}_e$) was estimated by dividing by the mean proportion of passage ($\bar{p}$) through 5 August for the 10 years (1987-1988, 1990, 1992-1993, 1995, and 1998-2001) when the sonar project operated through at least 9 August:

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

where:

$$\bar{p} = \frac{\sum_g p_g}{10}, \tag{12}$$

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

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

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

where:

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

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

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

The "alternative" daily estimate (or net-apportioned estimate) of Chinook salmon passage was calculated by multiplying the unfiltered sonar passage estimate by the proportion $\hat{q}_i$ of Chinook salmon in drift gillnet catches near the sonar site (Reimer 2004):

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

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

$$\hat{var}\left(\hat{y}'_i\right) = \hat{x}_i^2\,\hat{var}\left(\hat{q}_i\right) + \hat{q}_i^2\,\hat{var}\left(\hat{x}_i\right) - \hat{var}\left(\hat{q}_i\right)\hat{var}\left(\hat{x}_i\right). \tag{17}$$

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

# 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 -39.51 dB and -39.54 dB with the right- and left-bank transducers, respectively (HTI 2001; 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 -36.98 dB to -37.98 dB on the right bank and from -37.19 dB to -38.16 dB on the left bank (Table 4). Small fluctuations in mean target strength are expected throughout the season as target strength can vary with water temperature, depth, conductivity and other factors.

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[1] Unfiltered with respect to target strength, but restricted to upstream-bound targets passing at a distance greater than the smallest range thresholds used during the season (15 m on right bank, 10 m on left bank).

**Table 4**.-Results of 2002 *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] | 18-Oct | -39.51 | 0.65 | 395 | 6.1 | N/A[b] | N/A[b] |
| Kenai River | 14-May | -37.85 | 2.10 | 2,066 | 8.9 | 135 | 150 |
| Kenai River | 20-Jun | -37.98 | 1.51 | 1,146 | 27.3 | 150 | 200 |
| Kenai River | 1-Aug | -36.98 | 3.56 | 791 | 19.4 | 100 | 150 |
| | | | | | | | |
| Left Bank | | | | | | | |
| HTI[a] | 18-Oct | -39.54 | 0.42 | 301 | 6.1 | N/A[b] | N/A[b] |
| Kenai River | 14-May | -37.19 | 1.47 | 5,208 | 19.2 | 100 | 100 |
| Kenai River | 1-Aug | -38.16 | 2.44 | 2,085 | 17.9 | 75 | 100 |

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

[b] Not available or not applicable.

## TARGET TRACKING

In 2002, 67,984 targets were manually tracked, 7,453 during the early run and 60,531 during the late run. After filtering for range and target strength criteria and making temporal expansions, the proportion of upstream fish was 96% for the early run and 94% for the late run (Appendices F1 and F2).

The number of acquired echoes per fish varied by run, bank, and direction of travel. During the early run, upstream fish averaged 77 (SD = 48) and 53 (SD = 34) echoes per fish on the left and right banks, respectively. Downstream fish averaged 90 echoes (SD = 106) on the left bank and 73 echoes (SD = 85) on the right bank. Upstream fish during the late run averaged 97 (SD = 63) echoes on the left bank and 59 (SD = 38) echoes on the right bank. Downstream fish averaged 103 (SD = 89) echoes on the left bank and 69 (SD = 68) echoes per fish on the right bank.

## TIDAL AND TEMPORAL DISTRIBUTION

Upstream passage during both the early and late runs occurred mostly during the falling tide (50.5% and 50.7% respectively; Tables 5 and 6, Figure 7). Downstream passage also occurred primarily during the falling tide for both the early (54.2%) and late (45.0%) runs.

## SPATIAL DISTRIBUTION

### Vertical Distribution

Fish were bottom-oriented during both runs, although vertical distribution did vary somewhat by direction of travel, tide stage, and season (Appendices G1 and G2). During the early run, 85% of the upstream fish (Chinook targets) on the left bank and 82% on the right bank were on or below the acoustic axis (Figure 8). Downstream fish were less bottom-oriented (Appendix G1). Seventy-six percent of downstream fish on the left bank and 72% on the right bank were below the acoustic axis (Figure 8). Upstream fish (Chinook targets) on the left bank (mean = -0.42°, SD = 0.48, n = 1,496) were on average significantly lower (t = 1.84, P = 0.03) in the water column than downstream fish (mean = -0.25°, SD = 0.65, n = 29). On the right bank, upstream

**Table 5**.-Estimates of Chinook salmon passage by tide stage and direction of travel for the 2002 early run (16 May to 30 June).

| 2002 Early Run | Total Number of Fish | Rising | Falling | Low |
|---|---|---|---|---|
| Upstream | 7,162 | 2,561 | 3,616 | 984 |
| Row % | 100.0% | 35.8% | 50.5% | 13.7% |
| Column % | 95.9% | 96.0% | 95.6% | 96.5% |
| | | | | |
| Downstream | 307 | 106 | 166 | 35 |
| Row % | 100.0% | 34.4% | 54.2% | 11.5% |
| Column % | 4.1% | 4.0% | 4.4% | 3.5% |

Test for Independence: Chi-square = 2.06, df = 2, P = 0.357

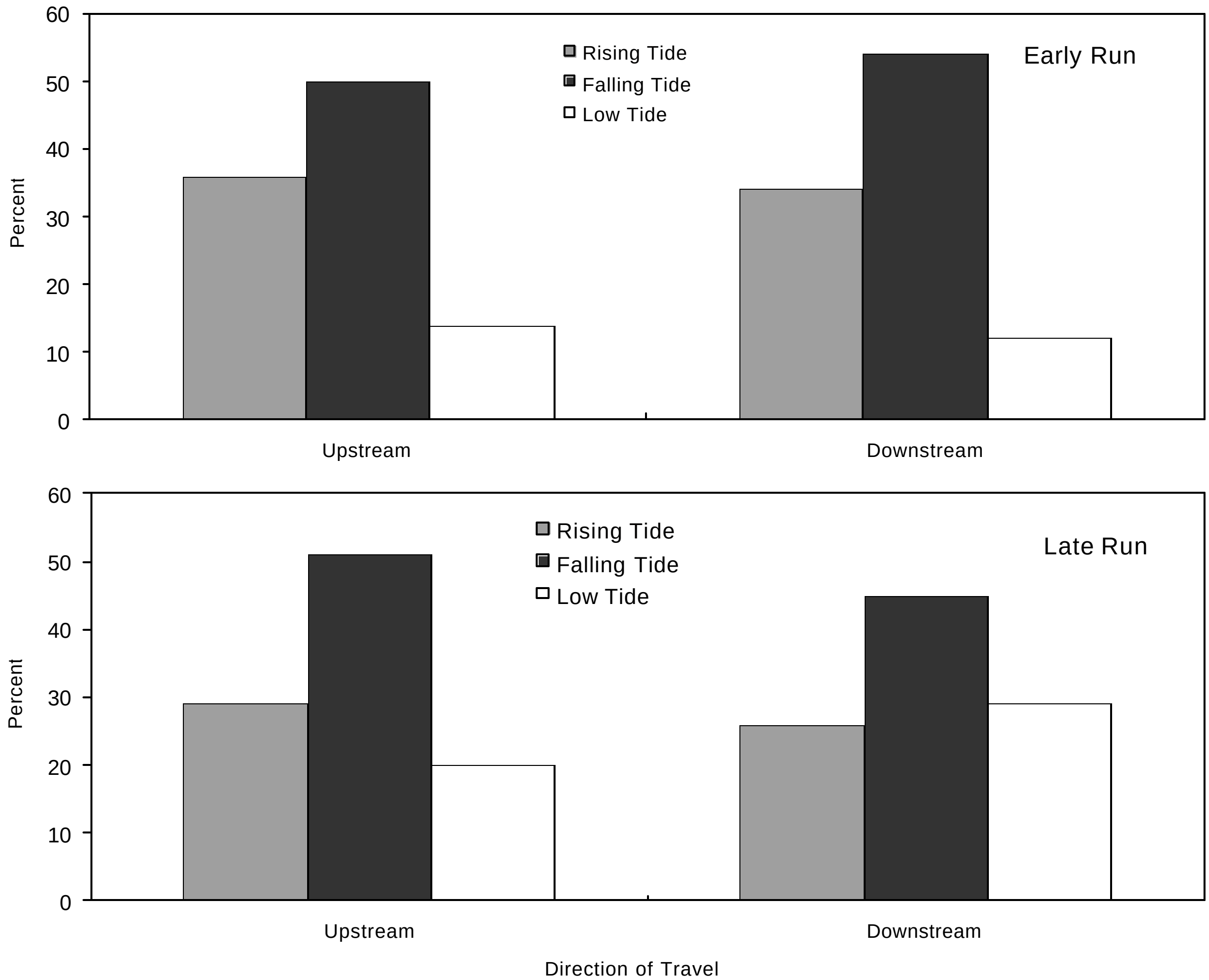
fish (mean = -0.40°, SD = 0.56, n = 1,289) were not significantly lower in the water column (t = 1.56, P = 0.06) than downstream fish (mean = -0.29°, SD = 0.54, n = 71). Upstream traveling fish on both banks were bottom oriented during all tide phases, but were distributed slightly higher in the water column during the rising tide phase (Figure 9).

Late-run fish also showed a tendency to travel along the river bottom (Figure 10 and Appendix G2). Eighty-three percent of upstream fish on the left bank and 77% of upstream fish on the right bank were on or below the acoustic axis. Seventy-one percent of downstream fish on each bank were on or below the acoustic axis. Upstream fish on the left bank (mean = -0.35°, SD = 0.46, n = 9,292) traveled lower (t = 5.86, P << 0.001) in the insonified water column than downstream fish (mean = -0.28°, SD = 0.47, n = 473). Similarly, upstream fish on the right bank (mean = -0.25°, SD = 0.46, n = 14,041) traveled lower (t = 4.33, P << 0.001) in the insonified water column than downstream fish (mean = -0.17°, SD = 0.41, n = 499). Upstream traveling fish on both banks were distributed slightly higher in the water column during the rising tide stage (Figure 11).

**Table 6**.-Estimates of Chinook salmon passage by tide stage and direction of travel for the 2002 late run (1 July to 5 August).

| 2002 Late Run | Total Number of Fish | Rising | Falling | Low |
|---|---|---|---|---|
| Upstream | 38,948 | 11,210 | 19,755 | 7,983 |
| Row % | 100.0% | 28.8% | 50.7% | 20.5% |
| Column % | 94.0% | 94.6% | 94.7% | 91.6% |
| | | | | |
| Downstream | 2,481 | 636 | 1,116 | 729 |
| Row % | 100.0% | 25.6% | 45.0% | 29.4% |
| Column % | 6.0% | 5.4% | 5.3% | 8.4% |

Test for Independence: Chi-square = 111.22, df = 2, P < 0.0001



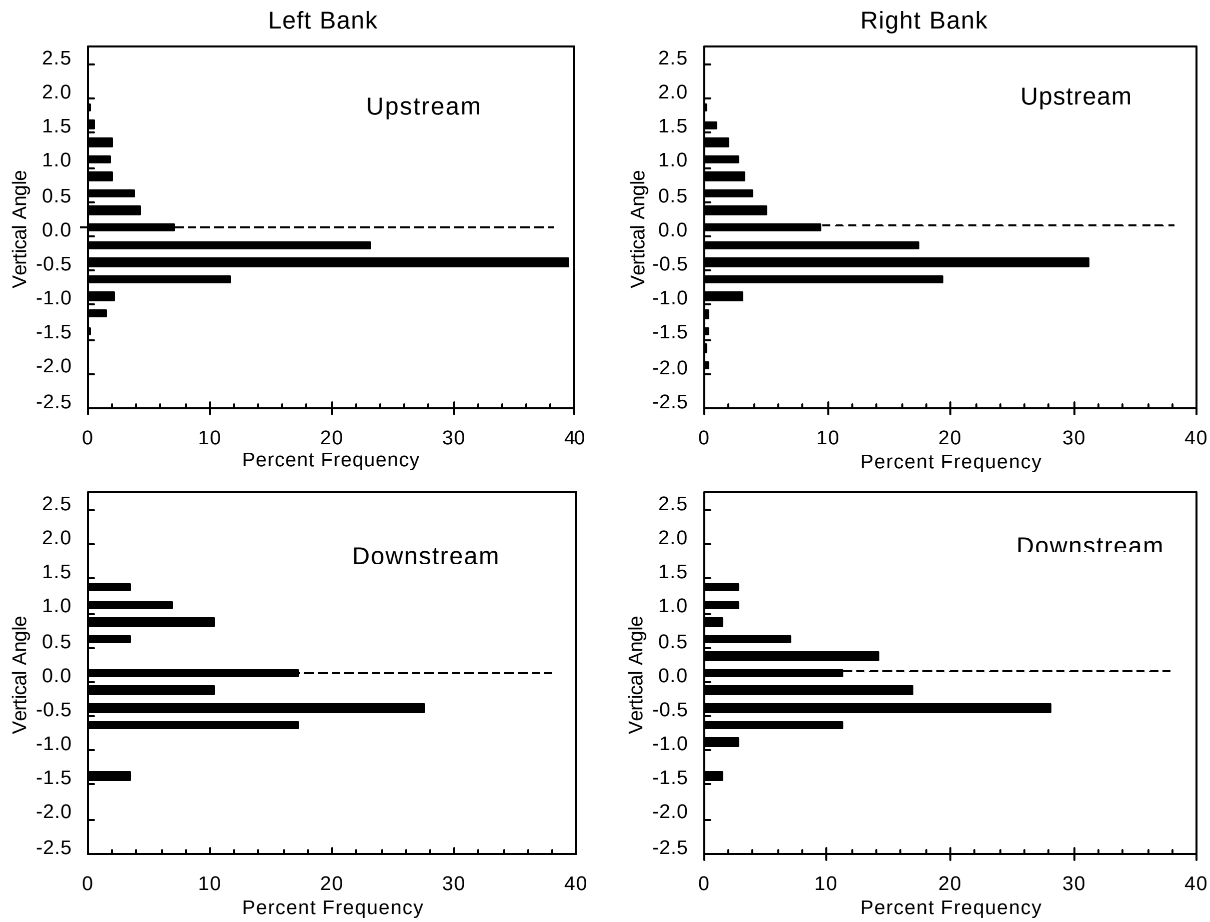

Note: Data have been filtered by range and target strength criteria.

**Figure 7**.-Distribution of upstream and downstream migrating fish by tide stage during the early (top panel) and late (bottom panel) runs, Kenai River, 2002.

## Range Distribution

During the early run, upstream fish on the left bank were distributed evenly throughout the offshore ranges, but fish on the right-bank exhibited a nearshore (i.e. 34-38 m) peak in passage (Figure 12). Upstream range distributions during the early run were not statistically different from downstream distributions for both left (Anderson-Darling, P = 0.08) and right (Anderson-Darling, P = 0.38) banks (Figure 12). Range distributions were similar among the three tide stages on the left bank, with the exception of increased nearshore (i.e. 12-18 m) passage during low tide (Figure 13). Right-bank range distributions were bimodal during falling and low tides (Figure 13).

During the late run, upstream fish on the left bank were evenly distributed throughout the range; upstream-moving fish on the right bank exhibited a bimodal range distribution (Figure 14). Range distributions were significantly different between upstream- and downstream-moving fish




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

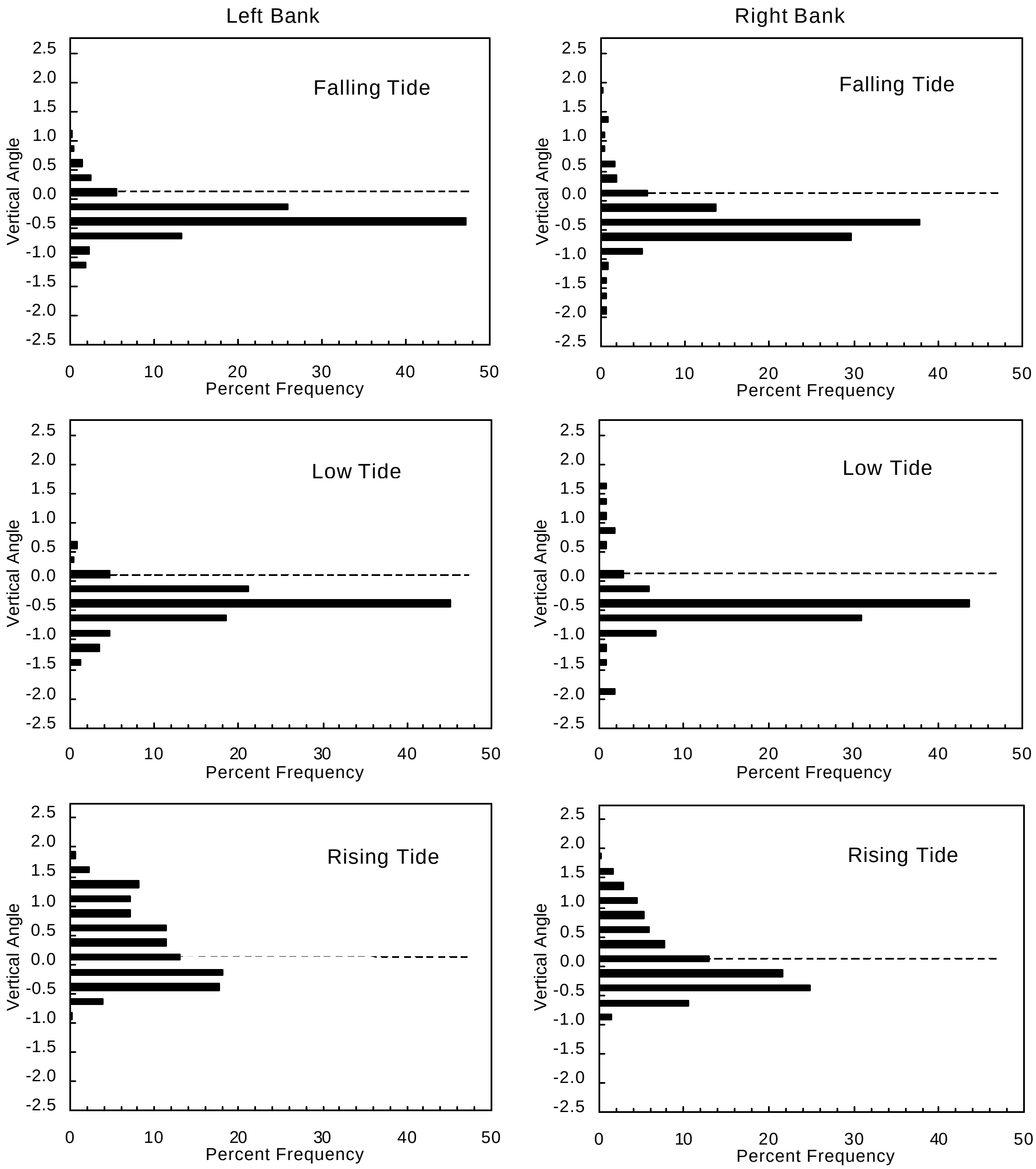
**Figure 8**.-Vertical distributions of early-run upstream and downstream migrating fish on the left and right banks, Kenai River, 2002.

on both the left (Anderson-Darling, P <<< 0.001) and right (Anderson-Darling, P <<< 0.001) banks; downstream fish exhibited higher offshore distribution on each bank (Figure 14). All three tide stages (falling, low, and rising) exhibited similar range distributions on the left bank during the late run, while the right bank experienced a pronounced bimodal distribution during the falling and low tides and a more even distribution during the rising tide (Figure 15).

Estimates of upstream fish passage by bank were higher for the left bank during the early run and for the right bank during the late run (Tables 7 and 8). During the early run 56% of upstream passage was estimated to occur on the left bank, while 44% occurred on the right bank (Table 7). During the late run 53% of upstream passage was estimated to occur on the right bank and 47% on the left bank (Table 8).

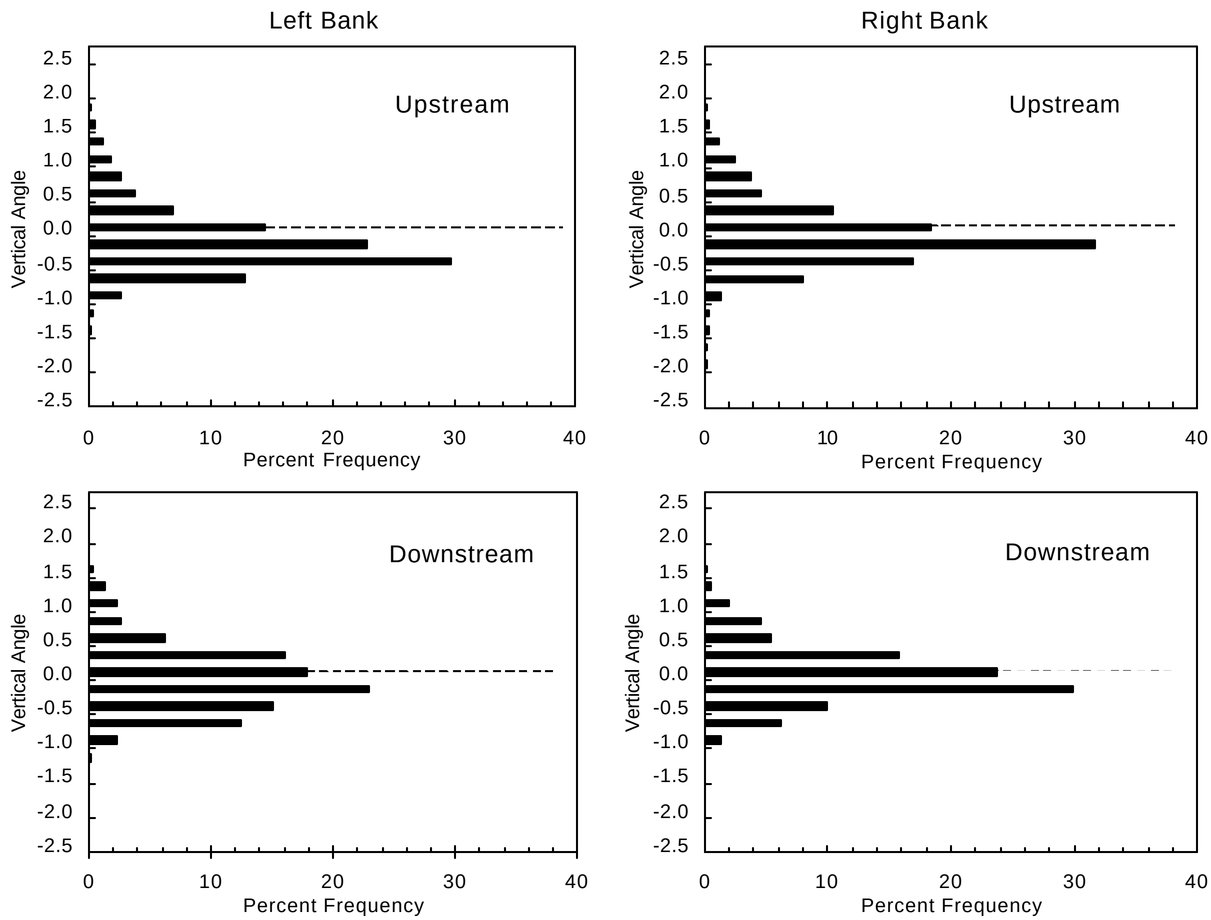
## Target Strength

Target strength distributions varied by bank, direction of travel, and run. Table 9 shows target strength statistics for fish that met minimum range and target strength criteria, whereas Figure 16 and Figure 17 show target strength distributions and statistics that include all tracked targets.




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

**Figure 9**.-Vertical distributions of early-run upstream fish during falling, low, and rising tide stages on the left and right banks, Kenai River, 2002.



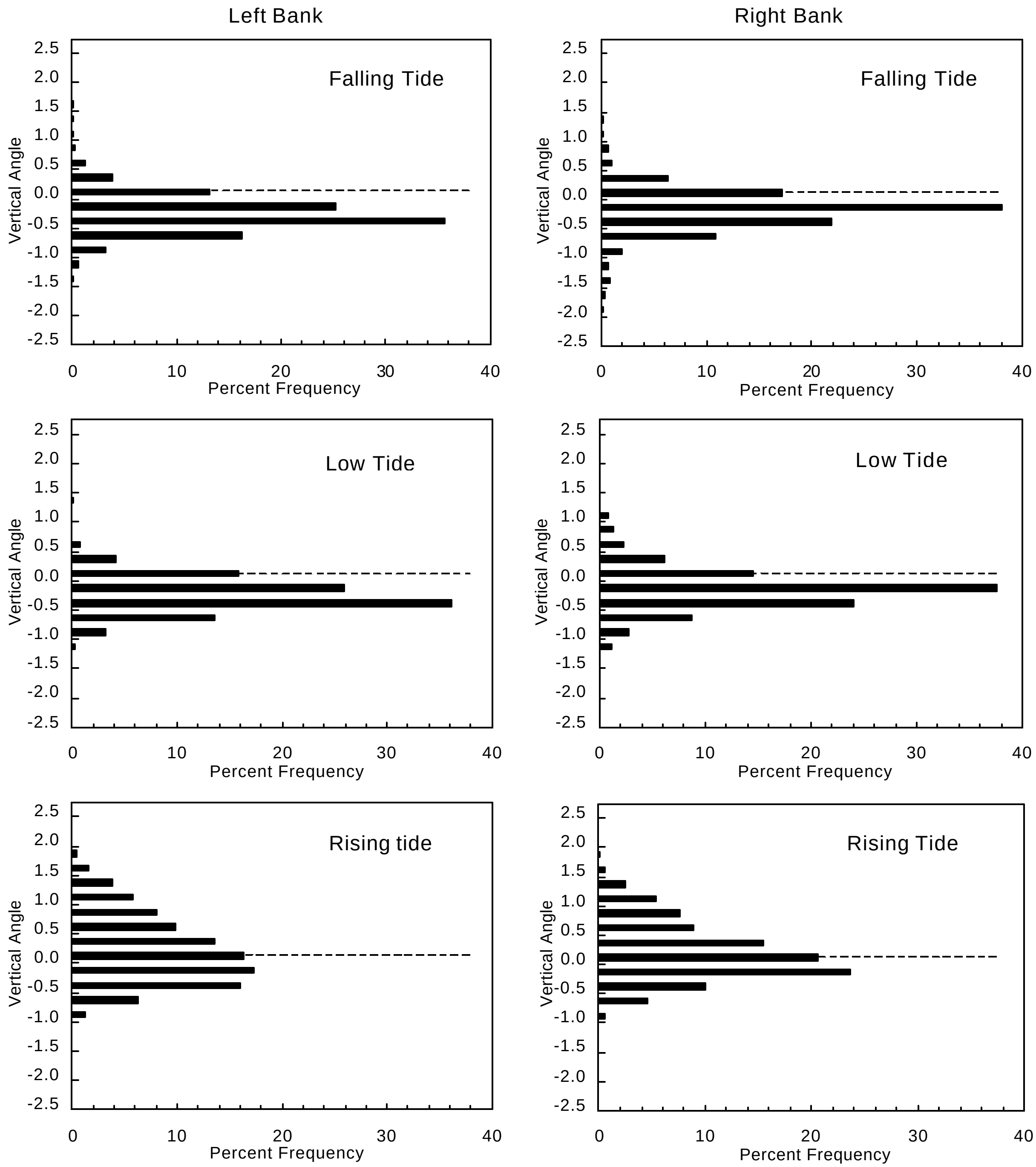

Note: Data have been filtered by range and target strength criteria.

**Figure 10**.-Vertical distributions of late-run upstream and downstream fish on the left and right banks, Kenai River, 2002.

Mean target strength estimates for all upstream targets and the variability of those estimates were similar between banks for both the early and late run (Figures 16 and 17). Mean target strength estimates for all downstream targets were also similar between banks, with early-run right bank targets showing the least variability (Figures 16 and 17).

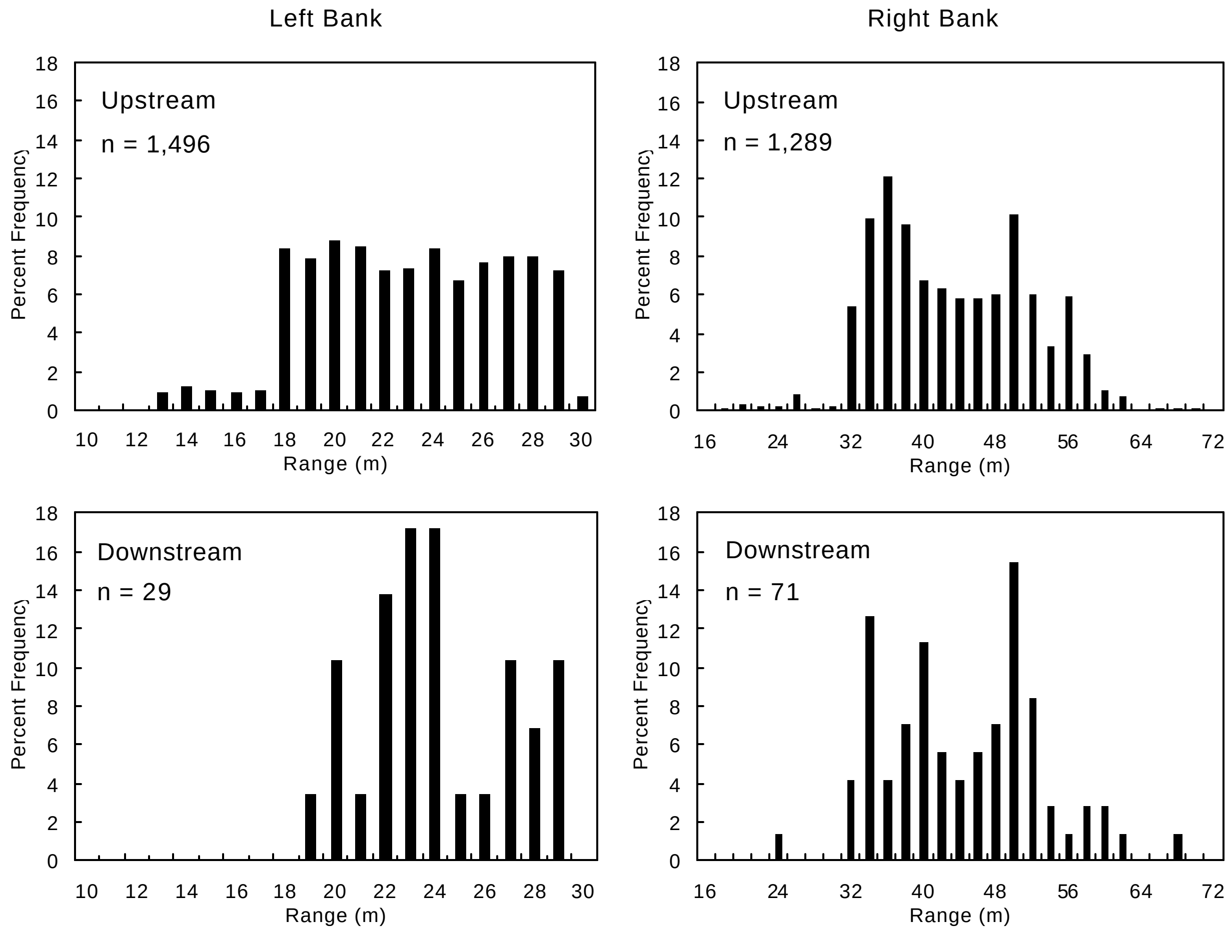
During the early run on the left bank, mean target strength of Chinook salmon was similar ($t = -1.32$, $P = 0.09$) among upstream and downstream traveling fish, as was mean target strength variability ($F = 1.11$, $P = 0.32$; Table 9). On the right bank, mean target strength for upstream traveling fish was slightly higher ($t = -4.36$, $P << 0.01$), and variability was greater ($F = 0.55$, $P < 0.01$; Table 9). The statistical significance of the difference in mean target strength between upstream and downstream traveling fish was likely an artifact of sample size rather than a meaningful difference in mean target strength.

During the late run on the left bank, mean target strength of Chinook salmon was higher ($t = -6.14$, $P << 0.01$) among upstream traveling fish than among downstream traveling fish, and variability was similar ($F = 0.89$, $P = 0.60$, Table 9). On the right bank during the late run, mean target strength was again higher ($t = -7.46$, $P << 0.01$) among upstream traveling fish, as was




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

**Figure 11**.-Vertical distributions of late-run upstream fish during falling, low, and rising tide stages on the left and right banks, Kenai River, 2002.




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

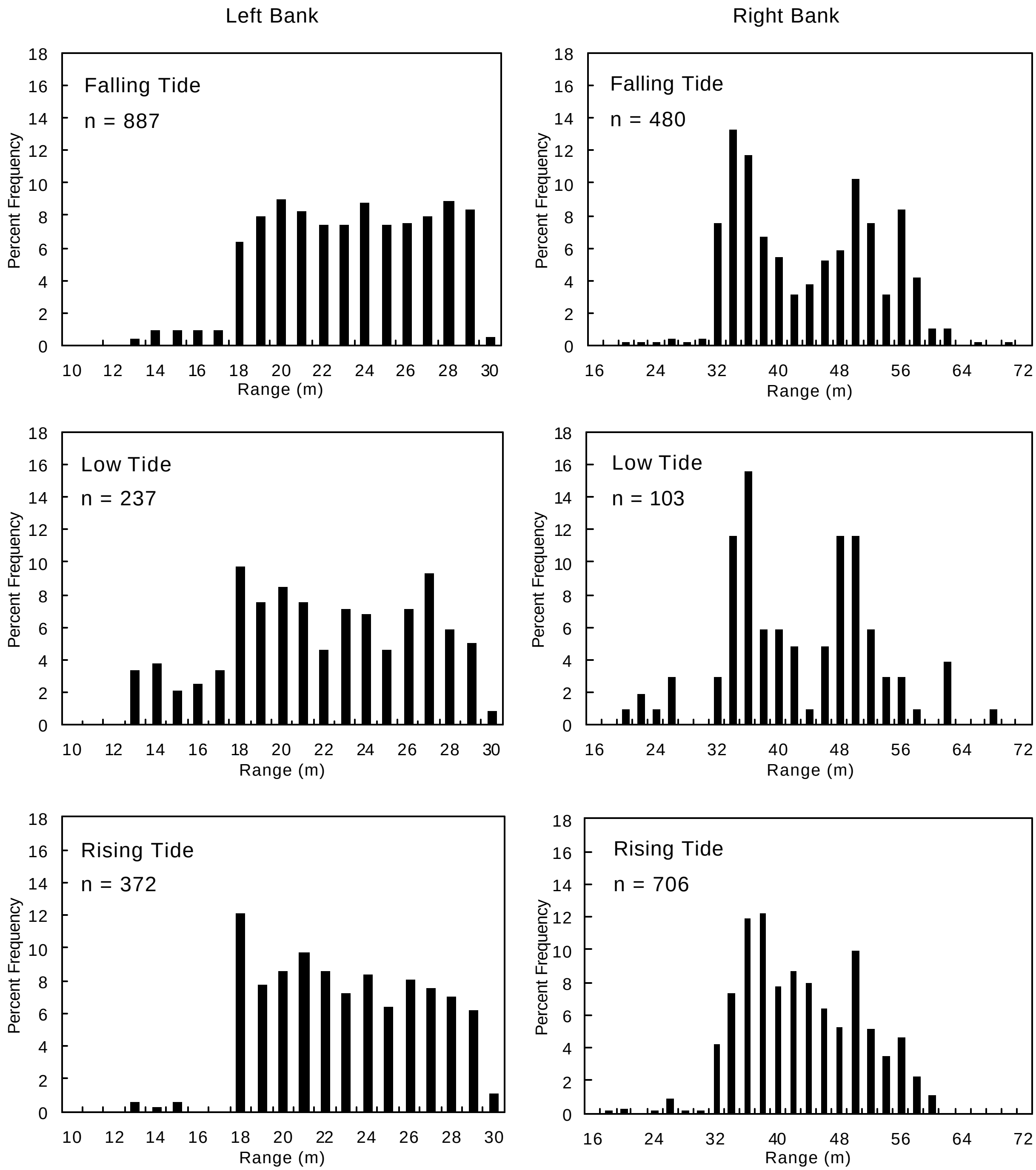
**Figure 12**.-Range distributions of early-run upstream and downstream migrating fish on the left and right banks, Kenai River, 2002.

mean target strength variability (F = 0.66, P << 0.01; Table 9). Again, the statistical significance of the difference in mean target strength between upstream and downstream traveling fish was likely an artifact of sample size.

## Passage Estimates

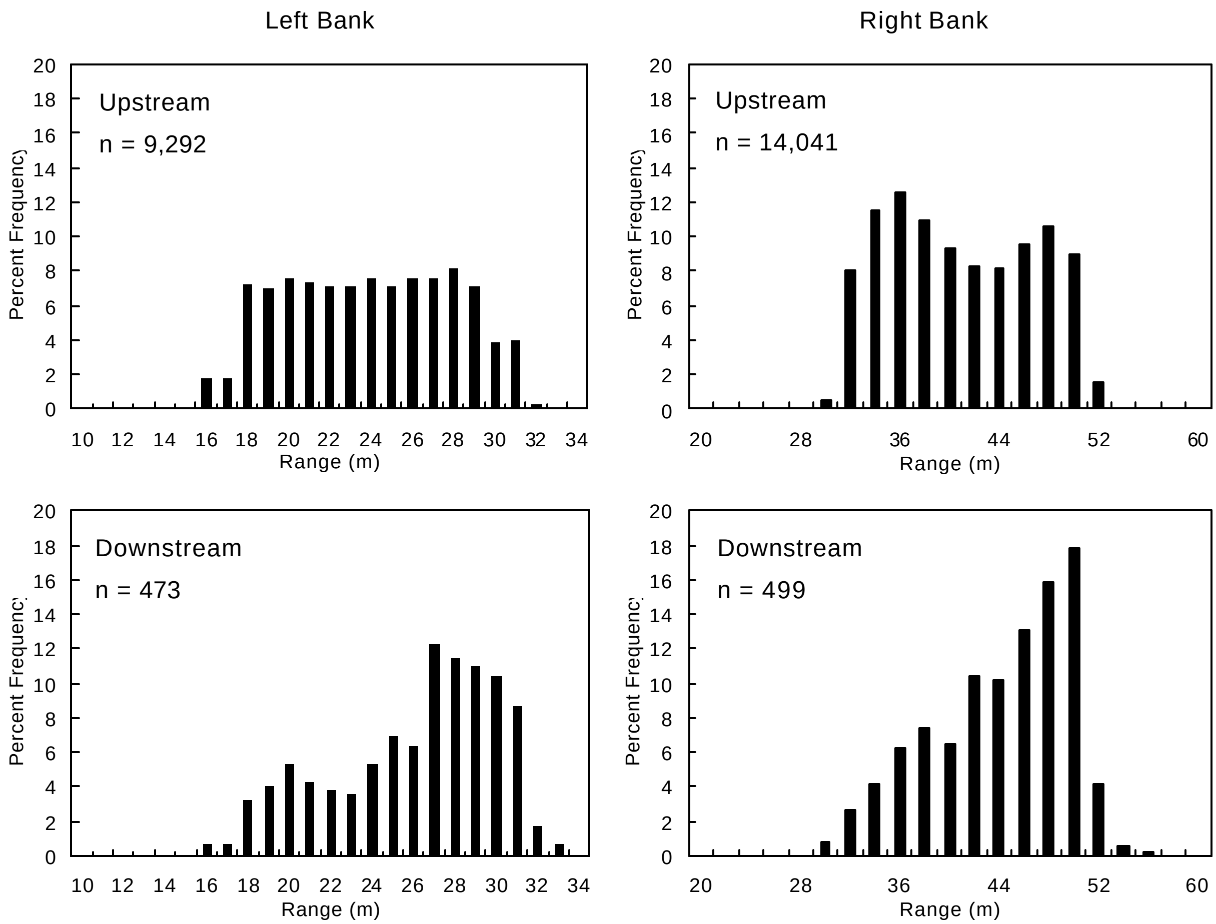
Daily estimates of Chinook salmon passage were generated for 16 May-5 August. Sampling was terminated at 2240 hours on 5 August. During the 82-day season, a total of 554 hours of acoustic data were processed from the right bank and 576 hours from the left bank. This represented 28% of the total available sample time on the right bank and 29% on the left bank.

Final upstream Chinook salmon passage from 16 May through 5 August was estimated at 46,110 (SE = 535) fish, composed of 7,162 (SE = 169) early-run fish and 38,948 (SE = 508) late-run fish (Tables 7, 8, 10, and 11). Late-run passage extrapolated through 10 August was estimated at 41,807 (SE = 1,353) fish. The daily peak of the early run occurred on 9 June; 50% of the run passed by 15 June (Figure 18). When compared with historic mean escapement timing the 2002 early run was later than average, especially after 16 June (Figure 18 and Appendix H1). The




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

**Figure 13**.-Range distributions of early-run upstream fish during falling, low, and rising tide stages on the left and right banks, Kenai River, 2002.




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

**Figure 14**.-Range distributions of late-run upstream and downstream migrating fish on the left and right banks, Kenai River, 2002.

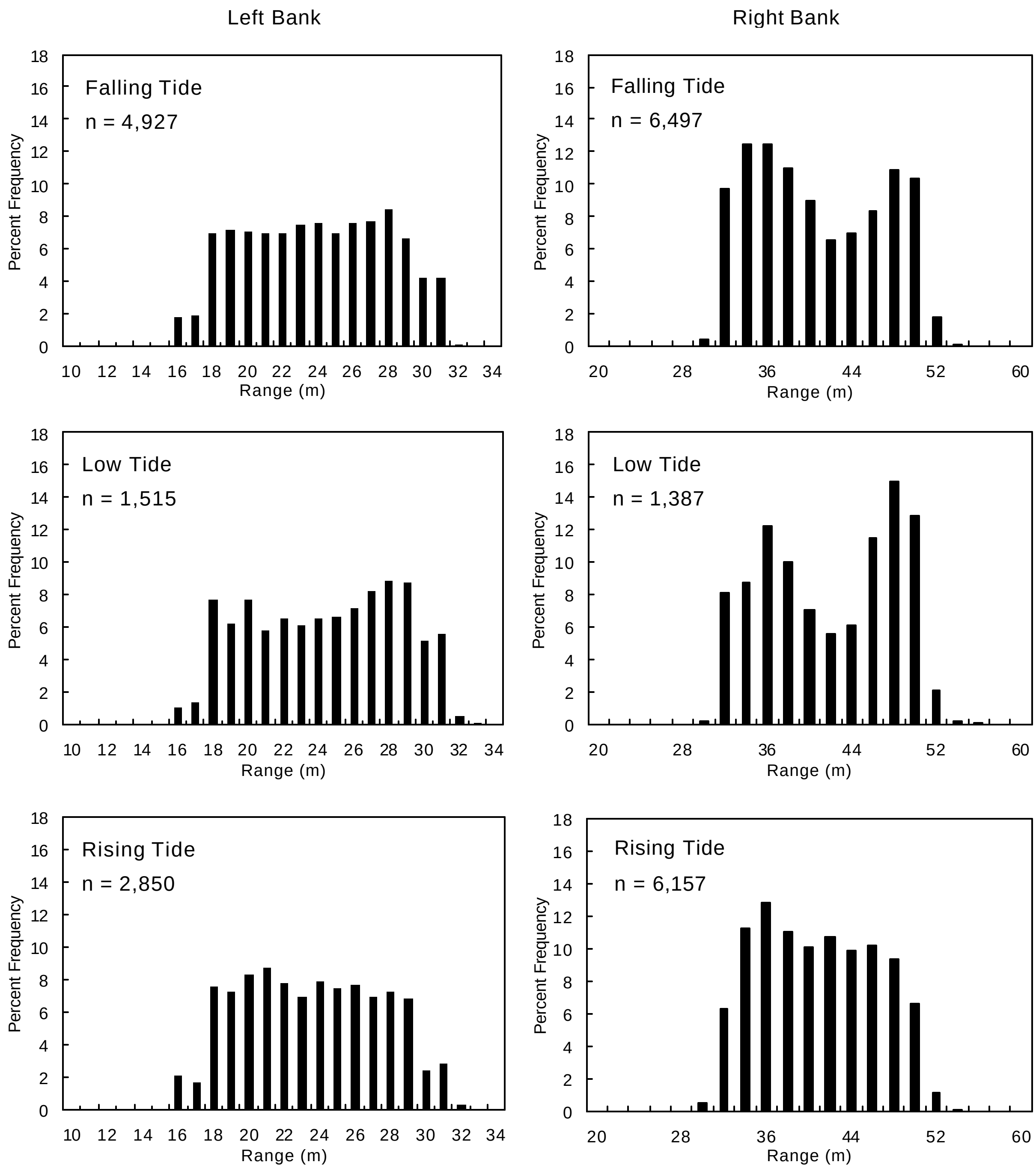
daily peak of the late run occurred on 3 July; 50% of the late run passed by 16 July, based on estimated passage through 10 August (Figure 19). When compared with historic mean escapement timing, the late run experienced record early migratory timing in early July and remained well ahead of the average throughout the remainder of the run (Figure 19 and Appendix H2).

# DISCUSSION

## SPATIAL DISTRIBUTION

### Bank Preference

Historically, the right bank has been heavily favored by migrating fish during both the early and late runs, and the proportion of fish traveling up the right bank increased as the season progressed (Bosch and Burwen 1999; Burwen and Bosch 1995a, b, 1996, 1998; Eggers et al. 1995; Miller and Burwen 2002). In recent years, this trend has not been as obvious. The 1996 and 1997 early runs experienced heavy left-bank passage: almost half the early-run upstream




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

**Figure 15**.-Range distributions of late-run upstream migrating fish during falling, low, and rising tide stages on the left and right banks, Kenai River, 2002.

**Table 7**.-Estimates of early-run fish passage by direction of travel, 2002.

| Bank | Estimate of Upstream Component | Estimate of Downstream Component | Estimate of Total Fish Passage[a] |
|---|---|---|---|
| Right Bank | 3,148 | 220 | 3,368 |
| Left Bank | 4,014 | 87 | 4,101 |
| Total | 7,162 | 307 | 7,469 |

[a] Total passage (upstream component plus downstream component) is provided to maintain comparability between recent (1995-2002) fish passage estimates derived from split-beam sonar and composed of only upstream targets, and past (1987-1994) estimates generated by dual-beam sonar and composed of both upstream and downstream targets. Dual-beam sonar was not capable of determining direction of travel, so prior to 1995 all targets were assumed to be upstream targets.

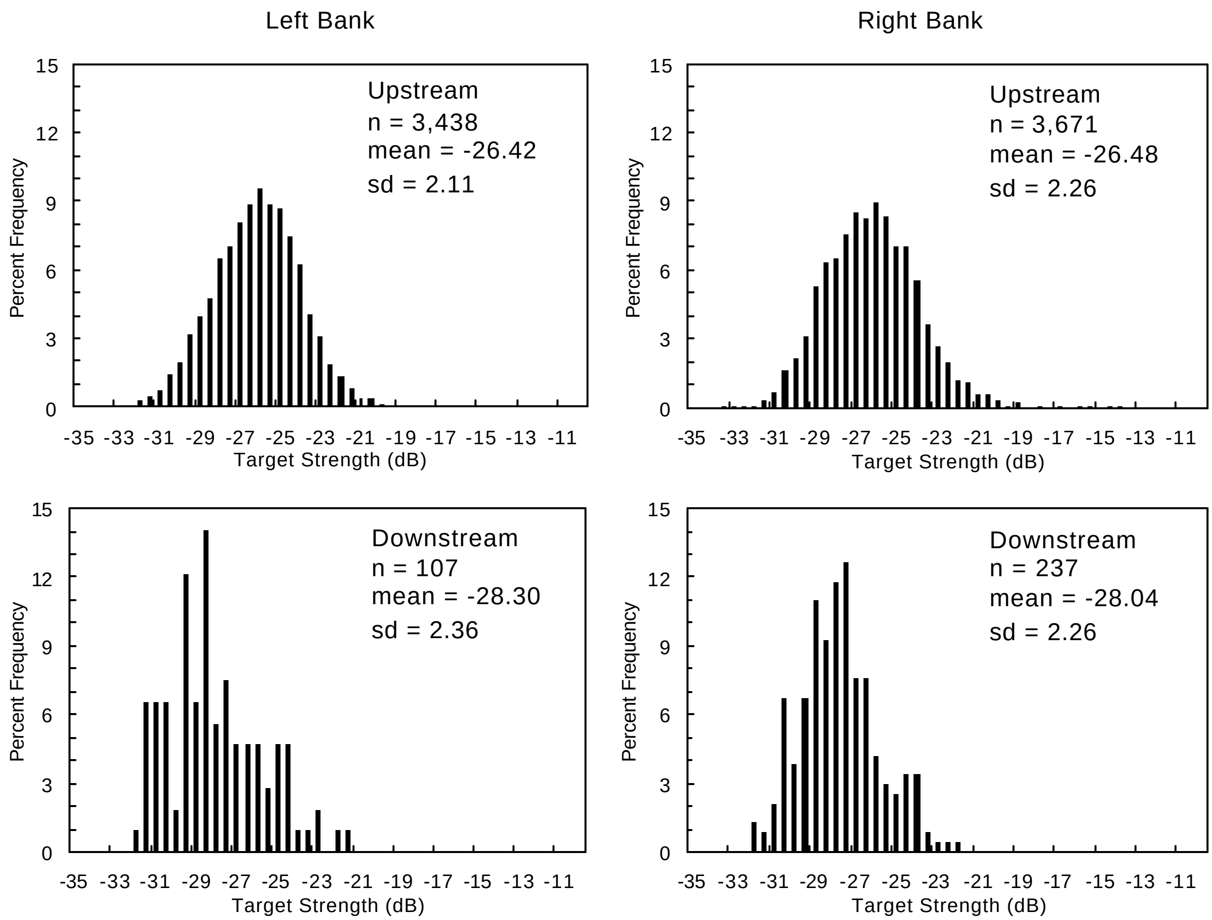
**Table 8**.-Estimates of late-run fish passage by direction of travel, 2002.

| Bank | Estimate of Upstream Component | Estimate of Downstream Component | Estimate of Total Fish Passage[a] |
|---|---|---|---|
| Right Bank | 20,711 | 1,211 | 21,922 |
| Left Bank | 18,237 | 1,270 | 19,507 |
| Total | 38,948 | 2,481 | 41,429 |

[a] Total passage (upstream component plus downstream component) is provided to maintain comparability between recent (1995-2002) fish passage estimates derived from split-beam sonar and composed of only upstream targets, and past (1987-1994) estimates generated by dual-beam sonar and composed of both upstream and downstream targets. Dual-beam sonar was not capable of determining direction of travel, so prior to 1995 all targets were assumed to be upstream targets.

**Table 9**.-Mean target strength (dB) for upstream and downstream targets by river bank (Chinook only) during the early (16 May-30 June) and late (1 July-5 August) runs, 2002.

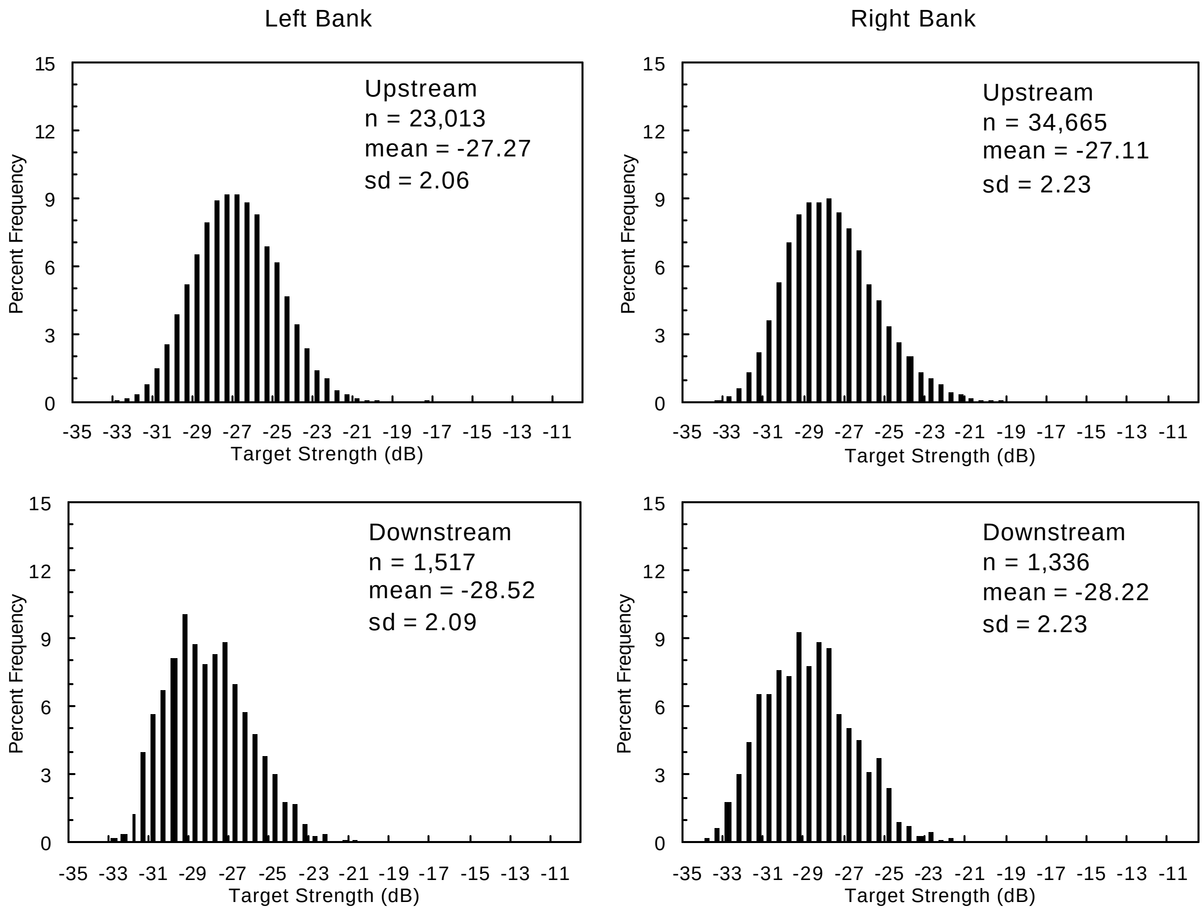
| Location | Upstream Mean Target Strength (dB) | SD | N | Downstream Mean Target Strength (dB) | SD | N |
|---|---|---|---|---|---|---|
| Early Run | | | | | | |
| Left Bank | -25.48 | 1.57 | 1,496 | -25.69 | 1.65 | 29 |
| Right Bank | -25.75 | 1.77 | 1,289 | -26.46 | 1.31 | 71 |
| Late Run | | | | | | |
| Left Bank | -25.99 | 1.41 | 9,292 | -26.40 | 1.34 | 473 |
| Right Bank | -25.69 | 1.78 | 14,041 | -26.20 | 1.45 | 499 |




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

**Figure 16**.-Early-run target strength distributions for all upstream and downstream targets on the left and right banks, Kenai River, 2002.

passage occurred on the left bank during both years (Burwen and Bosch 1998; Bosch and Burwen 1999). The 1999 and 2001 early and late runs both experienced a higher proportion of passage on the left bank than on the right bank (Miller and Burwen 2002; Miller et al. 2003). In 2002 the left bank passage was greater than right bank passage during the early run and almost as large as the right bank passage during the late run (Tables 10 and 11). The apparent changes in bank preference do not appear to be related to a changing bottom contour, as the bottom profile at the site has remained relatively stable over the past several years. Bosch and Burwen (1999) pointed out that below average discharge rates during the early runs of 1996 and 1997 might have influenced bank preference. Below average discharge rates also occurred in 1999 (Miller et al. 2002). However, discharge rates in 2001 and 2002 were average or well above average during both runs (Miller et al. 2003, USGS 2002). Thus discharge rates do not appear to fully account for changes in bank preference. Relocation of the left-bank transducer several meters downstream of its historic location during the 2001 season, and the subsequent improved aim, may have contributed to the higher left-bank passage estimate in that the improved aim was able to detect fish that would not have been detected with the old aim. Increased left-bank



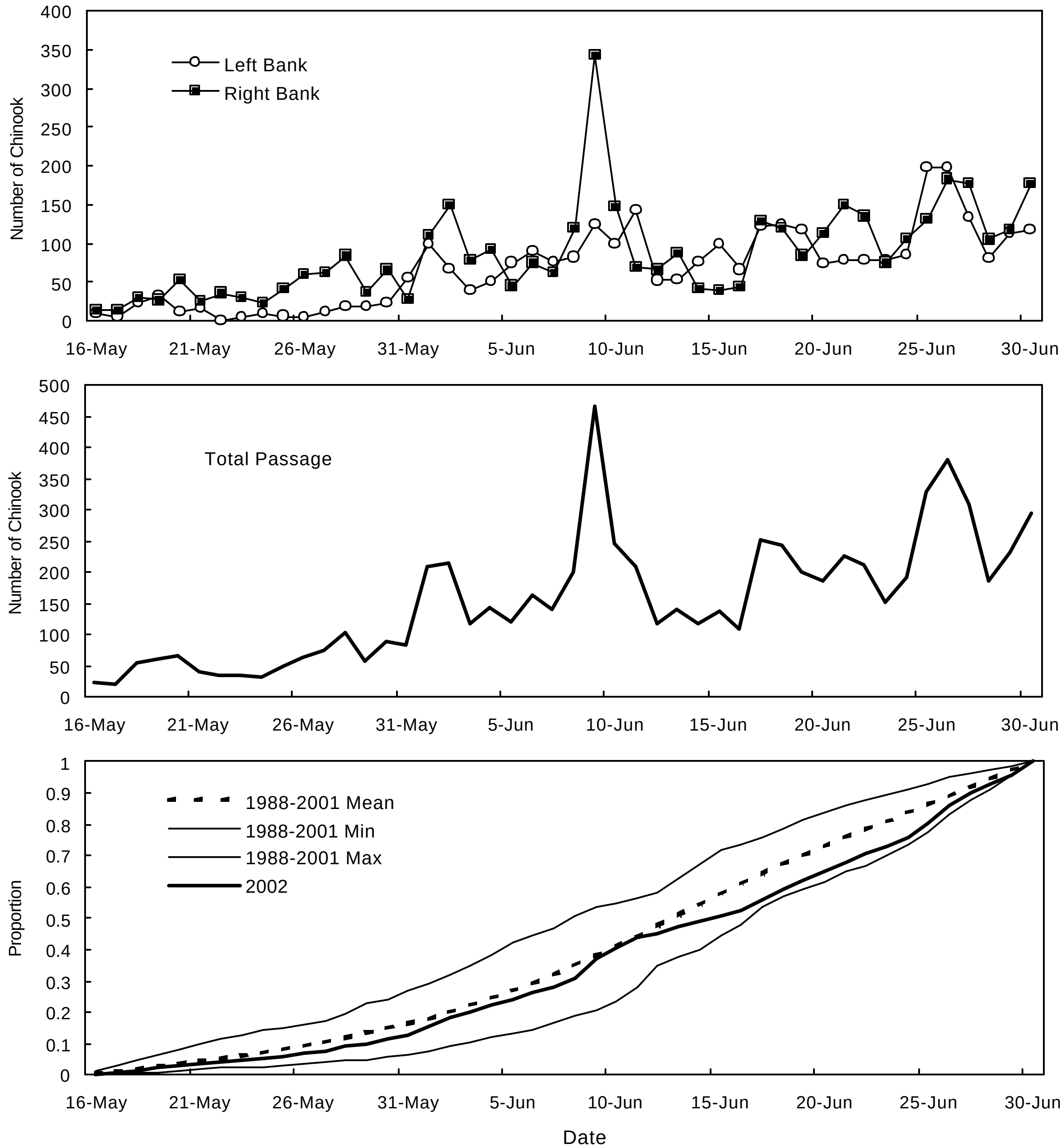

Note: Data have not been filtered by range and target strength criteria.

**Figure 17**.-Late-run target strength distributions for all upstream and downstream targets on the left and right banks, Kenai River, 2002.

preferences observed in previous years, however, suggest that the increased left-bank proportions in 2001 and 2002 likely resulted from factors other than, or in addition to, increased fish detectability.

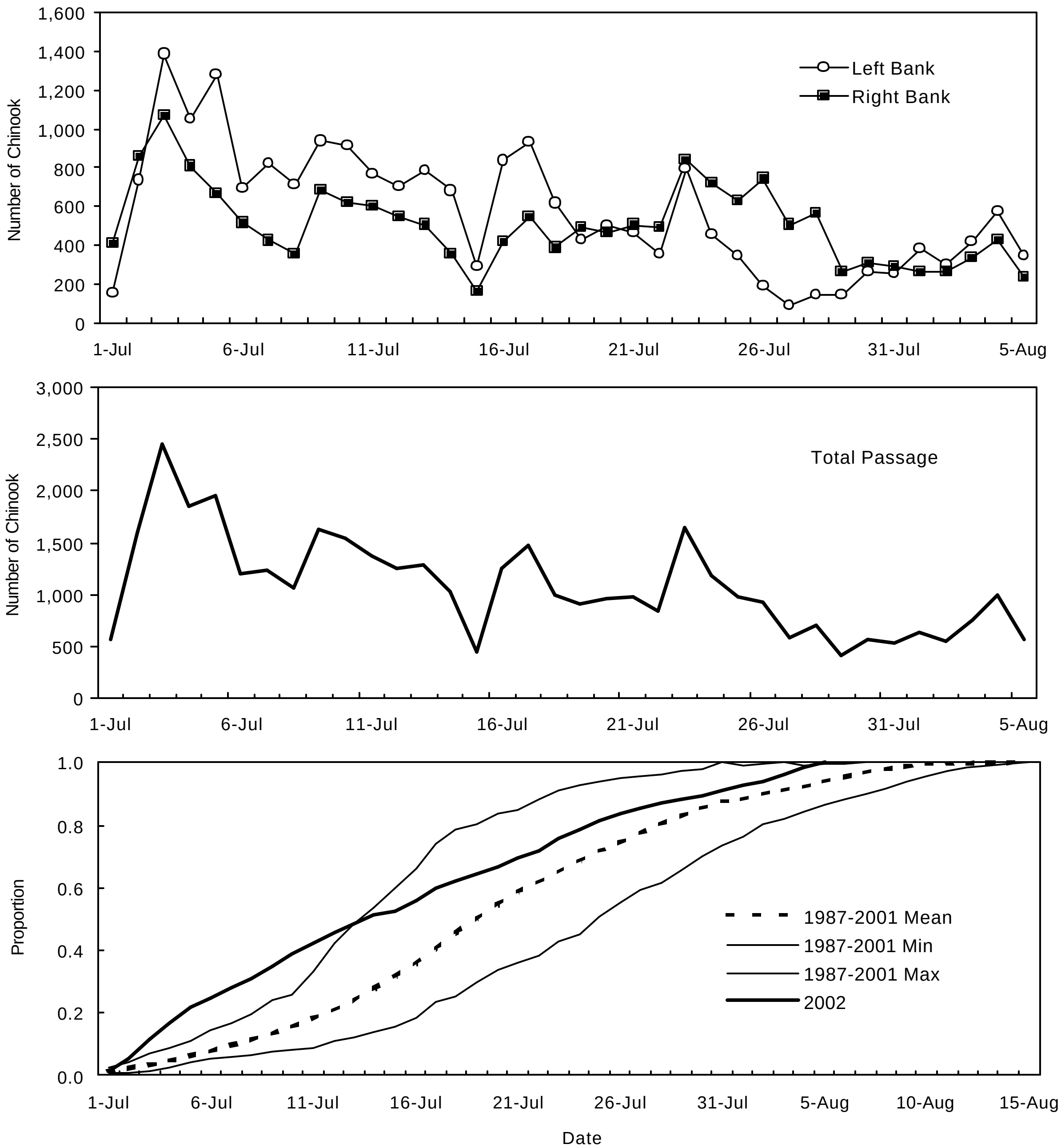
## Vertical Distribution

Monitoring the spatial distribution of migrating fish is particularly important at the present site, where tide-induced changes in water level have been shown to affect fish distribution. A primary concern is that fish may swim over the beam during rising and falling tide stages. Because the site experiences extreme semidiurnal tidal fluctuations that average 4 m and are as high as 7 m (Figure 3), it is not possible to insonify the entire cross-sectional area of the river that can potentially be used by migrating Chinook salmon. Fish position data suggest that most upstream fish are within the insonified zone. When sockeye are not present in large numbers, most fish are observed migrating in the offshore, bottom section of the river where beam coverage is maximized. Although there were slightly more fish in the upper half of the beam during the rising tide stage on both banks during the 2002 early and late runs (Figures 9 and 11), very few fish occupied the upper half of the beam overall. Data collected in previous years




Note: Mean in bottom panel is based on estimates of total passage for 1988-1997 and upstream passage for 1998-2001.

**Figure 18**.-Daily sonar estimates of passage by bank (top panel), total passage (center panel), and historical cumulative proportions for the early run of Chinook salmon returning to the Kenai River, 2002.




Note: Mean in bottom panel is based on estimates of total passage for 1987-1997 and upstream passage for 1998-2001.

**Figure 19**.-Daily sonar estimates of passage by bank (top panel), total passage (center panel), and historical cumulative proportions for the late run of Chinook salmon returning to the Kenai River, 2002.

**Table 10**.-Estimated daily upstream passage of Chinook salmon, Kenai River sonar, early run, 2002.

| Date | Left Bank | Right Bank | Daily Total | Cumulative Total |
|---|---|---|---|---|
| 16-May | 15 | 9 | 24 | 24 |
| 17-May | 15 | 6 | 21 | 45 |
| 18-May | 30 | 24 | 54 | 99 |
| 19-May | 27 | 33 | 60 | 159 |
| 20-May | 54 | 12 | 66 | 225 |
| 21-May | 26 | 16 | 42 | 267 |
| 22-May | 36 | 0 | 36 | 303 |
| 23-May | 31 | 5 | 36 | 339 |
| 24-May | 23 | 10 | 33 | 372 |
| 25-May | 42 | 6 | 48 | 420 |
| 26-May | 61 | 4 | 65 | 485 |
| 27-May | 63 | 12 | 75 | 560 |
| 28-May | 84 | 19 | 103 | 663 |
| 29-May | 38 | 19 | 57 | 720 |
| 30-May | 66 | 24 | 90 | 810 |
| 31-May | 29 | 56 | 85 | 895 |
| 1-Jun | 111 | 99 | 210 | 1,105 |
| 2-Jun | 149 | 67 | 216 | 1,321 |
| 3-Jun | 79 | 40 | 119 | 1,440 |
| 4-Jun | 93 | 51 | 144 | 1,584 |
| 5-Jun | 45 | 75 | 120 | 1,704 |
| 6-Jun | 75 | 90 | 165 | 1,869 |
| 7-Jun | 63 | 77 | 140 | 2,009 |
| 8-Jun | 120 | 82 | 202 | 2,211 |
| 9-Jun | 342 | 124 | 466 | 2,677 |
| 10-Jun | 147 | 99 | 246 | 2,923 |
| 11-Jun | 69 | 142 | 211 | 3,134 |
| 12-Jun | 66 | 52 | 118 | 3,252 |
| 13-Jun | 88 | 54 | 142 | 3,394 |
| 14-Jun | 41 | 77 | 118 | 3,512 |
| 15-Jun | 39 | 99 | 138 | 3,650 |
| 16-Jun | 44 | 66 | 110 | 3,760 |
| 17-Jun | 129 | 122 | 251 | 4,011 |
| 18-Jun | 119 | 124 | 243 | 4,254 |
| 19-Jun | 84 | 117 | 201 | 4,455 |
| 20-Jun | 113 | 74 | 187 | 4,642 |
| 21-Jun | 150 | 78 | 228 | 4,870 |
| 22-Jun | 135 | 78 | 213 | 5,083 |
| 23-Jun | 75 | 78 | 153 | 5,236 |
| 24-Jun | 107 | 86 | 193 | 5,429 |
| 25-Jun | 132 | 198 | 330 | 5,759 |
| 26-Jun | 183 | 198 | 381 | 6,140 |
| 27-Jun | 177 | 133 | 310 | 6,450 |
| 28-Jun | 105 | 81 | 186 | 6,636 |
| 29-Jun | 117 | 114 | 231 | 6,867 |
| 30-Jun | 177 | 118 | 295 | 7,162 |
| Total | 4,014 | 3,148 | 7,162 | |

**Table 11**.-Estimated daily upstream passage of Chinook salmon, Kenai River sonar, late run, 2002.

| Date | Left Bank | Right Bank | Daily Total | Cumulative Total |
|---|---|---|---|---|
| 1-Jul | 409 | 154 | 563 | 697 |
| 2-Jul | 861 | 735 | 1,596 | 1,463 |
| 3-Jul | 1,071 | 1,385 | 2,456 | 2,538 |
| 4-Jul | 807 | 1,048 | 1,855 | 3,252 |
| 5-Jul | 666 | 1,283 | 1,949 | 3,928 |
| 6-Jul | 514 | 691 | 1,205 | 4,573 |
| 7-Jul | 422 | 819 | 1,241 | 5,460 |
| 8-Jul | 355 | 714 | 1,069 | 6,211 |
| 9-Jul | 681 | 937 | 1,618 | 6,779 |
| 10-Jul | 618 | 915 | 1,533 | 7,687 |
| 11-Jul | 599 | 770 | 1,369 | 8,545 |
| 12-Jul | 546 | 699 | 1,245 | 9,120 |
| 13-Jul | 504 | 784 | 1,288 | 10,268 |
| 14-Jul | 355 | 679 | 1,034 | 11,716 |
| 15-Jul | 159 | 291 | 450 | 13,054 |
| 16-Jul | 418 | 835 | 1,253 | 14,255 |
| 17-Jul | 547 | 934 | 1,481 | 16,670 |
| 18-Jul | 386 | 615 | 1,001 | 18,735 |
| 19-Jul | 490 | 425 | 915 | 20,303 |
| 20-Jul | 462 | 502 | 964 | 21,297 |
| 21-Jul | 505 | 465 | 970 | 22,083 |
| 22-Jul | 488 | 357 | 845 | 22,580 |
| 23-Jul | 842 | 795 | 1,637 | 23,106 |
| 24-Jul | 723 | 452 | 1,175 | 23,635 |
| 25-Jul | 628 | 346 | 974 | 24,311 |
| 26-Jul | 743 | 187 | 930 | 24,978 |
| 27-Jul | 505 | 86 | 591 | 25,754 |
| 28-Jul | 567 | 140 | 707 | 26,823 |
| 29-Jul | 261 | 145 | 406 | 27,752 |
| 30-Jul | 310 | 261 | 571 | 28,260 |
| 31-Jul | 287 | 253 | 540 | 29,143 |
| 1-Aug | 260 | 382 | 642 | 29,598 |
| 2-Aug | 258 | 295 | 553 | 30,057 |
| 3-Aug | 334 | 418 | 752 | 30,561 |
| 4-Aug | 424 | 571 | 995 | 31,401 |
| 5-Aug | 232 | 343 | 575 | 31,982 |
| Total passage through 5 August | 18,237 | 20,711 | 38,948 | |
| Extrapolated passage through 10 August[a] | | | 41,807 | |

[a] Extrapolation based on mean proportion of passage through 5 August for years 1987-88, 1990, 1992-93, 1995, and 1998-2001.

showed that fish have maintained a strong bottom orientation during all three tide stages during both the early and late runs (Burwen et al. 1995; Eggers et al. 1995).

Because the vast majority of fish travel close to the river bottom (Figures 8 and 10), our greatest concern is missing fish passing under the sonar beam. No fish were detected below the -2.0° beam angle (Figures 8 and 10). Even with the decreased ability to detect targets on the edge of the beam, we assume there would be larger numbers of targets detected in this region if substantial numbers of fish were traveling below the effective beam, given the large acoustic size of Chinook salmon.

### Range Distribution

Because transducer deployment locations varied throughout the season (Figure 4) due to changing water levels, fish range distributions by bank and run were standardized based on the most nearshore deployment locations within that run. Hence, fish range distributions for a given bank and the distances mentioned below reflect distance from the most nearshore deployment location for that bank.

The range distribution of upstream-moving fish on the left bank indicates that fish were dispersed throughout the insonified range during both the early and late runs. The offshore truncation of the left-bank early- and late-run range distribution (Figures 12 and 14) was the result of transducer locations and river bottom contour restricting the left-bank maximum insonified range to 30-32 m. Low passage inside of 18 m during both the early and late runs (Figures 12 and 14) was the result of using range thresholds to eliminate nearshore sockeye salmon from Chinook salmon counts. The nearshore range distribution was partially influenced by varying range thresholds and by tripod relocations closer to shore as the water level rose.

The right-bank range distribution also exhibited nearshore truncation during both the early and late runs due to range filters eliminating nearshore targets (Figures 12 and 14). The apparent large increase in passage near 32 m was an artifact of the range thresholds eliminating most of the targets inside of 32 m. The low nearshore passage (inside 32 m), most evident during the early run, resulted from range threshold changes and transducer tripod relocations (Figures 4, 12, and 14).

In recent years the delineation between nearshore-traveling sockeye and offshore-traveling Chinook seems to have become more obscured (Miller and Burwen 2002). These apparent bursts of high-sockeye passage are often brief and periodic, related to the tide cycle. Consequently, in 2002, we began to selectively exclude individual sample periods when we had evidence that substantial numbers of sockeye were passing the site within the counting range. These excluded hourly samples are listed in Appendix E1. We believe this technique reduced the potential for overestimating Chinook salmon passage, at the possible cost of creating bias in the opposite direction. If Chinook passage was relatively high during the excluded samples, our Chinook passage estimates are biased conservatively low by excluding those periods.

## TARGET STRENGTH

From 1996 through 2000, the left bank produced higher mean target strength estimates on average than did the right bank (6% higher for the early run, 9% for the late run; Burwen and Bosch 1998; Bosch and Burwen 1999, 2000; Miller and Burwen 2002; Miller et al. 2002). The higher mean target strength observed on the left bank was attributed to threshold-induced bias rather than actual differences in fish size. It was concluded that the acoustically reflective gravel substrate on the left bank prevented the sonar beam from being aimed as close to the river bottom on that bank as it was on the right. Because left-bank fish were, on average, farther from the acoustic axis than right-bank fish, a greater proportion of small echoes from left-bank fish failed to meet the voltage threshold, thus biasing target strength estimates upward. In addition, the higher background noise experienced on the left bank resulted in higher variability in positional estimates, which also resulted in a positive target strength bias.

In 2002, mean target strengths were very similar between the left and right banks during both the early and late runs (Figures 16 and 17). The similarity in mean target strength between banks was also observed in 2001, and was attributed to the new left-bank transducer location and the improved left-bank aim that resulted in more on-axis targets (Miller et al. 2003). The similarities between right- and left-bank mean target strength in 2002 was again likely due to the new (2001) left-bank transducer location and the improved aim.

Downstream unfiltered targets were smaller (~2 dB) than upstream unfiltered targets during the early run (Figure 16). The proportion of downstream targets was also slightly larger in the unfiltered data set than in the filtered data set during the early run (5% vs. 4%; Table 9 and Figure 16). Smaller downstream unfiltered targets and a larger proportion of downstream targets in the unfiltered data set indicate that the target strength threshold is most likely filtering out downstream traveling debris that were incorrectly classified as downstream swimming fish, or that smaller fish were more likely to travel downstream. During the late run, downstream targets were again slightly smaller (~1 dB) than upstream targets and the proportion of downstream targets was similar (~4%) for filtered and unfiltered data (Table 9, Figure 17). The tendency for downstream traveling targets to have smaller average target strengths than upstream-traveling targets has been documented in prior years (Bosch and Burwen 1999; Bosch and Burwen 2000; Miller and Burwen 2002; Miller et al. 2002; Miller et al. 2003). Discerning between debris-like traces and a fish traveling downstream can be difficult, and crewmembers are instructed to include downstream targets as valid fish traces when in doubt. Some misclassification of downstream-traveling debris as fish is inevitable. This is the reason that this project and many others choose to ignore downstream targets rather than subtract them from upstream estimates even when direction of travel is known. Typically, the proportion of downstream targets is small, and the potential error that would be introduced by misclassifying debris as downstream traveling fish is of greater concern.

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

## DIRECTION OF TRAVEL

All tracked targets have been classified by direction of travel since 1995, when split-beam technology was first implemented. Since then, the downstream component of the early run has varied from 2% to 12% and averaged 7%, while the downstream component of the late run has ranged from 3% to 14% and has averaged 6% (Bosch and Burwen 1999, 2000; Burwen and Bosch 1996, 1998; Miller and Burwen 2002; Miller et al. 2002, 2003). The downstream component of the late run during 6 of the past 7 years has equaled 6% or less with the exception of the 14% anomaly estimated in 1998 (Bosch and Burwen 2000). Downstream passage in 2002 averaged 4% during the early run and 6% during the late run (Tables 5 and 6).

The daily proportion of downstream targets in 2002 varied during the early run (Appendix F1). Late-run proportions were relatively low during the first half of the run, but increased during the second half, especially during the last 8 days of sonar operations (Appendix F2). The late-run downstream component averaged 5% before 29 July, but averaged 14% after that date. A similar late-season trend was observed in 1998, 2000, and 2001 (Bosch and Burwen 2000; Miller and Burwen 2002; Miller et al. 2003) and may be attributed to mainstem spawners lingering in the sonar beam and slowly swimming upstream and then back downstream, thus increasing the downstream count.

## COMPARISON OF PASSAGE ESTIMATES WITH OTHER INDICES

Past research indicates that sonar estimates of Chinook passage are not equally reliable under all circumstances. Recent research efforts have focused on identifying conditions when sonar estimates may not be reliable. Our foremost concern is that we may be including substantial numbers of sockeye in Chinook estimates during periods of high sockeye passage. Therefore, sonar estimates of Chinook passage were compared with several other indices of Chinook and sockeye abundance to aid in evaluating the sonar's accuracy with respect to both species apportionment and run magnitude. These indices include CPUE and species composition from gillnets drifted at the sonar site, Chinook CPUE in the sport fishery, daily estimates of sockeye salmon at the river mile-19 sonar site, and experimental mixture model estimates of species composition based on echo envelope length ("pulse width") measurements.

Gillnets have been drifted just downriver of the sonar site for several years (Reimer et al. 2002). Substantial changes to the gillnetting procedures were implemented in 2002. Drifts were done with two mesh sizes (5.0 in and 7.5 in stretched) instead of one (7.5 in only), nets were constructed of multi-monofilament (formerly cable-lay braided nylon), and the color of the mesh was changed to more closely match that of the river. These changes had the effects of increasing net efficiency, and decreasing the effect of water clarity on net catches (Reimer 2004). We also believe that the revised netting program produces less-biased estimates of species composition because overall size selectivity is reduced.

Inriver sport fish CPUE, estimated with an intensive creel survey (Reimer 2004), can be a useful index of Chinook salmon abundance. Its main drawbacks include sensitivity to changing river conditions (especially water clarity) and fishery regulations (e.g. bait restrictions).

The river mile-19 sockeye sonar site, located upriver of the Chinook sonar site, provides an index of inriver sockeye salmon abundance. This sonar project is conducted from 1 July through mid August by the Commercial Fisheries Division and targets only nearshore sockeye salmon (Westerman and Willette 2003). Although travel time between the river mile-8.6 Chinook sonar site and the river mile-19 sockeye sonar site undoubtedly varies, we believe it averages 1 to 2 days. Information from this project aids in determining periods when Chinook estimates are most likely to be biased high.

Tethered fish experiments since 1995 have uncovered several hydroacoustic indices of fish size that are superior to target strength, including the standard deviation of echo envelope length (ELSD, Burwen et al. 2003). We have developed methods that model the frequency distribution of observed ELSD as a mixture of distributions from two or more component species (Fleischman and Burwen 2003). This approach yields robust estimates of species composition even when fish size distributions overlap and change over time. Currently, such estimates have two limitations. First, measurements of ELSD appear to be inflated when fish migrate at high densities, so we have only produced mixture model estimates for the early run, when fish density remained low. Second, the mixture model requires empirical estimates of sockeye and Chinook length distributions from the gillnet catches. Limited gillnet sample sizes made it necessary to pool the data to produce weekly, rather than daily, estimates of species composition.

### Early Run

The 2002 early-run passage estimate of 7,162 Chinook salmon was the lowest recorded since sonar enumeration of early-run passage began in 1988 (Appendix H1). Target detection exercises and *in situ* calibration verifications (Table 4) conducted in May and June indicated the sonar equipment was operating properly and that target detectability was probably not an issue. It is possible that large eulachon *Thaleichthys pacificus* migrations observed in May could have contributed to the record low early-run passage estimate. Sound shadowing effects caused by the eulachon migrations forced us to exclude some of the most severely affected hourly samples from calculation of early-run daily passage estimates. It is possible that these factors could have biased May passage estimates low.

In contrast, the 2002 early sockeye run appears to have been one of the largest on record (Larry Marsh, ADF&G, Division of Sport Fish, Soldotna, personal communication). The combination of the small Chinook salmon run and the large sockeye run raises the possibility that the Chinook estimate could have been biased high in June, due to misclassifying sockeye salmon as Chinook salmon. Gillnet CPUE estimates confirmed large numbers of sockeye salmon relative to Chinook salmon on and around 9 June (Figure 20).

However, several lines of evidence suggest that neither of these potential biases were substantial. First, gillnet CPUE and sport fish CPUE tracked early-run sonar estimates fairly well (Figure 21). Some variability was apparent, but both showed an increasing trend as the season progressed. Sport fish CPUE was only available through 9 June due to the emergency closure of the fishery on 11 June.

Also, two alternative estimates of Chinook salmon abundance were consistent with the official early-run estimates presented in this report. Net-apportioned estimates, which are the product of unfiltered sonar estimates and proportion of Chinook salmon in the gillnet catches (Equation 16), tracked the sonar estimates fairly well and totaled 6,132 (SE = 371) for the early run (Figure 22, Appendix I1). Mixture model estimates based on ELSD frequency distributions totaled 9,134 (SE = 471; Appendix J). Because the official estimate of 7,162 (SE = 169) early-run Chinook salmon was bounded between the two alternative estimates, and because all three indicate a small run, we are fairly confident that the official estimate is not greatly in error.

### Late Run

The 2002 late-run inriver passage estimate of 38,948 Chinook salmon was below average (Appendix H2) while the river mile-19 sockeye salmon passage estimate of 957,924 (Westerman *In prep;* Westerman and Willette 2003) was above average. Based on sockeye salmon gillnet CPUE and river mile-19 sockeye salmon sonar estimates (Figure 23), substantial numbers of sockeye salmon were passing the Chinook sonar site throughout much of July. Gillnet CPUE data show several peaks in sockeye passage at the Chinook sonar site in July with the largest peak occurring on 18 July. The river mile-19 sockeye salmon sonar site experienced a large peak in sockeye passage on 19 July and a smaller peak on 7 July. This again raises the possibility that the sonar estimates are too high because of species classification errors.

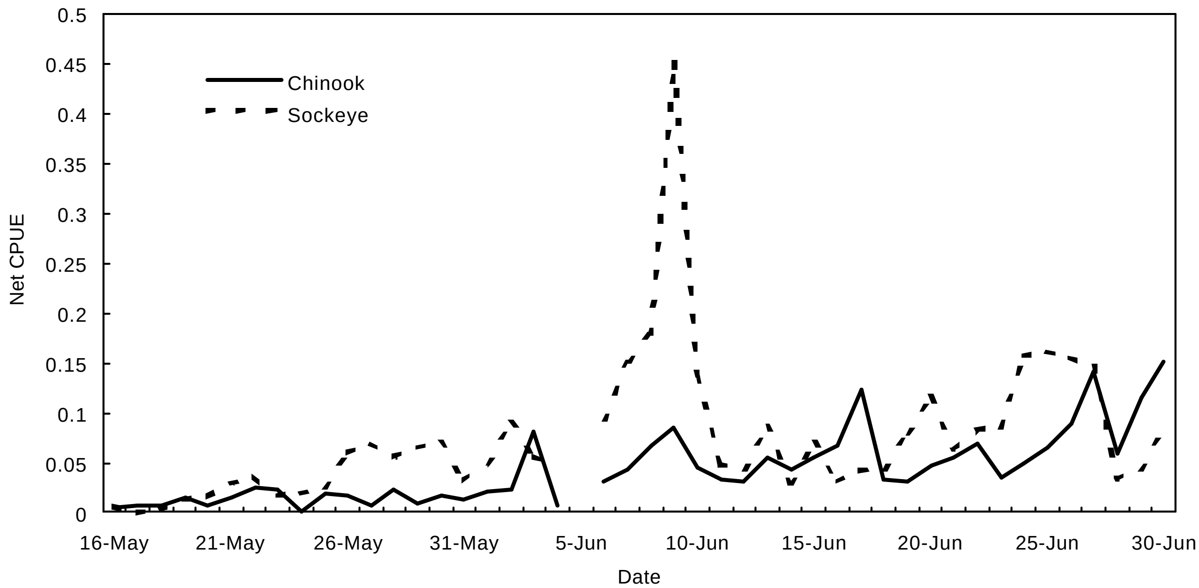


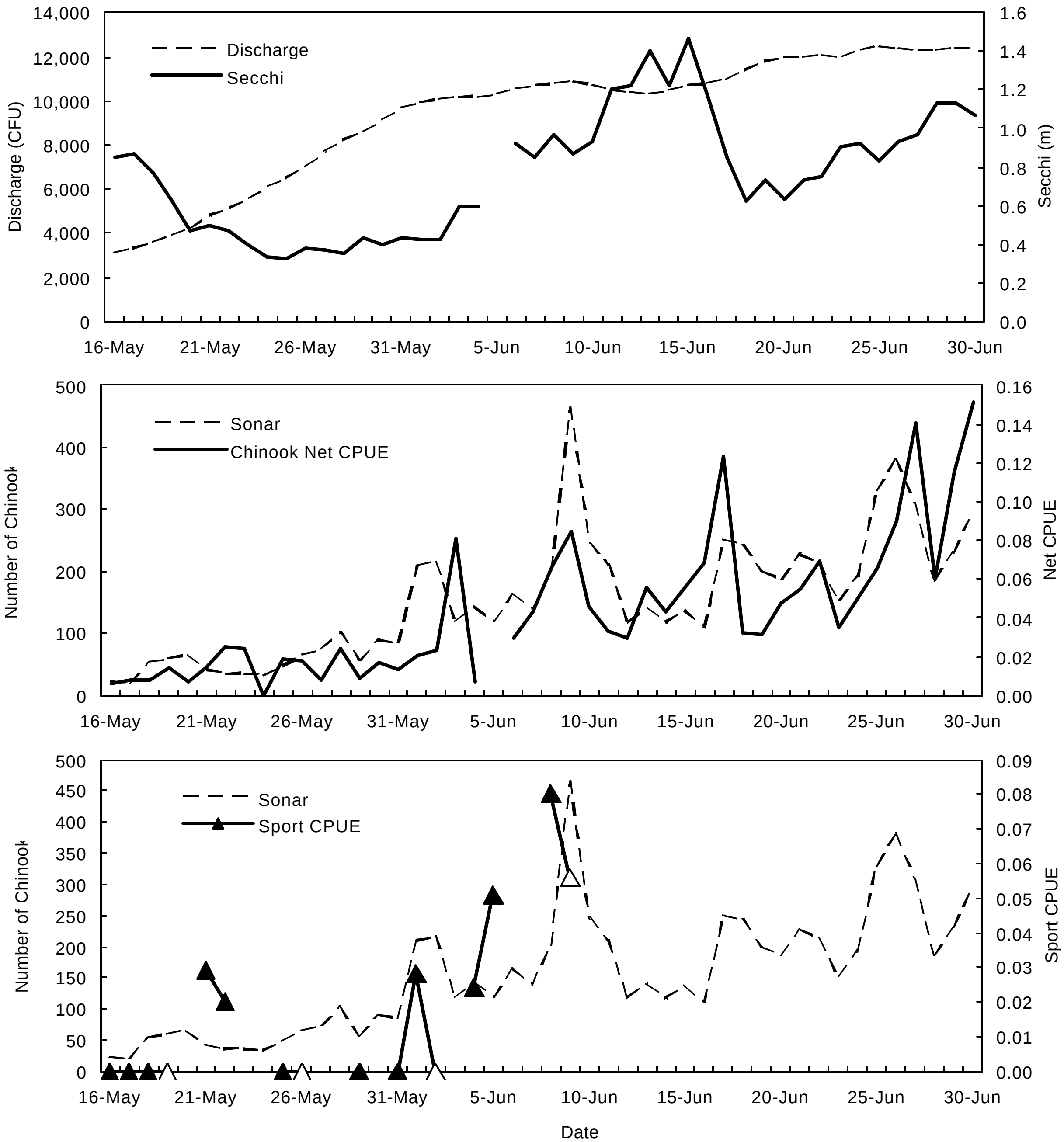

**Figure 20**.-Daily CPUE of Chinook and sockeye salmon from inriver netting, early run (16 May-30 June), Kenai River, 2002.

However, as in the early run, comparison of the sonar numbers with other indices and estimates suggests that this was not a large problem for the late run in 2002.

First, timing of Chinook and sockeye gillnet CPUE suggest sockeye passage had little influence on Chinook passage estimates (Figure 23). Peak Chinook gillnet CPUE occurred on 3 July, the same day that peak Chinook sonar passage occurred, while peak sockeye gillnet CPUE occurred on 18 July. Although sockeye gillnet CPUE increased from 1 July to 3 July, the corresponding increase in Chinook gillnet CPUE suggests that the increased Chinook sonar passage observed during this time was likely due to an actual increase in Chinook passage and not misclassification of sockeye. If significant misclassification of sockeye occurred, one would expect it to have taken place on or around 18 July when peak sockeye gillnet CPUE was observed. On the contrary, Chinook sonar passage experienced a decline on the day of peak sockeye gillnet CPUE (18 July).

Second, alternative estimates based on gillnet catches agreed fairly well with the official sonar estimate. Net-apportioned estimates were lower than official passage estimates during much of early July, and higher than the official estimates during much of late July (Figure 22). However the two tracked quite well from 29 July through 5 August, and overall, the net apportioned estimate for the entire late run was very similar to (only 7% higher than) the official estimate (Appendix I2).

Third, Chinook salmon sport fish CPUE tracked the official sonar passage estimates fairly well. Peak sport fish CPUE occurred on 2 July, and slightly smaller peaks were observed on 6 July and 14 July (Figure 23). Variability between sonar passage estimates and sport CPUE was greater during the first half of July than during the second half of July. Chinook sport fish CPUE and sonar passage estimates each exhibited a general decreasing trend throughout July.




Note: Net CPUE and sport fish CPUE taken from Reimer (*In prep*). The sport fishery was closed on 11 June. No sport fish CPUE data were available after 9 June. Open triangles represent days on which only unguided anglers were allowed to fish.

**Figure 21**.-Daily discharge rates collected at the Soldotna Bridge, Secchi depth readings taken in front of the sonar site, Chinook sonar passage estimates, inriver gillnet CPUE, and Chinook sport fish CPUE, early run (16 May-30 June), Kenai River, 2002.

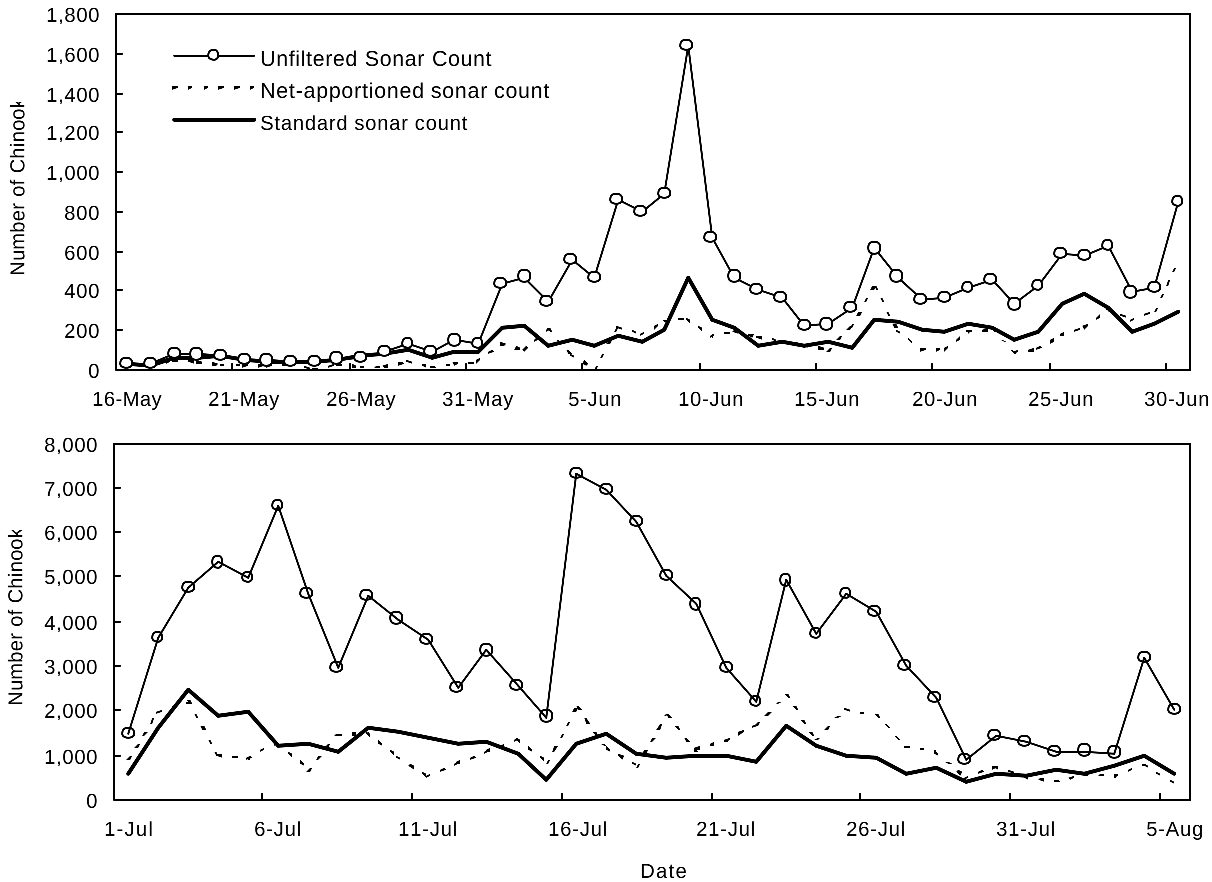



**Figure 22**.-Estimated early- (top) and late-run (bottom) Chinook salmon passage based on unfiltered sonar counts, net-apportioned sonar counts, and standard (filtered) sonar counts, Kenai River, 2002.

In summary, most lines of evidence suggest that the sonar estimates were reasonably accurate in 2002. Specifically, estimates were not greatly inflated by the presence of sockeye salmon.

## OUTLOOK

We continue to pursue several avenues of investigation for improving our estimation of Chinook salmon abundance. We are satisfied that the refinements made to the netting program in 2002 have resulted in improved net-apportioned estimates, and we plan to continue to use them experimentally as an objective alternative index of Chinook abundance. Likewise, ELSD mixture model estimates have proven useful during the early run.

It is possible that current echo length measurements can be improved to provide more precise estimates of fish size. We are currently funding a graduate student at the University of Washington who is concentrating on some of the details of echo envelope measurement. We are also working to reduce or correct for the effect of fish density on echo length measurements, in hopes that the mixture model estimates would then be useful during both early and late runs.

Finally, we continue to test an experimental imaging sonar (DIDSON), which is capable of producing video-like images of fish, but has the drawback of being limited to relatively short ranges. In 2002, we quantified the ability of the DIDSON to measure fish size. Details of this research are described by Burwen and Fleischman (*In prep*).

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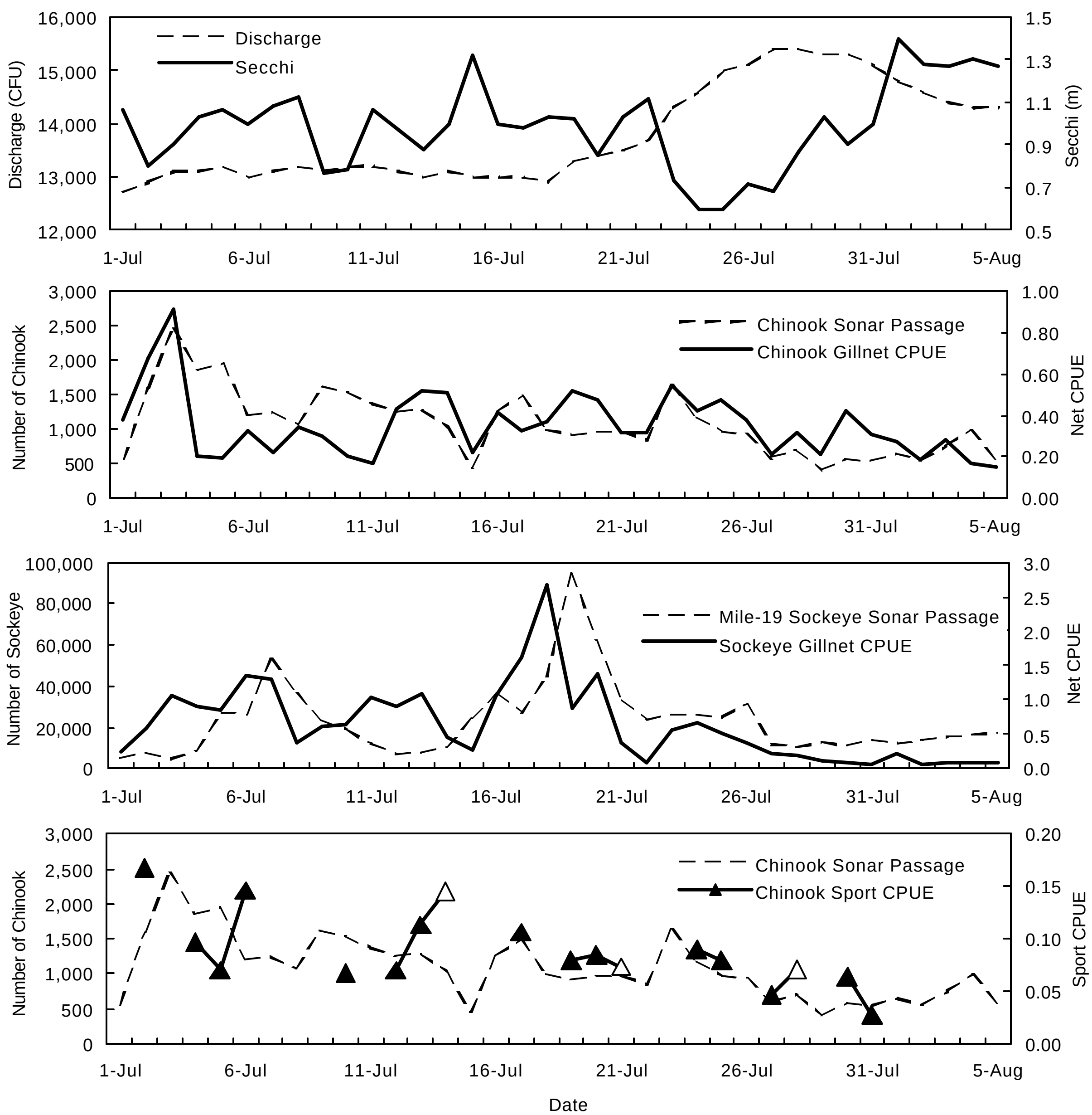


Note: River mile-19 sockeye sonar estimates taken from Westerman (*In prep*). Net CPUE and sport fish CPUE taken from Reimer (*In prep*). The Chinook sport fishery closed by regulation on 31 July, so no sport fish CPUE data were available after this date. Open triangles represent days on which only unguided anglers were allowed to fish.

**Figure 23**.-Daily discharge rates collected at the Soldotna Bridge, Secchi depth readings taken in front of the sonar site, Chinook sonar passage estimates, inriver gillnet CPUE, river mile-19 sockeye sonar passage estimates, and Chinook sport fish CPUE, late run (1 July-5 August), Kenai River, 2002.

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# APPENDIX A.  TARGET STRENGTH ESTIMATION

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

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

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

where:

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

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

In practice, the location of the target in the beam ($\theta$ and $\phi$) 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 $\theta$ and $\phi$ 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 $\theta$ and $\phi$ are estimated by comparing the phases of signals received by opposing pairs of adjacent quadrants. The beam pattern factor is a function of $\theta$ and $\phi$, determined during laboratory calibration.

# APPENDIX B. MID RIVER SONAR COVERAGE

**Appendix B1**.-Sonar coverage near the thalweg.

Prior to the 2001 season, the right and left bank transducers were located directly across the river from each other (Figure B1.1). The range encompassed by each transducer was determined by finding the center of the river channel (thalweg) using a depth finder, deploying a large target in the water column directly over the thalweg, then ranging sonar coverage out to the target from both transducers (Miller and Burwen 2002). The end range was then reduced on each bank by approximately 1 m to prevent counting the same fish on both banks. In this manner, the entire cross-section of the river between the two transducers was assumed to be insonified.

River bottom profiles of the left bank sonar site conducted in the spring of 2001 suggested that a more uniform bottom profile, and therefore an improved left bank sonar aim, could be achieved by moving the left bank transducer 35 m downstream from the location used in past years (Figures B1.2, B1.3; Miller et al. 2003). For this reason, the left bank transducer in 2001 was relocated 35 m downstream from its old location. Comparison of left bank vertical target distributions for 2000 and 2001 indicates the left bank was aimed closer to the river bottom in 2001, thus reducing the possibility of fish passing beneath the sonar beam (Figure B1.4). In addition, cross-sectional plots of targets in the water column indicated more even beam coverage along the river bottom throughout the left bank range in 2001 (Figure B1.5).

Although relocation of the left bank transducer downstream appeared to have improved the aim on that bank, it also resulted in an apparent gap in beam coverage in the middle of the river (Figure B1.5). Because the right and left bank transducers were no longer located directly across the river from each other (i.e. because the left-bank transducer was located 35 m downstream from the right-bank transducer) it was now more difficult to verify that the entire cross-section of the river between the two transducers was insonified. We assumed that as long as each bank's transducer was deployed the same distance from shore in 2001 as it was in 2000, and as long as there were no major changes in the river bottom contour, then the counting ranges on both banks would be similar in 2001 versus 2000 (Figure B1.6). We found, however, that the range covered by the left bank transducer at its new location in 2001 was less than that in 2000, resulting in an apparent gap in beam coverage. This gap in beam coverage ranged up to 7 m in length. In order to account for Chinook salmon in the mid-portion of the river not encompassed by the sonar beams, we produced a daily mid-river expansion estimate in 2001 and adjusted the total daily passage based on this expansion (Miller et al. 2003).

The right and left bank transducer deployment locations in 2002 were similar to deployment locations in 2001 (i.e. the left bank transducer was deployed approximately 35 m downstream from the right bank transducer). However, based on range measurements taken in 2002, there appeared to be an overlap in right and left bank coverage during the early part of the season and an apparent gap in coverage during the later half of the season. River bottom profiles conducted at the sonar site in May 2002, as well as the apparent overlap in coverage at the beginning of the season, made us question the appropriateness of expanding the sonar estimate on days that the sonar beams failed to cover the middle portion of the river. A close review of the 2002 profiles indicated that the thalweg did not remain a uniform distance from the left bank as one moves from the old left bank transducer deployment location to the new deployment location (Figure B1.7 and Figure B1.8). The thalweg appeared closer to the left bank at the old upriver location and farther from the left bank at the new downriver location (Figure B1.9). In addition, a comparison of replicate profiles taken at the same locations suggests that variability exists between replicate profiles (Figure B1.8).

We had considered using a hybrid profile composed of the left bank profile taken at the left bank transducer location and the right bank profile taken at the right bank transducer location to estimate the actual gap in midriver coverage accounting for the change in thalweg position between the two locations. Basically the portion of the left-bank profile from the left bank to the thalweg was combined with the portion of the right-bank profile from the right bank to the thalweg (Figure B1.10). The portion of the mid-river not insonified was then determined using tripod locations and counting ranges. Assuming fish did not cross the thalweg as they migrated upriver, and assuming our bottom profiles and range measurements were accurate, we could produce an expansion factor for the uninsonified middle portion of the river and adjust the daily sonar passage estimates based on this mid-river expansion factor. Unfortunately, we found that the size of the mid-river gap was dependent on how the thalweg was defined and on which profile transects were used to form the hybrid transects (Figure B1.11). The variability associated with the river bottom profiles and range measurements, and the uncertainty of fish behavior in the vicinity of the thalweg, prompted us to reconsider producing a mid-river expansion factor in 2002. We believe that the possibility of overestimating the mid-river passage is too great and that we would rather produce a more conservative estimate by not adjusting for the mid-river gap in coverage.

Beginning in 2003 we intend to conduct a comprehensive bathymetric survey that will provide more accurate profile information enabling us to better compare the old and new left bank sites and evaluate the extent of the possible midriver gap in sonar coverage. Detailed flow measurements will also be collected and may be used in modeling of fish migration behavior based on varying flow regimes across the river.

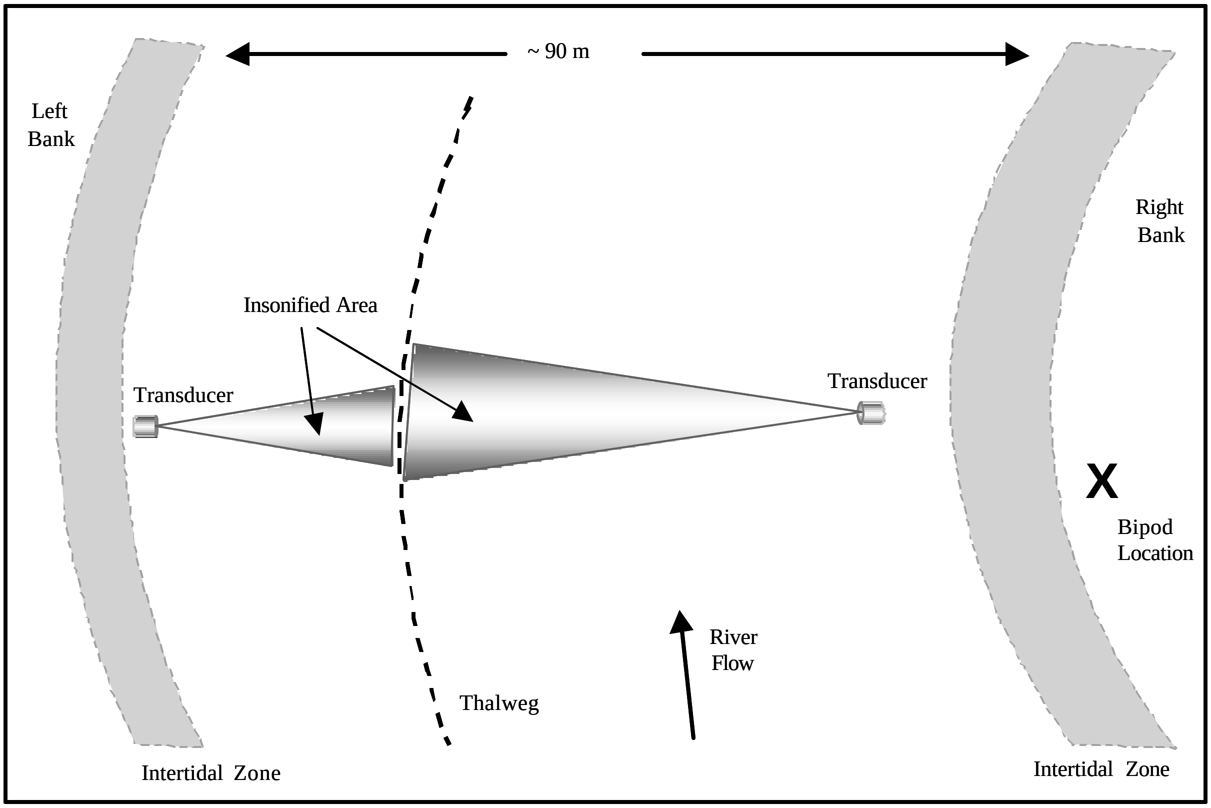



**Figure B1.1**.-Aerial view of Kenai River Chinook sonar site showing right and left bank transducer locations and insonified area in 2000.

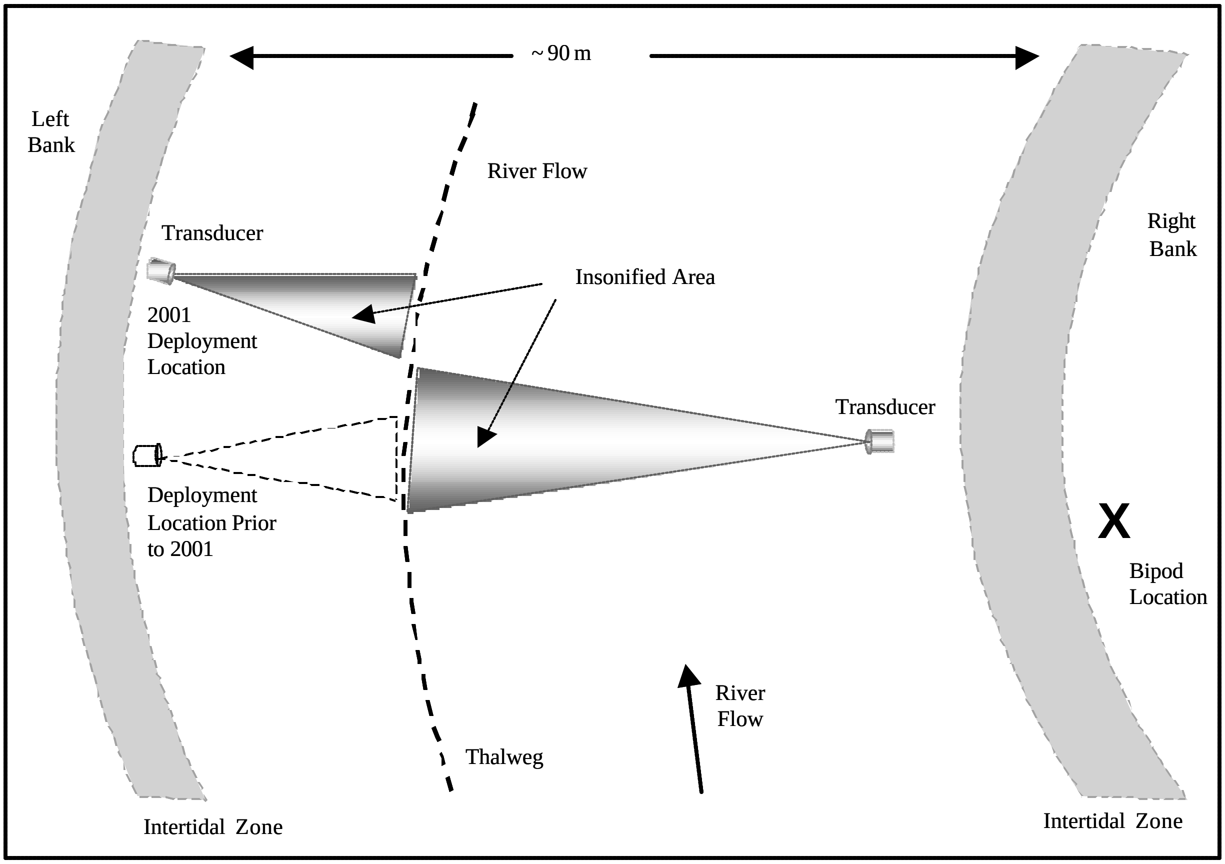



**Figure B1.2**.-Aerial view of Kenai River Chinook sonar site showing right- and left-bank transducer locations and insonified area in 2001.

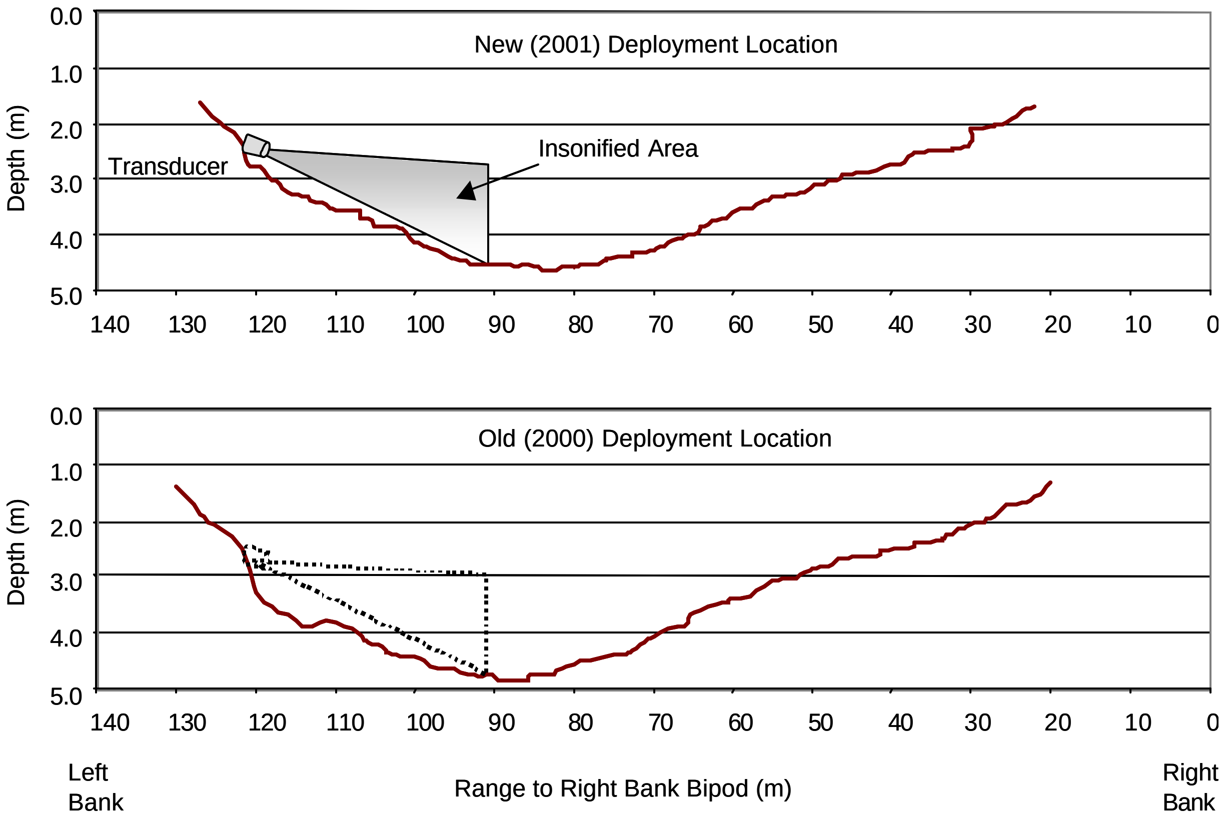
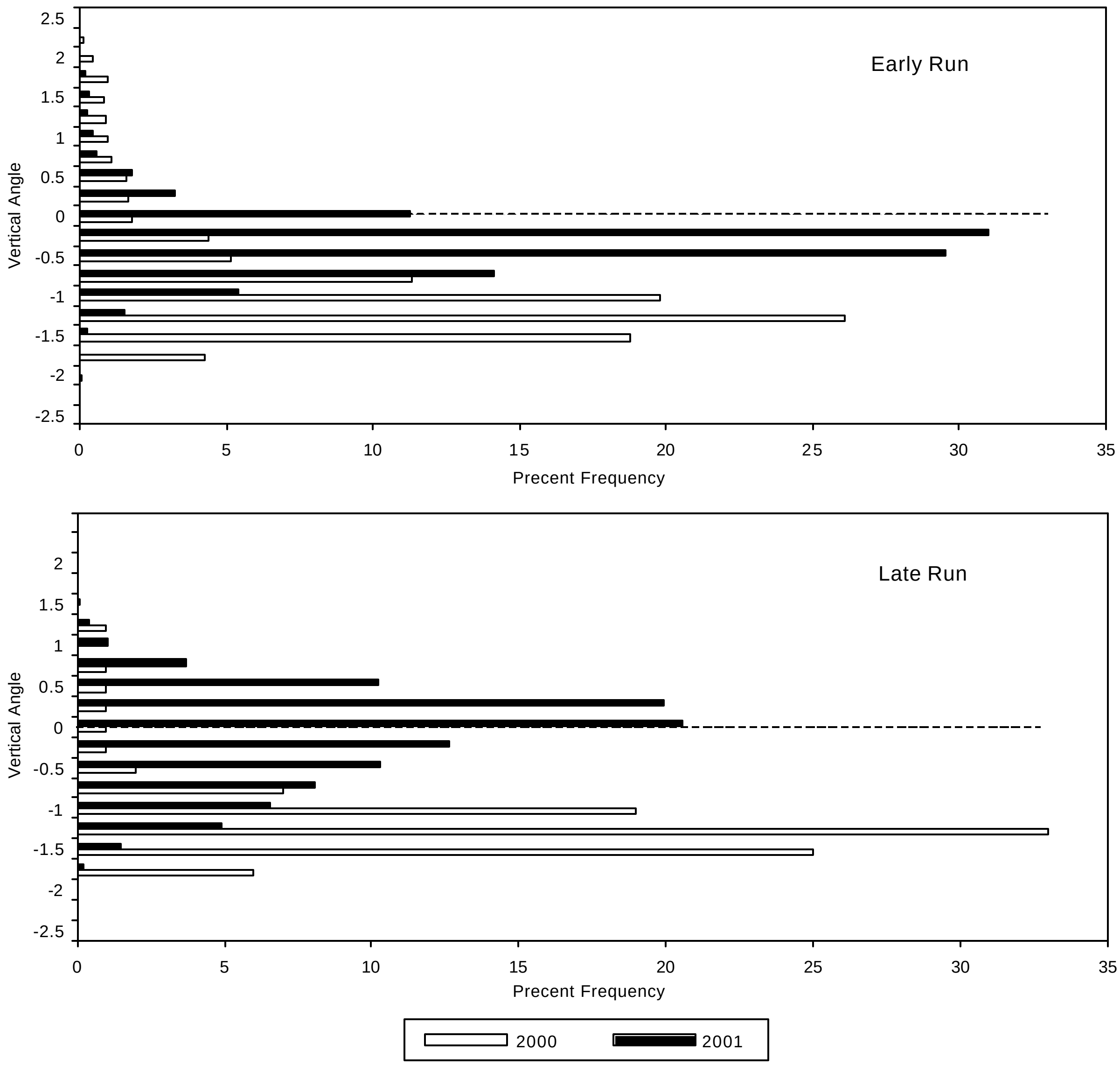



**Figure B1.3**.-River bottom profiles of the new (2001) left bank deployment location and the old (2000) left bank deployment location, Kenai River.




Note: 2000 data taken from Miller and Burwen (2002) and 2001 data taken from Miller et al. (2003). Data have been filtered by range and target strength criteria.

**Figure B1.4**.-Vertical distributions of early- and late-run upstream fish on the left bank of the Kenai River in 2000 and 2001.

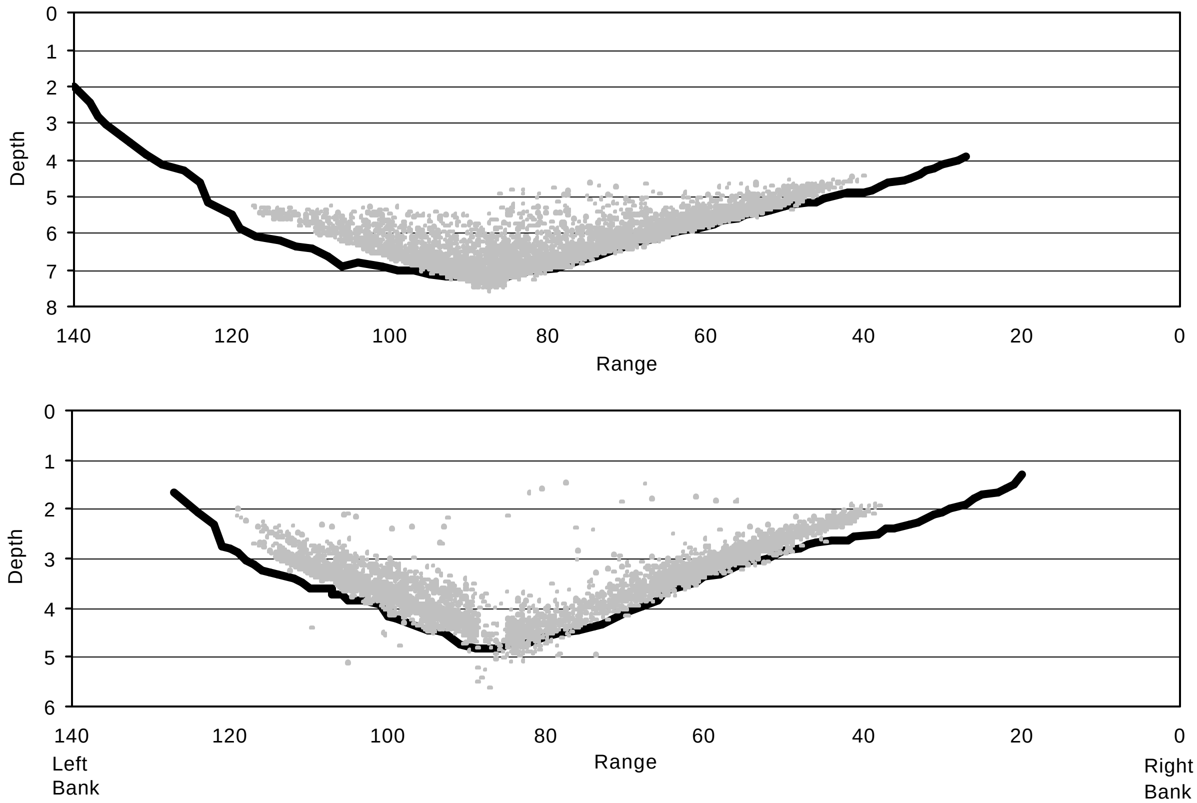



**Figure B1.5**.-Unfiltered target distribution by range and depth for the 2000 (top) and 2001 (bottom) Kenai River early runs (16 May-30 June).

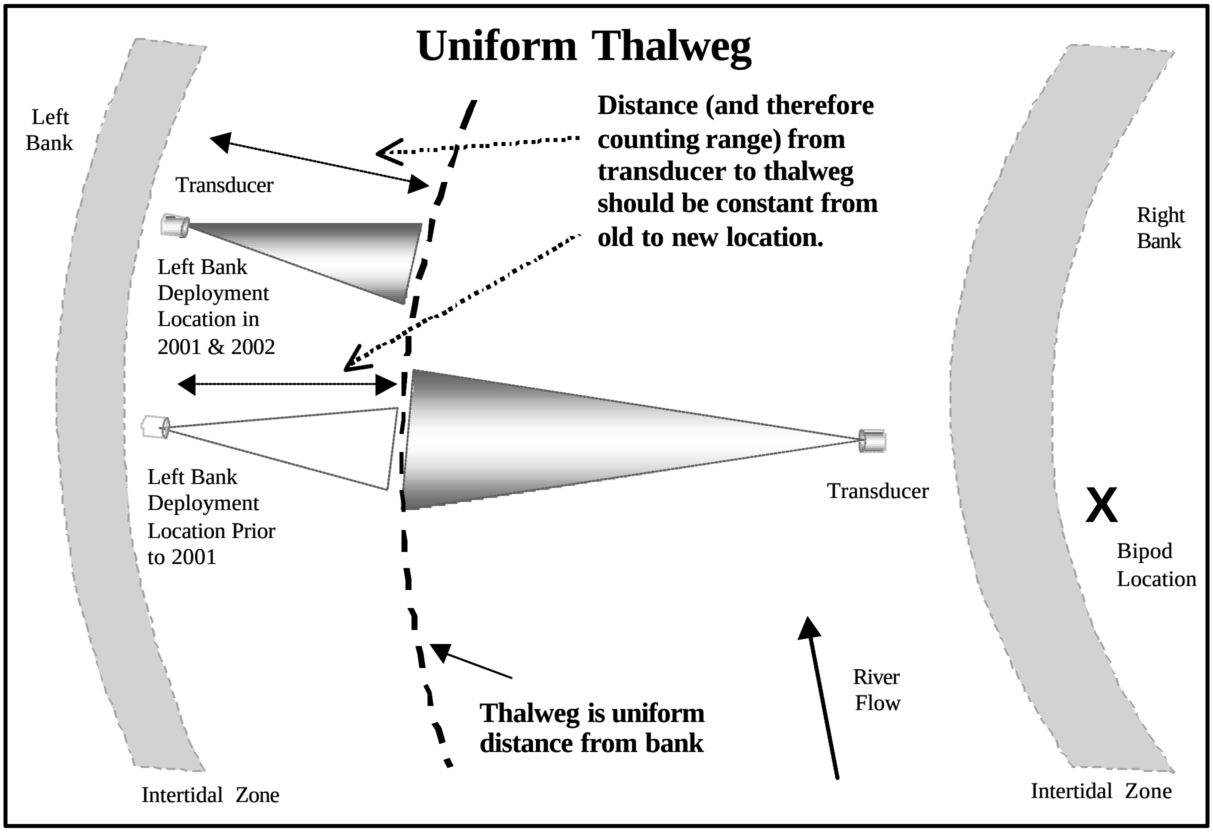



**Figure B1.6**.-Aerial view of Kenai River Chinook sonar site showing right and left bank transducer locations and insonified area in 2001 based on a thalweg that is a uniform distance from the bank.

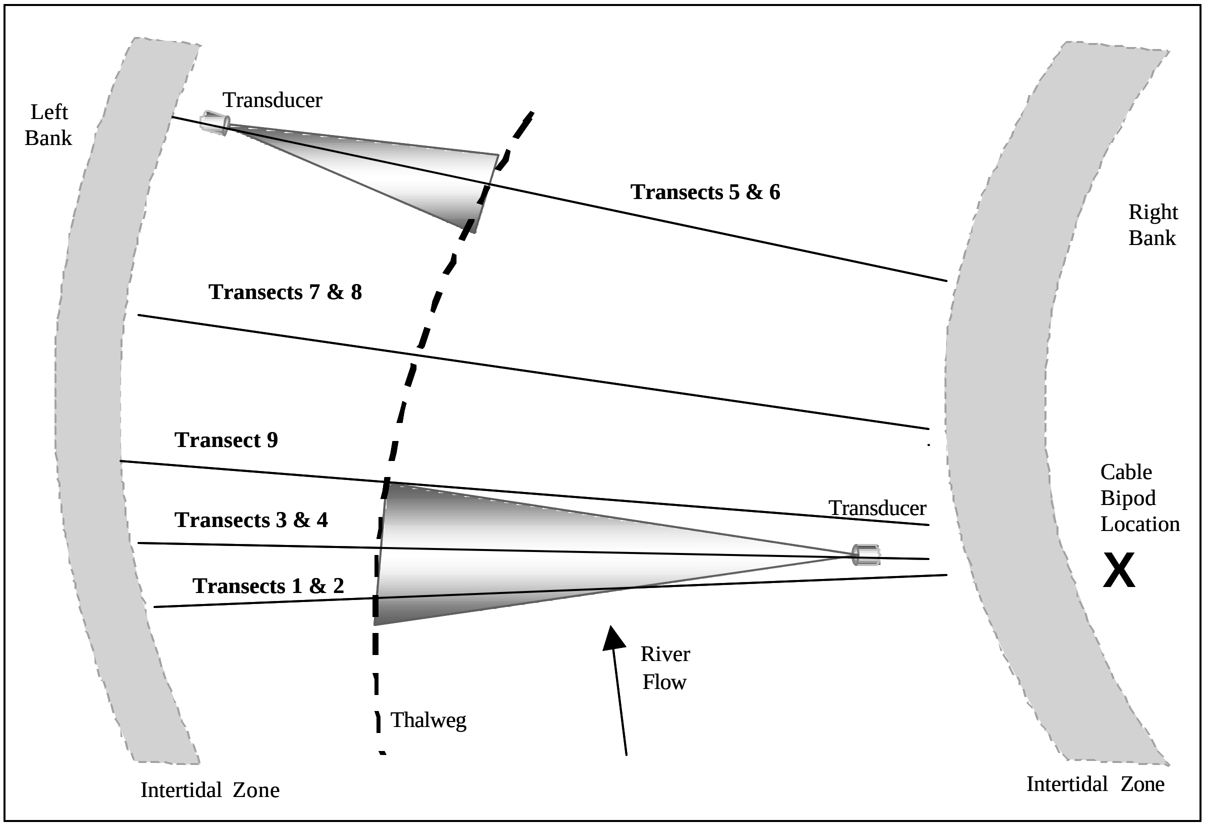



**Figure B1.7**.-River bottom profile transect locations at the Kenai River Chinook salmon sonar site, May 8, 2002.

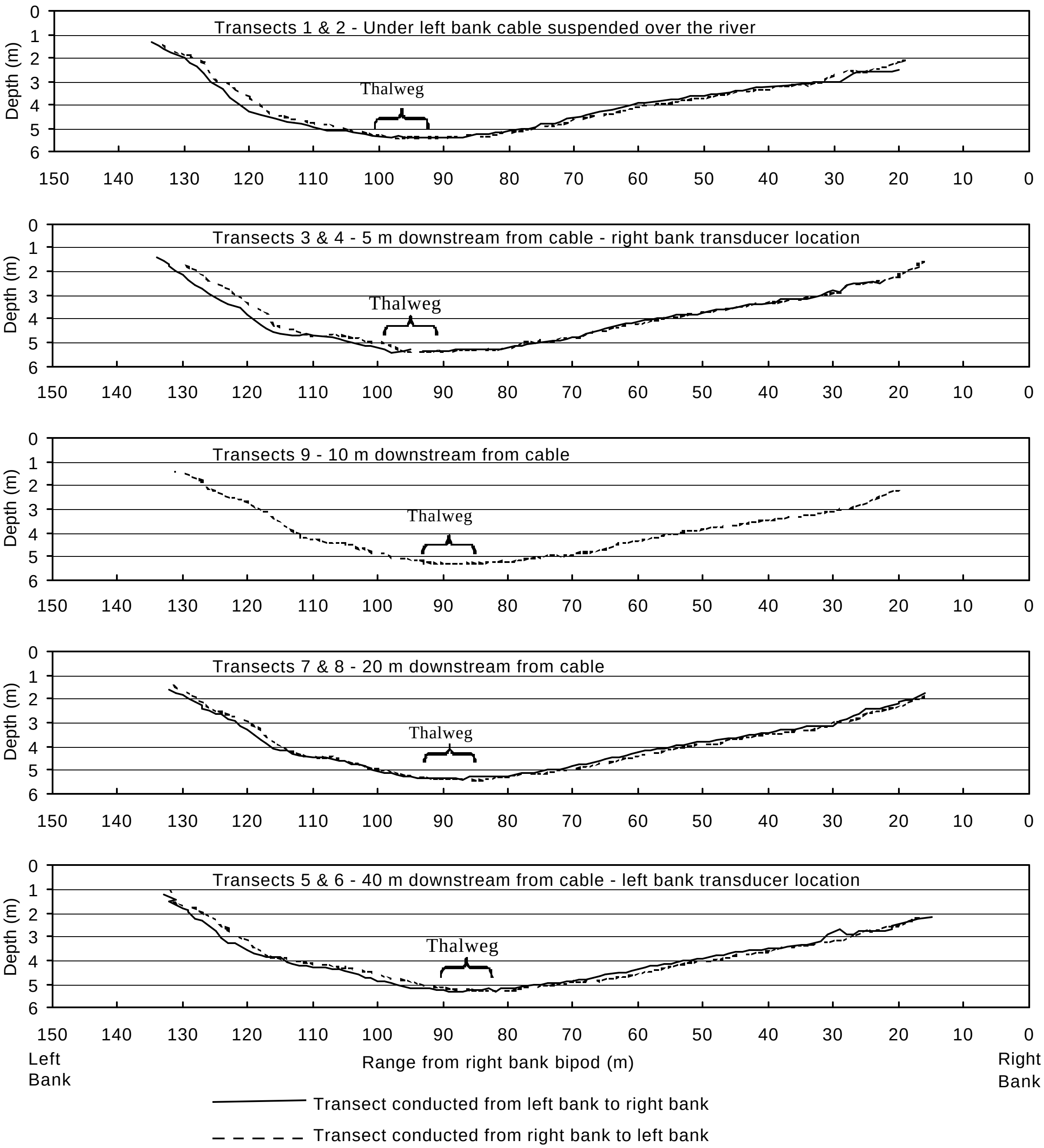



**Figure B1.8**.-Consecutive Kenai River bottom profiles in relation to the left bank cable crossing location, showing replicate profiles and thalweg location, May 8, 2002.

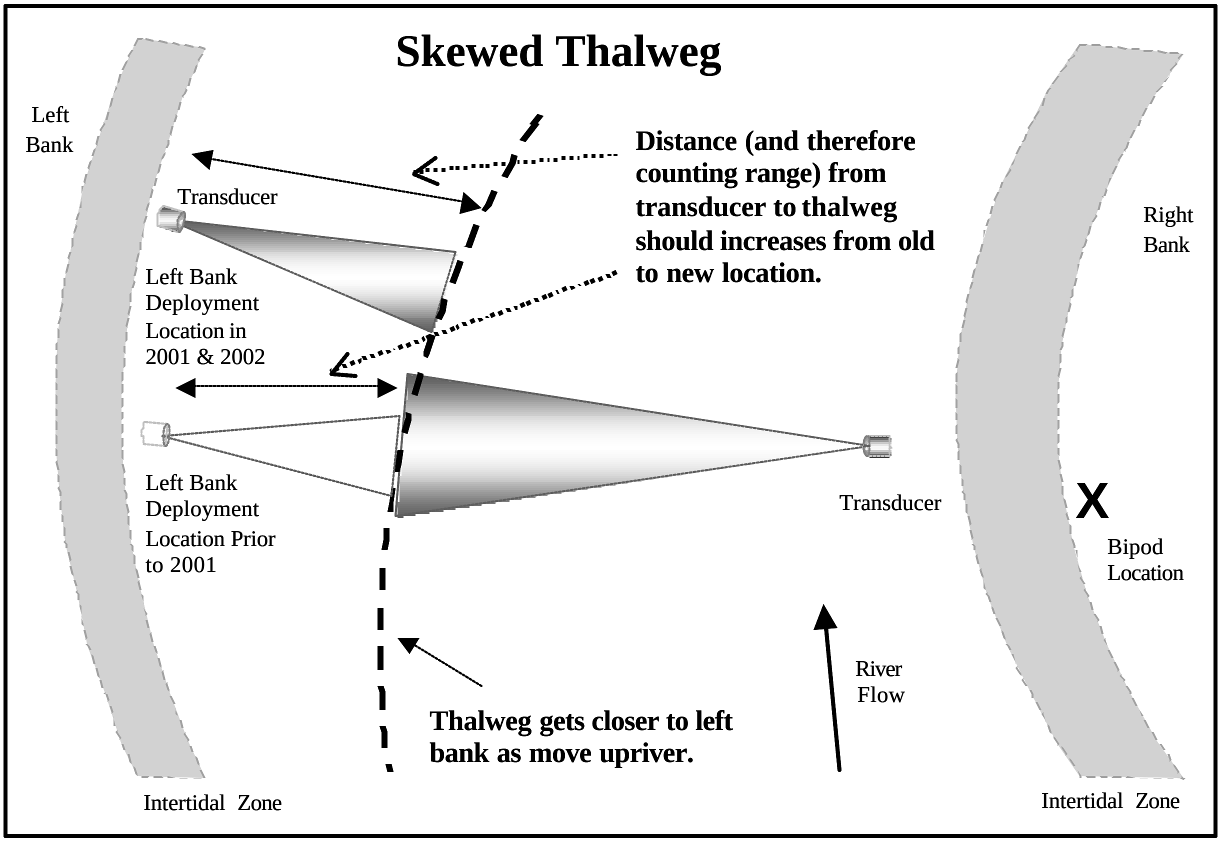



**Figure B1.9**.-Aerial view of Kenai River Chinook sonar site showing right and left bank transducer locations and insonified area in 2002 based on a thalweg that gets farther from the left bank as one moves downriver.

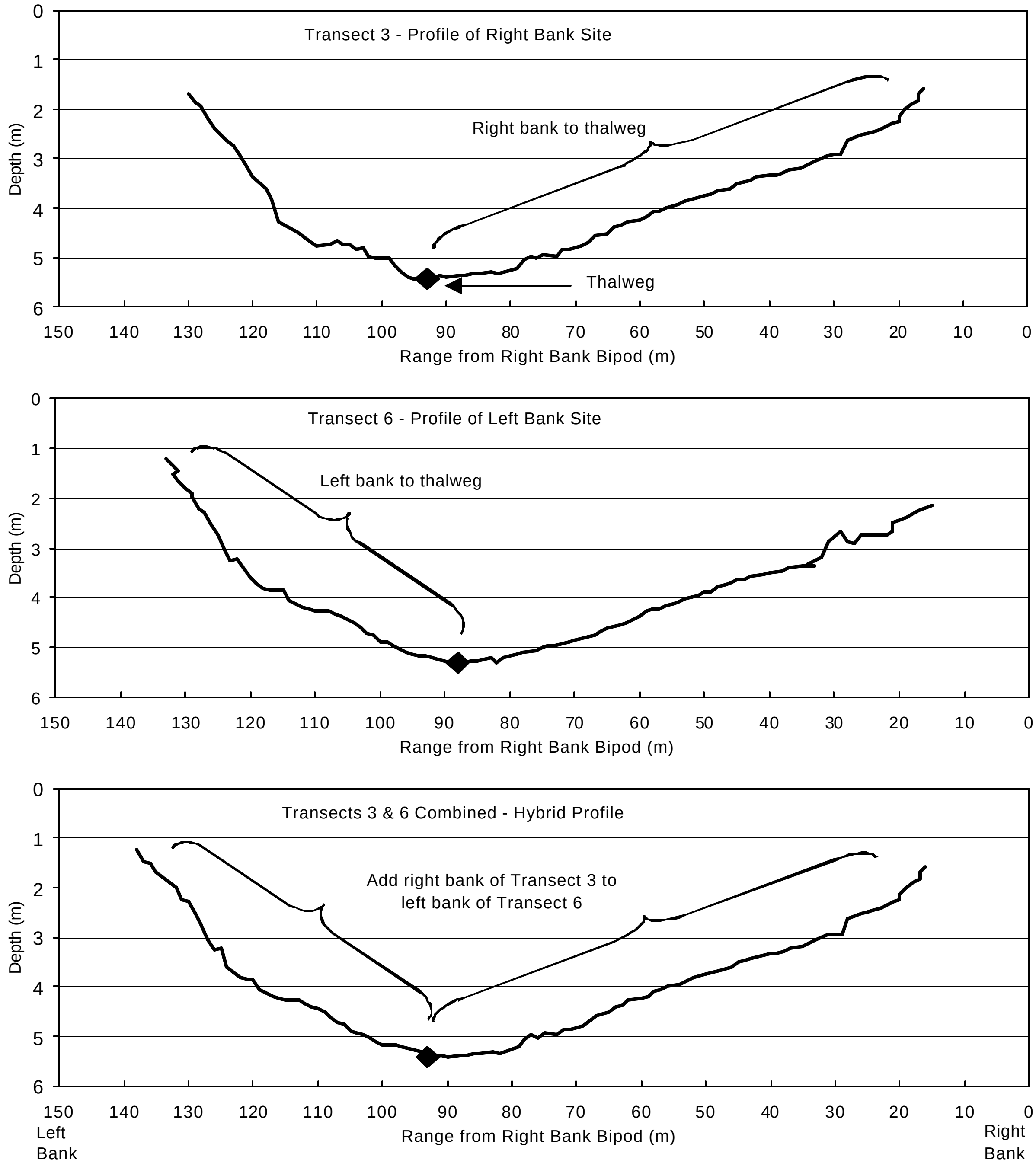



**Figure B1.10**-Creation of a hybrid river bottom profile using transects conducted on May 8, 2002 at the right bank transducer location (transect 3) and the left bank transducer location (transect 6), Kenai River.

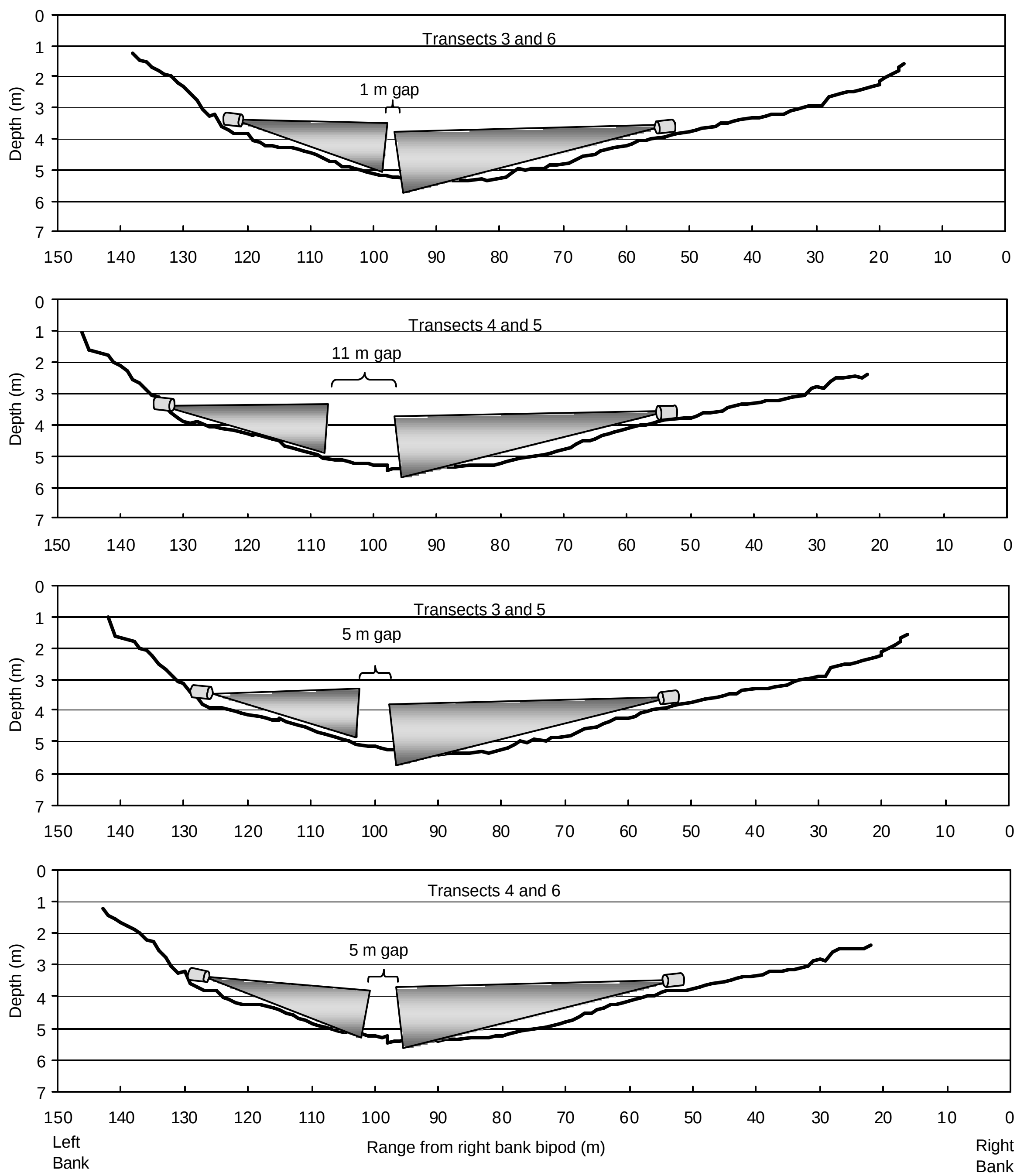



**Figure B1-11**.-Hybrid river bottom profiles showing right and left bank transducer placement, counting range, and the size of the resulting mid-river gap, Kenai River, 2002.

# APPENDIX C.  SYSTEM PARAMETERS

**Appendix C1**.-Example of system parameters used for data collection on the right bank (transducer 733).

* Start Processing at Port 1 -FILE_PARAMETERS- Mon July 1 06:00:07 2002

* 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 | | 13200 | maxp - maximum number of pings in a block NUS |
| 103 | -1 | | 32767 | maxbott - maximum bottom range in samples NUS |
| 104 | -1 | | 61 | N_th_layer - number of threshold layers |
| 105 | -1 | | 5 | max_tbp - maximum time between pings in pings |
| 106 | -1 | | 5 | min_pings - minimum number of pings per fish |
| 507 | -1 | FED5 | | timval - 0xFED5 corresponds to about 20 kHz NUS |
| 108 | -1 | | 1 | mux_on - means multiplexing enabled on board NUS |
| 109 | -1 | | 200 | mux_delay - samples delay between sync and switching NUS |
| 110 | -1 | | 0 | decimate_mask - decimate input samples flag NUS |
| 112 | -1 | | 1 | echogram_on - flag for DEP echogram enable 0=off, 1=on |
| 113 | -1 | | 1 | Hourly Sampling flag 1=On 0=Off |
| 118 | -1 | | 5 | maxmiss - maximum number of missed pings in auto bottom |
| 119 | -1 | | 0 | bottom- |
| 120 | -1 | | 1 | 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 | | 61 | N_int_layers-number of integration strata |
| 123 | -1 | | 61 | N_int_th_layers - number of integration threshold strata |
| 124 | -1 | | 0 | int_print - print integrator interval results to printer |
| 125 | -1 | | 0 | circular element transducer flag for bpf calculation |
| 126 | -1 | | 80 | grid spacing for Model 404 DCR (in samples, 16 s/m) |
| 127 | -1 | | 1 | TRIG argument #1 - trigger source |
| 128 | -1 | | 0 | TRIG argument #2 - digital data routing |
| 130 | -1 | | 0 | TVG Blank (0=Both Start/End,1=Stop Only,2=Start Only,3=None) |
| 200 | -1 | | 20 | sigma flag 0.0 = no sigma, else sigma is output |
| 201 | -1 | | 220.53 | sl - transducer source level |
| 202 | -1 | | -170.54 | gn - transducer through system gain at one meter |
| 203 | -1 | | -18 | rg - receiver gain used to collect data |
| 204 | -1 | | 2.8 | narr_ax_bw - vertical nominal beam width |
| 205 | -1 | | 10 | wide_ax_bw - horizontal axis nominal beam width |
| 206 | -1 | | 0 | narr_ ax_corr - vertical axis phase correction |
| 207 | -1 | | 0 | wide_ax_corr - horizontal axis phase correction |
| 208 | -1 | | 11 | ping_rate - pulses per second |
| 209 | -1 | | 0 | echogram start range in meters |
| 210 | -1 | | 38 | echogram stop range in meters |
| 211 | -1 | | 650 | echogram threshold in millivolts |
| 212 | -1 | | 13.2 | print width in inches |
| 213 | -1 | | 0 | Chirp Bandwidth (0.0 = CHIRP OFF) |
| 214 | -1 | | 20 | Sampling within Hour Ending Time (in Decimal Minutes) |
| 215 | -1 | | 1500 | Speed of Sound (m/s) |
| 216 | -1 | | 200 | The Transducer's Frequency (kHz) |
| 217 | -1 | | -2.5 | min_angoff_v - minimum angle off axis vertical |
| 218 | -1 | | 2 | max_angoff_v - maximum angle off axis vertical |
| 219 | -1 | | -5 | min_angoff_h - minimum angle off axis horiz. |

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| | | | |
|---|---|---|---|
| 220 | -1 | 5 | max_angoff_ h - maximum angle off axis horiz. |
| 221 | -1 | -24 | max_dB_off - maximum angle off in dB |
| 222 | -1 | -15.7408 | ux - horizontal electrical to mechanical angle ratio |
| 223 | -1 | -32.6423 | uy - vertical electrical to mechanical angle ratio |
| 224 | -1 | 0 | ud_coef_a - a coeff. for up-down beam pattern eq. |
| 225 | -1 | -0.0035 | ud_coef_b - b coeff. for up-down beam pattern eq. |
| 226 | -1 | -2.4155 | ud_coef_c - c coeff. for up-down beam pattern eq. |
| 227 | -1 | 0.1084 | ud_coef_d - d coeff. for up-down beam pattern eq. |
| 228 | -1 | -0.1652 | ud_coef_e - e coeff. for up-down beam pattern eq. |
| 229 | -1 | 0 | lr_coef_a - a coeff. for left-rt beam pattern eq. |
| 230 | -1 | -0.0004 | lr_coef_b - b coeff. for left-rt beam pattern eq. |
| 231 | -1 | -0.2 | lr_coef_c - c coeff . for left-rt beam pattern eq. |
| 232 | -1 | 0.0006 | lr_coef_d - d coeff. for left-rt beam pattern eq. |
| 233 | -1 | -0.0002 | lr_coef_e - ecoeff. for left-rt beam pattern eq. |
| 234 | -1 | 4 | maximum fish velocity in meters per second |
| 235 | -1 | 1 | Echo Scope Bottom Location |
| 236 | -1 | 0.4 | maxpw - pulse width search window size |
| 238 | -1 | 36 | bottom - bottom depth in meters |
| 239 | -1 | 0 | init_slope - initial slope for tracking in m/ping |
| 240 | -1 | 0.2 | exp_cont - exponent for expanding tracking window |
| 241 | -1 | 0.2 | max_ch_rng - maximum change in range in m/ping |
| 242 | -1 | 0.04 | pw_criteia->min_pw_6-min -6 dB pulse width |
| 243 | -1 | 10 | pw_criteria->max_pw_6-max -6 dB pulse width |
| 244 | -1 | 0.04 | pw_criteria->min_pw_12 - min -12 dB pulse width |
| 245 | -1 | 10 | pw_criteria->max_pw_12 - max -12 dB pulse width |
| 246 | -1 | 0.04 | pw_criteria->min_pw_18 - min -18 dB pulse width |
| 247 | -1 | 10 | pw_criteria->max_pw_18 - max -18 dB pulse width |
| 249 | -1 | 10 | maximum voltage to allow in .RAW file |
| 250 | -1 | 0.2 | TX argument #1 - pulse width in milliseconds |
| 251 | -1 | 25 | TX argument #2 - transmit power in dB-watts |
| 252 | -1 | -12 | RX argument #1 - receiver gain |
| 253 | -1 | 90.9 | REP argument #1 - ping rate in ms per ping |
| 254 | -1 | 10 | REP argument #2 - pulsed cal tone separation |
| 255 | -1 | 1 | TVG argument #1 - TVG start range in meters |
| 256 | -1 | 100 | TVG argument #2 - TVG end range in meters |
| 257 | -1 | 40 | TVG argument #3 - TVG function (XX Log Range) |
| 258 | -1 | -6 | TVG argument #4 - TVG gain |
| 259 | -1 | 0 | TVG argument #5 - alpha (spreading loss) in dB/Km |
| 260 | -1 | 0.2 | minimum absolute distance fish must travel in x plane |
| 261 | -1 | 0.2 | minimum absolute distance fish must travel in y plane |
| 262 | -1 | 0.2 | minimum absolute distance fish must travel in z plane |
| 263 | -1 | 2 | bottom_window - auto tracking bottom window (m) |
| 264 | -1 | 3 | bottom_threshold - auto tracking bottom threshold (V) |
| 265 | -1 | 11.2 | TVG argument #7 - 20/40 log crossover (meters) |
| 266 | -1 | 0 | rotator - which rotator to aim |
| 267 | -1 | 0 | aim_pan - transducer aiming angle in pan (x, lf/rt) |
| 268 | -1 | 0 | aim_tilt - transducer aiming angle in tilt (y, u/d) |
| 401 | 0-60 | 1 to 61 | th_layer[0-60], bottom of 1st threshold layer - bottom of 61st threshold layer (m) |

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**Appendix C1**.-Page 3 of 3.

| | | | |
|---|---|---|---|
| 402 | 0-59 | 708 | th_val[0-59], threshold for 1st through 60th layers in millivolts |
| 402 | 60 | 9999 | th_val[60], threshold for 61st layer in millivolts |
| 405 | 0-59 | 1 | Integration threshold value for layers 1-60 (mV) |
| 405 | 60 | 9999 | Integration threshold value for layer 61 (mV) |
| 602 | -1 | 1017536 | Echo sounder serial number |
| 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 | LeftToRight | River flow direction |

**Appendix C2**.-Example of system parameters used for data collection on the left bank (transducer 738).

*** Start Processing at Port 2 -FILE_PARAMETERS- Mon Jul 1 06:20:00 2002**

* 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 | | 19200 | maxp - maximum number of pings in a block NUS |
| 103 | -1 | | 32767 | maxbott - maximum bottom range in samples NUS |
| 104 | -1 | | 51 | N_th_layer - number of threshold layers |
| 105 | -1 | | 5 | max_tbp - maximum time between pings in pings |
| 106 | -1 | | 5 | min_pings - minimum number of pings per fish |
| 507 | -1 | FED5 | | timval - 0xFED5 corresponds to about 20 kHz NUS |
| 108 | -1 | | 1 | mux_on - means multiplexing enabled on board NUS |
| 109 | -1 | | 200 | mux_delay - samples delay between sync and switching NUS |
| 110 | -1 | | 0 | decimate_mask - decimate input samples flag NUS |
| 112 | -1 | | 1 | echogram_on - flag for DEP echogram enable 0=off, 1=on |
| 113 | -1 | | 1 | Hourly Sampling flag 1=On 0=Off |
| 118 | -1 | | 5 | maxmiss - maximum number of missed pings in auto bottom |
| 119 | -1 | | 0 | bottom- |
| 120 | -1 | | 1 | 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 | | 51 | N_int_layers-number of integration strata |
| 123 | -1 | | 51 | N_int_th_layers - number of integration threshold strata |
| 124 | -1 | | 0 | int_print - print integrator interval results to printer |
| 125 | -1 | | 0 | circular element transducer flag for bpf calculation |
| 126 | -1 | | 80 | grid spacing for Model 404 DCR (in samples, 16 s/m) |
| 127 | -1 | | 1 | TRIG argument #1 - trigger source |
| 128 | -1 | | 0 | TRIG argument #2 - digital data routing |
| 130 | -1 | | 0 | TVG Blank (0=Both Start/End,1=Stop Only,2=Start Only,3=None) |
| 200 | -1 | | 20 | sigma flag 0.0 = no sigma, else sigma is output |
| 201 | -1 | | 217.72 | sl - transducer source level |
| 202 | -1 | | -172.26 | gn - transducer through system gain at one meter |
| 203 | -1 | | -18 | rg - receiver gain used to collect data |
| 204 | -1 | | 2.8 | narr_ax_bw - vertical nominal beam width |
| 205 | -1 | | 10 | wide_ax_bw - horizontal axis nominal beam width |
| 206 | -1 | | 0 | narr_ ax_corr - vertical axis phase correction |
| 207 | -1 | | 0 | wide_ax_corr - horizontal axis phase correction |
| 208 | -1 | | 16 | ping_rate - pulses per second |
| 209 | -1 | | 0 | echogram start range in meters |
| 210 | -1 | | 30 | echogram stop range in meters |
| 211 | -1 | | 400 | echogram threshold in millivolts |
| 212 | -1 | | 13.2 | print width in inches |
| 213 | -1 | | 0 | Chirp Bandwith (0.0 = CHIRP OFF) |
| 214 | -1 | | 40 | Sampling within Hour Ending Time (in Decimal Minutes) |
| 215 | -1 | | 1500 | Speed of Sound (m/s) |
| 216 | -1 | | 200 | The Transducer's Frequency (kHz) |
| 217 | -1 | | -2.5 | min_angoff_v - minimum angle off axis vertical |
| 218 | -1 | | 2 | max_angoff_v - maximum angle off axis vertical |
| 219 | -1 | | -5 | min_angoff_h - minimum angle off axis horiz. |

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**Appendix C2**.-Page 2 of 3.

| | | | |
|---|---|---|---|
| 220 | -1 | 5 | max_angoff_ h - maximum angle off axis horiz. |
| 221 | -1 | -24 | max_dB_off - maximum angle off in dB |
| 222 | -1 | -15.5102 | ux - horizontal electrical to mechanical angle ratio |
| 223 | -1 | -55.2207 | uy - vertical electrical to mechanical angle ratio |
| 224 | -1 | 0 | ud_coef_a - a coeff. for up-down beam pattern eq. |
| 225 | -1 | 0.004 | ud_coef_b - b coeff. for up-down beam pattern eq. |
| 226 | -1 | -2.531 | ud_coef_c - c coeff. for up-down beam pattern eq. |
| 227 | -1 | -0.0699 | ud_coef_d - d coeff. for up-down beam pattern eq. |
| 228 | -1 | -0.1615 | ud_coef_e - e coeff. for up-down beam pattern eq. |
| 229 | -1 | 0 | lr_coef_a - a coeff. for left-rt beam pattern eq. |
| 230 | -1 | 0 | lr_coef_b - b coeff. for left-rt beam pattern eq. |
| 231 | -1 | -0.2063 | lr_coef_c - c coeff . for left-rt beam pattern eq. |
| 232 | -1 | 0.0001 | lr_coef_d - d coeff. for left-rt beam pattern eq. |
| 233 | -1 | -0.0001 | lr_coef_e - ecoeff. for left-rt beam pattern eq. |
| 234 | -1 | 4 | maximum fish velocity in meters per second |
| 235 | -1 | 1 | Echo Scope Bottom Location |
| 236 | -1 | 0.4 | maxpw - pulse width search window size |
| 238 | -1 | 27.5 | bottom - bottom depth in meters |
| 239 | -1 | 0 | init_slope - initial slope for tracking in m/ping |
| 240 | -1 | 0.2 | exp_cont - exponent for expanding tracking window |
| 241 | -1 | 0.2 | max_ch_rng - maximum change in range in m/ping |
| 242 | -1 | 0.04 | pw_criteria->min_pw_6-min -6 dB pulse width |
| 243 | -1 | 10 | pw_criteria->max_pw_6-max -6 dB pulse width |
| 244 | -1 | 0.04 | pw_criteria->min_pw_12 - min -12 dB pulse width |
| 245 | -1 | 10 | pw_criteria->max_pw_12 - max -12 dB pulse width |
| 246 | -1 | 0.04 | pw_criteria->min_pw_18 - min -18 dB pulse width |
| 247 | -1 | 10 | pw_criteria->max_pw_18 - max -18 dB pulse width |
| 249 | -1 | 10 | maximum voltage to allow in .RAW file |
| 250 | -1 | 0.2 | TX argument #1 - pulse width in milliseconds |
| 251 | -1 | 25 | TX argument #2 - transmit power in dB-watts |
| 252 | -1 | -12 | RX argument #1 - receiver gain |
| 253 | -1 | 62.5 | REP argument #1 - ping rate in ms per ping |
| 254 | -1 | 10 | REP argument #2 - pulsed cal tone separation |
| 255 | -1 | 1 | TVG argument #1 - TVG start range in meters |
| 256 | -1 | 100 | TVG argument #2 - TVG end range in meters |
| 257 | -1 | 40 | TVG argument #3 - TVG function (XX Log Range) |
| 258 | -1 | -6 | TVG argument #4 - TVG gain |
| 259 | -1 | 0 | TVG argument #5 - alpha (spreading loss) in dB/Km |
| 260 | -1 | 0.2 | minimum absolute distance fish must travel in x plane |
| 261 | -1 | 0.2 | minimum absolute distance fish must travel in y plane |
| 262 | -1 | 0.2 | minimum absolute distance fish must travel in z plane |
| 263 | -1 | 2 | bottom_window - auto tracking bottom window (m) |
| 264 | -1 | 3 | bottom_threshold - auto tracking bottom threshold (V) |
| 265 | -1 | 11.2 | TVG argument #7 - 20/40 log crossover (meters) |
| 266 | -1 | 0 | rotator - which rotator to aim |
| 267 | -1 | 0 | aim_pan - transducer aiming angle in pan (x, lf/rt) |
| 268 | -1 | 0 | aim_tilt - transducer aiming angle in tilt (y, u/d) |
| 401 | 0-50 | 1 to 51 | th_layer[0-50], bottom of 1st threshold layer - bottom of 51st threshold layer (m) |

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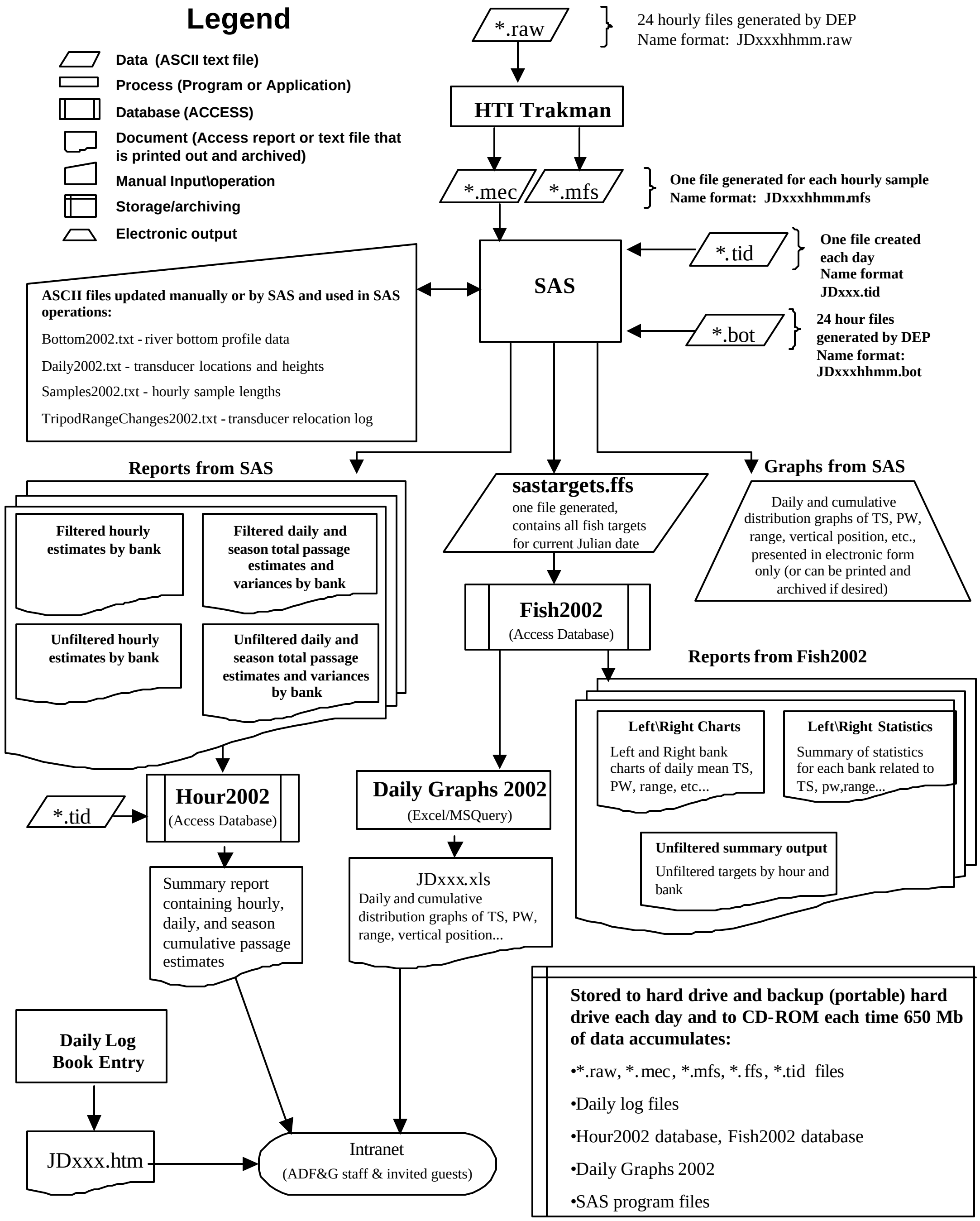
| | | | |
|---|---|---|---|
| 402 | 0-49 | 420 | th_val[0-49], threshold for 1st through 50th layers in millivolts |
| 402 | 50 | 9999 | th_val[50], threshold for 51st layer in millivolts |
| 405 | 0-49 | 1 | Integration threshold value for layers 1-50 (mV) |
| 405 | 50 | 9999 | Integration threshold value for layer 51 (mV) |
| 602 | -1 | 1017536 | Echo sounder serial number |
| 604 | -1 | 306738 | Transducer serial number |
| 605 | -1 | Spd-5 | Echogram paper speed |
| 606 | -1 | 9_pin | Echogram resolution |
| 607 | -1 | Board_External | Trigger option |
| 608 | -1 | LeftToRight | River flow direction |

# APPENDIX D.  DATA FLOW

**Appendix D1**.-Inseason data flow diagram for the Kenai River Chinook salmon sonar project, 2002.



# APPENDIX E. EXCLUDED HOURLY SAMPLES

**Appendix E1**.-Hourly samples excluded by bank from calculation of early- and late-run Chinook salmon daily passage estimates, Kenai River, 2002.

| Date | Excluded Sample Hours | |
|---|---|---|
| | Left Bank | Right Bank |
| EARLY RUN | | |
| 2-Jun | 1020 | |
| 6-Jun | | 0000, 1300 |
| 7-Jun | | 1500 |
| 8-Jun | | 0100 |
| 9-Jun | 520-620, 1720-2020 | 500-600, 1700-2000 |
| 12-Jun | 1920, 2020 | 0300, 0600 , 1900 |
| 14-Jun | | 1800, 2000 |
| 16-Jun | 2120-2220 | 0600-0700 |
| 17-Jun | | 2100 |
| 18-Jun | 1320 | 2200 |
| 26-Jun | 0720 | |
| 27-Jun | 1120 | 0700, 2000 |
| 28-Jun | | 0400, 1800 |
| 30-Jun | 1920, 2320 | 0700, 2200, 2300 |
| LATE RUN | | |
| 1-Jul | 2020 | 2000 |
| 2-Jul | 2320 | 0800-1000, 2100-2200 |
| 3-Jul | 2220-2320 | 1000-1100, 1600, 2300 |
| 4-Jul | 1620-1720 | 0400, 1100-1200, 1500-1900, 2300 |
| 5-Jul | 0020-0220, 0620, 2020, 2220-2320 | 0000-0300, 1300, 2200-2300 |
| 6-Jul | 0120-0220, 0620-0820, 1420-1920 | 0000-0100, 0700-0800, 1000-1100, 1400-2000 |
| 7-Jul | 0620, 0820-0920, 1420-1520, 1720-1920 | 0100, 0800-1000, 1400-1600, 1800-2100 |
| 8-Jul | 0220-0420, 1720-2020 | 0200, 0400, 1600-2000 |
| 9-Jul | 0220-0320, 1620-2020 | 0200-0300, 0500, 0700, 1600-2100 |
| 10-Jul | 0220, 0520-0720, 1520-1720 | 0200, 0500-0700, 1000, 1600, 1900-2200 |
| 11-Jul | 0320-0420, 0720, 1620, 1820, 2020 | 0300-0400, 0700, 0900-1200, 1600-2100 |
| 12-Jul | 0720-0820, 1720, 2220 | 0700-0800, 1000-1100, 1400, 1700, 2000-2100 |
| 13-Jul | 0420, 0720-0920, 1220-1320, 1720, 2120 | 0400, 0600, 0900-1300, 1800 |
| 14-Jul | 0520, 0920, 1820, 2120-2320 | 0500, 0800-0900, 1800, 2100, 2300 |
| 15-Jul | 0020, 0720-0820, 1920, 2320 | 0000, 0600-0800, 1100, 1800-1900, 2200-2300 |
| 16-Jul | 0720-1120, 2020-2120, 2320 | 0000, 0700-1300, 1500, 2000-2300 |
| 17-Jul | 0820-1120, 1420, 2120-2220 | 0000-0300, 0800-1600, 2100 |
| 18-Jul | 0120, 0620, 0920-1220, 1420-1620, 2220-2320 | 1000-1700, 2200-2300 |
| 19-Jul | 0620-0720, 1220-1620, 2220-2320 | 0000, 0800, 1100-1600, 2200-2300 |
| 20-Jul | 0720, 1320-1520, 1720 | 0700, 1200-1700, 1900, 2300 |
| 21-Jul | 1320-1820, 2020 | 0000, 1400-1900 |
| 22-Jul | 0120, 1420-1520 | 0100, 1500, 1700-1800 |
| 23-Jul | 0220, 0520-0720, 1520-1920 | 0200, 0500-0900, 1500-1600, 1800-1900 |
| 24-Jul | 0520, 0720-1020, 1520-2320 | 0900-1000, 1600, 1800, 2000-2100 |
| 25-Jul | 0320, 0720-1120, 1520-1720, 1920-2320 | 0700, 0900-1000, 1600-1700, |
| 26-Jul | 0020, 0420-0520, 0920-1120, 1720-2120, 2320 | 1700-1800 |
| 27-Jul | 0420-0620, 1020-1220, 1720-1920, 2220-2320 | 0500-0600, 1800-1900 |
| 28-Jul | 0020, 0620-0720, 1220, 1420, 1820 | 0600-0700, 2000 |
| 29-Jul | | 0020 |
| 30-Jul | | 1420 |
| 31-Jul | | 2020-2120 |
| 4-Aug | 1120-1920 | 0600, 0800, 1100-1300, 1500, 1700-2200 |
| 5-Aug | 1420-1520, 2020-2120 | 0600-1000, 1200, 1500, 1800, 2000-2200 |

# APPENDIX F. DAILY PROPORTIONS OF UPSTREAM AND DOWNSTREAM FISH FOR THE 2002 EARLY AND LATE KENAI RIVER CHINOOK SALMON RUNS

**Appendix F1**.-Daily proportions of upstream and downstream fish for the 2002 Kenai River early Chinook run.

| Date | Downstream Count | Upstream Count | Daily Total | % Downstream | % Upstream |
|---|---|---|---|---|---|
| 16 May | 6 | 24 | 30 | 20% | 80% |
| 17 May | 0 | 21 | 21 | 0% | 100% |
| 18 May | 0 | 54 | 54 | 0% | 100% |
| 19 May | 3 | 60 | 63 | 5% | 95% |
| 20 May | 6 | 66 | 72 | 8% | 92% |
| 21 May | 3 | 42 | 45 | 7% | 93% |
| 22 May | 0 | 36 | 36 | 0% | 100% |
| 23 May | 0 | 36 | 36 | 0% | 100% |
| 24 May | 3 | 33 | 36 | 9% | 91% |
| 25 May | 3 | 48 | 51 | 6% | 94% |
| 26 May | 0 | 65 | 65 | 0% | 100% |
| 27 May | 3 | 75 | 78 | 4% | 96% |
| 28 May | 6 | 103 | 109 | 6% | 94% |
| 29 May | 7 | 57 | 64 | 11% | 89% |
| 30 May | 3 | 90 | 93 | 3% | 97% |
| 31 May | 3 | 85 | 88 | 3% | 97% |
| 1 June | 12 | 210 | 222 | 5% | 95% |
| 2 June | 10 | 216 | 226 | 4% | 96% |
| 3 June | 3 | 119 | 122 | 3% | 97% |
| 4 June | 6 | 144 | 150 | 4% | 96% |
| 5 June | 12 | 120 | 132 | 9% | 91% |
| 6 June | 7 | 165 | 172 | 4% | 96% |
| 7 June | 9 | 140 | 149 | 6% | 94% |
| 8 June | 3 | 202 | 205 | 2% | 98% |
| 9 June | 4 | 466 | 470 | 1% | 99% |
| 10 June | 6 | 246 | 252 | 2% | 98% |
| 11 June | 7 | 211 | 218 | 3% | 97% |
| 12 June | 4 | 118 | 122 | 3% | 97% |
| 13 June | 27 | 142 | 169 | 16% | 84% |
| 14 June | 3 | 118 | 121 | 2% | 98% |
| 15 June | 9 | 138 | 147 | 6% | 94% |
| 16 June | 14 | 110 | 124 | 11% | 89% |
| 17 June | 10 | 251 | 261 | 4% | 96% |
| 18 June | 17 | 243 | 260 | 7% | 93% |
| 19 June | 6 | 201 | 207 | 3% | 97% |
| 20 June | 6 | 187 | 193 | 3% | 97% |
| 21 June | 12 | 228 | 240 | 5% | 95% |
| 22 June | 6 | 213 | 219 | 3% | 97% |
| 23 June | 6 | 153 | 159 | 4% | 96% |
| 24 June | 14 | 193 | 206 | 7% | 93% |
| 25 June | 18 | 330 | 348 | 5% | 95% |
| 26 June | 0 | 381 | 381 | 0% | 100% |
| 27 June | 10 | 310 | 320 | 3% | 97% |
| 28 June | 10 | 186 | 196 | 5% | 95% |
| 29 June | 6 | 231 | 237 | 3% | 97% |
| 30 June | 3 | 295 | 298 | 1% | 99% |
| Total | 307 | 7,162 | 7,470 | 4% | 96% |

**Appendix F2**.-Daily proportions of upstream and downstream fish for the 2002 Kenai River late Chinook run.

| Date | Downstream Count | Upstream Count | Daily Total | % Downstream | % Upstream |
|---|---|---|---|---|---|
| 1 July | 11 | 563 | 574 | 2% | 98% |
| 2 July | 53 | 1,596 | 1,649 | 3% | 97% |
| 3 July | 111 | 2,456 | 2,567 | 4% | 96% |
| 4 July | 38 | 1,855 | 1,893 | 2% | 98% |
| 5 July | 42 | 1,949 | 1,991 | 2% | 98% |
| 6 July | 100 | 1,205 | 1,305 | 8% | 92% |
| 7 July | 44 | 1,241 | 1,285 | 3% | 97% |
| 8 July | 46 | 1,069 | 1,115 | 4% | 96% |
| 9 July | 53 | 1,618 | 1,671 | 3% | 97% |
| 10 July | 23 | 1,533 | 1,556 | 1% | 99% |
| 11 July | 20 | 1,369 | 1,389 | 1% | 99% |
| 12 July | 58 | 1,245 | 1,303 | 4% | 96% |
| 13 July | 93 | 1,288 | 1,381 | 7% | 93% |
| 14 July | 91 | 1,034 | 1,125 | 8% | 92% |
| 15 July | 33 | 450 | 483 | 7% | 93% |
| 16 July | 41 | 1,253 | 1,294 | 3% | 97% |
| 17 July | 107 | 1,481 | 1,588 | 7% | 93% |
| 18 July | 46 | 1,001 | 1,047 | 4% | 96% |
| 19 July | 77 | 915 | 992 | 8% | 92% |
| 20 July | 64 | 964 | 1,028 | 6% | 94% |
| 21 July | 93 | 970 | 1,063 | 9% | 91% |
| 22 July | 121 | 845 | 966 | 13% | 87% |
| 23 July | 64 | 1,637 | 1,700 | 4% | 96% |
| 24 July | 14 | 1,175 | 1,189 | 1% | 99% |
| 25 July | 62 | 974 | 1,036 | 6% | 94% |
| 26 July | 85 | 930 | 1,015 | 8% | 92% |
| 27 July | 54 | 591 | 645 | 8% | 92% |
| 28 July | 32 | 707 | 739 | 4% | 96% |
| 29 July | 81 | 406 | 486 | 17% | 83% |
| 30 July | 91 | 571 | 662 | 14% | 86% |
| 31 July | 115 | 540 | 655 | 18% | 82% |
| 1 August | 66 | 642 | 708 | 9% | 91% |
| 2 August | 108 | 553 | 661 | 16% | 84% |
| 3 August | 119 | 753 | 872 | 14% | 86% |
| 4 August | 143 | 995 | 1,138 | 13% | 87% |
| 5 August | 83 | 575 | 658 | 13% | 87% |
| Total | 2,481 | 38,948 | 41,429 | 6% | 94% |

# APPENDIX G. AVERAGE VERTICAL ANGLE BY TIDE STAGE, RUN, BANK, AND FISH ORIENTATION (UPSTREAM OR DOWNSTREAM) FOR THE 2002 KENAI RIVER CHINOOK SALMON RUNS

**Appendix G1.**-Average vertical angle by tide stage and orientation for the 2002 Kenai River early Chinook run.

| Tide Stage / Fish Orientation | Average Vertical Angle | Standard Deviation | Sample Size |
|---|---|---|---|
| ***Left Bank*** | | | |
| Falling | | | |
| Downstream | -0.13 | 0.75 | 17 |
| Upstream | -0.55 | 0.29 | 887 |
| Tide Stage Total | -0.55 | 0.31 | 904 |
| Low | | | |
| Downstream | -0.47 | 0.06 | 2 |
| Upstream | -0.65 | 0.30 | 237 |
| Tide Stage Total | -0.65 | 0.30 | 239 |
| Rising | | | |
| Downstream | -0.41 | 0.47 | 10 |
| Upstream | 0.06 | 0.61 | 372 |
| Tide Stage Total | 0.05 | 0.61 | 382 |
| Left Bank Total | -0.41 | 0.49 | 1,525 |
| ***Right Bank*** | | | |
| Falling | | | |
| Downstream | -0.24 | 0.57 | 37 |
| Upstream | -0.63 | 0.40 | 480 |
| Tide Stage Total | -0.60 | 0.43 | 517 |
| Low | | | |
| Downstream | -0.16 | 0.83 | 9 |
| Upstream | -0.67 | 0.48 | 103 |
| Tide Stage Total | -0.63 | 0.53 | 112 |
| Rising | | | |
| Downstream | -0.42 | 0.31 | 25 |
| Upstream | -0.20 | 0.58 | 706 |
| Tide Stage Total | -0.20 | 0.57 | 731 |
| Right Bank Total | -0.39 | 0.55 | 1,360 |

**Appendix G2.**-Average vertical angle by tide stage and orientation for the 2002 Kenai River late Chinook run.

| Tide Stage / Fish Orientation | Average Vertical Angle | Standard Deviation | Sample Size |
|---|---|---|---|
| | ***Left Bank*** | | |
| Falling | | | |
| Downstream | -0.25 | 0.46 | 214 |
| Upstream | -0.51 | 0.32 | 4,927 |
| Tide Stage Total | -0.50 | 0.33 | 5,141 |
| Low | | | |
| Downstream | -0.26 | 0.45 | 115 |
| Upstream | -0.49 | 0.29 | 1,515 |
| Tide Stage Total | -0.48 | 0.31 | 1,630 |
| Rising | | | |
| Downstream | -0.17 | 0.52 | 144 |
| Upstream | -0.03 | 0.57 | 2,850 |
| Tide Stage Total | -0.04 | 0.57 | 2.994 |
| Left Bank Total | -0.35 | 0.47 | 9,765 |
| | ***Right Bank*** | | |
| Falling | | | |
| Downstream | -0.22 | 0.33 | 195 |
| Upstream | -0.43 | 0.34 | 6,497 |
| Tide Stage Total | -0.42 | 0.35 | 6,692 |
| Low | | | |
| Downstream | -0.24 | 0.38 | 84 |
| Upstream | -0.41 | 0.37 | 1,386 |
| Tide Stage Total | -0.40 | 0.37 | 1,471 |
| Rising | | | |
| Downstream | -0.11 | 0.46 | 220 |
| Upstream | -0.04 | 0.49 | 6,157 |
| Tide Stage Total | -0.04 | 0.49 | 6,377 |
| Right Bank Total | -0.25 | 0.46 | 14,540 |

# APPENDIX H. HISTORIC PASSAGE BY YEAR AND DATE (1987–2002).

**Appendix H1**.-Kenai River early-run Chinook salmon sonar passage estimates, 1987-2002.

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

-continued-

**Appendix H1**.-Page 2 of 2.

| Date/Year | 1987 | 1988 | 1989 | **1990** | **1991** | **1992** | 1993 | 1994 | 1995 | 1996 | **1997** | **1998**[a] | 1999[a] | **2000**[a] | 2001[a] | **2002**[a] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 June | NA | 556 | 258 | 153 | 150 | 106 | 187 | 321 | 357 | 603 | 213 | 111 | 633 | 192 | 259 | 210 |
| 2 June | NA | 545 | 194 | 294 | 240 | 107 | 412 | 266 | 369 | 741 | 241 | 189 | 444 | 250 | 316 | 216 |
| 3 June | NA | 598 | 233 | 225 | 362 | 232 | 324 | 298 | 549 | 873 | 376 | 192 | 540 | 282 | 328 | 119 |
| 4 June | NA | 755 | 246 | 178 | 177 | 190 | 255 | 304 | 693 | 1,051 | 324 | 186 | 924 | 266 | 255 | 144 |
| 5 June | NA | 782 | 280 | 192 | 316 | 166 | 276 | 351 | 429 | 943 | 427 | **162** | 876 | 139 | 519 | 120 |
| 6 June | NA | 493 | 384 | 156 | **296** | 319 | 327 | 198 | 807 | 741 | 327 | **150** | 807 | 186 | 432 | 165 |
| 7 June | NA | 506 | 545 | **304** | **215** | 515 | 198 | 384 | 843 | 773 | 591 | **283** | 672 | 237 | 427 | 140 |
| 8 June | NA | 771 | 890 | **414** | **243** | 375 | 297 | 306 | 999 | 918 | 441 | **300** | 609 | 108 | 486 | 202 |
| 9 June | NA | 569 | 912 | **339** | **444** | **486** | 378 | 462 | 789 | 1.140 | 391 | **234** | 504 | 135 | 591 | 466 |
| 10 June | NA | 333 | 913 | **272** | **275** | **264** | 453 | 432 | 876 | 684 | 527 | **327** | 439 | 207 | 639 | 246 |
| 11 June | NA | 320 | 710 | **453** | **334** | **234** | 549 | 423 | 774 | 882 | 512 | **600** | 596 | 315 | 575 | 211 |
| 12 June | NA | 302 | 577 | **568** | **400** | **394** | 600 | 329 | 417 | 864 | 537 | **1,168** | 723 | 165 | 1,357 | 118 |
| 13 June | NA | 188 | 599 | **445** | **369** | **236** | 951 | 376 | 492 | 1.071 | 681 | **719** | 393 | **337** | 939 | **142** |
| 14 June | NA | 289 | 458 | **330** | **268** | **174** | 811 | 514 | 691 | 1,111 | 424 | **912** | 610 | **309** | 647 | **118** |
| 15 June | NA | 510 | 335 | **658** | **441** | **312** | 407 | 306 | 636 | 1,116 | 318 | **951** | 436 | **571** | 600 | **138** |
| 16 June | NA | 808 | 397 | **485** | **615** | **239** | 616 | 453 | 648 | 420 | 348 | **770** | 696 | **441** | 499 | **110** |
| 17 June | NA | 535 | 514 | **267** | **330** | **339** | 567 | 315 | 750 | 495 | **405** | **675** | 807 | **765** | 364 | **251** |
| 18 June | NA | 533 | 464 | **238** | **493** | **320** | 606 | 435 | 808 | 697 | **315** | **498** | 742 | **591** | 607 | **243** |
| 19 June | NA | 200 | 295 | **331** | **437** | **390** | 422 | 636 | 419 | 657 | **399** | **510** | 771 | **348** | 559 | **201** |
| 20 June | NA | 175 | 498 | **369** | **314** | **548** | 504 | 402 | 594 | 315 | **408** | **351** | 1,247 | **319** | 418 | **187** |
| 21 June | NA | 373 | 520 | **257** | **457** | **372** | 621 | 570 | 438 | 351 | **252** | **309** | 1,192 | **522** | 417 | **228** |
| 22 June | NA | 312 | 614 | **267** | **433** | **297** | 399 | 366 | 375 | 396 | **390** | **273** | 819 | **456** | 345 | **213** |
| 23 June | NA | 375 | 547 | **240** | **396** | **213** | 607 | 550 | 178 | 401 | **225** | **294** | 935 | **462** | 272 | **153** |
| 24 June | NA | 674 | 564 | **322** | **251** | **337** | 720 | 696 | 450 | 573 | **285** | **288** | 1,151 | **408** | 240 | **193** |
| 25 June | NA | 582 | 374 | **258** | **235** | **362** | 808 | 734 | 429 | 684 | **332** | **228** | 1,292 | **186** | 213 | **330** |
| 26 June | NA | 436 | 369 | **322** | **261** | **330** | 1,051 | 597 | 334 | 504 | **381** | **219** | 731 | **359** | 203 | **381** |
| 27 June | NA | 549 | 309 | **231** | **340** | **291** | 1.158 | 639 | 946 | 228 | **363** | **207** | 678 | 615 | 220 | **310** |
| 28 June | NA | 827 | 425 | **240** | **327** | **253** | 798 | 681 | 696 | 303 | **297** | **308** | 537 | 489 | 224 | **186** |
| 29 June | NA | 495 | 376 | **208** | **258** | **121** | 728 | 929 | 984 | 234 | **570** | **363** | 753 | 516 | 191 | **231** |
| 30 June | NA | 915 | 292 | **193** | **270** | **197** | 660 | 649 | 615 | 351 | **582** | **276** | 687 | 441 | 403 | **295** |
| Total | | 20,880 | 17,992 | **10,768** | **10,939** | **10,087** | 19,669 | 18,403 | 21,884 | 23,505 | **14,963** | **13,103** | 25,666 | **12,479** | 16,676 | **7,162** |

[a] Upstream moving fish only reported.

Note: Bold and outlined numbers represent the dates that the Chinook fishery was restricted due to low inriver return.

**Appendix H2**.-Kenai River late-run Chinook salmon sonar passage estimates, 1987-2002.

| Date/Year | 1987 | 1988 | 1989 | **1990** | 1991 | **1992** | 1993 | 1994 | 1995 | 1996 | 1997 | **1998**[a] | 1999 [a] | 2000 [a] | 2001[a] | 2002[a] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 July | 507 | 526 | 769 | 578 | 267 | 364 | 539 | 663 | 350 | 341 | 486 | 491 | 453 | 461 | 697 | 563 |
| 2 July | 429 | 404 | 489 | 305 | 300 | 297 | 432 | 342 | 398 | 240 | 642 | 597 | 612 | 373 | 766 | 1,596 |
| 3 July | 405 | 398 | 353 | 486 | 333 | 320 | 325 | 625 | 353 | 303 | 600 | 480 | 486 | 370 | 1,075 | 2,456 |
| 4 July | 628 | 292 | 566 | 436 | 519 | 198 | 397 | 858 | 439 | 393 | 633 | 450 | 396 | 488 | 714 | 1,855 |
| 5 July | 596 | 482 | 1,106 | 853 | 316 | 225 | 429 | 705 | 667 | 1,067 | 657 | 606 | 369 | 787 | 676 | 1,949 |
| 6 July | 523 | 654 | 879 | 795 | 242 | 331 | 884 | 1,069 | 720 | 879 | 627 | 612 | 683 | 778 | 645 | 1,205 |
| 7 July | 769 | 379 | 680 | 929 | 186 | 247 | 1,572 | 1,050 | 931 | 780 | 1,158 | 660 | 936 | 1,020 | 887 | 1,241 |
| 8 July | 483 | 725 | 776 | 432 | 139 | 170 | 1,855 | 655 | 417 | 867 | 1,221 | 462 | 1,030 | 1,713 | 751 | 1,069 |
| 9 July | 384 | 471 | 1,404 | 309 | 393 | 205 | 1,876 | 744 | 519 | 768 | 1,618 | 480 | 1,047 | 1,632 | 568 | 1,618 |
| 10 July | 314 | 1,732 | 560 | 359 | 481 | 221 | 820 | 1,275 | 450 | 1,023 | 3,486 | 450 | 717 | 1,461 | 908 | 1,533 |
| 11 July | 340 | 1,507 | 2,010 | 778 | 403 | 143 | 1,238 | 509 | 325 | 1,146 | 5,649 | 171 | 1,059 | 1,038 | 858 | 1,369 |
| 12 July | 751 | 1,087 | 2,763 | 557 | 330 | 1,027 | 676 | 828 | 276 | 714 | 4,497 | 192 | 560 | 1,506 | 575 | 1,245 |
| 13 July | 747 | 2,251 | 910 | 1,175 | 308 | 605 | 3,345 | 1,066 | 570 | 1,128 | 5,373 | 262 | 401 | 2,327 | 1,148 | 1,288 |
| 14 July | 761 | 2,370 | 2,284 | 1,481 | 572 | 689 | 3,177 | 1,332 | 714 | 4,437 | 2,031 | 368 | 969 | 2,709 | 1,448 | 1,034 |
| 15 July | 913 | 2,405 | 1,111 | 1,149 | 542 | 745 | 2,233 | 2,211 | 750 | 3,222 | 4,042 | 1,118 | 636 | 2,808 | 1,338 | 450 |
| 16 July | 1,466 | 1,259 | 1,344 | 1,011 | 1,029 | 703 | 2,329 | 3,825 | 1,962 | 3,494 | 3,420 | 1,416 | 927 | 2,264 | 1,201 | 1,253 |
| 17 July | 1,353 | 1,520 | 963 | 2,395 | 2,052 | 570 | 2,037 | 4,692 | 1,128 | 2,253 | 4,584 | 1,424 | 3,558 | 1,915 | 2,415 | 1,481 |
| 18 July | 841 | 2,180 | 1,382 | 2,113 | 3,114 | 853 | 1,438 | 2,157 | 3,942 | 2,820 | 2,334 | 1,638 | 2,784 | 2,154 | 2,065 | 1,001 |
| 19 July | 2,071 | 1,724 | 425 | 1,363 | 1,999 | 1,128 | 715 | 3,493 | 4,692 | 2,236 | 1,146 | 1,146 | 1,869 | 1,919 | 1,568 | 915 |
| 20 July | 3,709 | 2,670 | 820 | 1,499 | 1,422 | 1,144 | 1,348 | 2,317 | 4,779 | 2,609 | 1,578 | 741 | 3,471 | 1,155 | 994 | 964 |
| 21 July | 3,737 | 3,170 | 916 | 787 | 1,030 | 799 | 981 | 1,695 | 3,132 | 3,435 | 894 | 1,608 | 3,354 | 933 | 786 | 970 |
| 22 July | 1,835 | 1,302 | 583 | 573 | 1,050 | 619 | 1,166 | 1,386 | 3,465 | 2,250 | 1,840 | 1,411 | 1,998 | 702 | 497 | 845 |
| 23 July | 1,700 | 1,502 | 756 | 642 | 2,632 | 1,449 | 1,163 | 1,050 | 2,421 | 3,050 | 1,441 | 808 | 1,875 | 760 | 526 | 1,637 |
| 24 July | 2,998 | 1,386 | 783 | 1,106 | 2,204 | **711** | 1,344 | 1,232 | 831 | 3,634 | 1,080 | 933 | 1,748 | 1,868 | 529 | 1,175 |
| 25 July | 1,915 | 999 | 495 | 810 | 1,306 | **1,713** | 2,245 | 1,412 | 840 | 3,240 | 532 | 542 | 1,937 | 1,761 | 676 | 974 |
| 26 July | 1,968 | 924 | 432 | 671 | 1,216 | **1,296** | 1,421 | 1,378 | 1,683 | 2,319 | 519 | 723 | 1,098 | 1,034 | 667 | 930 |
| 27 July | 1,523 | 960 | 618 | 755 | 1,195 | **1,561** | 1,952 | 1,244 | 1,806 | 1,782 | 438 | 807 | 3,066 | 992 | 775 | 591 |
| 28 July | 2,101 | 1,398 | 538 | **603** | 1,901 | **1,957** | 1,915 | 2,180 | 789 | 861 | 333 | **954** | 1,358 | 999 | 1,070 | 707 |
| 29 July | 1,923 | 1,400 | 441 | **546** | 1,146 | **1,533** | 1,363 | 1,327 | 558 | 474 | 401 | **1,255** | 1,185 | 1,029 | 928 | 406 |
| 30 July | 2,595 | 1,158 | 391 | **382** | 791 | **1,198** | 1,628 | 1,776 | 510 | 621 | 450 | **1,556** | 969 | 577 | 508 | 571 |
| 31 July | 2,372 | 910 | 383 | **316** | 974 | **951** | 862 | 1,808 | 480 | 1,548 | 420 | **1,344** | 1,308 | 549 | 883 | 540 |

-continued-

**Appendix H2**.-Page 2 of 2.

| Date/Year | 1987 | 1988 | 1989 | **1990** | 1991 | **1992** | 1993 | 1994 | 1995 | 1996 | 1997 | **1998**[a] | 1999[a] | 2000[a] | 2001[a] | 2002[a] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 August | 470 | 925 | 351 | **393** | 897 | **921** | 767 | 1.037 | 474 | | 247 | **909** | 591 | 695 | 455 | 642 |
| 2 August | 314 | 781 | 201 | **388** | 867 | **1,018** | 613 | 1,226 | 369 | | 291 | **1,512** | 468 | 421 | 459 | 553 |
| 3 August | 263 | 989 | 132 | **533** | 392 | **837** | 337 | 1,081 | 447 | | 213 | **1,006** | 642 | 294 | 504 | 752 |
| 4 August | 835 | 1,524 | 142 | **717** | 331 | **862** | 463 | 658 | 519 | | | **1,131** | 444 | 453 | 840 | 995 |
| 5 August | 904 | 1,091 | 107 | **723** | 174 | **861** | 711 | 536 | 404 | | | **1,094** | 436 | 489 | 581 | 575 |
| 6 August | 648 | 1,333 | 107 | **552** | 343 | **654** | 1,079 | 1,042 | 408 | | | **864** | 654 | 504 | 417 | |
| 7 August | 694 | 1,186 | 65 | **516** | 618 | **558** | 656 | 797 | 279 | | | **843** | 678 | 366 | 618 | |
| 8 August | 658 | 1,449 | | **682** | 600 | **217** | 669 | | 267 | | | **750** | 804 | 417 | 467 | |
| 9 August | 368 | 1,132 | | **679** | | **165** | 422 | | 272 | | | **570** | 328 | 399 | 232 | |
| 10 August | 312 | 755 | | **678** | | **249** | 252 | | | | | **496** | 165 | 397 | 200 | |
| 11 August | | 698 | | **547** | | | | | | | | | | | | |
| 12 August | | | | **362** | | | | | | | | | | | | |
| 13 August | | | | **221** | | | | | | | | | | | | |
| 14 August | | | | **139** | | | | | | | | | | | | |
| 15 August | | | | **150** | | | | | | | | | | | | |
| Total | 48,123 | 52,008 | 29,035 | **33,474** | 34,614 | **30,314** | 49,674 | 53,281 | 44,336 | 53,934 | 54,881 | **34,878** | 48,069 | 44,517 | 33,916 | 41,807[b] |

[a] Upstream fish only reported.

[b] Total includes 38,948 fish passage through 5 August with an additional 2,859 fish estimated to have passed from 6-10 August based on an extrapolation using historic mean proportion of passage through 5 August.

Note: Bold and outlined numbers represent dates when the Chinook fishery was restricted due to low inriver return.

## APPENDIX I. FILTERED (CONVENTIONAL), UNFILTERED, AND NET-APPORTIONED CHINOOK PASSAGE ESTIMATES, KENAI RIVER SONAR, EARLY AND LATE RUNS, 2002.

**Appendix I1**.-Filtered (conventional), unfiltered, and net-apportioned Chinook passage estimates, Kenai River sonar, early run, 2002.

| Date | Filtered (Conventional) | Unfiltered | Net-Apportioned |
|---|---|---|---|
| 16-May | 24 | 30 | 15 |
| 17-May | 21 | 27 | 27 |
| 18-May | 54 | 78 | 42 |
| 19-May | 60 | 72 | 37 |
| 20-May | 66 | 69 | 21 |
| 21-May | 42 | 52 | 17 |
| 22-May | 36 | 42 | 17 |
| 23-May | 36 | 54 | 31 |
| 24-May | 33 | 39 | 0 |
| 25-May | 48 | 51 | 22 |
| 26-May | 65 | 64 | 15 |
| 27-May | 75 | 90 | 10 |
| 28-May | 103 | 114 | 35 |
| 29-May | 57 | 75 | 9 |
| 30-May | 90 | 144 | 28 |
| 31-May | 85 | 127 | 36 |
| 1-Jun | 210 | 435 | 128 |
| 2-Jun | 216 | 491 | 101 |
| 3-Jun | 119 | 336 | 199 |
| 4-Jun | 144 | 551 | 75 |
| 5-Jun | 120 | 464 | 89[a] |
| 6-Jun | 165 | 857 | 212 |
| 7-Jun | 140 | 800 | 175 |
| 8-Jun | 202 | 890 | 243 |
| 9-Jun | 466 | 1,637 | 258 |
| 10-Jun | 246 | 662 | 167 |
| 11-Jun | 211 | 472 | 193 |
| 12-Jun | 118 | 399 | 163 |
| 13-Jun | 142 | 355 | 139 |
| 14-Jun | 118 | 222 | 123 |
| 15-Jun | 138 | 225 | 99 |
| 16-Jun | 110 | 308 | 213 |
| 17-Jun | 251 | 611 | 420 |
| 18-Jun | 243 | 468 | 197 |
| 19-Jun | 201 | 353 | 99 |
| 20-Jun | 187 | 417 | 114 |
| 21-Jun | 228 | 413 | 194 |
| 22-Jun | 213 | 456 | 201 |
| 23-Jun | 153 | 327 | 86 |
| 24-Jun | 193 | 407 | 98 |
| 25-Jun | 330 | 585 | 171 |
| 26-Jun | 381 | 584 | 214 |
| 27-Jun | 310 | 623 | 306 |
| 28-Jun | 186 | 387 | 249 |
| 29-Jun | 231 | 414 | 298 |
| 30-Jun | 295 | 848 | 546 |
| Total | 7,162 | 17,125 | 6,132 |

[a] No gillnet drifts conducted due to mechanical failures, species composition interpolated.

**Appendix I2**.-Filtered (conventional), unfiltered, and net-apportioned Chinook passage estimates, Kenai River sonar, late run, 2002.

| Date | Filtered (Conventional) | Unfiltered | Net-Apportioned |
|---|---|---|---|
| 1-Jul | 563 | 1,350 | 825 |
| 2-Jul | 1,596 | 3,623 | 1,945 |
| 3-Jul | 2,456 | 4,743 | 2,181 |
| 4-Jul | 1,855 | 5,307 | 984 |
| 5-Jul | 1,949 | 4,980 | 926 |
| 6-Jul | 1,205 | 6,600 | 1,265 |
| 7-Jul | 1,241 | 4,594 | 671 |
| 8-Jul | 1,069 | 2,968 | 1,442 |
| 9-Jul | 1,618 | 4,561 | 1,492 |
| 10-Jul | 1,533 | 4,050 | 956 |
| 11-Jul | 1,369 | 3,578 | 501 |
| 12-Jul | 1,245 | 2,514 | 802 |
| 13-Jul | 1,288 | 3,331 | 1,073 |
| 14-Jul | 1,034 | 2,531 | 1,349 |
| 15-Jul | 450 | 1,850 | 821 |
| 16-Jul | 1,253 | 7,294 | 2,041 |
| 17-Jul | 1,481 | 6,977 | 1,167 |
| 18-Jul | 1,001 | 6,222 | 758 |
| 19-Jul | 915 | 5,010 | 1,877 |
| 20-Jul | 964 | 4,290 | 1,096 |
| 21-Jul | 970 | 3,320 | 1,484 |
| 22-Jul | 845 | 2,191 | 1,677 |
| 23-Jul | 1,637 | 4,934 | 2,333 |
| 24-Jul | 1,175 | 3,729 | 1,349 |
| 25-Jul | 974 | 4,626 | 2,017 |
| 26-Jul | 930 | 4,203 | 1,896 |
| 27-Jul | 591 | 2,997 | 1,192 |
| 28-Jul | 707 | 2,274 | 1,068 |
| 29-Jul | 406 | 889 | 497 |
| 30-Jul | 571 | 1,434 | 736 |
| 31-Jul | 540 | 1,280 | 490 |
| 1-Aug | 642 | 1,121 | 422 |
| 2-Aug | 553 | 1,084 | 561 |
| 3-Aug | 752 | 1,464 | 740 |
| 4-Aug | 995 | 3,260 | 814 |
| 5-Aug | 575 | 2,082 | 356 |
| Total | 38,948 | 127,261 | 41,804 |

## APPENDIX J. ECHO LENGTH MIXTURE MODEL ESTIMATES OF SPECIES COMPOSITION AND CHINOOK ABUNDANCE, EARLY RUN 2002.

**Appendix J1**.-Echo length standard deviation mixture model and estimates derived from this model, Kenai River Chinook early run, 2002.

Echo length measurements can be superior to target strength as predictors of fish size and species in side-looking riverine sonar applications (Burwen and Fleischman 1998; Burwen et al. 2003). Unfortunately, because Kenai River sockeye and Chinook salmon overlap in size, even echo length measurements cannot ascertain the species of individual fish. Therefore we have developed other methods, based on mixture models, which extract maximal information about species composition from the frequency distribution of echo length measurements. An abbreviated description of the approach is presented here, along with results from the 2002 early run. See Fleischman and Burwen (2003) for more details on methodology and further discussion.

We used echo length standard deviation (ELSD) as the hydroacoustic correlate of fish size:

$$\text{ELSD} = \sqrt{\sum_{j=1}^{m}\left(w_j - \overline{w}\right)^2 \Big/ m-1}, \qquad \text{(J1)}$$

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

Recent work (unpublished) indicates that targets located far from the acoustic axis may suffer a slight negative bias in ELSD. Therefore only those fish less than 3 dB off-axis were used in analyses reported here. These fish comprised 65% of all fish in the 2002 early run dataset.

## MIXTURE MODEL

The probability density function (pdf) of hydroacoustic variable y (= ELSD) was modeled as a weighted mixture of two component distributions arising from sockeye and Chinook salmon (Figure J1.1),

$$f(y) = \pi_S f_S(y) + \pi_C f_C(y), \qquad \text{(J2)}$$

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

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

$$y_i = \beta_0 + \beta_1 x_i + \gamma z_i + \varepsilon_i, \qquad \text{(J3)}$$

where $z_i$ equaled 1 if fish i was a sockeye salmon, or 0 if Chinook, $\gamma$ was the mean difference in y between sockeye and Chinook after controlling for length, and $\varepsilon_i$ was normally distributed with mean 0 and variance $\sigma^2$.

Thus the component distributions $f_S(y)$ and $f_C(y)$ were functions of the length distributions $f_S(x)$ and $f_C(x)$ and the linear model parameters $\beta_0$, $\beta_1$, $\gamma$, and $\sigma^2$ (Figure J1). The species proportions $\pi_S$ and $\pi_C$ were the parameters of interest.

Length measurements were obtained from fish captured by gillnets (Reimer 2003) immediately downstream of our sonar site. Length data were paired with hydroacoustic data from the same time periods. In this analysis, we assume no gillnet size selectivity.

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

$$f_S(x) = \theta_{S1}\, f_{S1}(x) + \theta_{S2}\, f_{S2}(x) + \theta_{S3}\, f_{S3}(x)\ , \tag{J4}$$

$$f_C(x) = \theta_{C1}\, f_{C1}(x) + \theta_{C2}\, f_{C2}(x) + \theta_{C3}\, f_{C3}(x)\ , \tag{J5}$$

where $q_{Ca}$ and $q_{sa}$ are the proportions of Chinook and sockeye salmon in age component a,

$$f_{Sa}(x) \sim N(\mu_{Sa},\tau^2_{Sa}),\ \text{and} \tag{J6}$$

$$f_{Ca}(x) \sim N(\mu_{Ca},\tau^2_{Ca}). \tag{J7}$$

The overall design was therefore a mixture of (transformed) mixtures. That is, the observed hydroacoustic data were modeled as a two-component mixture of y, each component of which was transformed from a three-component normal mixture of x.

Three linear model parameters were regarded as unknown in the model: the intercept parameter $\beta_0$, the difference between sockeye and Chinook salmon $\gamma$, and the slope $\beta_1$. For the analyses presented in this paper, the error variance around the regression was regarded as fixed ($\sigma^2 = 0.43^2$). We employed Bayesian statistical methods because they provide realistic estimates of uncertainty and the ability to incorporate auxiliary information. We implemented the Bayesian mixture model in WinBUGS (Bayes Using Gibbs Sampler; Gilks et al. 1994).

Bayesian methods require that prior probability distributions be formulated for all unknowns in the model. Species proportions $\pi_S$ and $\pi_C$ were assigned an uninformative dirichlet (1,1) prior. Likewise, age proportions $\{\theta_{Sa}\}$ and $\{\theta_{Ca}\}$ were assigned dirichlet (1,1,1) priors. Informative normal priors, based on historical data, were used for the length-at-age means and variances. Based on the results of tethered-fish experiments, informative normal priors were also used for regression parameters in the Bayesian mixture model. Linear statistical models of tethered fish data reported by Burwen et al. (2003) provided estimates of the regression parameters $\beta_0$, $\beta_1$, and $\gamma$ with which to construct objective, data-based prior distributions (Table J1).

WinBUGS uses Markov chain Monte Carlo methods to sample from the joint posterior distribution of all unknown quantities in the model. We started two over-dispersed Markov chains for each run and monitored Gelman-Rubin statistics to assess convergence. Some data sets exhibited slow mixing and extreme autocorrelation. Therefore relatively long burn-ins of 10,000 or more samples were used. Samples were thinned 10 to 1 thereafter, and at least 10,000 samples per chain were retained.

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

Sample size limitations necessitated pooling the data by week. Week 1 was 16-22 May, week 6 was 20-26 June, and week seven (incomplete, since the early run ended 30 June) was 27-30 June. Posterior medians of the Chinook proportion parameter ? $_C$ were multiplied by unfiltered sonar estimates $\hat{x}$ to obtain estimates of absolute Chinook abundance y" for week w.

$$\hat{y}''_w = \hat{\pi}_{Cw} \sum_{i \in w} \hat{x}_i \; . \qquad \text{(J8)}$$

## RESULTS AND DISCUSSION

Weekly summary statistics from the marginal posterior distributions of several parameters are given in Table J1. Posterior distributions of regression parameters shifted only slightly among weeks. Observed and fitted ELSD frequency distributions are shown in Figure J2. Model fit appears to be good with parameters set to the posterior means, with the possible exception of week 7. Figure J3 compares mixture model estimates with the official estimates and net-apportioned estimates described in the main body of this report. Mixture model estimates totaled 9,134 (SE = 471) for the early run, somewhat higher than the official estimate of 7,162 (SE = 159) and the net apportioned estimate of 6,027 (SE = 321).

Conventional two-class univariate discrimination involves assigning individuals to one class or another depending on whether or not the value of the discriminating variable exceeds a threshold. When distributions overlap, threshold-based discrimination is subject to bias which worsens for species proportions near 0 and 1 (Figure J4). Furthermore, results are sensitive to fish size distributions. For instance, in the example illustrated in Figure J4, the number of Chinook salmon misclassified as sockeye (number with ELSD < 2.7) depends largely on the relative abundance of small Chinook, which can change over time. In fact, use of such a threshold by itself does not discriminate Chinook from sockeye, but rather large Chinook from sockeye and small Chinook.

Because the mixture model approach incorporates information about fish size distributions, and because it explicitly models the expected variability in hydroacoustic measurements, it is not subject to the above pitfalls. There is no bias against extreme proportions, and the estimates are germane to the entire population of Chinook salmon, not just those Chinook larger than sockeye. Finally, as long as length and hydroacoustic measurements are paired in time, mixture model estimates of species proportions are unbiased in the presence of temporal changes in fish size distribution.

Several of these advantages can be seen by comparing weeks 1 and 4 in Figure J2. The estimates of species composition (54% Chinook) are identical for the two datasets, even though the observed frequency distributions of ELSD are quite different. Week 1 has a pronounced mode in the upper range of ELSD values and week 4 does not, which would superficially indicate more Chinook salmon in week 1. Yet by comparing the Chinook components of the fitted distributions (cross symbols in Figure J2), one can see that there were substantial numbers of small Chinook in week 4 that had relatively small ELSD values. These small Chinook, which would not have been classified as Chinook with a threshold approach, were automatically taken into consideration by the mixture model.

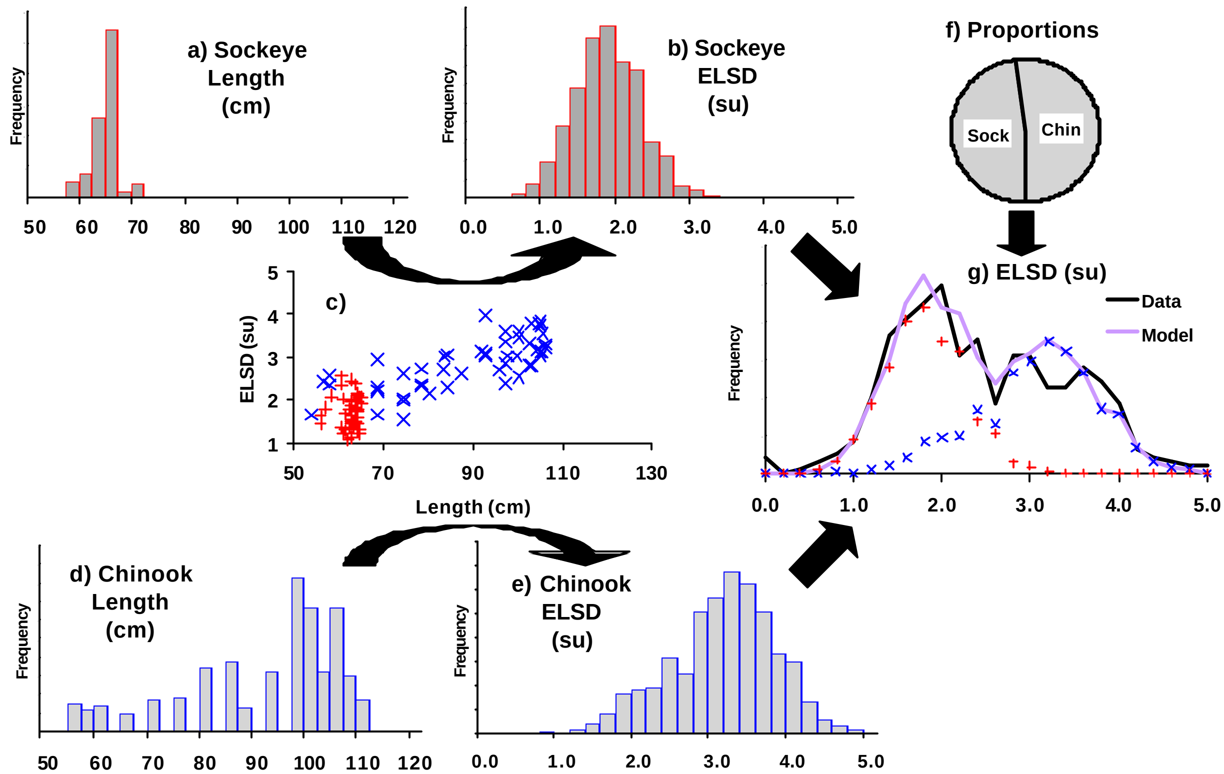



**Figure J1.1**.-Flow chart of mixture model described in the text. The frequency distribution of echo length standard deviation (ELSD, panel g) is modeled as a weighted mixture of species-specific ELSD distributions (b and e), which in turn are the products of species-specific size distributions (a and d) and the relationship between ELSD and fish length (c). The weights (species proportions, panel f) are the parameters of interest. Plus symbol = sockeye, x = Chinook. Checkered pattern = sockeye, cross-hatched = Chinook. Units for ELSD are 48 kHz digital sampling units.

**Table J1.1**.-Summary statistics of prior and marginal posterior distributions of parameters estimated from a Bayesian mixture model analysis of 7 weeks of Kenai River sonar and netting data, 2002.

| | Mean | Std Dev | 2.5% | Median | 97.5% |
|---|---|---|---|---|---|
| **Normal Priors** | | | | | |
| $b_0$ | 2.88 | 0.18 | | | |
| $b_1$ | 0.0319 | 0.0029 | | | |
| g | -0.33 | 0.11 | | | |
| **Week 1 Posteriors: 32 fish netted, 89 hydroacoustic targets** | | | | | |
| $b_0$ | 2.84 | 0.10 | 2.65 | 2.85 | 3.03 |
| $b_1$ | 0.0338 | 0.0027 | 0.0288 | 0.0337 | 0.0392 |
| g | -0.36 | 0.09 | -0.54 | -0.36 | -0.18 |
| $p_C$ | 0.542 | 0.083 | 0.392 | 0.537 | 0.719 |
| **Week 2 Posteriors: 47 fish netted, 88 hydroacoustic targets** | | | | | |
| $b_0$ | 2.81 | 0.10 | 2.61 | 2.81 | 3.01 |
| $b_1$ | 0.0330 | 0.0027 | 0.0280 | 0.0330 | 0.0386 |
| g | -0.38 | 0.09 | -0.56 | -0.38 | -0.19 |
| $p_C$ | 0.518 | 0.102 | 0.334 | 0.512 | 0.735 |
| **Week 3 Posteriors: 52 fish netted, 576 hydroacoustic targets** | | | | | |
| $b_0$ | 2.81 | 0.09 | 2.64 | 2.81 | 2.99 |
| $b_1$ | 0.0356 | 0.0026 | 0.0308 | 0.0355 | 0.0408 |
| g | -0.30 | 0.09 | -0.47 | -0.30 | -0.12 |
| $p_C$ | 0.244 | 0.043 | 0.165 | 0.242 | 0.334 |
| **Week 4 Posteriors: 168 fish netted, 1,215 hydroacoustic targets** | | | | | |
| $b_0$ | 2.73 | 0.07 | 2.59 | 2.74 | 2.88 |
| $b_1$ | 0.0383 | 0.0023 | 0.0339 | 0.0383 | 0.0423 |
| g | -0.37 | 0.09 | -0.55 | -0.38 | -0.20 |
| $p_C$ | 0.542 | 0.048 | 0.457 | 0.539 | 0.647 |
| **Week 5 Posteriors: 120 fish netted, 516 hydroacoustic targets** | | | | | |
| $b_0$ | 2.74 | 0.08 | 2.59 | 2.74 | 2.89 |
| $b_1$ | 0.0427 | 0.0027 | 0.0377 | 0.0427 | 0.0481 |
| g | -0.33 | 0.08 | -0.49 | -0.33 | -0.17 |
| $p_C$ | 0.518 | 0.043 | 0.436 | 0.517 | 0.604 |
| **Week 6 Posteriors: 143 fish netted, 771 hydroacoustic targets** | | | | | |
| $b_0$ | 2.74 | 0.08 | 2.58 | 2.74 | 2.89 |
| $b_1$ | 0.0387 | 0.0023 | 0.0342 | 0.0387 | 0.0433 |
| g | -0.40 | 0.09 | -0.57 | -0.40 | -0.23 |
| $p_C$ | 0.650 | 0.054 | 0.550 | 0.648 | 0.759 |
| **Week 7 Posteriors: 106 fish netted, 588 hydroacoustic targets** | | | | | |
| $b_0$ | 2.80 | 0.08 | 2.63 | 2.80 | 2.97 |
| $b_1$ | 0.0398 | 0.0023 | 0.0354 | 0.0397 | 0.0446 |
| g | -0.41 | 0.10 | -0.61 | -0.41 | -0.20 |
| $p_C$ | 0.713 | 0.066 | 0.592 | 0.710 | 0.849 |

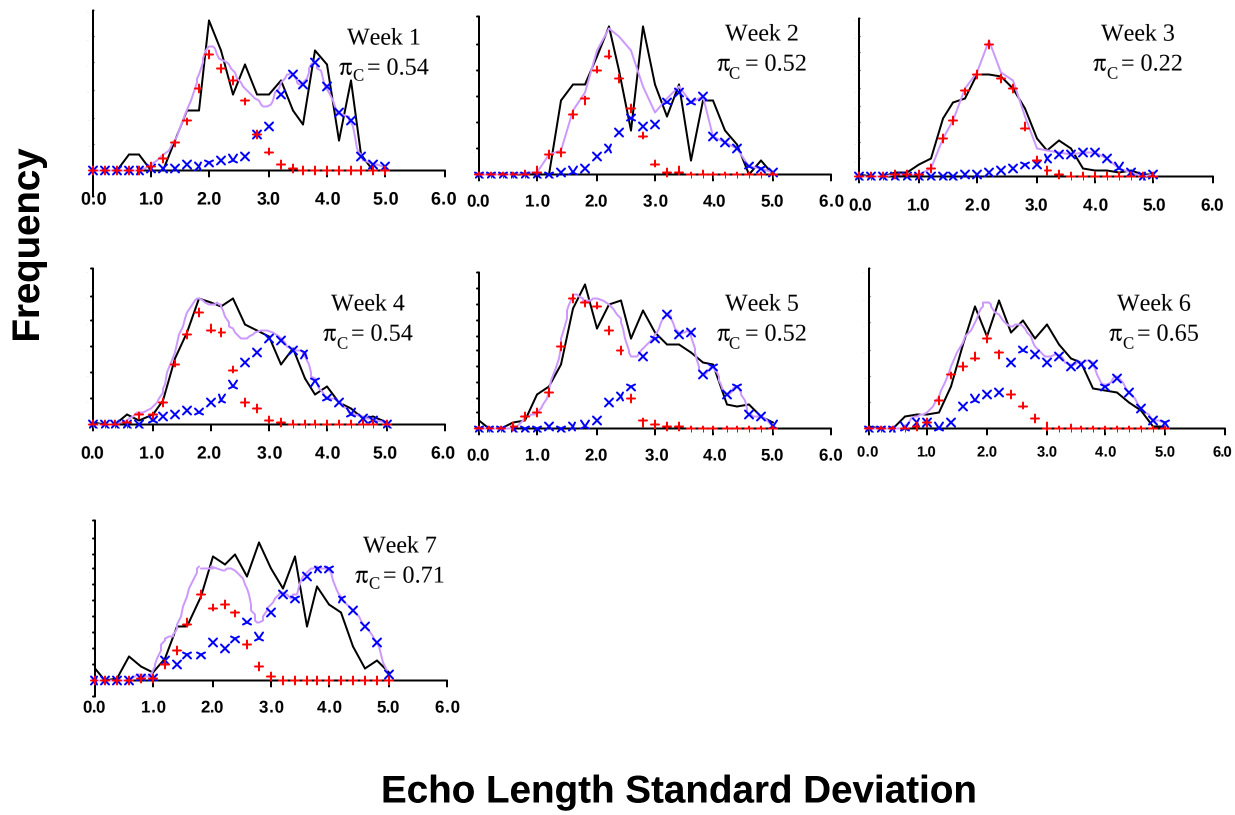



**Figure J1.2**.-Observed (black) and fitted (gray) frequency distributions of echo length standard deviation (ELSD) from the first 6 weeks of the 2002 early run. Dotted lines are the component distributions from sockeye (left) and Chinook salmon (right). Estimated proportion of Chinook salmon $\pi_c$ is listed in the header of each panel.

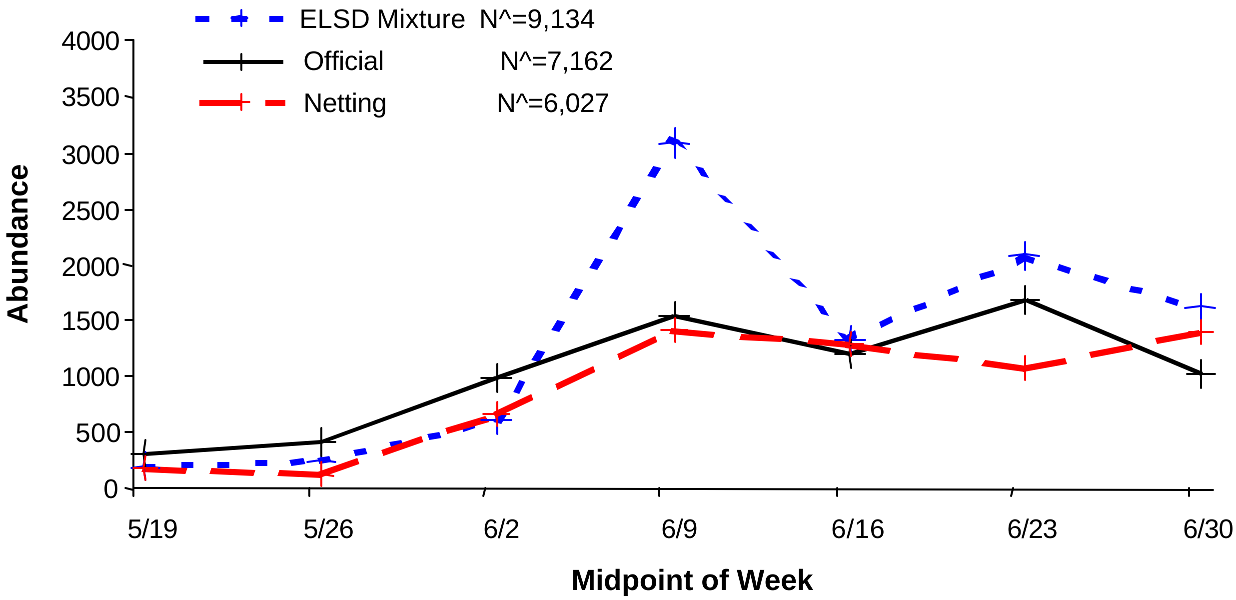



**Figure J1.3**.-Weekly Chinook salmon abundance estimates for the early run, 2002. Solid line = official estimates; dashed line = netting-apportioned estimates; dotted line = ELSD mixture model estimates.

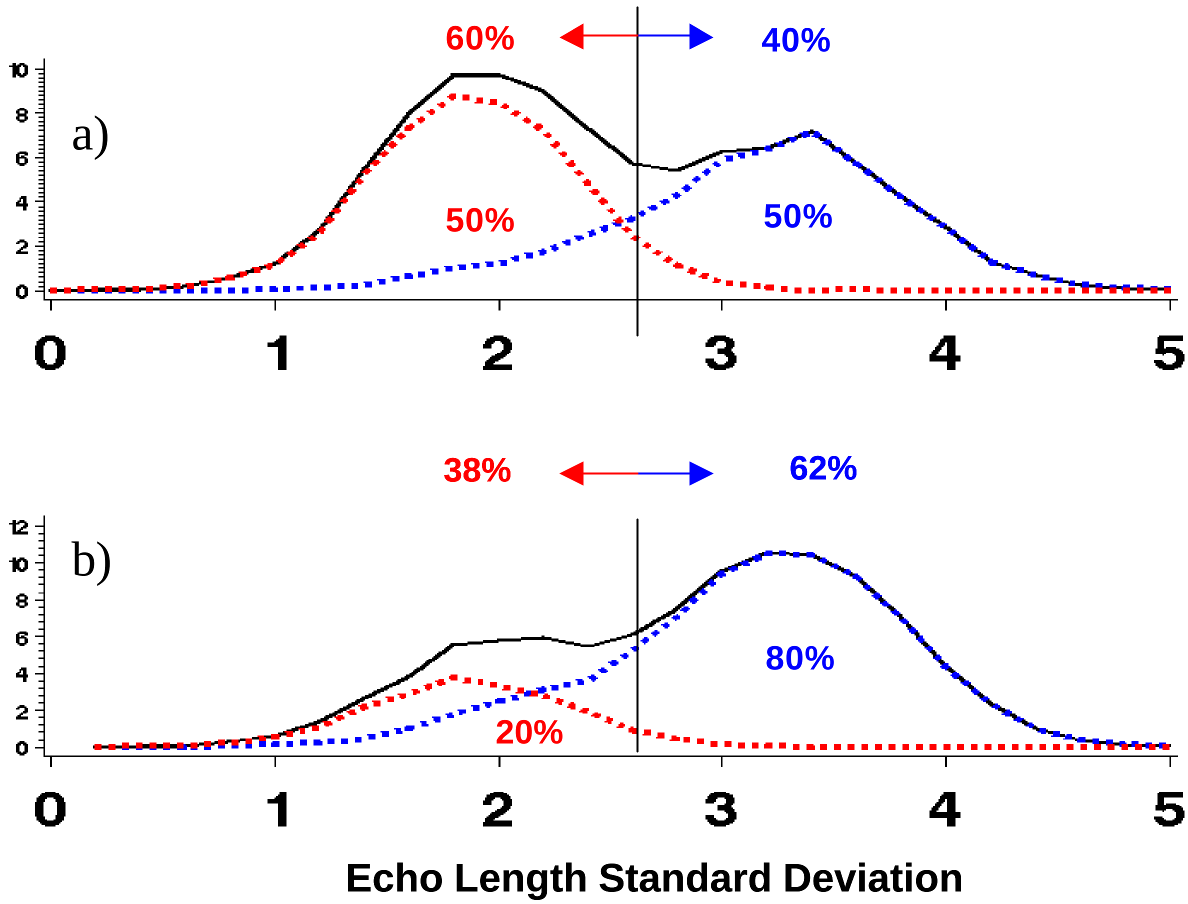



**Figure J1.4**.-Threshold-based discrimination is subject to bias with imprecise discriminators. Solid lines are simulated frequency distributions of echo length standard deviation arising from component distributions due to sockeye salmon (dotted lines, left) and Chinook salmon (dotted lines, right). (a) If the true species composition is 50% sockeye/50% Chinook, and a threshold criterion of 2.7 is used, estimated species composition will be 60%/40%. (b) If the true species composition is 20%/80%, estimated species composition will be 38%/62%.