Abundance Estimates of Chinook Salmon in the Kenai River Using Dual-Beam Sonar

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ABSTRACT: A real-time system for estimating abundance of upstream-migrating chinook salmon *Oncorhynchus tshawytscha* using side-looking, dual-beam sonar was developed for the Kenai River, Alaska, in 1984. The feasibility of using dual-beam sonar for counting and determining target strength of passing salmon was established during the initial 2 years of the study. A hydroacoustic system was engineered to insonify that area of the river used by migrating chinook salmon. Procedures were developed for in situ calibration of the hydroacoustic system and for estimating abundance and associated variance. Management-level operation of the project began in early July 1987. The estimates of chinook salmon passing the sonar site were consistent with independent estimates based on mark-recapture methods. The temporal, spatial, and target-strength distributions of the tracked fish were consistent with estimates of these distributions made using independent methods. Dual-beam sonar has proven to be a precise method for providing real-time estimates of the passage of upstream-migrating chinook salmon.

INTRODUCTION

The Kenai River drainage in southcentral Alaska supports important commercial, recreational, and personal use fisheries for sockeye *Oncorhynchus nerka* and chinook *O. tshawytscha* salmon. Both species occur in 2 distinct runs based on timing of entry into the Kenai River, the early run entering the river before and the late run after July 1. The early runs of chinook and sockeye salmon to the Kenai River are harvested almost exclusively in recreational fisheries (Nelson 1993), whereas the late runs are caught in commercial, recreational, and personal use fisheries (Nelson 1993; Ruesch and Fox 1992).

Fishing effort and catches in the Cook Inlet recreational fisheries that exploit both runs of chinook salmon increased significantly throughout the 1980s (Nelson 1993). In recent years, however, fishing effort and harvests have declined because of imposed restrictions responsing to conservation concerns. Late-run chinook salmon returning to the Kenai River were increasingly taken throughout the 1980s as bycatch in concurrent Cook Inlet commercial gillnet fisheries targeting late-run sockeye salmon. This bycatch of Kenai River chinook salmon increased directly with fishing time necessary to harvest consistently large runs of Cook Inlet sockeye salmon that have occurred since the early 1980s (Ruesch and Fox 1992).

Because of conservation concerns associated with the escalating directed and incidental catches of Kenai River chinook salmon, the Alaska Department of Fish and Game initiated studies in 1984 to develop estimates of Kenai River chinook salmon escapement. Study objectives were to (1) develop biological escapement goals, (2) evaluate the efficacy of fishery management measures taken to conserve the stock, and (3) develop specific fishery management plans in concert with the Alaska Board of Fisheries that allocate the burden of conservation among competing users of the resource. Two independent methods for estimating escapement were used. The first used standard mark-recapture methods (Cormack 1968; Seber 1982), and the second used side-looking, dual-beam sonar (Ehrenberg 1972) to count salmon migrating upstream. The mark-recapture methods provided postseason estimates of escapement (Hammarstrom and Larson 1986; Conrad and Larson 1987; Conrad 1988; Carlon and Alexandersdottir 1989; Alexandersdottir and

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Marsh 1990). Because the mark-recapture method relies on the recreational fishery as the vehicle for marked-fish recovery, the utility of this approach was limited when the recreational fishery was restricted to provide needed escapements. We believed the side-looking sonar approach, though developmental, would provide real-time estimates of daily passage that could be used for inseason management of the recreational and commercial fisheries in Cook Inlet.

Because other salmon species are present during the early and late runs of chinook salmon (i.e., sockeye salmon are present during the early and late chinook salmon runs and pink salmon *O. gorbuscha* and coho salmon *O. kisutch* are present near the end of the late run), methods were needed to discriminate chinook salmon from other species. Because of the large size of chinook salmon relative to the other species (Nelson 1993) and our theoretical ability to discriminate between disparate sizes based on target strength (Ehrenberg 1984), we developed and tested an assumption that chinook salmon could be enumerated based on target strength.

The feasibility of using dual-beam sonar for counting and determining target strength of salmon migrating upstream was evaluated during the initial 2 years of the project. After the feasibility work was completed, it was believed that target strength could be used to discriminate chinook salmon from sockeye salmon (Skvorc, P. A. and D. L. Burwen, Alaska Department of Fish and Game, unpublished report, draft 92-5001). Skvorc reported that a -28.5 dB threshold could discriminate between salmon of lengths <75 cm (i.e., sockeye salmon and age-1.2 and younger chinook salmon) and salmon >75 cm (i.e., older-aged chinook salmon). Later, Eggers (1994) determined that target strength could not make such discriminations due to high variability of target strength from repeated echoes from individual fish. This result had little practical effect on the chinook counts, however, because spatial segregation of chinook and sockeye salmon in the Kenai River facilitated chinook-specific counts.

This paper describes the feasibility studies (1985–1986) and management-level program (1987–1990) using dual-beam sonar to count chinook salmon. During this time a comprehensive hydroacoustic data acquisition and processing system was developed and used to manage the fisheries. Elements of this system are discussed: (1) a method of in situ calibration of the sonar hardware, (2) a method for transducer deployment designed to minimize noise and provide insonification of the cross section of the river utilized by the chinook salmon, (3) computer software capable of tracking and sizing individual targets, (4) methods for enumerating chinook salmon, and (5) procedures for estimating the magnitude and variance of chinook salmon passage.

ACOUSTIC TARGET IDENTIFICATION AND COUNTING

To count upstream-migrating chinook salmon using side-looking, dual-beam sonar, echoes from individual passing fish were recorded in digital format, echoes were collated by individual fish, and mean target strengths (acoustic sizes) were estimated. Chinook salmon counts by sample period were expanded based on the proportion of time and space sampled.

Echoes from individual fish were collated using computer-tracking software that examined the echo data (i.e., the output from the dual-beam processor), sorted the echoes into targets based on specific criteria, and output counts and mean target strengths for each sample interval. The counts from the tracking software were further edited using hard-copy chart recordings collected simultaneously with the electronic data.

Sonar Site

The sonar site, located 14 km from the mouth of the Kenai River (Figure 1), was selected for its acoustically favorable characteristics, its location relative to the riverine sport fishery, and its location relative to known chinook salmon spawning sites. The site has an absorptive bottom and a single channel sloping uniformly from each bank to the center. The location, downstream from most of the sport fishery, has low boat traffic. Reflections from boats and entrained air produced by the motors can often obscure reflections from fish passing through the sonar beam. The location is also downstream of suspected spawning sites for chinook salmon (Alexandersdottir and Marsh 1990), which reduces the probability that individual chinook salmon will loiter in the sonar beam or return downstream through the beam.

Data Acquisition and Processing

The basic components of the sonar system included elliptical dual-beam transducers, echosounder, multiplexer, and dual-beam processor (Figure 2). Other necessary equipment included a microcomputer that recorded, filed, and stored the output from the dual-beam processor; a digital-storage oscilloscope; a dual-channel thermal chart recorder; and 2 dual-axis,

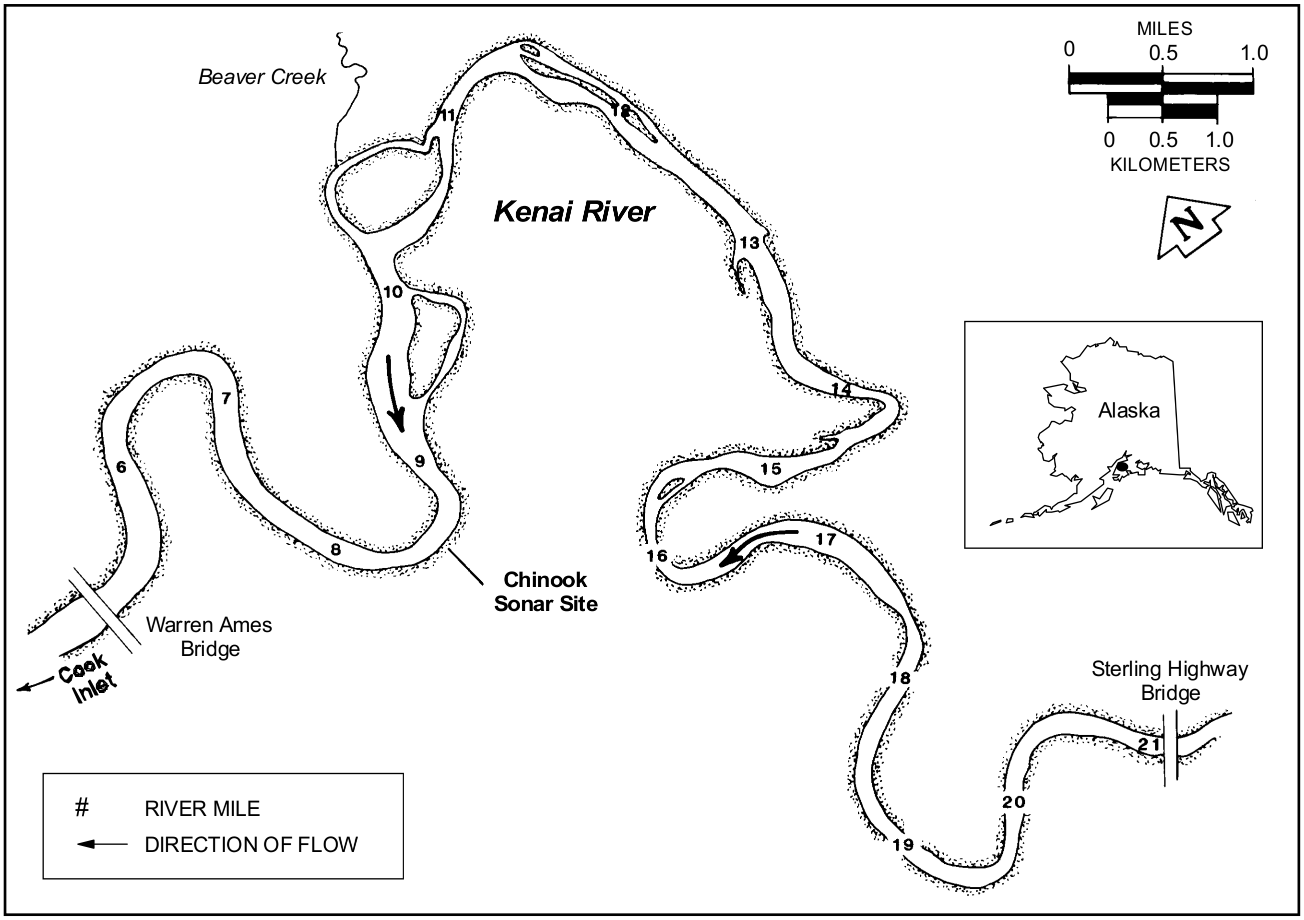

Figure1. Map of lower Kenai River showing location of the chinook salmon sonar site.

remotely operated, pan-and-tilt aiming units for transducers. A microcomputer and printer, located at the office, were used for secondary processing of the data.

Transducers were deployed on both sides of the river below the low tide level (Figure 3). Transducers located on the left bank were connected to the system via an overhead transmission cable. The water column above the intertidal areas and above the low tide level was not insonified (Figure 3). Virtually all of the water column below the low tide level on the right bank was insonified.

The transducers were aimed so that the sonar beam was tangent with the bottom of the river while maintaining acceptably low levels of bottom reverberation. Aiming criteria were established to maintain a minimum signal-to-noise ratio (SNR) of 10 dB. The SNR was expressed as the difference between the peak signal detected from fish and an average peak noise level detected (expressed in decibels). At high slack tide, SNRs of up to 20 dB were realized, whereas at low tide, surface reverberation reduced the SNR to near 10 dB. In general, SNRs decreased with range and were generally maintained at or above 12 dB.

Basic Data Collection

Basic data were collected over a 24-h sample period. Data were collected July 1 through August 10 in 1987. Thereafter, data were collected each day from May 16 through August 10, which covered the period of entry of both early- and late-run chinook salmon into the Kenai River. The project ended 1–2 d early if each daily count for 3 consecutive days after August 5 was <1% of the total passage estimate for the season to that date. To systematically count both banks, the sonar was operated on the right bank for the first 20 min of each hour, followed by a 5-min pause to switch to the left bank. The sonar was then operated on the left bank for the next 20 min. During the last 15 min of each hour, data-processing parameters were reset and equipment was maintained.

The dual-beam processor collected the basic information that enabled target strength to be calculated for individual echoes. Initially, all echoes were screened with the dual-beam processor to eliminate echoes from noise or other anomalies, such as echoes with pulse widths too wide or too narrow, amplitudes too high or too low, or ranges outside the specified boundaries. To avoid eliminating fish echoes, the criteria were more inclusive than exclusive. The following data were recorded for each echo not eliminated: (1) sequential number of the transmission (ping) that produced the echo, (2) echo number (i.e., there may

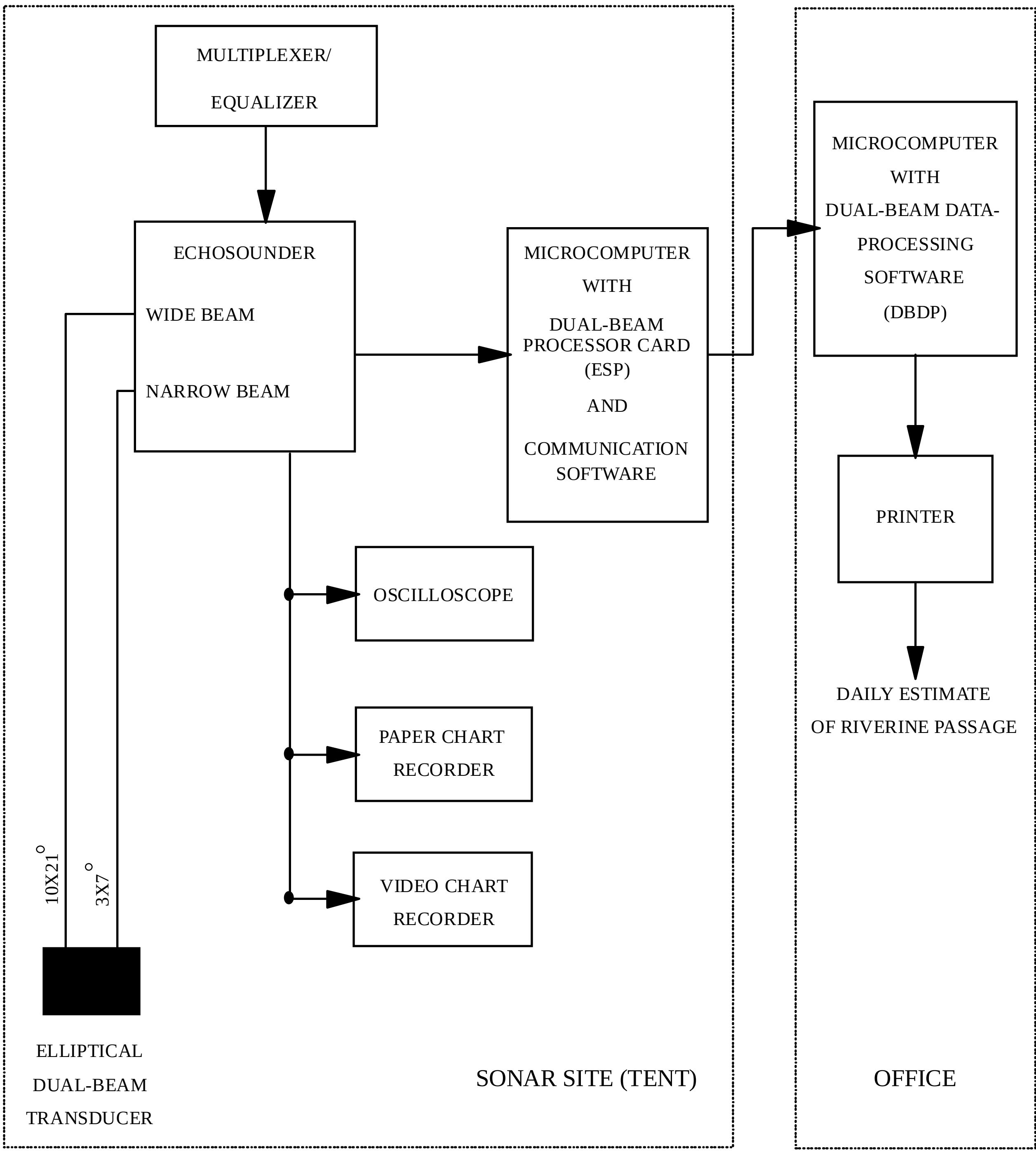

Figure 2. Block diagram of Kenai River chinook salmon sonar system and data flow.

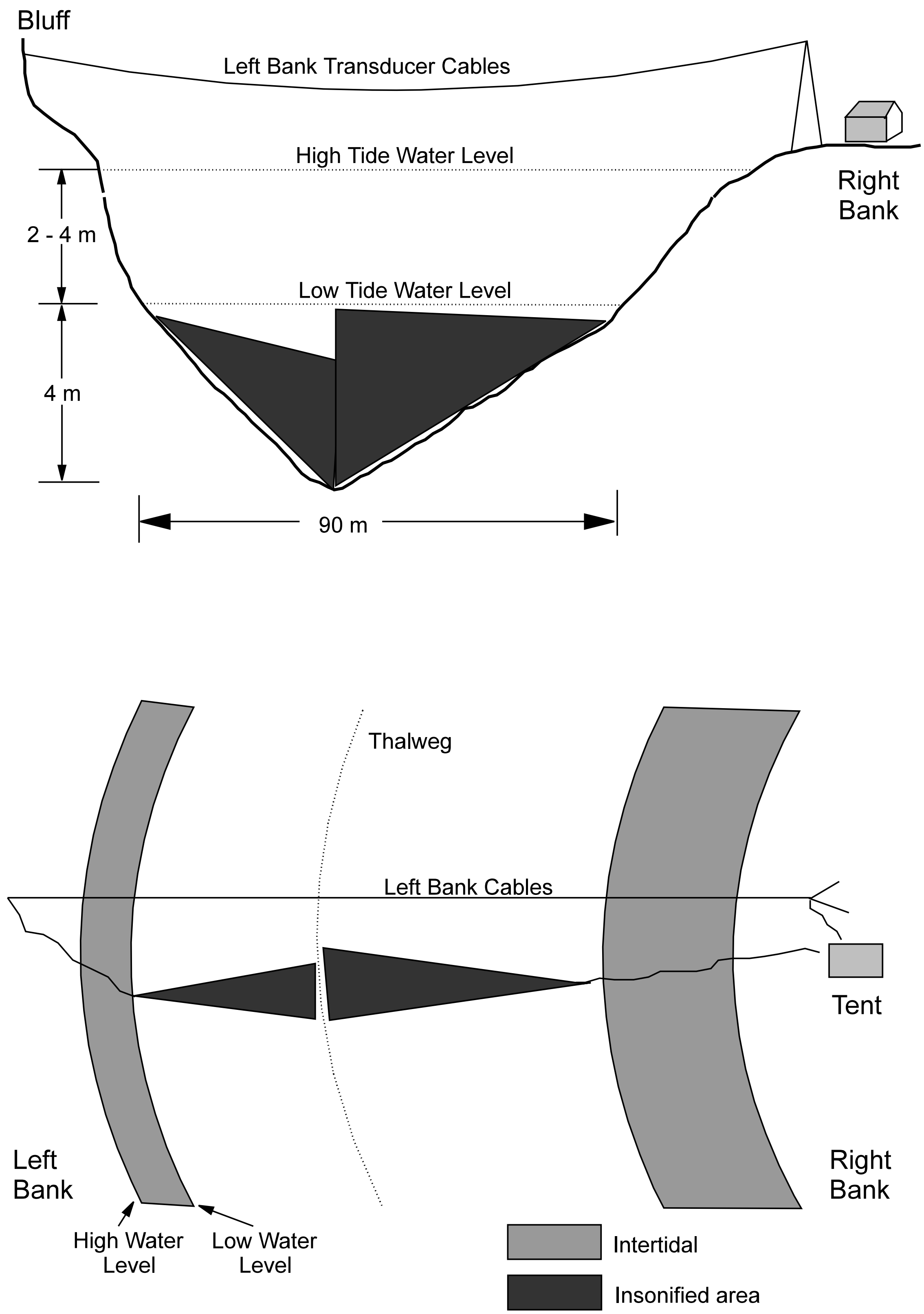

Figure 3. Cross-sectional (top) and overhead (bottom) views of Kenai River chinook salmon sonar site showing insonified portion of the river.

be several valid echoes per fish), (3) peak voltage from the wide beam, (4) peak voltage from the narrow beam, (5) range or distance from the transducer face, (6) pulse width at the half-power point from the wide beam, and (7) pulse width at the half-power point from the narrow beam. These data were stored in files that uniquely identified the sample in both space and time.

Chart recordings provided a visual representation of the targets passing through the sonar beam and were collected simultaneously with the echo data. The chart-recorder threshold was set 3 dB below that of the sonar system to provide an additional buffer of information beyond that provided by the sonar system.

Secondary Data Processing

Data collected over a 24-h period underwent further processing to determine counts and target strengths of individual fish for each 20-min sample period. The basic echo data files were processed with the tracking software (Figure 4) to eliminate targets that were not valid for target-strength estimation and to collate echoes into groups that potentially represented individual fish. Many echoes that passed the initial screening of the dual-beam processor could not be used to determine target strength. Every echo was evaluated against more rigorous and specific acceptance criteria (Ehrenberg 1972) that varied with the ambient conditions. These included minimum beam-pattern factor, minimum narrow-beam voltage threshold, maximum narrow-beam voltage threshold, minimum half-power pulse width, maximum half-power pulse width, minimum range, and maximum range. General values for these criteria were developed over the first 2 years of experimentation and are detailed in Burwen (1994). Daily values specific to tide and bank were subject to change throughout the season. Daily comparison of the tracked output against the chart recordings and in situ calibration determined the daily value of these parameters.

Clean echoes were collated into groups of echoes representing an individual target. The criteria used to link all echoes that were potentially attributable to a single fish target included (1) minimum number of pings to qualify as a fish, (2) maximum change in range between consecutive echoes, and (3) maximum time allowed between consecutive echoes. Echoes from sequential pings were also evaluated in the context of whether or not a fish could have actually moved through space and time in a manner that would yield the pattern of echoes observed. For example, if on ping number 1 a valid echo was received at a range of 25 m, a valid echo on ping number 2 at a range of 15 m could not have come from the same target if the pulse-repetition rate was 8 pings/sec. Such an echo pair would represent a swimming velocity of approximately 80 m/sec. These 3 tracking criteria were dependent on pulse-repetition rate, swimming speed of the fish, beam geometry, and transducer deployment. Comparison of the tracking-program output to the chart recordings allowed the operators to select input parameters for the program that minimized fish-tracking errors (i.e., deviations between number of fish tracked with the tracking software and fish counted on the chart recorder).

When all of the echoes that could be assigned to a single fish were identified, statistics for each echo and mean values for individuals were calculated by the tracking software. Summary tables provided the following for individual fish: fish number, mean narrow-beam peak voltage, mean wide-beam peak voltage, mean range, mean narrow-beam pulse width, mean wide-beam pulse width, mean target strength, mean beam-pattern factor, estimated angle of passage through the beam, time in the beam, and number of valid echoes from the fish. A summary table for each 20-min sample provided between-fish statistics and included total sample time, total number of tracked fish, mean target strength, standard deviation of the target-strength distribution, mean backscattering cross section, standard deviation of the backscattering cross section, number of echoes with beam-pattern factor >0 dB (i.e., the narrow-beam voltage greater than the wide-beam voltage), and distribution of beam-pattern factors >0 dB. The proportion and distribution of echoes with beam-pattern factors >0 dB were used to ensure that the narrow and wide channels were turned properly and that the data set was not excessively noisy.

The final screening process was a visual comparison of each fish's echoes (from the above data output files) against the chart recording collected during the same 20-min sample. This comparison was performed for every sample. This final visual comparison of the output of the program against a visual record of fish passage assured that non-fish targets, such as boat wakes, rocks, debris, etc., that may have passed the secondary screening process, were not considered valid fish targets. The number of valid targets with mean target strengths above a specified threshold were considered as the counts of chinook salmon passing during the respective 20-min sample period.

System Calibration

Estimated target strengths from the sonar were calibrated against a standard target of known acoustic

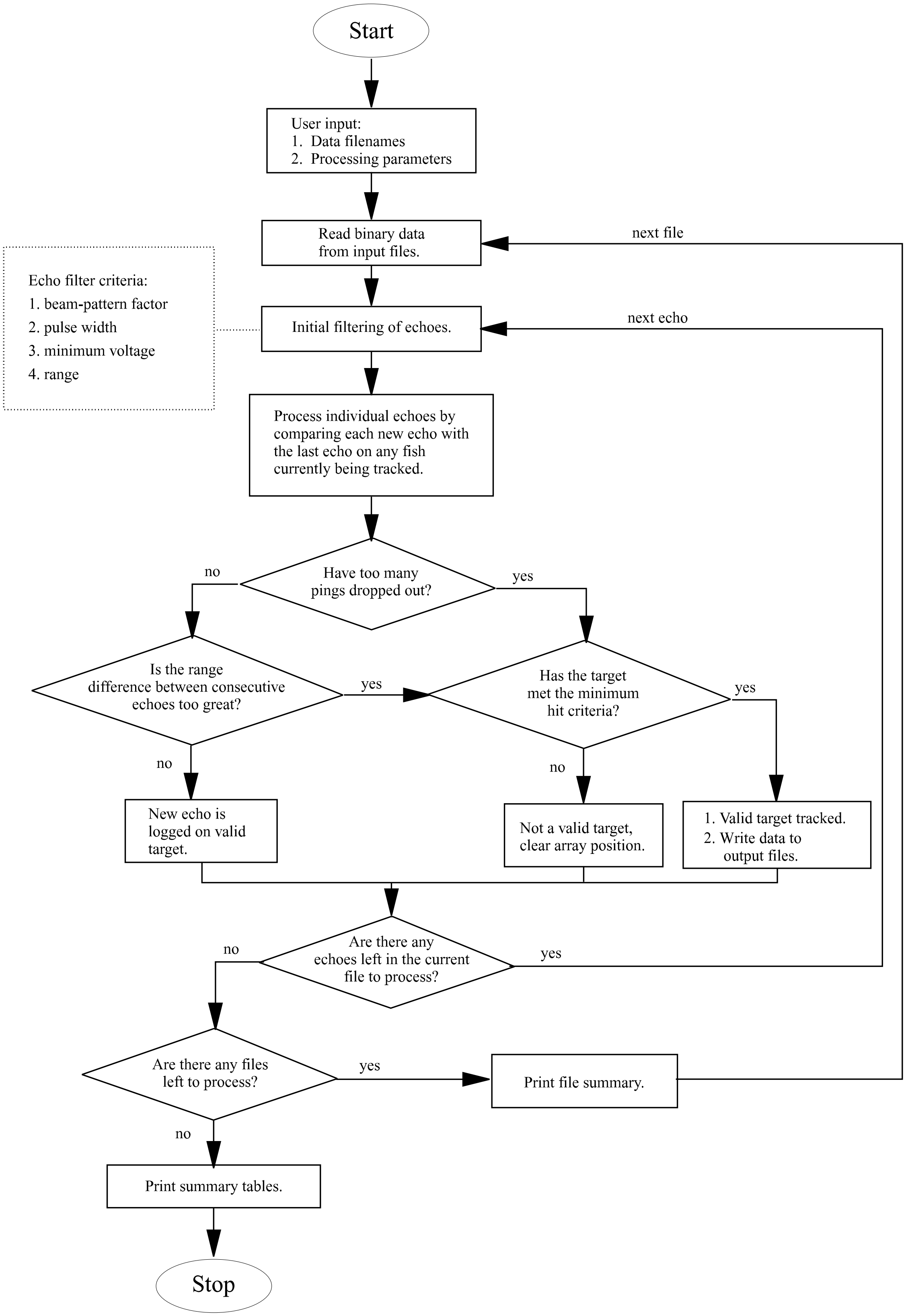

Figure 4. Flow chart of dual-beam data-processing software.

size. Development of in situ methods of calibration for the sonar hardware was necessary because calibration data provided by the manufacturer were rarely within 3 dB of our calculated values and were commonly not within 6 dB. A 10-cm lead sphere was initially used (1987–1989) because of its availability and low cost. Later (after 1990), a 38.1-mm tungsten-carbide steel sphere with more consistent acoustical properties (MacLennan and Simmonds 1992) was used. The target strengths of the standard targets were near the minimum size threshold for discriminating chinook salmon. The spheres were easy to handle and deploy, and the measured target strength was consistent within spheres (± 0.5 dB) and among spheres (± 1.5 dB).

Calibrations were conducted at high slack tide when ambient noise levels were low and the position of the target was stable due to a lack of current. The buoy system and sphere were deployed at low tide outside the sampling area. At this time the water depth was shallow enough so that exact location (i.e., the transducer aiming angle) of the suspended sphere could be determined for subsequent calibrations. During calibrations the transducer was aimed at the sphere and then suspended in mid-water according to transducer-aiming settings determined at the time the sphere was deployed. Fine aiming adjustments were made to align the beams so that the sphere was located on the maximum-response axis (MRA) as determined by equalizing the amplitudes of the wide- and narrow-beam echoes. Data were acquired for 15 min. A subsample was examined immediately for diagnostic purposes. The entire data set was analyzed later and considered in secondary data-processing procedures.

Periodic checks of the relative performance of the sonar system were made throughout each field season. Over the life of this project, the in situ calibration identified several subtle problems, such as a cracked wide-beam transducer element and reduced performance of the narrow-beam channel due to partial flooding of the cable. These would not have been detected without calibration and would have resulted in erroneous counts of chinook salmon.

Size Class/Species Discrimination

Potential for the use of target strength to discriminate chinook salmon from other salmon in the Kenai River was investigated by comparing fish target-strength distribution to the estimated ambient fish-length distribution. It was anticipated that modes in the fish target-strength distribution would match modes in the ambient fish-length distribution and that target-strength thresholds for discriminating chinook salmon could be estimated from these comparisons.

The ambient length distribution of sockeye salmon was taken from pooled lengths of fish captured in fish wheel samples in the Kenai River at the location of the sockeye salmon sonar counting project (RM 21) and from commercial catches in the eastside setnet fishery near the mouth of the Kenai River. Length distributions of sockeye salmon caught in the fish wheel and commercial fishery were similar; therefore, the ambient length distribution of sockeye salmon was estimated by a simple pooling of data from both sources.

Information on the length distribution of chinook salmon was available from measurements of fish sampled from commercial catches in the eastside set gillnet fishery near the mouth of the Kenai River, from the large-mesh gillnet catches of chinook salmon captured in a salmon tagging project, and from catches sampled from the Kenai River sport fishery. For lengths >600 mm there was very little difference in the length distribution among the 3 data sources (Figures 5C and 5D). Chinook salmon <600 mm were rarely sampled in the sport creel survey (S. Hammarstrom, Alaska Department of Fish and Game, Soldotna, personal communication) or in the large-mesh gillnets used in the tagging study. Fishers in the eastside setnet fishery used smaller-mesh gillnets and caught a broader size spectrum of chinook salmon. Because of potential for a mix of chinook salmon stocks in the commercial catches, only data from the inriver sampling (i.e., tagging and sport fishery catches) was used to estimate the ambient length distribution of chinook salmon. The ambient length distribution was estimated by averaging the probability densities (i.e., equal weighting) from the tagging and sport fish catches (the chinook data are combined in Figures 5C and 5D).

The primary objective of the sonar operations during the 1985 and 1986 season was to collect target-strength data. During those years the sonar system was aimed slightly off the bottom to minimize reverberation and maximize SNR. The maximum-response axis (MRA) threshold was set at approximately -40 dB, which corresponds to a half-power-point threshold of approximately -34 dB. This configuration most likely undercounted chinook salmon swimming very close to the bottom; however, it allowed smaller targets (down to approximately -40 dB) to be detected and a broader-length spectrum of fish targets to be sampled.

The estimated target-strength distributions for 1985 (n = 11,838) and 1986 (n = 3,322) were bimodally distributed (Figures 5A and 5B). Note that the lower end of the 1986 target-strength distribution was truncated at approximately -35 dB and reflects the MRA threshold. The mean target strength for the lower mode was -23.6 for 1985 and -32.2 dB for 1986. The mean target strength for the higher mode was -12.0 for 1985 and -19.7 dB for 1986. The target-strength data from 1985 were much higher than in 1986, approximately 7 dB greater. This difference was due to the calibration of the acoustic system as it was operated during the 1985 season being inconsistent with the calibration of the system as it was operated in 1986 and later. In both years the difference between mean target strength for the lower and upper modes of the target-strength distribution was approximately 12 dB (Figures 5A and 5B).

It is well known from various published studies that the acoustical backscattering cross section of fish is approximately proportional to the square of fish length and that target strength is linearly related to the common logarithm of fish length (Urick 1975; Love 1969; Buerkle 1987). Various models have been proposed that incorporate factors, other than length, which affect target strength: frequency and aspect.

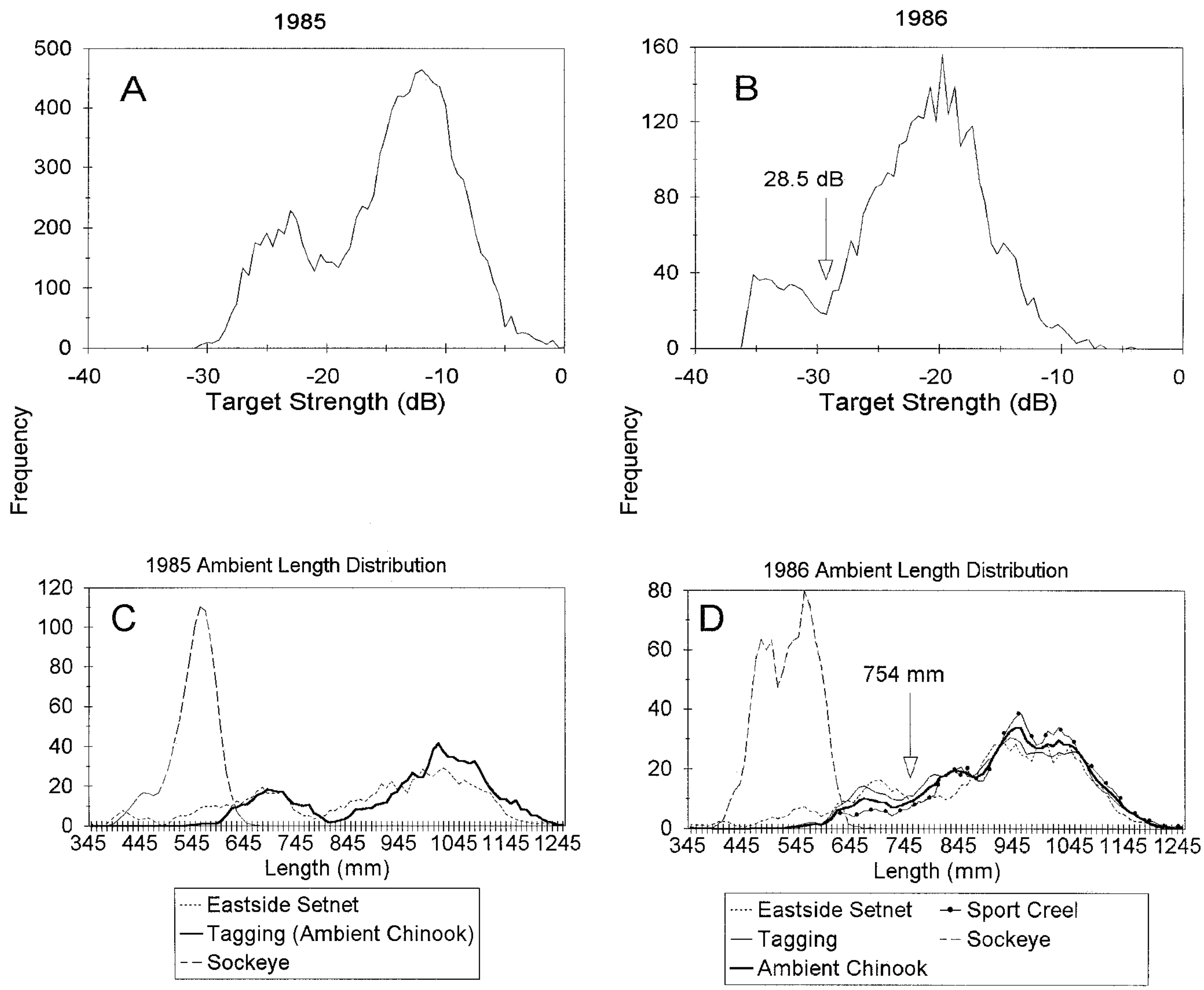

Figure 5. (A) Frequency distribution of acoustic target-strength (dB) data collected in 1985, (B) frequency distribution of acoustic target-strength (dB) data collected in 1986, (C) 1985 length (mm) frequency distribution for sockeye salmon (see text for description of data sources) and chinook salmon from ambient (i.e., tagging) and eastside setnet fishery, and (D) 1986 length (mm) frequency distributions for Kenai River sockeye and chinook salmon (chinook salmon were from tagging, eastside setnet fishery, sport fishery creel census, and ambient — i.e., combined tagging and sport fishery creel). All length frequency distributions in panels C and D were scaled to reflect sample size of 1,000 fish.

Table 1. Ambient length of Kenai River chinook and sockeye salmon, ratio of sockeye to chinook salmon length, and expected difference in mean target strength between sockeye and chinook salmon, 1985–1990.

Year	Chinook Salmon Mean Length (mm)	Sockeye Salmon Mean Length (mm)	Ratio of Sockeye to Chinook Salmon Mean Length	Expected Difference in Mean Target Strength (dB)
1985	947	541	0.57	4.9
1986	924	525	0.57	4.9
1987	960	556	0.58	4.7
1988	986	561	0.57	4.9
1989	969	561	0.58	4.8
1990	937	539	0.58	4.8

In situations where frequency and aspect are constant, these models can be expressed in the form

$$TS = A + B\log(L)\ , \qquad (1)$$

where TS is target strength (dB), L is fish length (mm), and A and B are estimated parameters. In many published studies on fish target strength, the slope (i.e., B in equation 1) of the various empirically determined relationships between target strength and the logarithm of fish length has been very close to 20.

The relative sizes (i.e., ratio of mean lengths) of targets for the 2 modes in a target-strength distribution can be estimated from the following relationship derived by subtracting mean target strengths based on equation (1) and solving for L_2 / L_1:

$$\frac{L_2}{L_1} = 10\left[\frac{TS_2 - TS_1}{20}\right]\ , \qquad (2)$$

where TS_1 is mean target strength for the lower mode of the target-strength distribution, TS_2 is mean target strength for the upper mode, and L_2 / L_1 is the ratio of mean lengths for the lower to the mean lengths of the upper mode of the target-strength distribution. The ratio of fish lengths for the 2 modes of the target-strength distributions for 1985 and 1986 was approximately 0.25. However, this result was inconsistent with the relative size of Kenai River sockeye and chinook salmon (Table 1).

Mean length of Kenai River chinook salmon was much greater than mean length of Kenai River sockeye salmon (Table 1), the ratio of sockeye-chinook length consistently being 0.57 to 0.58. The expected mean target strengths of Kenai River sockeye and chinook salmon, based on the observed ratio of sockeye salmon mean length to chinook salmon mean length, differed by 4.7 to 4.8 dB. The difference between the 2 modes observed in both 1985 and 1986 target-strength distributions (Figure 5) far exceeded the expected difference in mean target strengths based on relative sizes. The identity of the targets in the lower mode of the 1985 and 1986 target-strength distributions was unknown; however, it was unlikely that these targets were upstream-migrating salmon.

In 1987 the sonar operation emphasis shifted from target-strength measurement to counting fish. Because chinook salmon were strongly bottom-oriented, we aimed the transducers as close to the bottom as possible to count all of the passing salmon. Because the new aiming angle decreased the SNR, we increased the half-power-point threshold to avoid swamping the data collection and analysis system. In 1987 the half-power-point threshold was increased to -28.5 dB, which corresponds to an MRA threshold of -34.5 dB. Although some targets between -28.5 and -34.5 dB were likely to be detected, there was increasing bias against detecting targets <-28.5 dB, approaching zero probability of detection for targets <-34.5 dB. Therefore, to ensure an unbiased sample, all targets <-28.5 dB were discarded. This increased threshold effectively eliminated the mode of small targets observed for 1985 and 1986.

The 1987–1990 target-strength distributions were very similar for the early and late chinook salmon runs (Figure 6). The magnitude of differences in mean target strengths between early and late runs for 1987 through 1993 were <1.7 dB (Table 2). There was a decrease in the between-fish standard deviation of target strength during the period. This decrease in standard deviation was due to increased numbers of pings per fish examined for target strength (Table 2).

The ability to discriminate between chinook salmon and sockeye salmon in the Kenai River based on target strength cannot be ascertained from comparison of modes in target-strength and length distributions. There is a high degree of variability in target strength from repeated echoes from individual fish. In laboratory conditions Dahl and Mathisen (1982) observed within-fish target-strength standard deviations in the range of 5.2–6.2 dB for large trout (i.e., 35–55-cm fork length). Eggers (1994) showed, in stochastic computer simulations using Dahl and Mathisen's (1982) model of within-fish target-strength variability, that a bimodal sampling distribution of mean target strength would not be expected to occur for a mixed population of Kenai River sockeye and

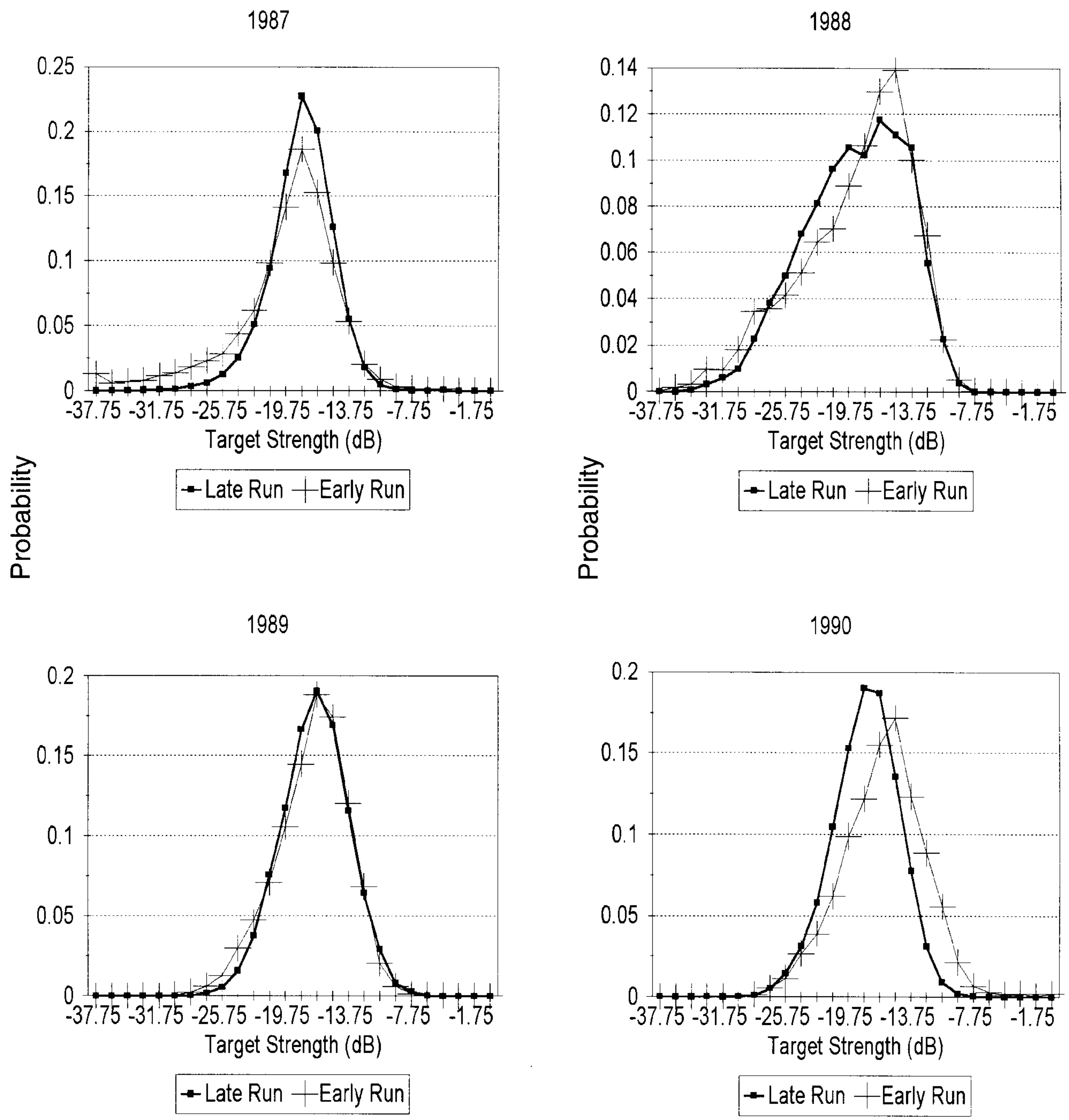

Figure 6. Frequency distribution of acoustic target strength (dB) by the Kenai River chinook salmon early-run period (before July 1) and late-run period (after July 1) for 1987–1990.

Table 2. Mean target strength, standard deviation target strength, mean number of pings per fish, and estimate of *A* parameter in equation (1) for chinook salmon early and late runs in the Kenai River, 1987–1993.

Year	Early Run				Late Run				Difference in Mean Target Strength: Early vs. Late Run
	Mean Target Strength (dB)	S.D. Target Strength (dB)	Mean Pings per Fish (no.)	Estimate of *A* Parameter in Equation (1)	Mean Target Strength (dB)	S.D. Target Strength (dB)	Mean Pings per Fish (no.)	Estimate of *A* Parameter in Equation (1)	
1987	-20.5	5.2	5.5	-60.1	-19.0	3.1	6.1	-58.6	-1.5
1988	-19.8	5.3	5.8	-59.7	-19.9	4.8	6.7	-59.8	0.1
1989	-18.0	3.5	12.5	-57.7	-17.7	3.2	10.6	-57.4	-0.3
1990	-17.2	4.0	12.9	-56.6	-18.9	3.2	12.3	-58.3	1.7
1991	-21.3	3.7	12.4		-21.6	2.8	14.1		0.3
1992	-16.8	4.4	12.4		-16.1	3.2	12.6		-0.7
1993	-22.9	2.4	16.9		-22.7	2.3	15.6		-0.2

chinook salmon, given the relatively low number of target-strength measurements routinely made per fish during sonar operations.

It was believed that sockeye and chinook salmon were spatially segregated in the Kenai River, with sockeye salmon occurring nearshore and chinook salmon occurring offshore. During the late run numerous targets were routinely observed within 15 m of the transducer on the left bank and within 10 m on the right bank. Although the gillnets used were large-meshed, sockeye salmon were rarely caught in the gillnet sampling conducted in the central portions of the river by the chinook salmon tagging project (S. Hammarstrom, Alaska Department of Fish and Game, Soldotna, personal communication) but were routinely caught in the shore-based gillnet operations. The very low catches of sockeye salmon in the offshore operations indicate that chinook salmon and sockeye salmon were spatially segregated. Therefore, excluding any targets detected within 15 m of the transducers on the left bank and within 10 m on the right bank, targets at greater distances were presumably chinook salmon.

Direction of Travel

Two experiments were conducted to determine direction of travel of the migrating chinook salmon. Because the sonar was located in the zone of tidal influence, fish could possibly swim upstream past the sonar with the rising tide and then downstream with the falling tide. The first experiment was conducted in 1986 as a part of routine operations; the transducers were aimed downstream at an angle of approximately 30° (Figure 7). The second experiment was conducted in 1990 with 2 independent single-beam transducers deployed in parallel (Figure 7).

In the 1986 experiment, fish swimming upstream entered the beam from downstream and exited the beam at a range shorter than they entered, and vice versa for targets traveling downstream. Direction of travel was determined from the calculated angle of passage routinely calculated from tracked targets. There were 3 distinct clusters in the calculated angle of passage (Figure 8) of the fish tracked in 1986: (1) a few fish ($n = 29$) had negative passage angles and were clearly migrating downstream, (2) a large number ($n = 797$) had a positive angle of passage and were clearly migrating upstream, and (3) a large number ($n > 900$) had an angle of passage that could not be determined. Targets that were close to the bottom were not in the beam long enough to determine change in range. It was also clear that fish were moving laterally in the beam because zero-range changes were observed for many fish. These fish were passing through the beam at an angle equal to the aiming angle of the transducer. There was no information to suggest that differential behavior occurred between downstream- and upstream-migrating fish. Based on the assumption that downstream-migrating fish were identified by a negative passage angle, the proportion of downstream-migrating fish was 3.5%.

Based on these results, the transducers were aimed directly offshore during sonar operations conducted after the 1986 season. This orientation was perpendicular to the direction of travel of the chinook salmon and maximized acoustic reflection at maximum lateral aspect. This provided a maximum probability of detecting fish.

However, a radiotagging study conducted on the Kenai River in 1989 and 1990 (Bendock and Alexandersdottir 1993) showed that 47 of 120 (39.2%) radiotagged chinook salmon released a short distance upstream from the sonar site traveled downstream. Because of the inconsistency between these results and the 1986 experiment and because of ambiguity in the 1986 experiment due to the large number of fish for which direction of travel could not be determined, a second experiment was conducted during the 1990 late run. In this experiment 2 parallel single-beam transducers were aimed directly offshore. Fish in the 2 beams were monitored simultaneously with a dual-channel chart recorder. This configuration assured there was no ambiguity in determining the direction of travel. Any upstream-migrating target entered the downstream beam first, then appeared in both beams, and then finally appeared only in the upstream beam. Similarly, any downstream-migrating target appeared first in the upstream beam and then in the downstream beam. During the 1990 parallel-beam study 2.5% of the observed fish migrated downstream, while the remainder (97.5%) migrated upstream.

SPATIAL DISTRIBUTION

Achieving the most precise estimate of abundance required that the transducers be deployed to insonify the cross-sectional area of the river used by passing chinook salmon. This task was complicated because of extreme semidiurnal tidal fluctuations that averaged 4 m and were as high as 7 m. During the initial year of the project, the transducers were placed on movable platforms that followed the rising and falling water, enabling the intertidal water column to be insonified. However, this procedure was abandoned because it was not possible to precisely control the beam location necessary to maintain tolerable SNR and to accurately detect bottom-oriented targets. After 1986 the transducers were fixed at just below the low water level (Figure 2), which allowed precise aiming of the transducer beam. However, substantial portions of the water column that fish could pass through were not insonified during tidal stages other than at slack tide. Because chinook salmon could pass through the non-insonified water columns behind the transducers or above the transducers, 2 experiments were conducted in 1986 to examine those possibilities.

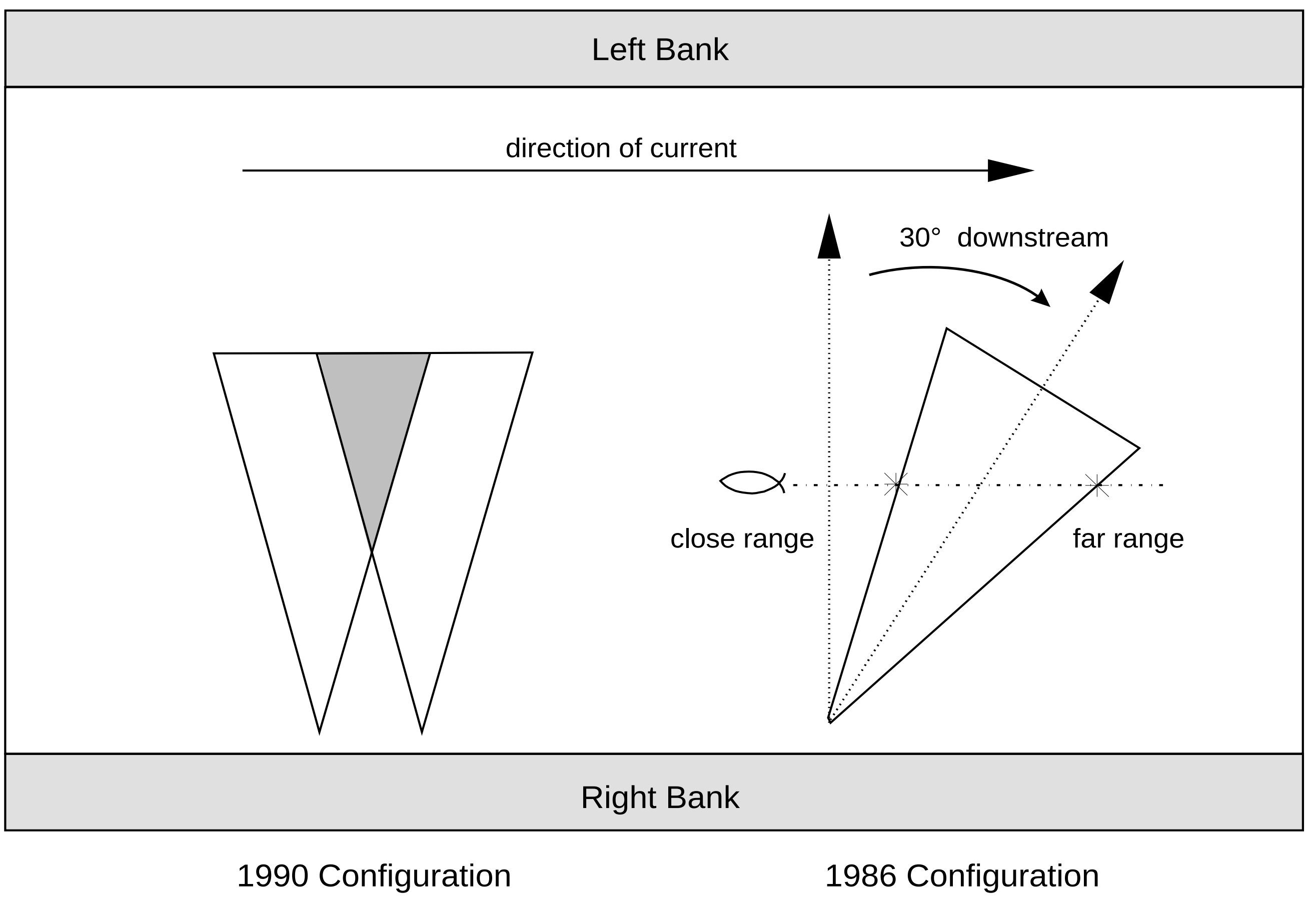

Figure 7. Transducer configurations used in experiments to determine direction of travel of targets in the Kenai River. Shown are the 1986 experiment (right), which used a single dual-beam transducer angled downstream, and the 1990 experiment (left), which used 2 parallel transducers aimed directly offshore.

In the first experiment a large-mesh (216-mm stretch mesh) gillnet was set between the transducer-deployment pod and the high-water point onshore. The mesh was sufficiently large enough to gill chinook salmon, and the net was fished continuously for 8 d during the peak of the late run. The net was checked prior to every low tide during that period. Although the experiment was conducted when the transducers were being moved with the tide, the net was probably fishing effectively during the rising tidal stages. Chinook salmon were actively moving upstream and at the time would have been caught had they been migrating through the river behind the transducers, but during the experiment only 6 sockeye salmon and 1 large (62 cm) male pink salmon were caught. These low catches were not indicative of sockeye and pink salmon abundance because the mesh was too large to effectively capture these species. All of the sockeye salmon were tangled in the mouth or maxillaries; pink salmon were gilled on the dorsal hump. Because this experiment was conducted during the peak of the chinook salmon run, it demonstrated that negligible passage of chinook salmon occurred in the intertidal areas behind the transducers.

Chinook salmon were occasionally seen surfacing at high slack tide and could have passed by the system undetected. A second experiment conducted with vertical-looking sonar examined the possibility of chinook salmon passing over the beam at high tide. The vertical-looking transducer was bracketed to the bow of a boat just below the surface of the water. The sonar system was activated and operated continuously as the outboard-powered boat directly crossed the river. The river was crossed 10 times during each high slack, low slack, flooding and ebbing tide. The pulse-repetition frequency was maximized based on the maximum water depth at the time of the transect.

The number of fish targets in each depth stratum for each tide stratum was counted. The counts were expanded by multiplying the stratum count by the ratio of maximum range to midpoint range. This accounted for differential probability of detection at range due to the conical shape of the sonar beam. Because vertical distributions were similar for high slack and

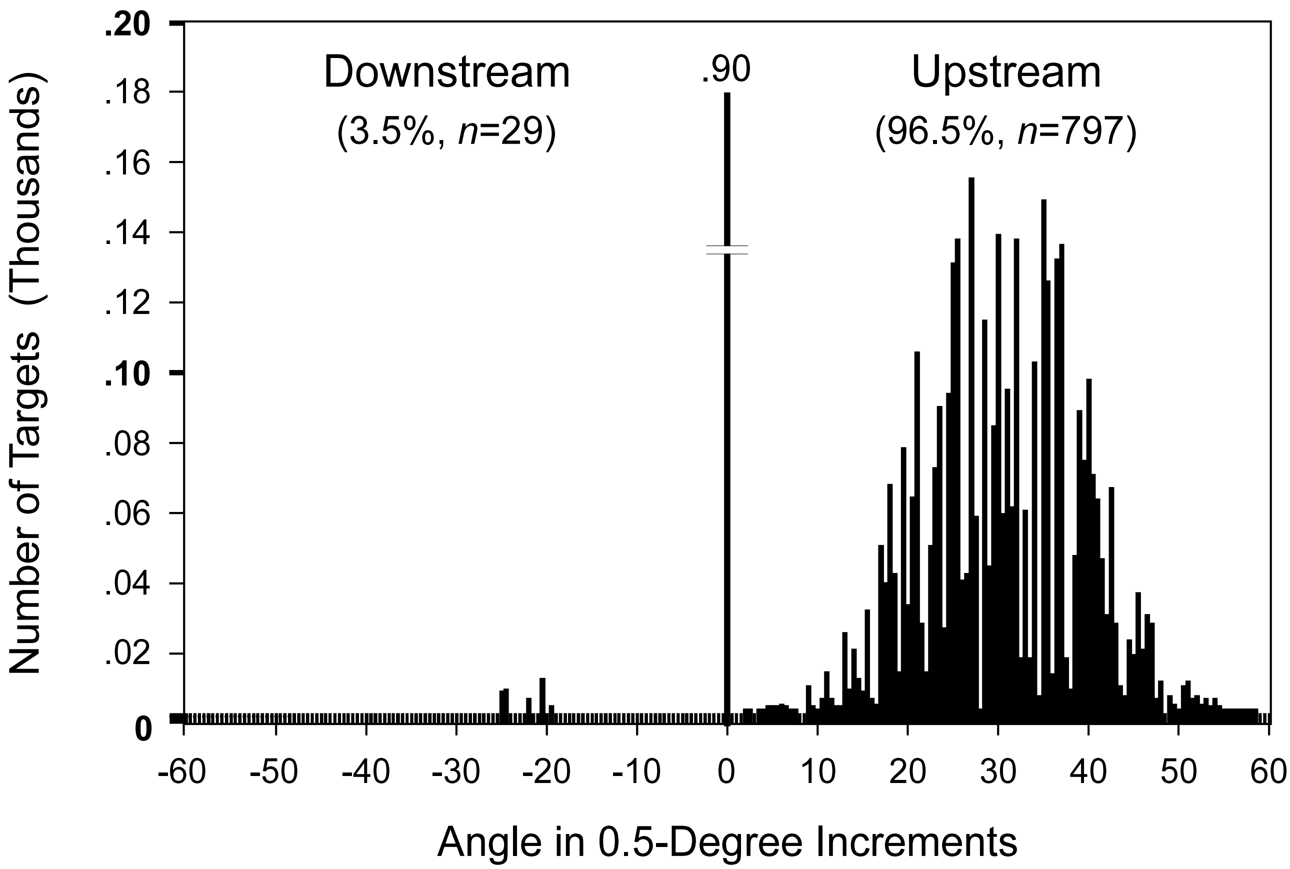

Figure 8. Distribution of upstream, downstream, and unknown direction-of-travel targets determined by angle of passage in the 1986 direction-of-travel experiment.

flooding tides, they were pooled as *high tide*. Similarly, the low slack and ebbing tides were pooled as *low tide* (Figure 9). There was a strong bottom orientation of targets at all tidal stages, the strongest occurring at low tide (Figure 9). Because chinook salmon presumably avoid a running boat and because of low probability of fish detection near the surface in the small volume of the transducer beam, it is likely that the counts of chinook salmon in the upper strata during low tide were biased low. During the high tide there were 4–7 m of water between the boat and 3–4-m strata (measured as 3–4 m off the bottom). No fish were counted above the 3–4-m strata. Because fish within 3.5 m of the boat were clearly detected at low tide, the lack of fish detected in the >4-m strata indicated that fish were not present in strata <4 m above the bottom during the high tidal stages.

This strong bottom orientation of chinook salmon observed in the vertical-looking sonar operations was also consistent with observations made in dual-beam sonar operations when we occasionally aimed the transducer beam to sample the off-bottom portion of the water column. These aimings consistently resulted in reduced sonar counts. Because these aimings degraded the sonar operations, they were not conducted in a manner sufficient to quantitatively determine bottom orientation. However, the observations of reduced counts in off-bottom deployments of the transducer and the observations of low beam-pattern factors suggested that chinook salmon tended to be located in the near-bottom portion of the sonar beam.

Passage of chinook salmon outside the insonified area was believed to be negligible because (1) chinook salmon were not caught in the limited gillnet sampling behind transducers, (2) all targets identified in vertical-looking sonar transects were within 4 m of the bottom (Figure 9), and (3) all of the water column within 4 m of the bottom on the right bank and most of the water column on the left bank (Figure 3) were insonified.

TEMPORAL DISTRIBUTION AND ESTIMATION OF ABUNDANCE

The frequency of passing chinook salmon was closely related to tidal stage; the highest frequency occurred approximately 2 h prior to high slack tide. Chinook salmon moved upstream on the flooding tide and held their positions during the ebbing and low slack tides (Figure 10).

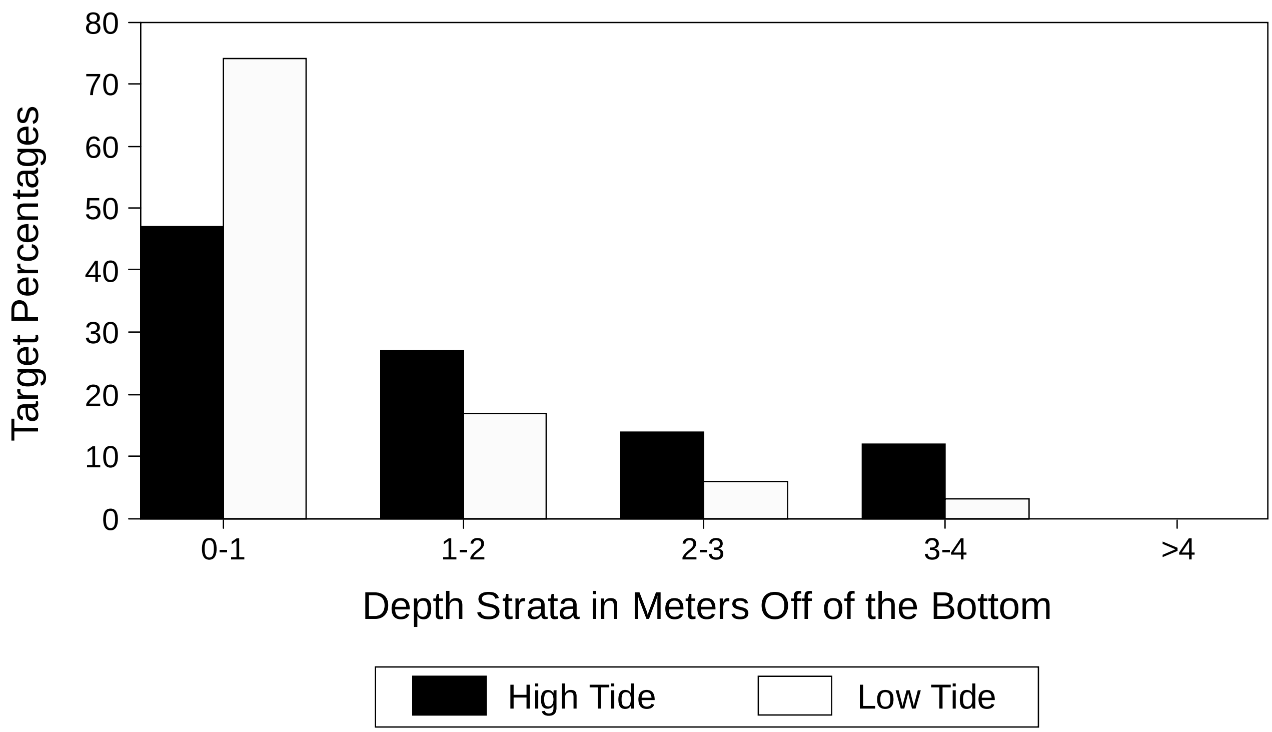

Figure 9. Depth distribution of acoustic targets during flood/high slack and ebb/low slack tide stages observed during 1986. At >4 m off the bottom, no targets were measured on high tide.

Daily passage for each bank was estimated by summing the 24 expanded hourly sonar counts. The expansions were for the 40-min period when the gear was on the opposite bank and for missing hourly counts. The total daily passage was the sum of each bank's passage.

An hourly estimate was calculated for each hour in which a count occurred, usually a simple 3-fold expansion of a 20-min count. When one bank's transducer was not operating, a 60-min count was taken on the opposite bank to reduce expansion error. All counts were standardized to 1 h using

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

where $\hat{Y}_{bj}$ is the estimated count for bank b and hour j, c_{bj} is the actual count for bank b and hour j, and t_{bj} is the number of minutes sampled for bank b and hour j.

Daily fish passage for periods when hourly counts were made ($\hat{y}_i$) was

$$\hat{y}_i = \sum_{j=1}^{24} \left[\hat{y}_{bj} + \hat{y}_{b'j} \right] \quad , \tag{4}$$

where $\hat{Y}_{b'j}$ is the estimated count for bank b' and hour j.

Missing counts for a given bank were extrapolated from the opposite bank count made during the same hour. The ratio estimator (Cochran 1977) was used to determine the magnitude of one bank's count relative to the opposite bank's count:

$$\hat{r}_b = \frac{\sum_{j=1}^{n_1} \hat{y}_{bj}}{\sum_{j=1}^{n_1} \hat{y}_{b'j}} \tag{5}$$

and

$$\hat{r}_{b'} = \frac{1}{\hat{r}_b} \quad , \tag{6}$$

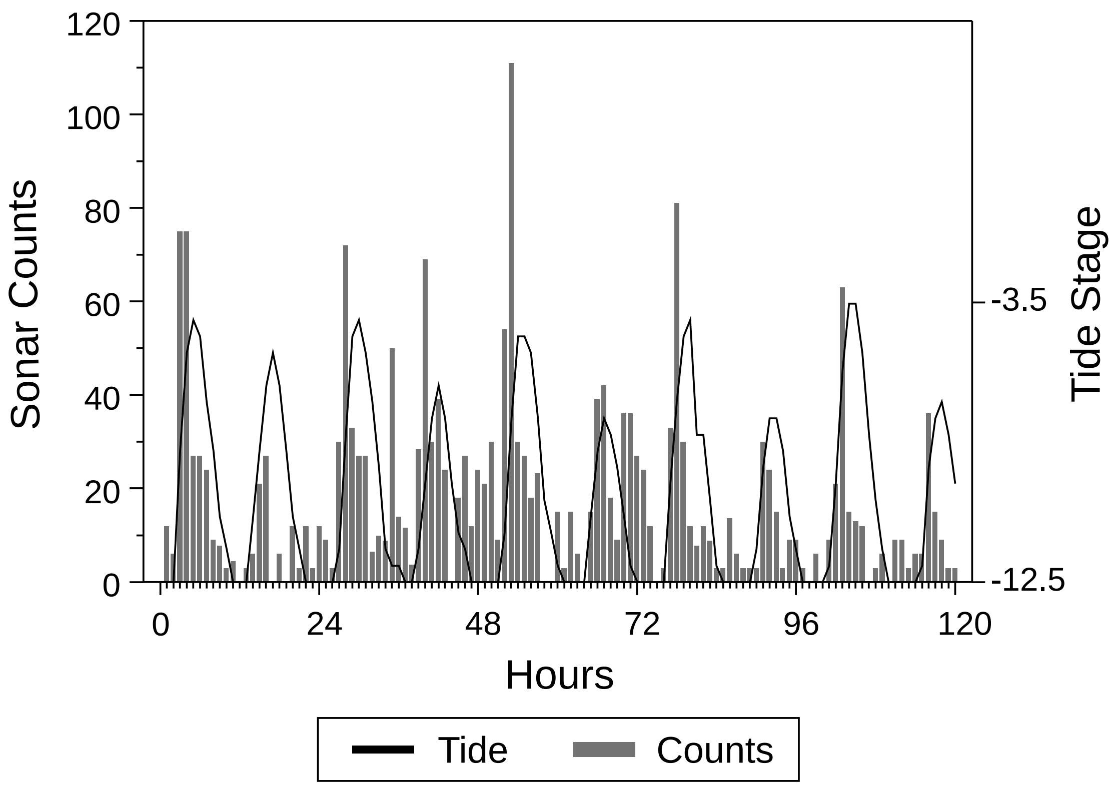

Figure 10. Relationship between hourly sonar counts (gray bars) and tide stage observed in the Kenai River June 13 through June 17, 1990, (approximately 129 h during the peak of the early chinook salmon run). Tide stage in feet from reference point on tide gauge located at the sonar site.

where $\hat{r}_b$ is the ratio of bank b to bank b', $\hat{r}_{b'}$ is the ratio of bank b' to bank b, $\hat{y}_{bj}$ is the expanded count of bank b during hour j, $\hat{y}_{b'j}$ is the expanded count of the opposite bank during hour j, and n_1 is the number of hours for which both banks were sampled for the same number of minutes. Only hourly periods with both banks counted for the normal 20-min period were used to estimate $\hat{r}_b$.

The estimate of $\hat{r}_b$ evolved inseason as further counts were made. To obtain the most accurate inseason estimate, the ratio of right- to left-bank counts was recalculated each day based on the cumulative data up to that date. Extrapolations were based on the most current extrapolation coefficient obtained using the entire season's data to date. Thus, at the end of the early and late runs, all extrapolations were recalculated using the extrapolation coefficient based on data for the entire season.

The estimated count on bank b when not operating during hour m ($\hat{y}_{bm}$) and the estimated count of bank b' when not operating during hour m ($\hat{y}_{b'm}$) were

$$\hat{y}_{bm} = \hat{r}_b \hat{y}_{b'm} \tag{7}$$

and

$$\hat{y}_{b'm} = \hat{r}_{b'} \hat{y}_{bm} \quad . \tag{8}$$

There were rare occasions when transducers on both banks were simultaneously inoperative. In those situations the entire daily count was estimated by expanding the limited counts that were made as

$$\hat{d}_i = \frac{1440}{t_{bi} + t_{b'i}} \left(c_{bi} + c_{b'i} \right) \quad , \tag{9}$$

where $\hat{d}_i$ is the estimated daily count for bank b on day i, t_{bi} is the number of minutes operated on bank b and day i, $t_{b'i}$ is the number of minutes operated on bank b' and day i, c_{bi} is the number of fish counted on bank b and day i, and $c_{b'i}$ is the number of fish counted on bank b' and day i.

Total passage (Y) was the sum of the expanded hourly counts (Y_h), the extrapolated counts (X_b and $X_{b'}$), and the interpolated counts for days where the sonar gear was inoperative for both banks (D):

$$\hat{Y} = \hat{Y}_h + \hat{X}_b + \hat{X}_{b'} + \hat{D} \quad , \tag{10}$$

where

$$\hat{Y} = \sum_{i=1}^{N} \hat{y}_i \quad , \tag{11}$$

$$\hat{x}_b = \hat{R}_b \sum_{m=1}^{M_b} \hat{y}_{b'm} \quad , \tag{12}$$

$$\hat{x}_{b'} = \hat{R}_{b'} \sum_{m=1}^{M_{b'}} \hat{y}_{bm} \quad , \tag{13}$$

and

$$\hat{D} = \sum_{i=1}^{N} \hat{d}_i \quad , \tag{14}$$

where $\hat{x}_b$ is the estimated count when bank b was not operating, $\hat{x}_{b'}$ is the estimated count when bank b' was not operating, $\hat{R}_b$ is the final ratio estimate based on all hours when both banks were sampled for the same number of minutes, $\hat{M}_b$ is the total number of extrapolated hours on bank b, $\hat{M}_{b'}$ is the total number of extrapolated hours on bank b', and N is the number of days counted in the run.

Two quantifiable sources of error were recognized in this sample design. One was the variance (expansion error) induced by expanding 20-min counts into hourly estimates. The other source of error was the variance (extrapolation error) caused by missing counts.

The method of successive difference (Wolter 1985) was used to estimate the variance induced by expanding the 20-min counts into hourly estimates. This method uses the following systematic sample-variance estimator:

$$Var\left(\hat{y}_h\right) = \left(N_h - n_b - n_{b'}\right)^2 \left[\frac{1-f_h}{N_h}\right] \sum_{j=2}^{N_h} \frac{\left(\hat{y}_j - \hat{y}_{j-1}\right)^2}{2\left(N_h - 1\right)} \quad , \tag{15}$$

where $\hat{y}_j$ is the estimated number of fish passing the sonar site on both banks during hour j, N_h is the total number of 1-h sample periods for the specific run, and $\left(1 - f_h\right)$ is the finite population-correction factor for expanded counts (≈ 0.66).

Variance of the extrapolated passage estimates was calculated based on Cochran (1977) as follows:

$$Var\left(\hat{x}_b\right) = \left(n_1 + n_b\right)^2 \left(1 - f_b\right) \frac{\sum_{m=1}^{n_1} \left(\hat{y}_{bj} - \hat{r}_b \hat{y}_{b'm}\right)^2}{n_1\left(n_1 - 1\right)} \tag{16}$$

and

$$Var\left(\hat{x}_{b'}\right)=\left(n_1+n_{b'}\right)^2\left(1-f_{b'}\right)\frac{\sum_{m=1}^{n_1}\left(\hat{y}_{b'j}-\hat{r}_{b'}\hat{y}_{bm}\right)^2}{n_1\left(n_1-1\right)} \quad , \tag{17}$$

where n_b is the number of hours during the run when bank b was not operating, $n_{b'}$ is the number of hours during the run when bank b' was not operating, $(1-f_b)$ and $(1-f_{b'})$ are finite population correction factors, f_b is $n_1/\left(n_1+n_b\right)$, and $f_{b'}$ is $n_1/\left(n_1+n_{b'}\right)$.

A method for estimating variance for the counts that were estimated in situations when both transducers were not operational (D) has not been developed. Estimates of variance did not include this component; however, this error would be small because of the infrequency of this circumstance.

Estimates of variance for the total run passage (Y) were the sum of the variance components:

$$Var\left(\hat{Y}\right)=Var\left(\hat{y}_h\right)+Var\left(\hat{x}_b\right)+Var\left(\hat{x}_{b'}\right). \tag{18}$$

Estimates of total passage of chinook salmon (raw counts available in Hammarstrom et al. 1986; Conrad and Larson 1987; Conrad 1988; Carlon and Alexandersdottir 1989; Burwen 1994) were made for the 1987–1990 early and late runs (Table 3). Confidence intervals (α = 0.025) were also made for 1988–1990 (Table 3). Fish passage was not estimated during the early run of 1987, and data needed to calculate each component of the variance were not available until 1988. Because a large fraction of the upstream passage of chinook salmon was counted, the precision of the estimates was very high. The width of the 95% confidence intervals ranges from a low of ± 3.8% (late run 1988) to a high of ± 6.3% (late run 1990).

DISCUSSION

The -28.5 dB target-strength threshold, set primarily because of high ambient noise levels, could not discriminate between sockeye and chinook salmon because of high within-fish variability in target strength relative to the between-fish variability in mean target strength (Eggers 1994). The transducers were aimed to detect the bottom-oriented chinook salmon in the central areas of the river, and in making estimates of chinook salmon abundance, we assumed that every fish target detected at ranges >15 m on the left bank and >10 m on the right bank was an upstream-migrating chinook salmon. This assumption rested on observations of very low catches of sockeye salmon in test fisheries in the central portions of the river. However, the test fishing operations were not designed to rigorously test the assumption that sockeye salmon do not migrate in the central portion of the river. There was potential for an upward bias in chinook-abundance estimates due to counting of sockeye salmon.

Observed target-strength data from the sonar were consistent with the assumption that the targets were chinook salmon. Estimates of the A parameter in equation (1) were computed from mean target strength and ambient mean length of chinook salmon based on the following relation:

$$A=\overline{TS}-B\,Log_{10}L \quad ,$$

which assumed that the population counted was chinook salmon. Estimates of A were made for the early and late runs for 1987 through 1990 and ranged from 56.6 to 60.1 (Table 2). These estimates were very similar to the value (58.4) estimated by Eggers (1994) from side-aspect target-strength data for large trout in Dahl and Mathisen (1982).

Mean target strengths for the early and late runs were very similar. The average difference (i.e., early-run mean target strength minus late-run mean target strength) for 1987 to 1993 was -0.1 dB (Table 2). This similarity in mean target strength occurred despite a 10-fold or more difference in abundance of sockeye salmon between the early and late runs. Because the mean target strength of sockeye salmon was 4.8 dB lower than the mean target strength of chinook salmon, and if sockeye salmon were occurring in the sonar counts, one might expect the mean target strengths of the counts from the late-run period, when sockeye salmon were present in the river, to be lower than the early-run period. The similarity of mean target strengths of the sonar counts from the early- and late-run periods suggests that sockeye salmon were not routinely present in central portions of the river insonified by the sonar.

The magnitude of the chinook salmon undercount bias in the sonar estimates of passage was believed to be low. This belief was based on (1) the lack of chinook salmon catch in limited test fishing with large-mesh gillnets behind the transducers, and (2) the absence of targets in the upper portion of the water column from transects made with vertical-looking sonar. The sampling power of these experiments to determine the spatial distribution of chinook salmon was not powerful enough to determine the magnitude of this bias.

Table 3. Sonar and tagging abundance estimates with 95% confidence intervals (in brackets) for early and late runs of chinook salmon in the Kenai River, 1987 through 1990.

	Sonar		Tagging	
Year	Early Run[a]	Late Run[b]	Early Run	Late Run
1987	no estimate[c]	48,123 [no estimate]	25,643 [16,632, 34,653]	65,024 [16,824, 113,224]
1988	20,880 [19,976, 21,784]	52,008 [50,013, 54,003]	25,047 [15,684, 34,410]	110,869 [61,589, 160,149]
1989	17,992 [17,295, 18,689]	29,035 [27,676, 30,394]	23,253 [9,702, 36,804]	57,279 [26,554, 88,004]
1990	10,768 [10,193, 11,343]	33,474 [31,360, 35,588]	no estimate[d]	no estimate[d]

[a] Early run occurs 16 May – 30 June
[b] Late run occurs 1 July – mid August
[c] No estimate because sonar only operated 3 June – 30 June
[d] No estimates generated because fisheries restrictions were implemented

The gillnet sampling behind the transducers was not sufficiently comprehensive in space and time to exclude the possibility of upstream migration of chinook salmon in areas of the river not insonified. The vertical-looking sonar has a very limited ability to detect fish near the transducer and the possibility of boat avoidance at high tides cannot be discounted.

Based on the 1990 parallel-transducer experiment, a small percentage (2.5%) of chinook salmon migrated downstream. This appeared to be inconsistent with the relatively large fraction (47/120) of downstream-migrating chinook salmon observed via radiotagging in 1989 and 1990 (Bendock and Alexandersdottir 1990). The radiotagged chinook salmon were initially captured with hook-and-line sport fishing gear for transmitter implantation. The capture process involved significant handling of the fish; the relatively large fraction of downstream-migrating fish after tagging and release was attributed to handling (Bendock and Alexandersdottir 1990). The percentage of downstream-migrating chinook salmon from the radiotagging study can be used as a quantitative model for chinook salmon emigration after capture and release in the sport fishery. Using this model, the number of downstream-migrating salmon (937) due to handling by the inriver sport fishery was estimated by applying the percentage of downstream-migrating fish (39.2%) based on radiotagging to the estimated number of fish caught and released (2,390) in the 1990 late-run Kenai River sport fishery (D. Nelson, Alaska Department of Fish and Game, Soldotna, personal communication). The estimated number of downstream-migrating fish handled by the 1990 late-run sport fishery was 2.8% of the 1990 late-run sonar estimate of passage. This is consistent with the estimate of 2.5% downstream-migrating fish in the 1990 parallel-transducer experiment and suggests that the downstream migrants at the sonar site were releases from the upstream sport fishery.

The daily estimates of passage made with side-looking, dual-beam sonar were highly correlated with independent indicators of daily abundance based on the 1987–1989 inriver tagging studies (Hammarstrom and Larson 1986; Conrad and Larson 1987; Conrad 1988; Carlon and Alexandersdottir 1989; Alexandersdottir and Marsh 1990). The daily catch of chinook salmon per unit of fishing effort during inriver fish sampling near the sonar site (from approximately 2 km upstream to 4 km downstream of the site), was highly correlated with the daily estimates of the number of passing chinook salmon (Figure 11). Pearson correlation coefficients between daily estimates from the sonar and daily catch per unit effort were 0.922 in 1987, 0.854 in 1988, and 0.849 in 1989.

The estimates of total passage made with sonar were consistently lower than the estimates of total escapement made with tagging (Table 3). Sonar tagging proportions ranged from a low of 0.5 (1989 late run) to a high of 0.89 (1988 early run). However, the 95% confidence intervals for the tagging estimates were relatively large and generally included the point estimate of passage based on sonar (Table 3).

The inconsistencies between sonar and tagging estimates were presumably due to low precision in the tagging estimates as well as relative biases that were potentially inherent in each method (i.e., high bias with

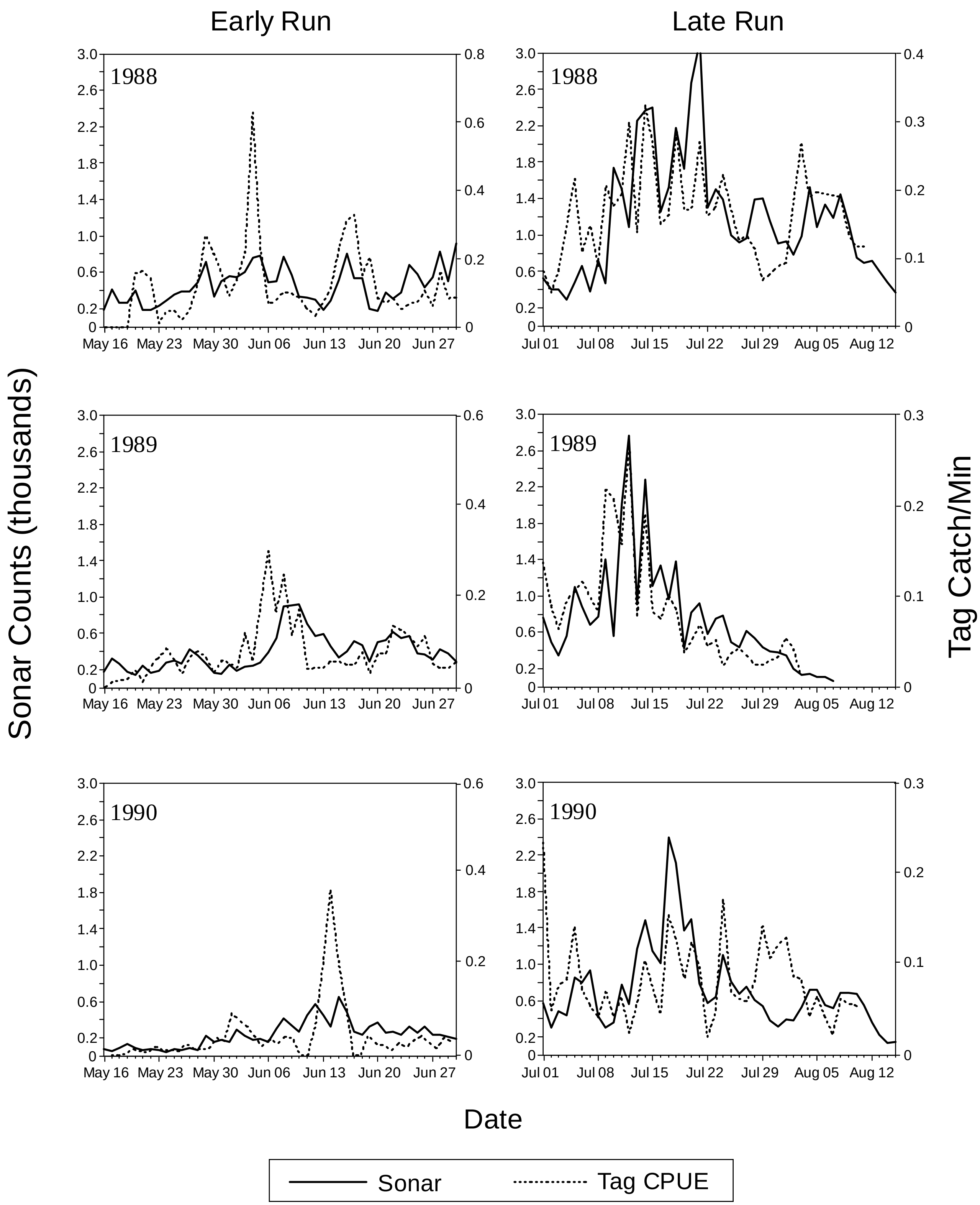

Figure 11. Daily estimates of chinook salmon passage (thousands) and daily catch per unit effort (fish/min drifted) in tagging studies for the early (left) and late (right) runs in the Kenai River, 1988 through 1989.

tagging and low bias with sonar). The low precision and high bias were more apparent in late-run tagging estimates (Bernard and Hansen 1992). Because of the higher abundance of late-run chinook salmon and the constant fishing effort to deploy tags, the tagging rate on the early run was much higher than the late run; because of the depensatory tagging rate, the late-run estimates were less precise and more biased than the early-run estimates (Bernard and Hansen 1992).

Unaccounted tag loss causes an upward bias in abundance estimates. There was an additional bias in the tagging estimates due to loss of tagged fish when handling effected downstream migration. Radiotagging experiments showed this loss was greater for the late run than for the early run (Bendock and Alexandersdottir 1993) because more of the late run migrating downstream was intercepted in the commercial fishery that occurs off the Kenai River.

Because of the statistical problems with the tagging estimates, a comparison of the sonar and tagging estimates was valid only for the early run. Early-run sonar and tagging estimates were available for 1988 and 1989. The tagging estimate was 19% greater than the sonar estimate for 1988 and 29% greater for 1989 (Table 2). Because the 95% confidence intervals for the tagging estimates included the sonar point estimate of abundance (Table 2) and allowing for bias of the tagging estimate, sonar and tagging estimates were consistent.

The use of side-looking, dual-beam sonar has been demonstrated to be a precise and potentially biased method of providing real-time estimates of the passage of upstream-migrating chinook salmon in the Kenai River. Because of the consistency of the early-run sonar estimates with the early-run tagging estimates, we believe sonar bias was negligible. The upstream-migrating chinook salmon were clearly bottom-oriented and migrated within the cross section of the river insonified. The vast majority of counted chinook salmon were migrating upstream. The target-strength data were consistent between early run and late run and indicate that the targets counted were chinook salmon. The temporal patterns of chinook salmon movement were dramatically influenced by tidal effects on the river currents. The chinook salmon moved upstream during periods of decreasing river currents on flooding tide and tended to hold during periods of increasing river currents on ebbing tide. This observation was consistent with the hypothesis that chinook salmon migrate upstream when bioenergetic costs are minimal. Because of the large sample volumes possible with side-looking sonar, the precision of the estimated passage was very high. Roughly one-third of the upstream-passing chinook salmon were counted, and the 95% confidence intervals were within a few percentage points of the estimated passage. The emerging data on Kenai River chinook salmon escapement have been used to establish initial biological escapement goals (McBride et al. 1989; Sonnichsen and Alexandersdottir 1991) for the early and late runs. The project is necessary for implementation of Kenai River chinook salmon management plans (ADF&G 1991), which set escapement objectives and allocate the burden of Kenai River chinook salmon conservation between the commercial gillnet and inriver recreational fisheries.

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