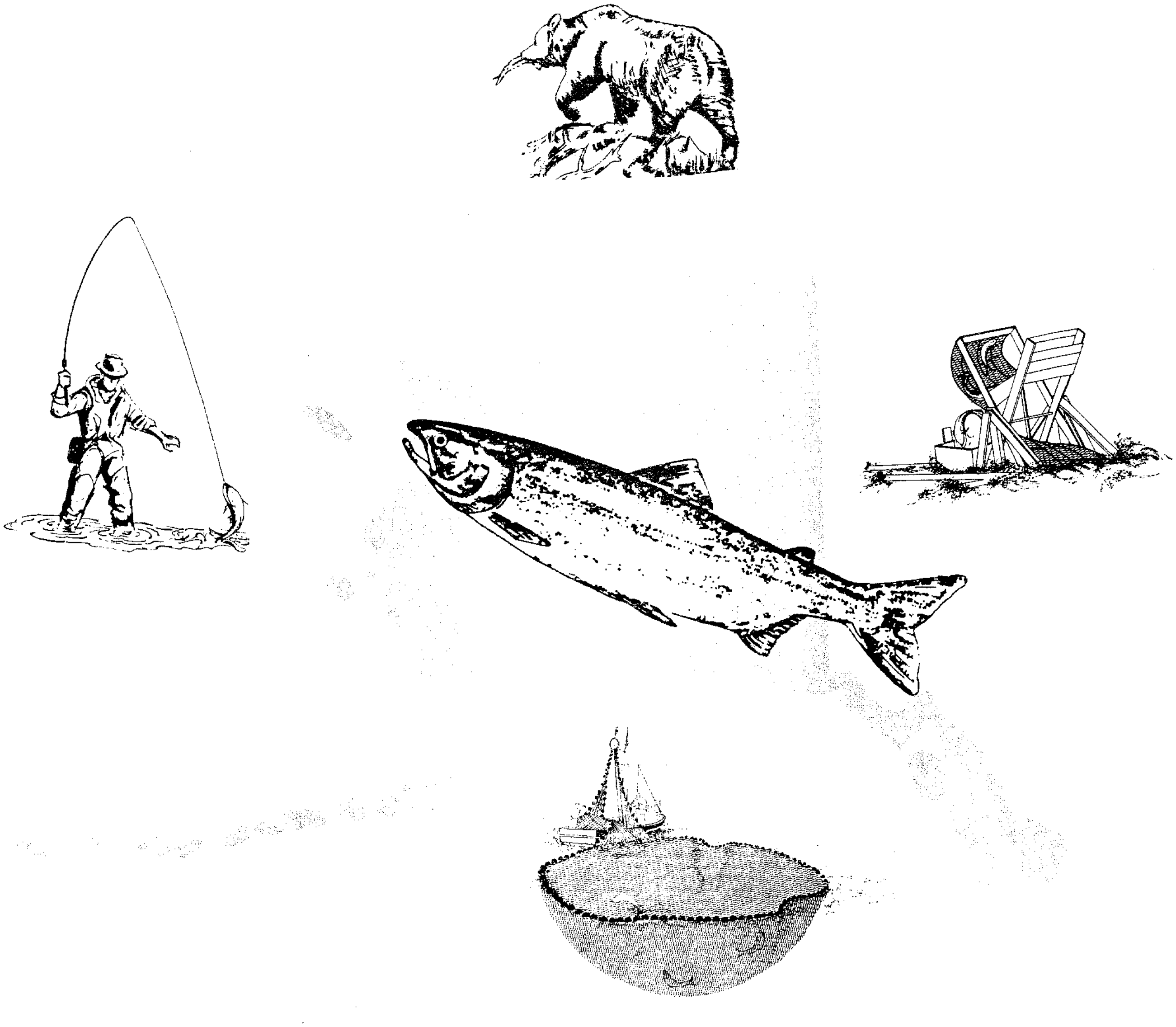
ENUMERATION OF CHANDALAR RIVER FALL CHUM SALMON USING SPLIT-BEAM SONAR, 1995

Alaska Fisheries Progress Report Number 96-2



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ABSTRACT

A five-year split-beam hydroacoustic study was initiated in 1994 to assess the population status of adult fall chum salmon *Oncorhynchus keta* on the Chandalar River, a tributary of the Yukon River. Objectives for the 1995 season were to continue developing site-specific operational methods, evaluate site characteristics, describe possible data collection biases, and provide a post-season estimate of adult chum salmon escapement. Elliptical transducers were sited on opposite river banks to optimize sonar beam coverage and aimed perpendicular to the river current. Both sites were in continuous operation from August 8 through September 22, except for a period of high water in late August.

Background noise levels were low, ranging from −49 to −42 dB on the left bank and −52 to −49 dB on the right bank. Throughout the season, *in situ* standard target strength measurements of a 38.1 mm tungsten carbide sphere were within 3.5 dB of factory values. Variability (SD) of on-axis target strength measurements during *in situ* calibrations were low, ranging from 0.48 to 1.05 dB. Variability increased as the standard target was moved off-axis.

Over 1,880 hours of digital echo processor data were "cleaned" and manually tracked, resulting in 256,090 fish written to file. Excluding down time from the high water event, 97% of the season's available sample time was monitored. Upstream traveling fish accounted for 98% of the total count; followed by 1% downstream and 1% undetermined. The number of acquired echoes per upstream fish averaged 18.5 on the left bank and 16.6 on the right bank. On average, upstream fish had a significantly higher number of acquired echoes than downstream fish.

Passage of upstream fish on the left bank showed a strong diel pattern with highest rates occurring during late night/early morning hours. Right bank diel patterns were not evident. Upstream fish were shore-oriented and traveled close to the river bottom. Downstream fish exhibited a wider spatial distribution. Average target strengths of upstream fish were approximately 2 dB higher than downstream fish. Throughout the season, the daily spatial position and target strengths of upstream fish remained fairly constant.

In situ target strength values were collected from 42 free-swimming fish marked with helium balloons. No correlation was found between fish length and acoustic size for chum salmon between 53 and 63 cm in length. Target strength was highly variable within each 1 cm length group. The spatial position (vertical and horizontal) of marked fish as they passed through the beam did not significantly differ from unmarked fish.

Chum salmon (N = 347) made up 99% of the catch from 41 h of gill netting. Chum salmon averaged 59 cm in length, ranging from 50-69 cm. Males made up 80% of the chum salmon catch. The 1995 data were similar to catch statistics from previous years, when catch was almost exclusively chum salmon. Results indicate that a species apportionment program is not needed for the Chandalar River.

The adjusted 1995 fall chum salmon escapement count through September 22 was 280,999 upstream fish, 4.8 times the 1986-1990 average of 58,628 fish. Passage of upstream fish increased through August 23, then remained high throughout the counting season. The highest daily count was 10,708 fish on September 13 and the median passage date was September 7. The right bank accounted for 59% of the total adjusted escapement. The precision of the estimate was believed to be high, since few adjustments to the actual count were needed (89% of the run was manually tracked). Spatial distribution of upstream fish suggested that few fish were undetected by the sonar. The adjusted count for 1995 represented a conservative estimate of total escapement because the passage rate stayed high through the last day of counting (8,227 upstream fish on September 22).

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INTRODUCTION

Accurate salmon escapement counts on Yukon River tributaries are important for assessing annual harvest management guidelines, predicting run strength based on brood year returns, monitoring long-term population trends, and influencing current U.S./Canada salmon treaty negotiations for allocating trans-boundary chinook *Oncorhynchus tshawytscha* and chum salmon *O. keta* stocks. Weirs, counting towers, mark-recapture programs, ground surveys, and hydroacoustics are methods used to obtain total escapement estimates of specific Yukon River salmon stocks (Bergstrom et al. 1996).

The Yukon River drainage, encompassing 854,700 km^2, is among the largest producers of wild chinook and chum salmon in North America. The salmon resources of this unique river support important subsistence and commercial economies throughout the drainage. The U.S. Fish and Wildlife Service, through Section 302 of the Alaska National Interest Lands Conservation Act, has a responsibility to ensure that salmon populations on refuge lands be conserved in their natural diversity, international treaty obligations be met, and subsistence opportunities be maintained. An important component of this mandate is accurate spawning escapement estimates for the major salmon stocks in the drainage.

In limited use in Alaska since the early 1960's (Gaudet 1990), fixed-location hydroacoustics provided counts of migrating adult salmon in rivers where other sampling techniques were not feasible, i.e., limited by visibility or sample volume. In 1992, the first riverine application of split-beam sonar technology was used to monitor upstream migrations of mainstem Yukon River salmon (Johnston et al. 1993; Huttunen and Skvorc 1994). Split-beam hydroacoustics has several advantages over single and dual-beam sonar systems. The split-beam technique provides three-dimensional positioning for each returning echo. This information is used to determine direction of travel and swimming behavior for each passing target. Also, the split-beam method is less influenced by noise than the dual-beam method (Ehrenberg 1983; Traynor and Ehrenberg 1990), giving more unbiased target strength estimates of returning echoes.

From 1986 to 1990, the U.S. Fish and Wildlife Service used fixed-location hydroacoustics to enumerate adult fall chum salmon escapement on the Chandalar River, located in the Yukon Flats National Wildlife Refuge (Daum et al. 1992). The results of this study indicated that Chandalar River fall chum salmon were the second largest stock of fall chum salmon in the U.S. portion of the Yukon River drainage. Because of the importance of Chandalar River fall chum salmon as a refuge and subsistence resource, and the recent declining trend of some Yukon River salmon stocks (Bergstrom 1995), a five-year study was initiated in 1994 to reassess the population status using split-beam hydroacoustics.

The initial year, 1994, was used to develop site-specific operational methods, evaluate site characteristics, and describe possible data collection biases (Daum and Osborne 1995). In 1995, a post-season estimate of total chum salmon escapement and *in situ* target strength evaluations were attempted. The specific objectives for the 1995 season were to:

1) develop operational methods and procedures for collection of continuous (24 h/d) acoustic data;
2) describe hydrographic conditions related to site selection and the acoustic environment;
3) calibrate the split-beam acoustic system;
4) verify the completeness of the acoustic data set and fish track all processor-produced files so only suspected fish targets are included in the data set;
5) analyze acoustic data to describe fish behavior and possible sampling biases;
6) collect species composition data to assess the need for species apportionment; and
7) describe run timing and estimate escapement of fall chum salmon.

STUDY AREA

The Chandalar River is a fifth order tributary of the Yukon River, draining from the southern slopes of the Brooks Range. It consists of three major branches: East; Middle; and North forks (Figure 1). Principal water sources include rainfall, snowmelt, and, to a lesser extent, meltwater from small glaciers and perennial springs (Craig and Wells 1975). Summer water turbidity is highly variable, depending on rainfall. The region has a continental subarctic climate characterized by the most extreme temperatures in the State: −41.7 to 37.8°C (U.S. Department of the Interior 1964). Precipitation ranges from 15 to 33 cm annually with the majority falling between May and September. The river is typically ice-free by early June and freeze-up occurs in late September to early October.

The lower 19 km of the Chandalar River is influenced by a series of slough systems connected to the Yukon River. River banks are typically steep with overhanging vegetation and downed trees caused by active bank erosion. Gravel bars are absent in this area and the bottom substrate is primarily sand and silt. Water velocities are generally less than 0.75 m/s. Twenty-one to 22.5 km upstream from its confluence with the Yukon River, the Chandalar River is confined to a single channel with steep cut banks alternating with large gravel bars. Above this area, the river becomes braided with many islands and multiple channels.

The sonar site (located at River Kilometer 21.5) was previously described by Daum et al. (1992; Figure 2). Site selection requirements included: 1) single channel; 2) moderate laminar flow; 3) gradually sloping bottom gradient; 4) absence of highly reflective bottom substrate; 5) downriver from known salmon spawning areas; and 6) active fish migration. The left bank (looking downstream) has a steeper bottom gradient and faster water velocity than the right bank. Bottom substrate consist of small rounded cobble/gravel on the left bank and sand/silt on the right bank.

METHODS

Data Collection (Objective 1)

Fixed-location split-beam hydroacoustics was used to monitor the upstream migration of adult fall chum salmon on the Chandalar River in 1995. Systems were sited on opposite river banks to optimize sonar beam coverage of the river cross-sectional area. Both sites were operational from August 8 through September 22, except for one period of high water beginning on August 17. During the high water event, the left bank system missed three days of sampling and the right bank system missed six days.

Equipment description

Two Hydroacoustic Technology, Inc. (HTI) split-beam systems were used throughout the study. Each system consisted of a 200 kHz split-beam echo sounder, digital echo processor, elliptical-beam transducer, 150 m transducer cable, chart recorder, oscilloscope, digital audio tape recorder, and data analysis computer (Figure 3). Specific component descriptions and operations are detailed in HTI manuals (HTI 1994a, 1994b). A Remote Ocean Systems underwater rotator was attached to the transducer housing to facilitate remote aiming. For each bank, sonar equipment was housed in a portable shelter and powered by a 3.5 kW gasoline-powered generator. System additions in 1995 included optical disk drives and networking capabilities, allowing communication and fast data transfer between the echo sounder, echo processor, and analysis computer. FM slide, frequency modulation hardware, was installed in the right bank echo sounder to reduce background noise levels (Ehrenberg 1995).

Echo sounder settings

Echo sounder settings differed between banks. Left bank settings were: 25 dB_W transmit power; -18 dB_V total receiver gain; $40 \cdot \log_{10}(R)$ time-varied gain function, where R = target range (m); 0.2 ms pulse width; and 10 pings/s ping rate. Right bank settings were: 19 dB_W transmit power; -18 dB_V total receiver gain; $20 \cdot \log_{10}(R)$ time-varied gain function; 1.17 ms pulse width; and 6.25 pings/s ping rate. Sounder settings were influenced by the desire to transmit the highest power into the water (transmit power) while using the lowest amplification (receiver gain) to receive returning echoes. FM slide, *in situ* calibration, and signal cross-talk also affected echo sounder settings. The time-varied gain function on the right bank was incorrectly set by the manufacturer, causing range dependent errors in voltage calculations from returning echoes (*see Discussion*).

Data acquisition

Three system components were used to record hydroacoustic data: digital echo processor; chart recorder; and digital audio tape recorder. The digital echo processor received output from the echo sounder, processed and stored acoustic data, and provided real-time screen displays of fish passage. Excluding the high water event, the processor was run continuously throughout the season, except for short periods used for *in situ* calibration, transducer aiming, and generator maintenance. All down times were recorded in processor-generated data files and log books.

Processor data files were created once per hour. Files included only returning echoes that met user-controlled pulse width, angle off-axis (vertical and horizontal), signal strength threshold, and range criteria (Table 1). A detailed description of file contents can be found in Johnston et al. (1993) and HTI (1994b). On both banks, the echo acceptance criterion for minimum vertical angle off-axis was decreased below the nominal beam angle of each transducer so echoes from fish traveling very close to the bottom substrate would be accepted into the processor data files. Pulse width criteria were widened from 1994 settings, allowing more returning echoes to be included in the data base. Voltage threshold values were kept constant throughout the season and were similar between banks, -39.9 dB on-axis (0.2 V) for the left bank and -39.8 dB (0.3 V) for the right bank. Acquisition range changed due to transducer re-deployment as water levels varied, left bank varied from 10-16 m and right bank from 80-90 m. All changes to processor settings were recorded in hourly files and log books. Files were backed-up daily; data were transferred via network to a computer for data analyses and compressed onto optical disks for storage. The network, installed in 1995, allowed data to be backed-up and analyzed without interrupting real-time data collection.

Permanent chart recordings were collected for 2 h/d throughout the season and run concurrently with the digital echo processor. Unlike digital echo processor data files, echogram recordings were not filtered by pulse width or angle off-axis criteria. Echograms were used for data back-up, transducer aiming, and visual evaluation of the echo sounder and fish tracking performance. Voltage threshold settings were kept constant throughout the season and were equal to echo processor settings. The acquisition range for chart recordings was increased beyond echo processor settings. This allowed echograms to be examined for fish traveling beyond the data acquisition range of the echo processor. All chart recorder settings and changes were recorded on real-time echograms and in log books.

Digital audio tape recordings were made throughout the season to collect permanent records of background noise levels and standard target calibrations. Recordings were direct outputs from the echo sounder, i.e., incoming signals were not filtered for threshold, pulse width, or angle off-axis criteria.

Transducer deployment

One elliptical-beam transducer per bank was used throughout the 1995 season. Elliptical-beam transducers maximize sampling volume for targets moving horizontally in the water column (migrating fish) while maintaining a small vertical angle fitted to shallow water conditions (as in rivers). The nominal beam widths (measured at -3 dB down the acoustic axis) were 4.6 by 10.8° on the left bank and 2.8 by 11.3° on the right bank. Low side-lobe transducers were used so the beam could be aimed close to the river bottom (-16.7 dB for the left bank and -19.5 dB for the right bank).

The transducers and remote-controlled rotators were mounted on aluminum T-bars and secured in place with sandbags at a depth of 0.6-1.5 m (Figure 4). Transducers were oriented perpendicular to river flow and positioned as close to the river bottom as substrate and contour allowed, usually within 10 cm of the bottom. Before deployment, the transducer face was washed with soap solution to eliminate foreign matter and air bubbles that could affect performance. A wire fence weir (5 x 10 cm mesh) was installed 1 m downstream and extended beyond the transducer face. Fish moving upstream and close to shore would encounter the weir, be forced to move offshore, and then pass through the sonar beam. Weirs were extended roughly twice the distance past calculated near-field distance values (MacLennan and Simmonds 1992) for each transducer, 1.3 m on the left bank and 3.2 m on the right bank.

Transducers were aimed using dual-axis remote rotators, allowing vertical and horizontal adjustments. Precise aiming was critical because most fish traveled close to the bottom. A small rise in vertical aim could allow fish to pass undetected under the beam. Chart recordings, oscilloscope readings, and real-time displays from the digital echo processor were used to determine proper aiming. The low acoustic reflectivity of right bank substrate (silt and sand) required the use of a target (approximately −24 dB in acoustic size) placed on the bottom during transducer aiming. The right bank transducer could be aimed slightly into the bottom substrate, enhancing detection of bottom-oriented fish. Whenever the transducer assembly was moved, proper beam orientation was checked by vertically sweeping a stationary standard target through the beam (*see Methods, System calibration*). All changes in transducer aiming and re-deployment were recorded in log books.

Hydrographic Conditions (Objective 2)

River profile and beam fit

Determining a site-specific river profile is essential before initiating annual sonar operations. Transducer beam selection and bottom irregularities that may allow fish to go undetected can be determined from accurate river profiles. Bottom profile measurements were made from July 27-30, 1995. A Lowrance chart recording depth sounder, with an 8° transducer mounted below a river boat's hull, was used for recording water depth. Transect markers were spaced along each bank at 15 m intervals. Transects were run perpendicular to river flow from each marker to the thalweg, keeping boat speed as constant as possible. Buoys were placed at known distances from shore and used as reference points when performing transects. Charts were redrawn, adjusting horizontal distances from buoy location data. These bathymetric maps were used to select the best beam fit and transducer deployment site for each bank.

Hydrologic measurements

A river elevation gauge was installed by the right bank sonar site and monitored throughout the season. Water elevation was recorded daily to the nearest 0.6 cm. A permanent gauging site was established in 1989 so water levels among years could be compared (Daum et al. 1992). Water temperature (°C) and conductivity (μS/cm) were measured daily using a mercury-filled thermometer and Hach mini-conductivity meter.

Background noise

Noise can affect the ability to detect acoustic targets (MacLennan and Simmonds 1992). Average peak amplitude noise levels at range were recorded throughout the season in the active (transmitting/receiving) and passive (receiving) condition using a digital oscilloscope.

Permanent recordings of noise levels were stored on digital audio tapes. Noise measurements were expressed in similar units to signal strength (dB), using

$$TS_n = 20 \cdot log_{10}(V) - SL - G_o - R_g, \quad (1)$$

where TS_n= noise signal strength (dB), V= noise level (V), SL = source level ($dB_{\mu Pa}$), G_o= through-system gain ($dB_{\mu Pa}$), and R_g= receiver gain (dB_V).

System Calibration (Objective 3)

Complete system calibration was performed pre-season by HTI using the comparison method referenced in Urick (1983). Transducer calibration data (power output and receiving sensitivity) and beam pattern plots were provided (HTI 1995). Before data collection began, current calibration data were entered into parameter files for the digital echo processor and were used to calculate threshold settings for processor data and chart recordings. Beam pattern plots were used to describe the nominal beam widths for specific transducers. Target strength measurements were also recorded from a standard target, 38.1 mm tungsten carbide sphere (Foote and MacLennan 1984), suspended 6 m beyond the transducer and positioned on the acoustic axes. The right bank echo sounder was factory calibrated without the FM slide frequency modulation hardware. Installation of FM slide occurred in the field on August 2, 1995.

In situ calibration data were collected three times during the season using the 38.1 mm tungsten carbide sphere. The target was washed in soap solution and suspended in the water column by a monofilament line attached to a fiberglass pole. The real-time echo position display from the digital echo processor facilitated accurate positioning of the sphere in the acoustic beam. The target was kept 4 to 6 m beyond the transducer face, exceeding the near-field distance for each transducer. When the target's location stabilized, acoustic data were electronically collected from the standard target. With each bank's transducer aimed in the data acquisition position (bottom edge of beam on the river bottom), two standard target measurements were made. One measurement was taken with the standard target positioned on the beam's acoustic axes, allowing comparisons to factory calibration data. The second measurement was made by lowering the target near the bottom edge of the beam, attempting to duplicate the vertical position of bottom-oriented fish. This target position permitted an examination of target strength bias related to vertical target location. Mean target strength values for the standard target positioned on and off-axis were compared for each calibration period using a two-sample *t* test for means with unequal variances (Zar 1984). Variability in target strength measurements between the on and off-axis target positions were compared using a *F* test (Zar 1984). During calibration, noise levels were recorded on digital audio tapes and echo processing parameters documented. All erroneous echoes were deleted from data files before analysis.

Acoustic Data Verification and Fish Tracking (Objective 4)

Before analyses of acoustic data began, all hourly files from the digital echo processor were examined for completeness and data integrity. Subsequently, the processor files were "cleaned" of erroneous data (echoes from passing debris, rocks, motor boat wake, and acoustic noise). This was accomplished by manually tracking each suspected fish target with HTI Trakman software, version 1.11. Acoustic data from each echo in a suspected fish target were examined for upstream/downstream directional progression and range variability. Anomalous echoes were discarded. As a result, hourly tracked fish files were produced which included only suspected fish targets, although some downstream debris could not be differentiated from downstream fish. A description of tracked fish files (**.ech* and **.fsh* files) can be found in Johnston et al. (1993) and HTI (1994b). For clarity, all tracked targets will be referred to as fish. Fish were grouped into upstream and downstream categories based on direction of travel values reported in the tracked fish files. If the total distance traveled in the upstream/downstream direction was < 0.1 m, that fish was excluded from any directional analyses. For each bank, hourly sample times and upstream/downstream fish counts were tabulated. Also, the number of acquired echoes per fish were tabulated and plotted. Mean number of acquired echoes between upstream and downstream fish by bank were compared using a two-sample t test for means with unequal variances. Only tracked data were used in all subsequent analyses contained in this report.

Acoustic Data Analyses (Objective 5)

Temporal distribution of tracked fish

Descriptions of diel fish passage rates are needed to develop future sampling schedules and daily count adjustments. Hourly passage rates (fish/h) for upstream fish were calculated for all hours with sample times ≥ 15 min. Hourly rates were plotted by bank. Also, seasonal mean hourly passage rates for upstream fish were determined using only days with 24 h of continuous data, 33 days on the left bank and 35 days on the right bank. Hourly passage rates were expressed as proportions (%) of the daily count so high passage days did not bias results. Mean hourly passage rates (%) and standard deviations were calculated for the entire season and plotted by bank.

Spatial distribution of tracked fish

Fish position data provide an assessment of the likelihood of not detecting fish that pass above, below, or beyond the detection range of the sonar beam. Also, spatial information furnish insight into behavioral differences between upstream and downstream swimming fish and between fish of different species. Midpoint range (horizontal distance from transducer) values were calculated for all tracked fish and used for subsequent analyses,

$$R_m = R_s + (D_r/2), \qquad (2)$$

where R_m= midpoint range (m), R_s= starting range coordinate (m), and D_r= distance traveled in range direction. Midpoint vertical positions of tracked fish were calculated and converted to angle off-axis measurements before analyses,

$$V_m = arcsine\ \{[V_s+(D_v/2)]/R_m\}, \tag{3}$$

where V_m= vertical midpoint angle off-axis (°), V_s = starting vertical coordinate (m), D_v = distance traveled in vertical direction (m), and R_m= midpoint range (m). Range and vertical distributions of upstream and downstream fish were plotted for the season. Seasonal mean range and vertical position of upstream and downstream fish were compared by bank using a two-sample *t* test for means with unequal variances. Also, daily mean values were calculated and plotted.

Target strength distribution of tracked fish

Acoustic target strength data may be useful in differentiating fish species according to size, filtering out small debris, and assessing sampling bias due to voltage threshold settings. Mean target strength values for each fish were calculated. Target strength distributions of upstream and downstream fish were plotted for the season. Mean target strengths of upstream and downstream fish were compared using a two-sample *t* test for means with unequal variances. Also, daily mean values were calculated and charted. Right bank target strength data were not presented because of the incorrect factory setting for the time-varied gain function in the FM slide hardware which affected target strength measurements (*see Discussion*).

Fish orientation in the beam and noise-induced bias affect the precision of target strength estimates. Precision of target strength estimates were measured using within-fish target strength variability for upstream and downstream fish. Standard deviations for each fish were plotted and mean values were calculated. Mean within-fish target strength variability (SD) between upstream and downstream fish was compared using a two-sample *t* test for means with unequal variances.

Theoretical target strength values are used to estimate appropriate voltage threshold settings for acoustic data collected from fish of specified lengths. Approximate echo acceptance voltage thresholds for Chandalar River fall chum salmon were determined pre-season using a derivation of Love's (1977) side-aspect equation,

$$TS_S = 10 \cdot \log_{10}[(0.0075\ m/cycle)^2 \cdot 0.074 \cdot (L/0.0075\ m/cycle)^{1.9} / 4\pi], \tag{4}$$

where TS_S = side-aspect target strength (dB) ± 15° and L= fish length (m). Expected target strength values for Chandalar River fall chum salmon having lengths between 50-70 cm (Daum et al. 1992) were calculated. Since equation (4) was derived from entrained, anesthetized non-salmonids, biases may be introduced when applying the formula to free-swimming, sexually ripe salmon. A target strength experiment with free-swimming fish was attempted to: 1) evaluate the appropriateness of using Love's equation to estimate target strengths of Chandalar River fall chum salmon; and 2) describe the variability of *in situ* target strength measurements in a riverine acoustic environment. Chum salmon were captured with gill nets and length was measured to the nearest centimeter, from mid-eye to the fork in the caudal fin. One small helium-filled balloon was attached to the dorsal fin of each salmon using 5 m of light weight monofilament fishing line. Marked fish were then released below the left bank sonar site and visually followed past the left bank transducer. Fish were recorded simultaneously by the echo processor and chart recorder. Electronic files and charts were time stamped for easy identification. Echoes from marked fish were manually tracked using Trakman software and written to file. Files with multiple fish targets were deleted to ensure that only marked fish were included in the analyses. The hypothesis that acoustic target strength increased with fish length was tested using simple linear regression analysis (Zar 1984). The variability of *in situ* target strength measurements for fish of equal length was described and related to Love's equation. Differences in spatial positioning between ballooned and unmarked upstream fish were assessed by comparing the average ranges and vertical positions of the two groups using a two-sample t test for means with unequal variances.

Species Composition (Objective 6)

Fish species composition was determined from gill net catch. Nets were 30.5 m long and 3.7 m deep, with stretch mesh sizes of 11.4 and 14.9 cm. Nets were set from shore on both banks and drifted near-shore on the left bank. Drift netting was abandoned early in the season due to large numbers of snags in the river. Each mesh size was fished approximately 4 h/week throughout the season. Nets were checked frequently to minimize fish mortality. Fishing effort, fish species captured, and fish lengths were recorded. Salmon were measured to the nearest centimeter, from mid-eye to the fork in the caudal fin. Non-salmon species were measured from the tip of the snout to the fork in the caudal fin. Fish were caudal fin marked for recapture identification. Chum salmon length data from the two mesh sizes were compared using a two-sample t test and F test.

Run Timing and Escapement Estimate (Objective 7)

Daily and seasonal estimates of upstream fish passage were calculated from tracked fish files. Though infrequent, time lapses in data acquisition (*see Methods, Data collection*) required adjusting tracked fish counts before daily and seasonal totals were calculated. Adjustments were made for partial hours, missing hours, and missing days. Partial hourly counts ($\geq$ 15 and < 60 min) were standardized to 1 h, using

$$C_e = (60 / T) \cdot C_a , \tag{5}$$

where C_e= estimated hourly count, T = number of minutes sampled in the hour, and C_a= actual upstream count during the sampled time. Counts from hours with sample times < 15 min were discarded and treated as missing hours.

Daily counts for each bank were calculated by summing all 24 hourly counts. On days when one or more hourly counts were missing, the missing hours were extrapolated from seasonal mean hourly passage rates for each bank (*see Methods, Acoustic data analyses; Figure 12*), using

$$C_m = [R_h / (100 - R_h)] \cdot \sum C_h, \qquad (6)$$

where C_m = estimated hourly count for missing hour, R_h = seasonal mean hourly passage rate (%) for missing hour, and $\sum C_h$ = sum of all non-missing hourly counts for that day. Then daily counts were generated by summing all missing hourly estimates with all non-missing hourly counts.

During the high water event, the missed daily counts for each bank were estimated by linear interpolation between the daily count before and after the event. Adjusted daily and seasonal totals of upstream fish passage were tabulated and graphed.

RESULTS

Hydrographic Conditions (Objective 2)

River profile and beam fit

A bathymetric map of the specific sonar sites with estimated ensonified zones is presented in Figure 5. River bottom slopes were approximately 7.2° on the left bank and 3.1° on the right bank, corresponding to vertical transducer beam widths (echo acceptance criteria) of 5.8 and 3.4°, respectively. On the right bank, the bottom slope decreased by approximately 0.3° from the 1994 season (Daum and Osborne 1994); likely caused by sand and silt deposited from last year's flood. The left bank's data acquisition range was limited due to a decrease in bottom slope at approximately 16 m from the transducer. The final 10 m distance to the thalweg was not acoustically sampled due to this bottom inflection. Right bank beam coverage was nearly complete, with acquisition range extending close to the thalweg (roughly 90 m distance from the transducer).

Hydrologic measurements

River depth and width varied considerably during the season. River stage was highest on August 16 (5.5 m deep and 188 m wide) and lowest on August 31 (3.6 m deep and 140 m wide). For the majority of the 1995 season, water levels were substantially higher than the 1989-1990 average (Figure 6). Water temperature generally decreased as the season progressed from 15 to 6°C and conductivity remained fairly constant, ranging from 230 to 320 μS/cm (Figure 7).

Background noise

Background noise levels on the left bank varied from −49 to −42 dB for the data acquisition range of 1-16 m. Noise generally increased with range. Passive noise level (no transmitting) was −64 dB at 100 m range.

Right bank noise levels ranged from -52 to -49 dB for the data acquisition range of 1-90 m. Noise was highest 1-40 m out from the transducer. Passive noise level was -64 dB at 100 m range.

System Calibration (Objective 3)

Mean target strength measurements of the standard target from factory calibrations were within 1.5 dB of the predicted value of -39.5 dB (MacLennan and Simmonds 1992), -38.08 dB for the left bank system and -38.23 dB for the right bank system. The initial field calibration of the right bank system (FM slide installed) revealed a difference of approximately 6 dB from the factory calibration (FM slide not installed). The transmit power was reduced by 6 dB (echo sounder setting changed to 19 dB_W) to correct for this variation.

For the season, mean on-axis target strength measurements from *in situ* calibrations were within 3.5 dB of factory values (Table 2). For all three calibration periods, right bank mean on-axis target strength measurements were significantly greater than off-axis values (P values < 0.001). Left bank calibrations did not exhibit any trends. Target strength variability was low during all on-axis calibrations, with standard deviations varying from 0.48 to 1.05 dB. For each calibration period, the variability in target strength measurements for the standard target positioned near the bottom edge of the beam was significantly greater than the target positioned on-axis (P values < 0.001).

Acoustic Data Verification and Fish Tracking (Objective 4)

Summary information for all tracked echo processor files are presented in Tables 3 and 4. All data files for the entire season were manually tracked, resulting in 256,090 fish from over 1,880 hours of "clean" processed data. Excluding down time from the high water event, 97% of the season's available sample time was monitored. Upstream fish accounted for 98% of the total count, followed by 1% downstream and 1% undetermined. The number of acquired echoes per upstream fish averaged 18.5 on the left bank (range of 3-322) and 16.6 on the right bank (range of 3-240), with medians of 16 and 14 hits per fish, respectively (Figures 8 and 9). Downstream fish averaged 14.7 echoes per fish on the left bank (range of 4-240) and 12.4 on the right bank (range of 3-232), with medians of 12 and 9 hits per fish, respectively. On average, upstream fish had significantly more acquired echoes per fish than downstream fish for each bank (P values < 0.001).

Acoustic Data Analyses (Objective 5)

Temporal distribution of tracked fish

Passage of upstream fish on the left bank exhibited a strong diel pattern with highest passage rates occurring during late night/early morning hours (Figure 10). Right bank fish did not show any trend in diel distribution for the season (Figure 11). Mean hourly passage rates for left bank fish also showed a strong diel tendency among upstream fish (Figure 12). These results are similar to findings from the 1994 season (Daum and Osborne 1994).

Spatial distribution of tracked fish

Upstream fish were shore-oriented and appeared to be well within the range of detection for both banks (Figures 13 and 14). Approximately 90% of upstream fish were within 7 m of the left bank transducer and 20 m of the right bank transducer. Downstream fish were more spread out across the full detection range. For both banks, the average range of upstream fish was significantly less than downstream fish (*P* values < 0.001). Over the entire season, the daily mean ranges of upstream fish were generally closer to shore than downstream fish (Figure 15). Also, the daily mean ranges of upstream fish were fairly constant throughout the season, with left bank values varying from 4 to 6 m and right bank values varying from 10 to 16 m. Downstream daily range averages were highly variable.

Vertical fish position data indicated that upstream fish on both banks were bottom-oriented (Figures 16 and 17). Approximately 99% of upstream fish on the left bank and 91% of fish on the right bank were below the acoustic axis. On both banks, downstream fish were more widely distributed throughout the ensonified zone. The average vertical position of upstream fish was significantly lower than downstream fish for both banks (*P* values < 0.001). This tendency was also apparent in the daily vertical position between upstream and downstream fish (Figure 18). Daily means for upstream fish were very constant throughout the season, indicating stability of transducer aim and fish position on both banks.

Target strength distribution of tracked fish

Mean target strength was significantly different between upstream and downstream fish on the left bank (*P* < 0.001; Figure 19). Target strengths of upstream fish, on average, were approximately 2 dB higher than downstream fish. The voltage threshold setting of 0.2 V probably introduced very little bias to upstream fish target strength estimates since the majority of fish target strengths were substantially above threshold. The average daily target strengths of upstream and downstream fish on the left bank generally followed the same trend, upstream fish were acoustically larger than downstream fish (Figure 20). Upstream mean target strengths stayed fairly constant throughout the season, having daily target strength variability similar to standard target calibrations (around 3 dB). Mean within-fish target strength variability was greatest for upstream fish (*P* < 0.001; Figure 21), with a mean standard deviation of 4.14 dB for upstream fish and 3.87 dB for downstream fish.

Target strength measurements were taken from 42 ballooned fish as they passed the left bank transducer, with an average of 33 acquired echoes per fish (Table 5). Fish lengths varied from 53 to 63 cm. Five fish passed through the beam twice (traveling upstream through the beam, falling back, and swimming upstream past the beam again), allowing two distinct measurements of individual fish. No correlation was found between fish length and acoustic size ($r = 0.098$; $P = 0.54$), i.e., target strength did not increase with fish length (Figure 22). Target strength was highly variable within each 1 cm length group. For example, chum salmon with lengths of 60 cm had measured acoustic sizes from −30.58 to −21.86 dB. This high variability in target strength values for fish of equal length rendered the application of

Love's equation inappropriate. Using actual target strength measurements, Love's equation would have predicted that the 60 cm fish mentioned previously were between 47 and 136 cm in length (Table 6). The spatial position of ballooned fish as they passed through the beam did not appear to differ from unmarked fish. All marked fish passed well below the acoustic axis, averaging -1.87°. No significant differences were found between the mean spatial positions (both vertical and horizontal) of ballooned and unmarked fish (P values > 0.1).

Species Composition (Objective 6)

In 1995, gill nets captured 349 fish: 347 chum salmon; one chinook salmon *Oncorhynchus tshawytscha*; and one northern pike *Esox lucius*. Chum salmon made up 99% of the catch. The chinook salmon was captured on the first day of sampling, August 9. For the season, total effort was 41 h, distributed between the two mesh sizes (Table 7). Chum salmon averaged 59 cm in length, ranging from 50-69 cm. Males made up 80% of the catch. None of the caudal-marked fish were recaptured. Length frequency distributions of chum salmon captured from both mesh sizes are presented in Figure 23. Mean fish length was greater ($P < 0.005$) and associated variance smaller ($P < 0.02$) for the larger mesh gear.

Run Timing and Escapement Estimate (Objective 7)

The adjusted 1995 fall chum salmon escapement count for the Chandalar River was 280,999 upstream fish (Table 8), the highest estimate since sonar operations began in 1986. The 1995 count was 4.8 times the 1986-1990 average of 58,628 fish (Daum et al. 1992; Figure 24). Daily counts were over 1,000 fish/d for 39 of the 46 counting days. Passage of upstream fish increased through August 23, then continued high throughout the remainder of the counting season. The highest daily count was 10,708 fish on September 13. The median passage date was September 7, similar to 1986-1990 results. Run timing between banks was different, with left bank counts increasing earlier and dropping off quicker than right bank counts (Figure 25). The right bank accounted for 59% of the total adjusted escapement.

Few adjustments to the upstream fish count were needed, since over 89% of the run was actually tracked (251,017 out of the final adjusted upstream count of 280,999 fish). Adjustments for partial hours made up only 11% of all hourly counts, with the majority of incomplete hours having sample times > 0.75 h. Adjustments for missing hours made up only 3% of all hourly counts. The largest block of missing data was from the high water event beginning on August 17, with the left bank system missing three complete days and the right bank system missing six days. This represented 10% of the entire 46 day sampling period, 6.5% on the left bank and 13% on the right bank.

DISCUSSION

In an attempt to lower high background noise levels found on the right bank in 1994, FM slide hardware was installed into the right bank's echo sounder in 1995. Noise levels decreased by approximately 14 dB after installation. Unfortunately, the time-varied gain function was incorrectly set by the manufacturer to $20 \cdot \log_{10}(R)$, resulting in biased voltage readings from incoming acoustic signals (both background noise and target strength estimates). The incorrect setting caused higher than expected signal amplification for targets closer than 11.2 m from the transducer and lower than expected amplification for signals past 11.2 m. However, the shore-oriented behavior and acoustic size of Chandalar River chum salmon reduced the probability of missing fish. Acoustic data supports the assumption that few fish were missed. Upstream fish on the right bank had similar range distributions between years and fish that were acoustically tracked at long distances from the transducer (50-80 m) had long, continuous echo traces across the full beam width. The success of FM slide in eliminating noise problems on the right bank could not be quantitatively evaluated, but likely made only minor improvements to signal/noise ratios (S. Johnston, Hydroacoustic Technology, Inc., personal communication). It is believed that high noise levels on the right bank are due largely to surface and bottom acoustic reverberation caused by shallow bathymetry, which only a narrower vertical beam transducer would correct. Therefore, a 2.0 by 10.0° transducer will be used during the 1996 season.

Fish position data suggested that most upstream fish were within the ensonified zone of detection during the 1995 season. Chart recordings revealed that few targets passed beyond the acquisition range used for acoustic data collection. However, the final 10 m distance to the thalweg was not ensonified on the left bank due to the bottom inflection at approximately 16 m offshore of the transducer. The left bank sonar site was moved approximately 100 m downstream from the 1994 site. Even though range acquisition did not improve, upstream fish behavior did change. Fish were significantly closer to the transducer in 1995 (*t* test, $P < 0.001$), with fewer fish near the outer range limit of acoustic detection. The shore/bottom orientation of Chandalar River chum salmon was consistent with previous behavioral observations of upstream migrating fall chum salmon on the Sheenjek (Barton 1995) and mainstem Yukon rivers (Johnston et al. 1993).

The *in situ* target strength experiment on the Chandalar River suggested that target strength measurements could not differentiate between chum salmon of different lengths. On the Kenai River, Eggers (1994) and Burwen et al. (1995) were unable to discriminate between sockeye *Oncorhynchus nerka* and chinook salmon based on target strength. The high variability found in target strength values, both within-fish and between fish, were likely caused by low signal/noise ratios found in riverine environments, fish behavior, and backscattering properties of the target. Results from 1995 *in situ* calibrations showed up to a four-fold increase in target strength variability for the standard target positioned near the bottom of the beam compared to an on-axis position. Since Chandalar River chum salmon are bottom-oriented, high variability in target strength measurements would be expected. To obtain accurate estimates of fish target strength, the voltage threshold for acoustic data collection should be set substantially lower than predicted target strength values for fish of given lengths. Otherwise, smaller acoustic signals may be ignored, resulting in elevated target strength calculations for some fish (MacLennan and Simmonds 1992).

Large numbers of non-target fish species on the Chandalar River could influence the ability to accurately estimate chum salmon passage using hydroacoustics. If fish species could not be acoustically differentiated, species apportionment techniques would be required. Gill netting results from 1995 were consistent with previous years on the Chandalar River (Daum and Osborne 1995; Daum and Simmons 1991; Daum et al. 1991; Simmons and Daum 1989). Chum salmon made up over 99% of the catch in each of the five seasons. Of the 820 fish captured, only four were not chum salmon (two humpback whitefish *Coregonus pidschian*, one chinook salmon, and one northern pike). Acoustic data indirectly supports the catch results. A temporal change in either spatial distribution (range or vertical position), direction of travel, swimming behavior in the beam, or average target strength of tracked fish may indicate a shift in species composition, especially in highly concentrated migratory species such as whitefishes. Daily mean ranges, vertical positions, and target strengths of upstream fish were very constant throughout the 1995 season, suggesting that large numbers of other fish species were not present. As such, the species apportionment netting program will be discontinued during the fall chum salmon migration unless in-season sonar data indicate otherwise. Future fall estimates of upstream fish passage on the Chandalar River will assume that all counts represent chum salmon.

The adjusted 1995 count of 280,999 fall chum salmon on the Chandalar River was the highest on record and was consistent with other upper Yukon River escapement estimates. Both the Sheenjek River and mainstem Yukon River border escapement projects reported record run sizes in 1995 (Bergstrom et al. 1996). The Sheenjek River, located 116 km upstream from the Chandalar River, had similar run characteristics. Both rivers had high daily counts throughout the season, with the median passage date on the Sheenjek River (September 9) lagging two days behind the Chandalar River's median date (L. Barton, Alaska Department of Fish and Game, personal communication).

The precision of the 1995 adjusted seasonal estimate for Chandalar River fall chum salmon is believed to be high, since few adjustments to the actual tracked fish count were needed. Variances and associated confidence intervals were not calculated around the seasonal estimate for two reasons. First, a method for estimating the variance for the block of time missed during the high water event (nine days) has not been developed. Second, since acoustic data were collected for 97% of the remaining time (excluding the high water event), the associated variance would be small. Using this variance estimate to describe the variance around the total seasonal estimate would have underestimated the actual value. On the Kenai River, the 95% confidence interval around the seasonal estimate of upstream-passing chinook salmon ranged from ± 3.8 to ± 6.3% when roughly 33% of the run was acoustically counted (Eggers et al. 1995). The mainstem Yukon River sonar project yielded estimates of chum salmon with 90% confidence intervals of ± 4.8 and ± 6.9%, when approximately 31% of the run was counted and species apportionment also had to be estimated (Fleischman et al. 1995). The precision of the Chandalar River estimate should be higher than the values described in these similar hydroacoustic projects, since the Chandalar River study had far greater run coverage (both in sample time and volume) and species apportionment was not necessary.

Providing timely escapement counts to fishery managers is an overall objective of this project. Verification and tracking of the acoustic data base is essential before accurate daily and seasonal counts can be determined for Chandalar River fall chum salmon. However, tracking software is still in a developmental state, making data "cleaning" and fish tracking a very labor intensive activity. In 1996, an attempt will be made to provide daily in-season counts of Chandalar River fall chum salmon passage. As in 1995, sampling schedules for the 1996 season will attempt 24-h continuous acoustic monitoring from each bank. Sub-sampling may become necessary if in-season manual fish tracking falls behind schedule due to large numbers of salmon or unforseen deficiencies in software development.

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Table 1. Echo acceptance criteria used for digital echo processing, Chandalar River, 1995. Range values represent the variation in individual settings during the season.

Bank	Pulse width (ms) at -6 dB	Vertical angle off-axis (°)	Horizontal angle off-axis (°)	Threshold (dB)	Range (m)
Left	0.10 to 0.30	-3.50 to 2.30	-5.40 to 5.40	-39.9	10 to 16
Right	0.10 to 0.30	-2.00 to 1.40	-5.50 to 5.50	-39.8	80 to 90

Table 2. Target strength measurements of a 38.1 mm tungsten carbide sphere, Chandalar River, 1995.

Type of calibration	Date	Mean target strength (dB)	SD	N	Position of target
		Left bank			
Factory	Jul 3	-38.08	0.39	1,732	On-axis
In situ	Aug 5	-37.85	1.05	2,720	On-axis
In situ	Aug 15	-37.82	0.82	2,706	On-axis
In situ	Aug 15	-34.54	3.07	1,005	Bottom of beam
In situ	Sep 19	-35.61	0.78	2,953	On-axis
In situ	Sep 19	-35.59	2.10	2,108	Bottom of beam
		Right bank			
Factory	Jun 30	-38.23	0.42	1,468	On-axis
In situ	Aug 7	-36.75	0.57	1,920	On-axis
In situ	Aug 7	-37.38	1.20	1,685	Bottom of beam
In situ	Aug 13	-35.09	0.48	1,788	On-axis
In situ	Aug 13	-36.35	1.97	1,559	Bottom of beam
In situ	Sep 7	-34.86	0.52	1,945	On-axis
In situ	Sep 7	-36.28	0.93	2,052	Bottom of beam

Table 3. Hydroacoustic data collected from the left bank, Chandalar River, 1995.

Date	Sample time (h)	Upstream count	Downstream count	Unknown count	Total count
Aug 8	23.21	286	4	8	298
9	23.59	210	2	3	215
10	23.66	179	1	4	184
11	22.81	106	8	4	118
12	23.68	203	12	2	217
13	23.34	244	11	5	260
14	23.45	258	26	9	293
15	21.14	458	11	5	474
16	19.29	965	28	14	1,007
20	6.36	936	4	19	959
21	23.30	3,575	17	52	3,644
22	23.37	3,582	9	46	3,637
23	23.24	3,843	13	76	3,932
24	22.61	2,943	18	68	3,029
25	23.51	1,632	15	83	1,730
26	19.10	1,676	9	28	1,713
27	23.71	2,971	9	24	3,004
28	20.76	2,715	14	25	2,754
29	23.53	2,579	3	33	2,615
30	23.57	2,645	10	27	2,682
31	21.04	2,118	12	19	2,149
Sep 1	23.56	2,612	9	31	2,652
2	23.51	2,589	6	32	2,627
3	23.82	3,406	15	90	3,511
4	19.68	2,793	4	67	2,864
5	23.66	2,422	11	83	2,516
6	23.53	2,274	3	32	2,309
7	23.51	2,110	14	97	2,221
8	23.63	2,582	22	43	2,647
9	23.66	3,530	19	32	3,581
10	23.63	2,691	41	30	2,762
11	23.41	3,564	45	94	3,703
12	23.38	3,779	50	36	3,865
13	23.62	4,309	35	102	4,446
14	23.61	4,339	33	52	4,424
15	23.53	4,481	28	142	4,651
16	23.60	3,619	21	30	3,670
17	23.52	3,543	11	77	3,631
18	23.79	3,267	23	26	3,316
19	22.24	2,876	13	26	2,915
20	23.67	2,653	11	22	2,686
21	23.59	3,039	14	24	3,077
22	23.83	2,128	20	11	2,159
Total	972.25	102,730	684	1,733	105,147

Table 4. Hydroacoustic data collected from the right bank, Chandalar River, 1995.

Date	Sample time (h)	Upstream count	Downstream count	Unknown count	Total count
Aug 8	22.74	205	1	0	206
9	23.35	122	3	0	125
10	23.24	140	0	0	140
11	23.55	142	5	0	147
12	23.63	147	5	0	152
13	22.00	349	5	0	354
14	23.36	643	9	5	657
15	23.44	684	10	4	698
16	10.56	220	11	0	231
23	10.48	1,393	22	7	1,422
24	23.51	2,811	17	7	2,835
25	23.56	3,411	25	10	3,446
26	23.32	4,122	36	6	4,164
27	21.26	4,238	38	3	4,279
28	23.34	4,436	49	6	4,491
29	23.65	4,104	49	10	4,163
30	23.68	3,935	24	10	3,969
31	23.54	4,144	35	9	4,188
Sep 1	23.40	4,479	55	8	4,542
2	23.45	5,247	256	14	5,517
3	23.79	6,021	190	23	6,234
4	22.90	3,880	67	15	3,962
5	23.66	3,317	54	17	3,388
6	23.71	3,722	56	8	3,786
7	22.90	3,769	46	16	3,831
8	23.76	5,386	52	16	5,454
9	23.73	6,191	38	33	6,262
10	23.71	6,597	61	12	6,670
11	23.72	6,187	119	35	6,341
12	22.37	5,026	54	7	5,087
13	23.61	6,234	113	15	6,362
14	23.20	5,557	112	13	5,682
15	23.62	4,882	123	20	5,025
16	23.68	4,587	76	5	4,668
17	23.46	4,708	124	13	4,845
18	23.54	4,897	73	11	4,981
19	23.31	4,902	57	20	4,979
20	23.68	5,046	44	7	5,097
21	23.74	6,442	77	19	6,538
22	23.44	5,964	59	2	6,025
Total	908.59	148,287	2,250	406	150,943

Table 5. Target strength measurements (on-axis) for free-swimming fall chum salmon, left bank, Chandalar River, 1995. Paired letters denote fish that have passed through the beam more than once.

Fish length (cm)	Target strength (dB)	SD	Range	Acquired echoes
53	-26.46	3.14	-20.74 to -33.50	18
54	-31.82	3.61	-22.30 to -38.87	33
55	-24.13	7.09	-7.08 to -36.71	136
55	-22.60	8.06	-10.46 to -33.59	15
56	-31.65	2.97	-28.02 to -37.17	11
56a	-27.64	3.94	-22.40 to -35.87	23
56a	-27.20	4.63	-21.92 to -35.73	13
56	-24.50	4.54	-18.63 to -33.48	22
57	-27.71	4.55	-17.55 to -35.76	55
57	-26.68	3.94	-17.34 to -33.58	34
57	-25.14	4.69	-15.04 to -33.53	69
58	-29.17	4.59	-21.34 to -34.79	14
58	-27.45	3.51	-21.48 to -32.80	13
58	-27.03	4.04	-19.36 to -34.05	23
58	-26.24	5.68	-12.57 to -38.08	29
58b	-25.85	5.76	-14.22 to -35.18	47
58	-24.81	4.26	-18.27 to -31.64	22
58	-24.25	6.07	-8.67 to -34.78	42
58b	-24.04	5.89	-8.35 to -38.14	157
59c	-30.64	2.25	-27.10 to -33.91	11
59c	-29.82	2.75	-25.62 to -33.49	9
59	-28.59	4.39	-17.94 to -36.10	14
59	-28.23	3.96	-22.96 to -32.29	6
59	-27.97	3.51	-22.18 to -34.58	15
59	-27.43	5.63	-14.40 to -34.14	16
60d	-30.58	3.29	-25.39 to -36.08	18
60e	-27.89	4.75	-15.67 to -34.90	42
60e	-27.10	5.00	-18.56 to -38.47	15
60d	-26.71	3.97	-19.27 to -33.74	18
60	-26.68	4.47	-17.74 to -34.83	48
60	-26.02	5.09	-9.50 to -35.23	44
60	-23.57	5.57	-10.12 to -34.52	29
60	-22.06	6.27	-7.22 to -34.93	50
60	-21.86	6.75	-6.86 to -33.76	35
61	-28.29	3.84	-17.63 to -36.63	48
61	-26.11	5.12	-13.42 to -37.49	64
62	-31.41	2.92	-25.20 to -36.96	15
62	-26.25	5.98	-8.58 to -32.03	13
62	-22.65	8.04	-7.30 to -35.75	37
62	-21.39	6.80	-9.42 to -32.85	22
63	-27.51	3.57	-20.81 to -34.53	19
63	-26.12	2.79	-20.51 to -29.65	9

Table 6. Target strength values (side-aspect) and corresponding fish lengths derived from Love's equation.

Fish length (cm)	Target strength (dB)	Fish length (cm)	Target strength (dB)
10	-43.42	130	-22.26
15	-40.08	135	-21.95
20	-37.71	140	-21.65
25	-35.86	145	-21.36
30	-34.36	150	-21.08
35	-33.09	155	-20.81
40	-31.99	160	-20.55
45	-31.01	165	-20.29
50	-30.14	170	-20.05
55	-29.36	175	-19.81
60	-28.64	180	-19.57
65	-27.98	185	-19.35
70	-27.37	190	-19.13
75	-26.80	195	-18.91
80	-26.27	200	-18.71
85	-25.77	205	-18.50
90	-25.29	210	-18.30
95	-24.85	215	-18.11
100	-24.42	220	-17.92
105	-24.02	225	-17.73
110	-23.64	230	-17.55
115	-23.27	235	-17.37
120	-22.92	240	-17.20
125	-22.58	245	-17.03

Table 7. Total catch, effort, and length of chum salmon captured by gill nets, Chandalar River, August 9-September 15, 1995.

				Mid-eye length (cm)			
Mesh size (cm)	Total catch	Effort (h)	Males (%)	N	Mean length (cm)	SD	Length range (cm)
11.4	173	19.62	77	170	58	3.4	50-68
14.9	174	21.47	82	171	59	2.9	52-69
Total	347	41.09	80	341	59	3.2	50-69

Table 8. Daily adjusted fall chum salmon count, Chandalar River, 1995. Asterisks represent daily estimate by linear interpolation due to high water.

Date	Left bank	Right bank	Combined	Cumulative	Cumulative (%)
Aug 8	302	215	517	517	0.18
9	215	126	341	858	0.31
10	181	142	323	1,181	0.42
11	116	146	262	1,443	0.51
12	206	150	356	1,799	0.64
13	250	378	628	2,427	0.86
14	226	662	928	3,355	1.19
15	511	698	1,209	4,564	1.62
16	1,249	494	1,743	6,307	2.24
17	1,756*	877*	2,633	8,940	3.18
18	2,264*	1,259*	3,523	12,463	4.44
19	2,771*	1,642*	4,413	16,876	6.01
20	3,278	2,024*	5,302	22,178	7.89
21	3,678	2,407*	6,085	28,263	10.06
22	3,660	2,789*	6,449	34,712	12.35
23	3,960	3,172	7,132	41,844	14.89
24	3,138	2,858	5,996	47,840	17.03
25	1,680	3,485	5,165	53,005	18.86
26	2,216	4,253	6,469	59,474	21.17
27	2,997	4,753	7,750	67,224	23.92
28	3,028	4,544	7,572	74,796	26.62
29	2,652	4,182	6,834	81,630	29.05
30	2,686	3,991	6,677	88,307	31.43
31	2,504	4,233	6,737	95,044	33.82
Sep 1	2,662	4,571	7,233	102,277	36.40
2	2,643	5,339	7,982	110,259	39.24
3	3,426	6,074	9,500	119,759	42.62
4	3,518	4,054	7,572	127,331	45.31
5	2,457	3,380	5,837	133,168	47.39
6	2,317	3,769	6,086	139,254	49.56
7	2,145	3,987	6,132	145,386	51.74
8	2,625	5,465	8,090	153,476	54.62
9	3,571	6,276	9,847	163,323	58.12
10	2,734	6,688	9,422	172,745	61.48
11	3,620	6,250	9,870	182,615	64.99
12	3,890	5,373	9,263	191,878	68.28
13	4,377	6,331	10,708	202,586	72.09
14	4,397	5,698	10,095	212,681	75.69
15	4,567	4,960	9,527	222,208	79.08
16	3,675	4,649	8,324	230,532	82.04
17	3,626	4,813	8,439	238,971	85.04
18	3,290	4,984	8,274	247,245	87.99
19	3,059	5,027	8,086	255,331	90.87
20	2,693	5,143	7,836	263,167	93.65
21	3,080	6,525	9,605	272,772	97.07
22	2,138	6,089	8,227	280,999	100.00
Total	116,074	164,925	280,999		

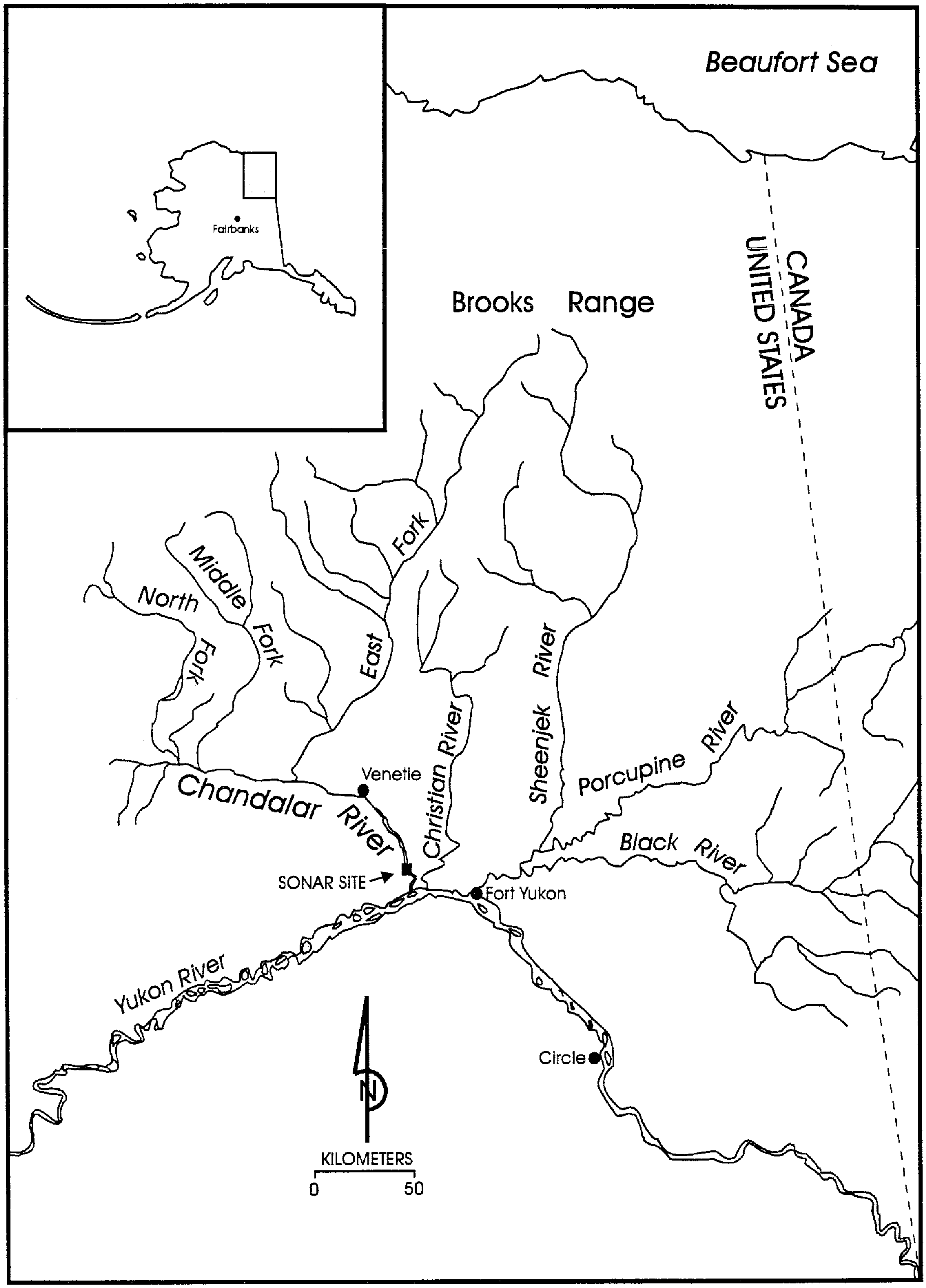

Figure 1. Major tributaries of the Yukon River near the U.S./Canada border.

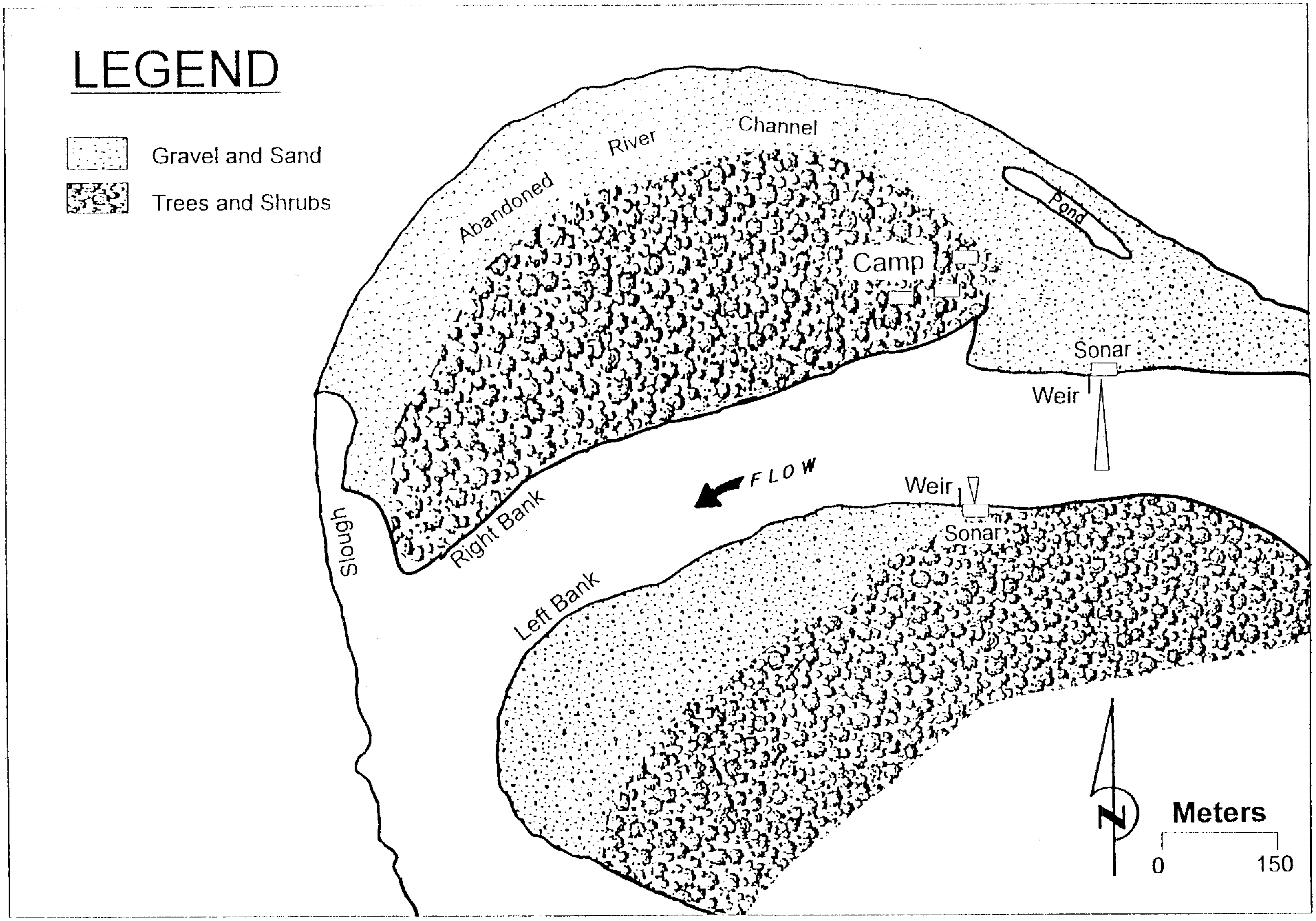

Figure 2. Site map of the Chandalar River sonar facilities, 1995.

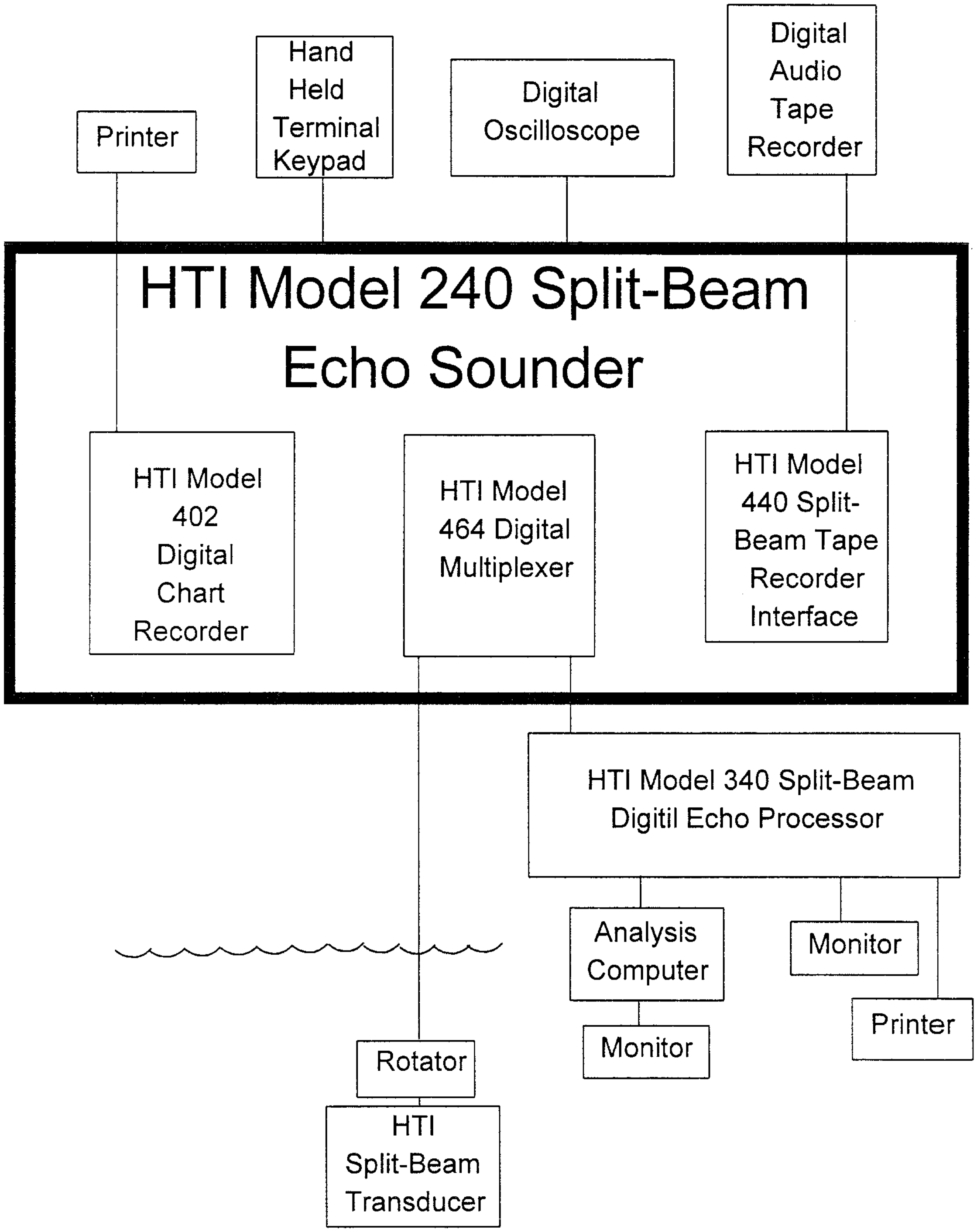

Figure 3. Split-beam hydroacoustic system, Chandalar River, 1995.

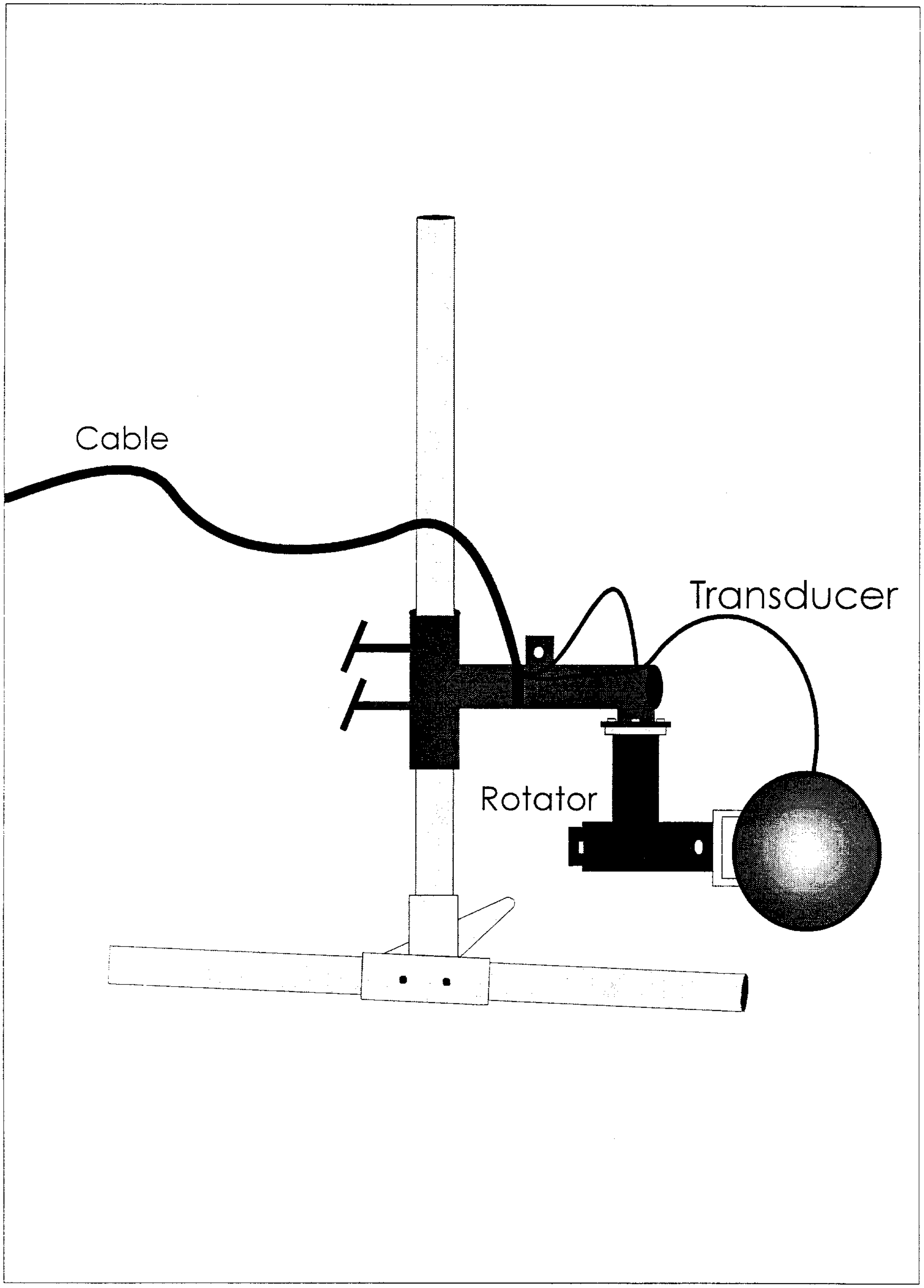

Figure 4. Split-beam transducer, remote rotator, and pod assembly, Chandalar River, 1995.

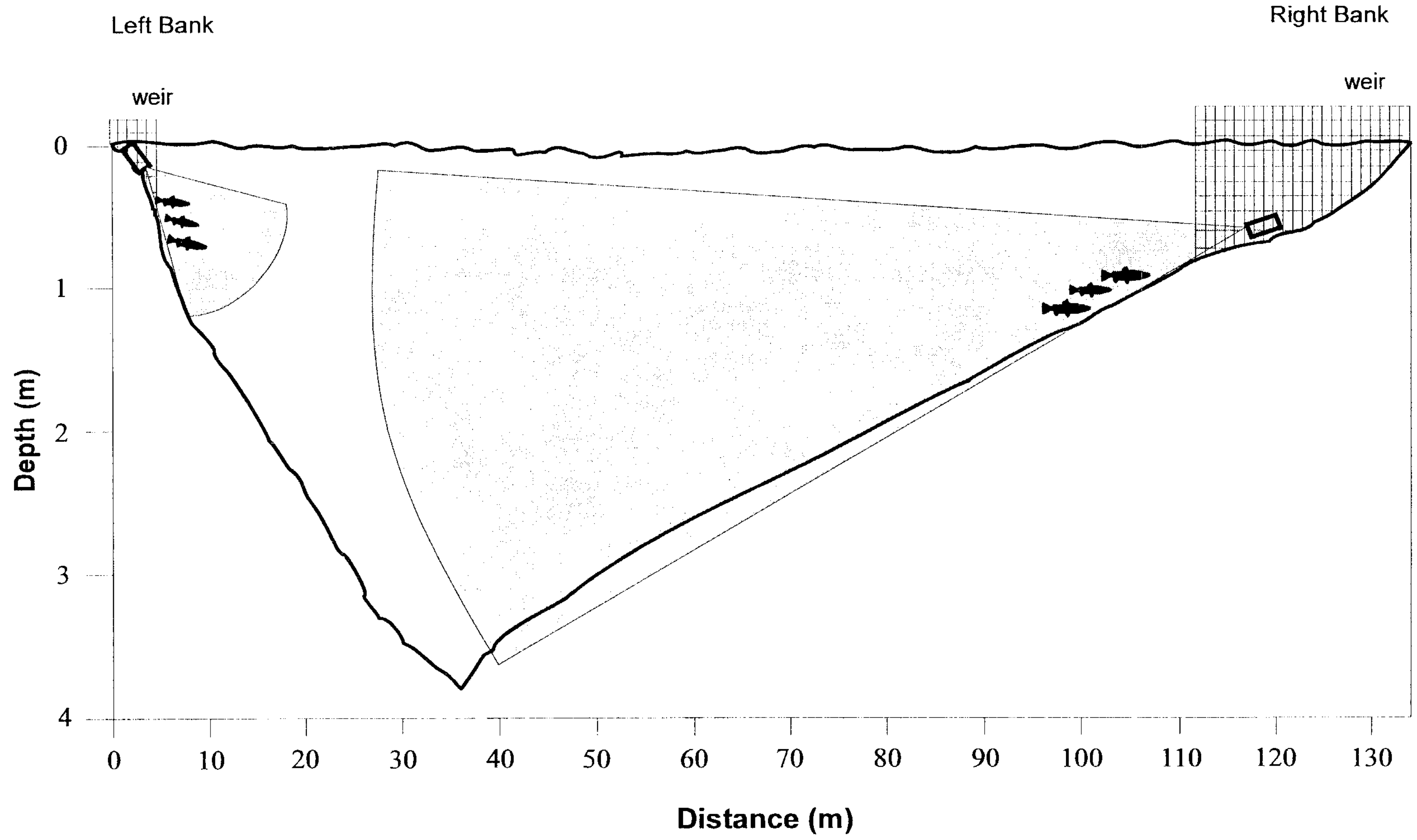

Figure 5. River channel profile and estimated ensonified zones of the left and right banks, Chandalar River, 1995. Different axis scales were used to enhance visibility.

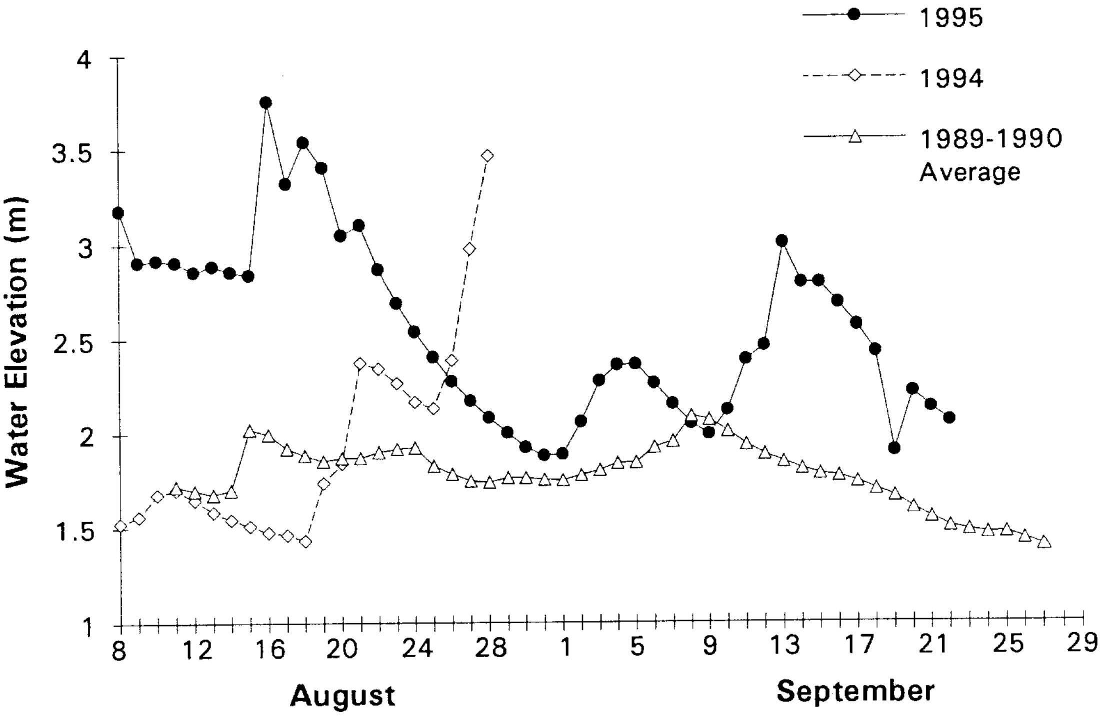

Figure 6. Daily water elevation during sonar operation, Chandalar River, 1989-1990 average, 1994, and 1995.

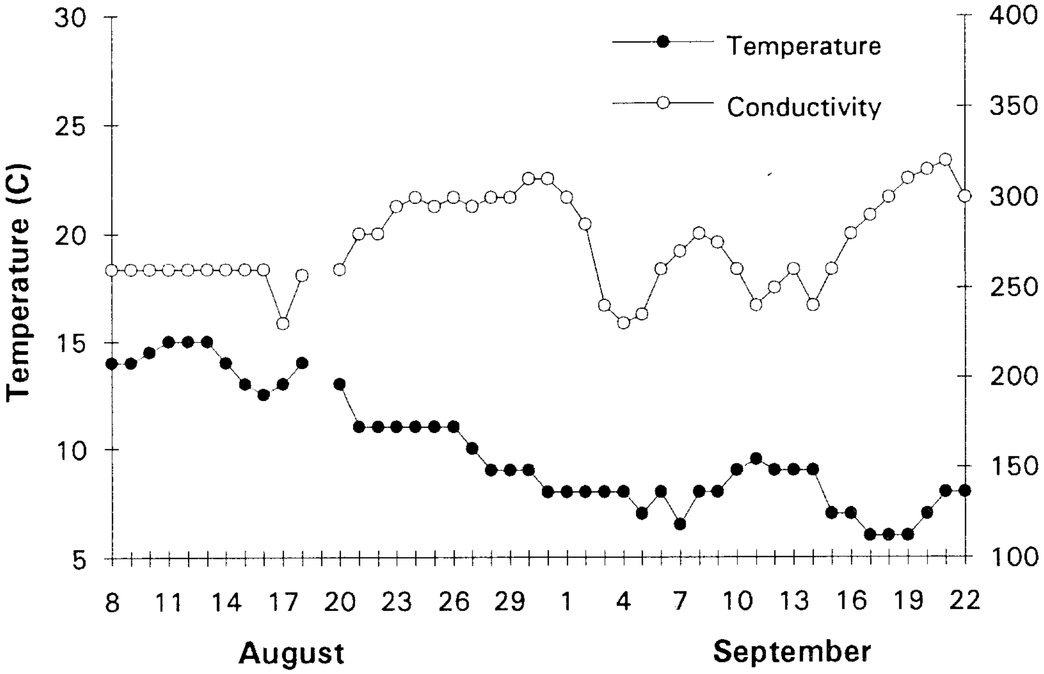

Figure 7. Daily water temperature and conductivity measurements, Chandalar River, August 8-September 22, 1995.

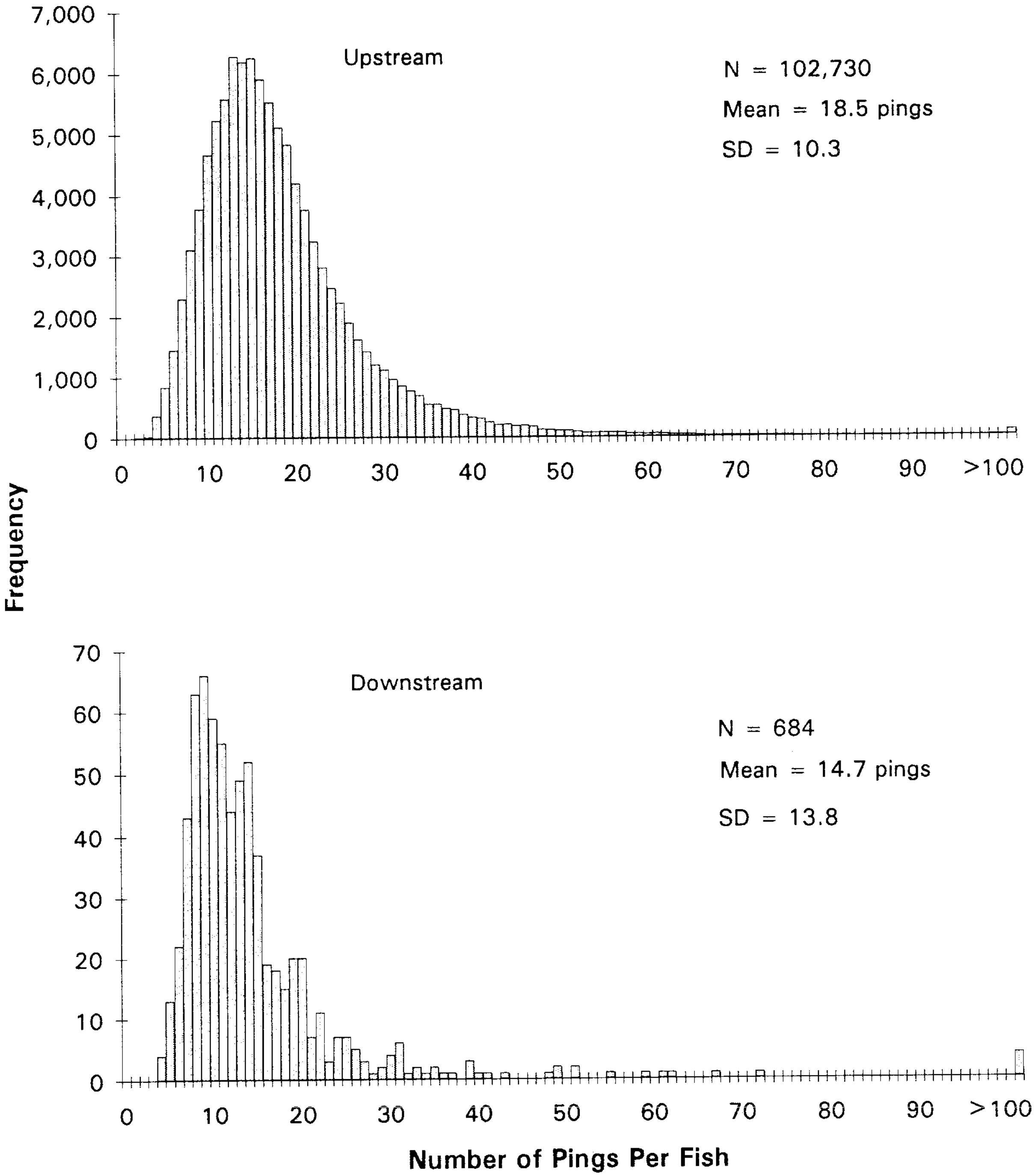

Figure 8. Number of acquired echoes per tracked fish, left bank, Chandalar River, August 8-September 22, 1995.

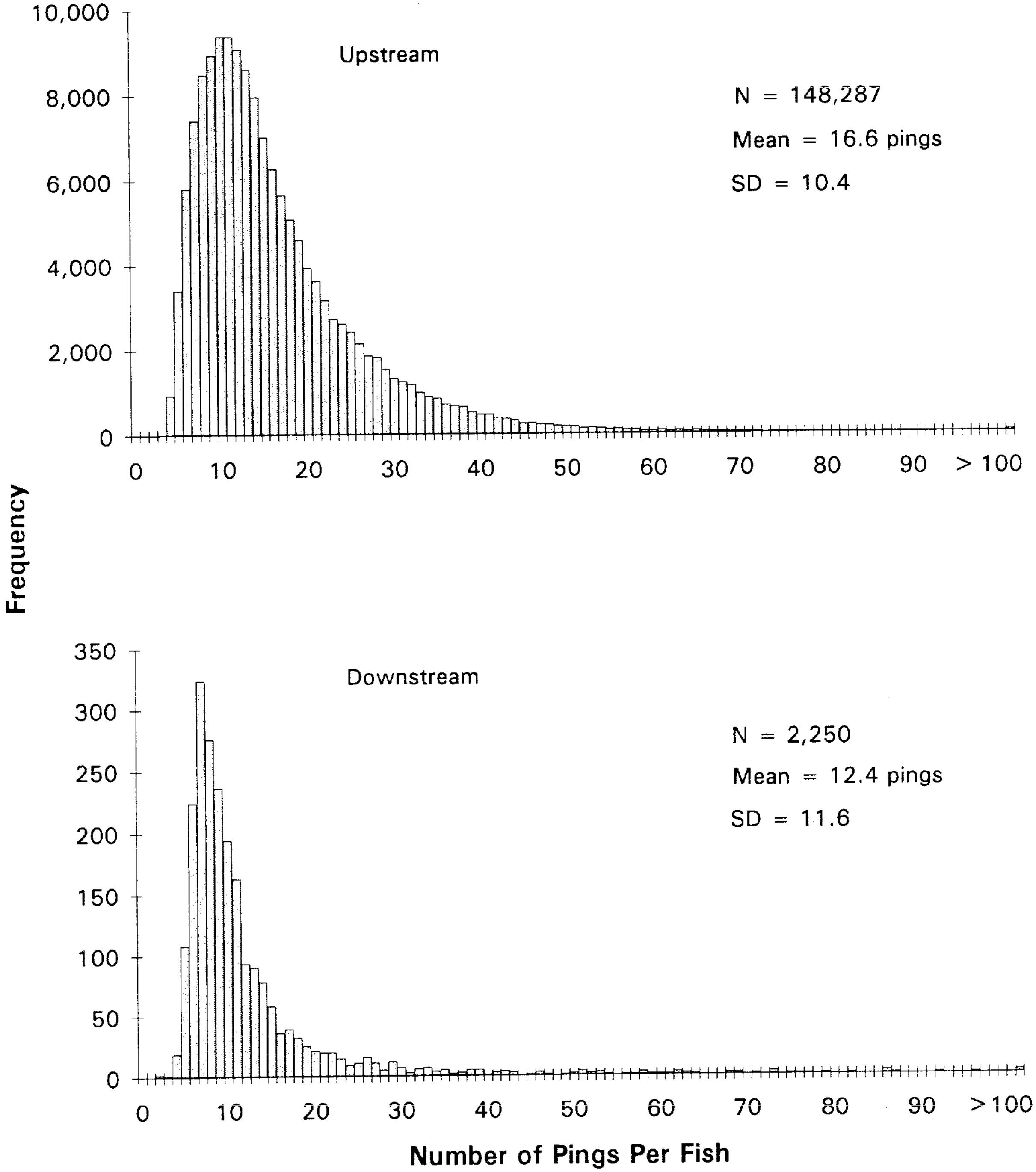

Figure 9. Number of acquired echoes per tracked fish, right bank, Chandalar River, August 8-September 22, 1995.

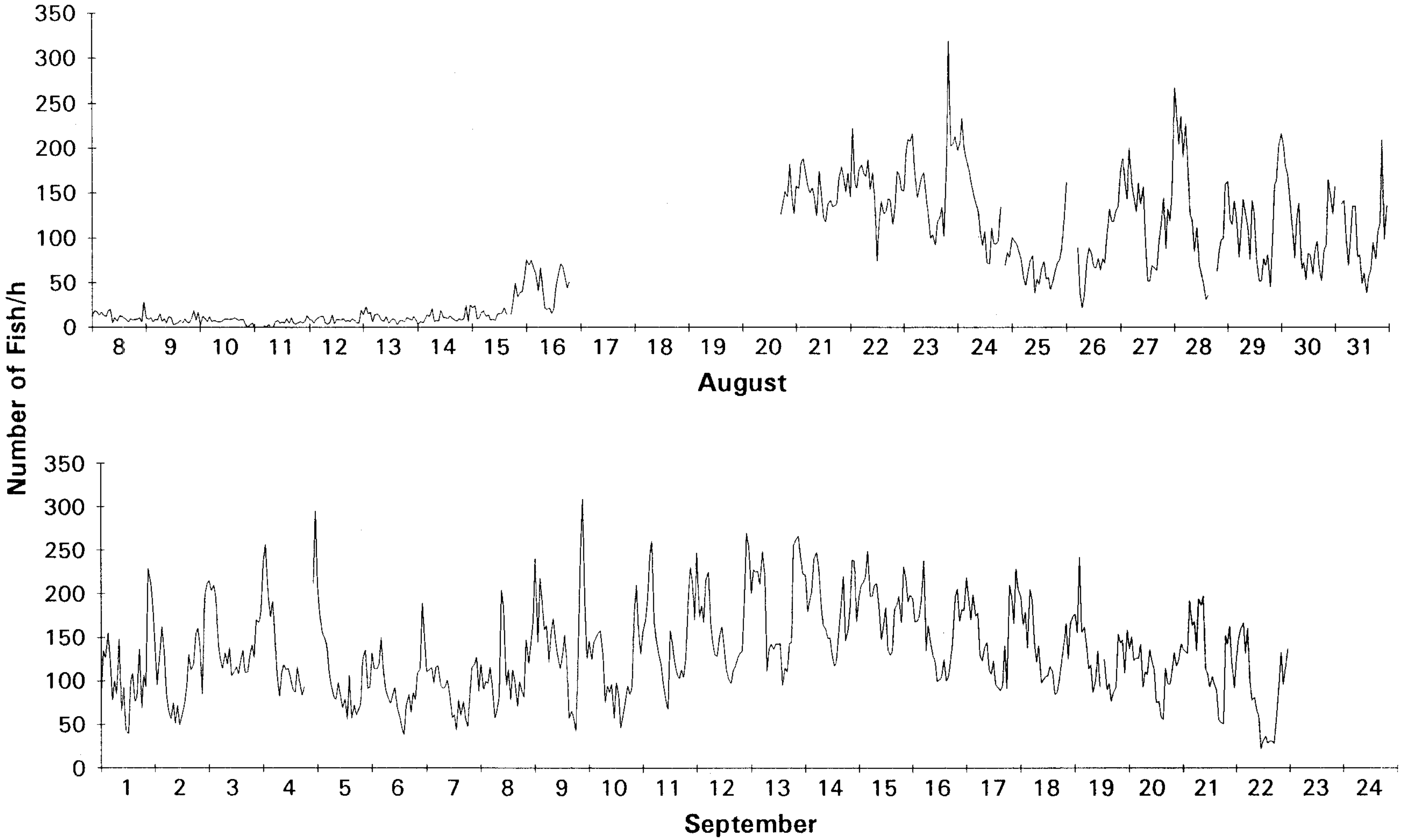

Figure 10. Diel distribution of upstream fish, left bank, Chandalar River, August 8-September 22, 1995.

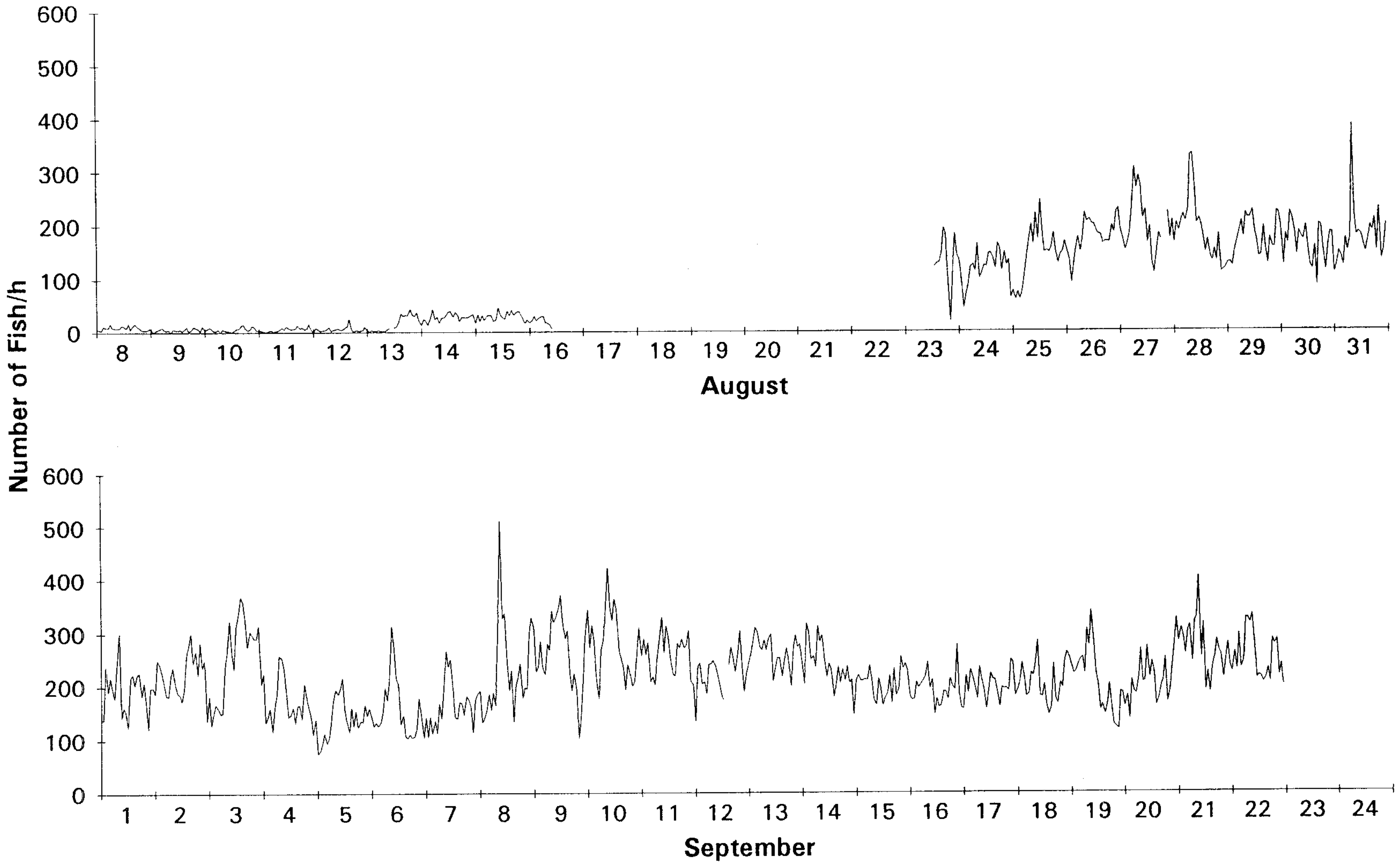

Figure 11. Diel distribution of upstream fish, right bank, Chandalar River, August 8-September 22, 1995.

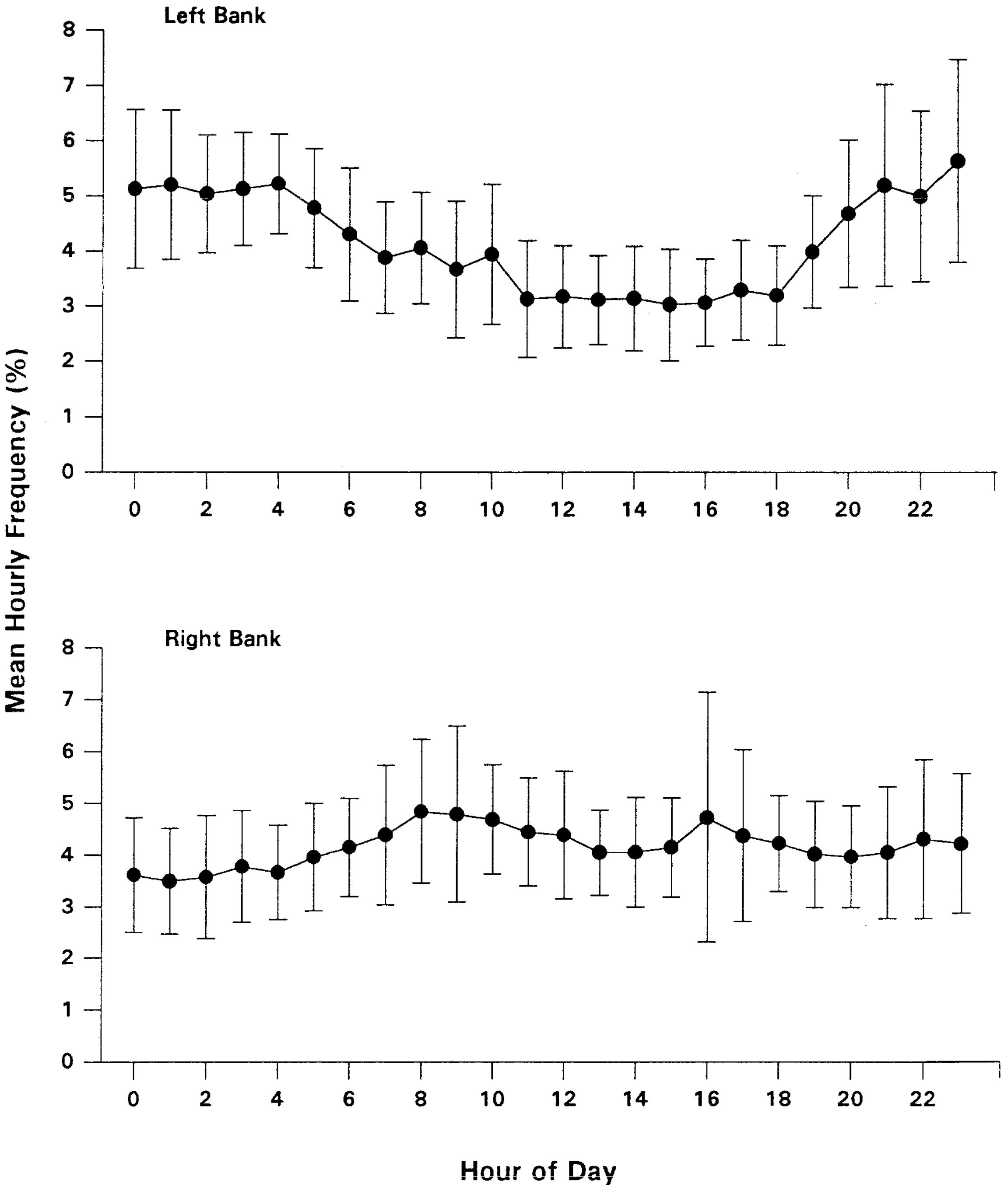

Figure 12. Mean (± SD) hourly frequency of upstream fish, Chandalar River, 1995. Data from 33 days of continuous 24 h data on the left bank and 35 days on the right bank.

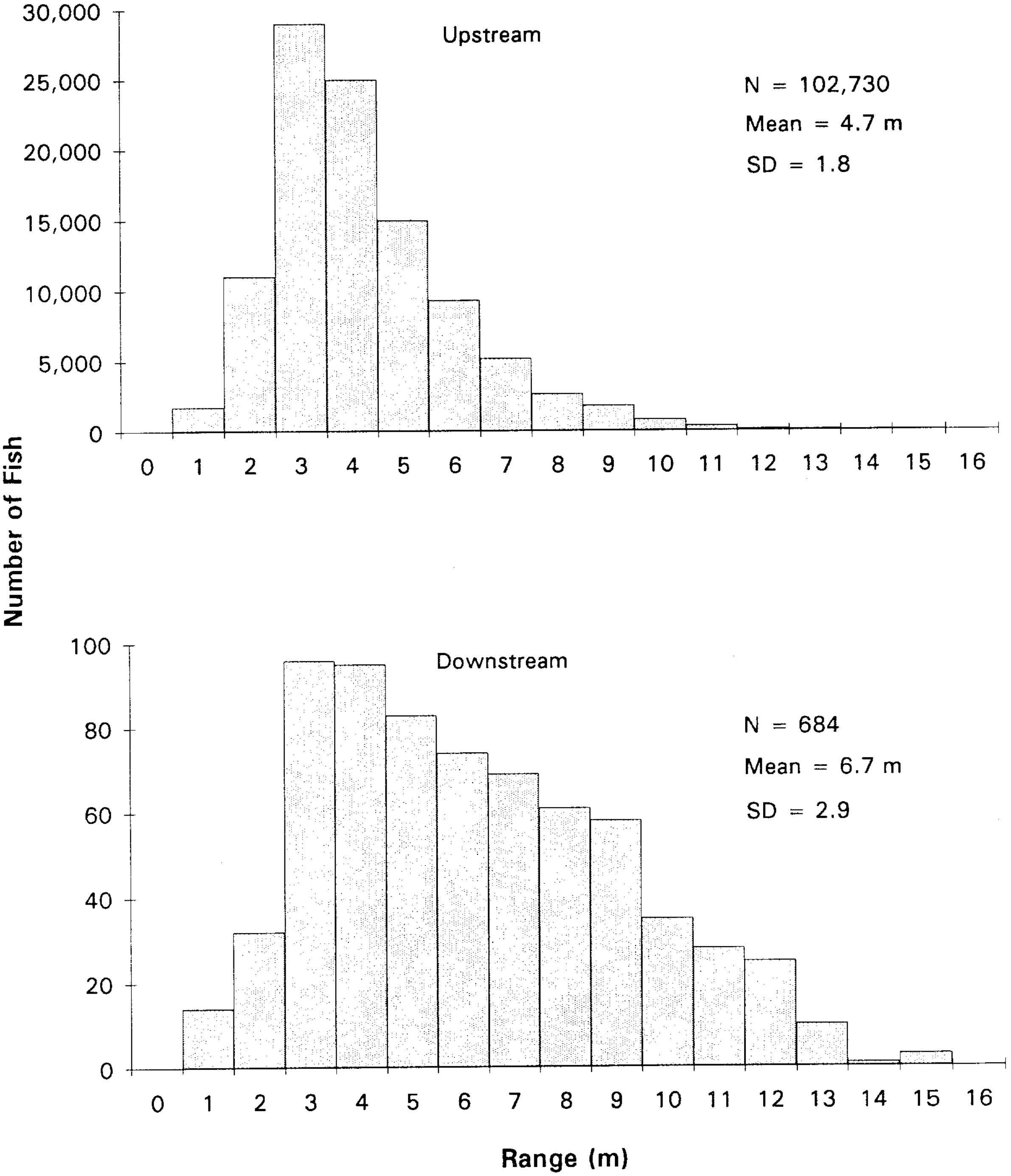

Figure 13. Range (horizontal distance from transducer) distribution of upstream and downstream fish, left bank, Chandalar River, August 8-September 22, 1995.

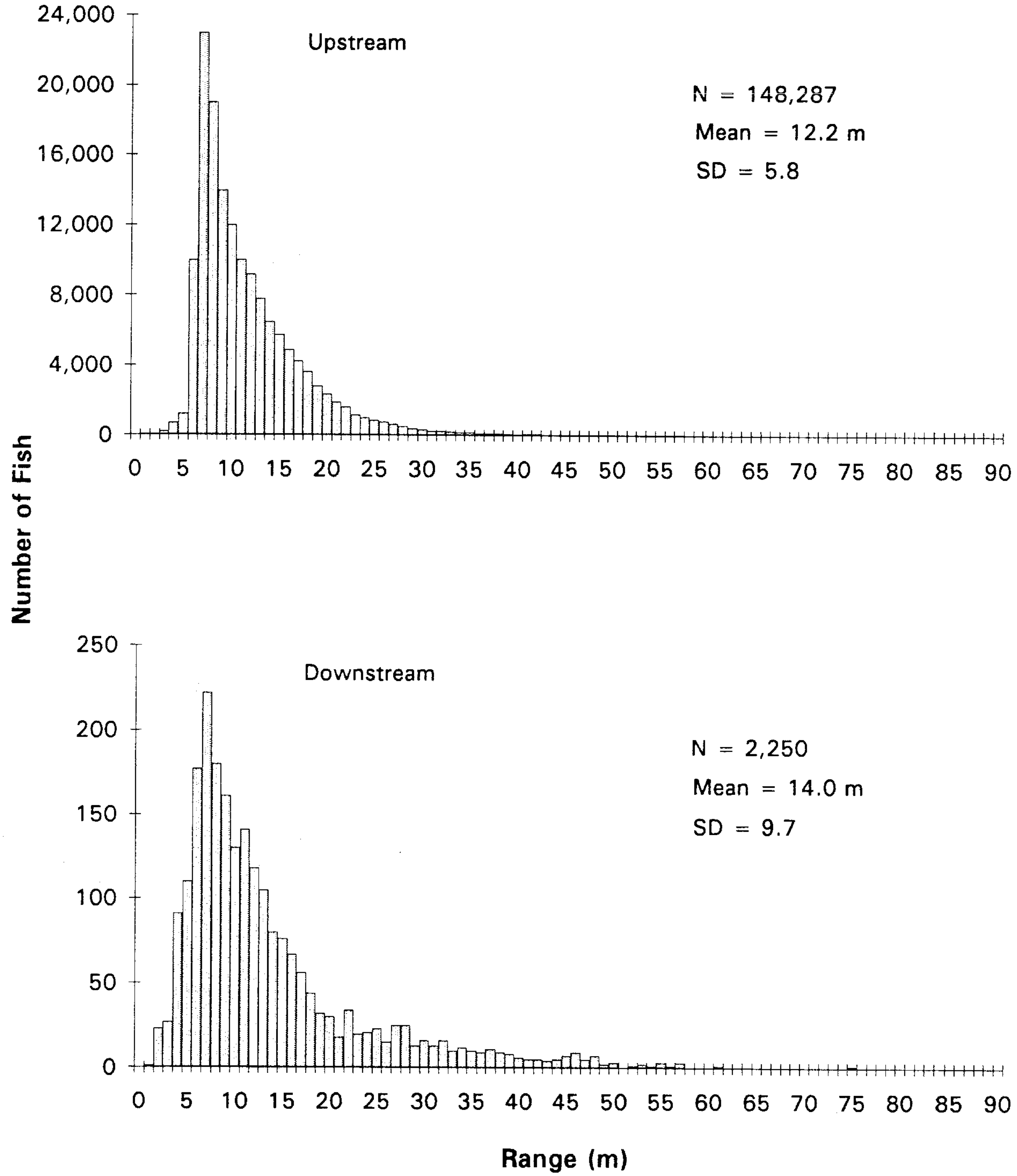

Figure 14. Range (horizontal distance from transducer) distribution of upstream and downstream fish, right bank, Chandalar River, August 8-September 22, 1995.

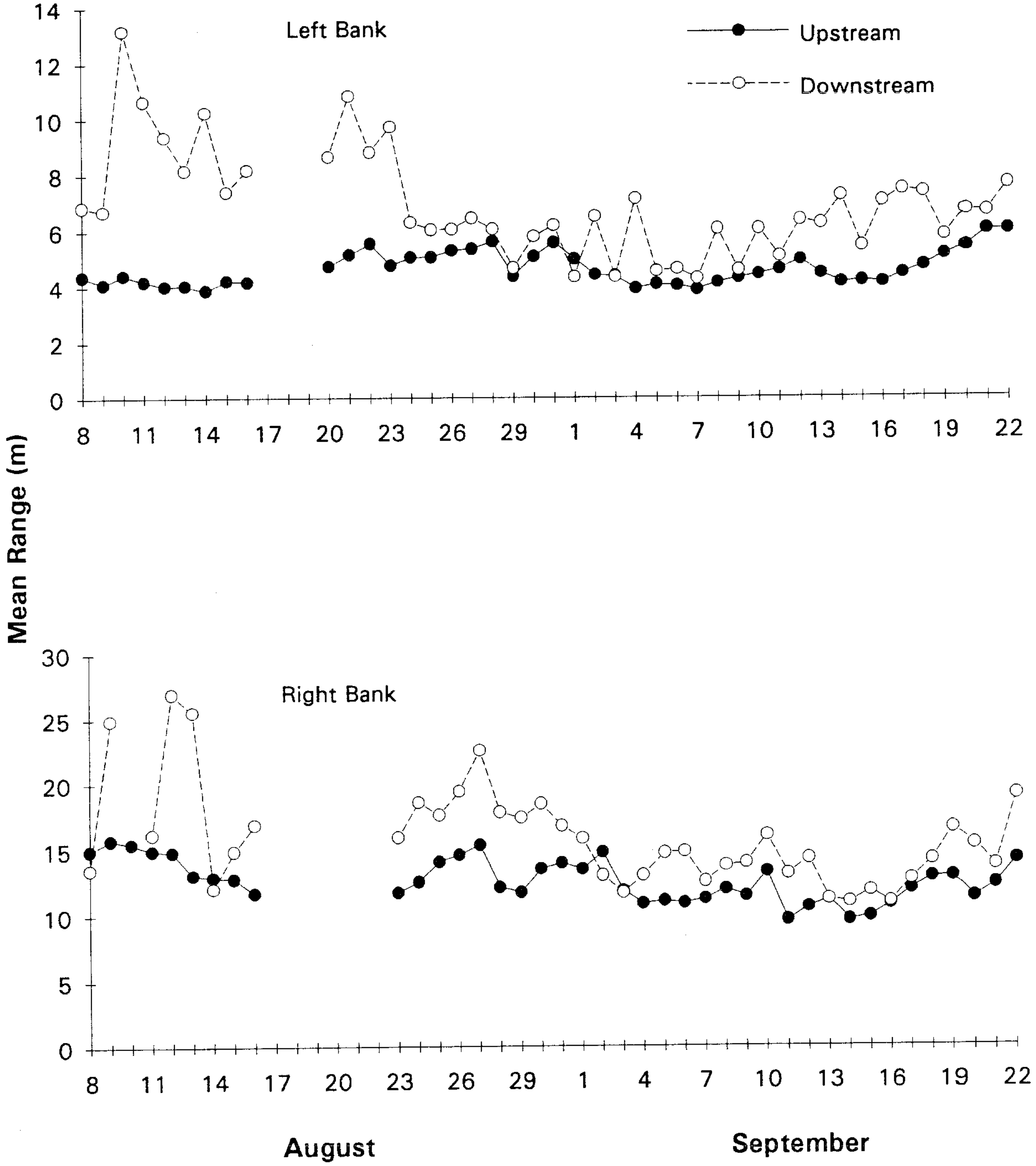

Figure 15. Mean daily range of upstream and downstream fish by bank, Chandalar River, August 8-September 22, 1995.

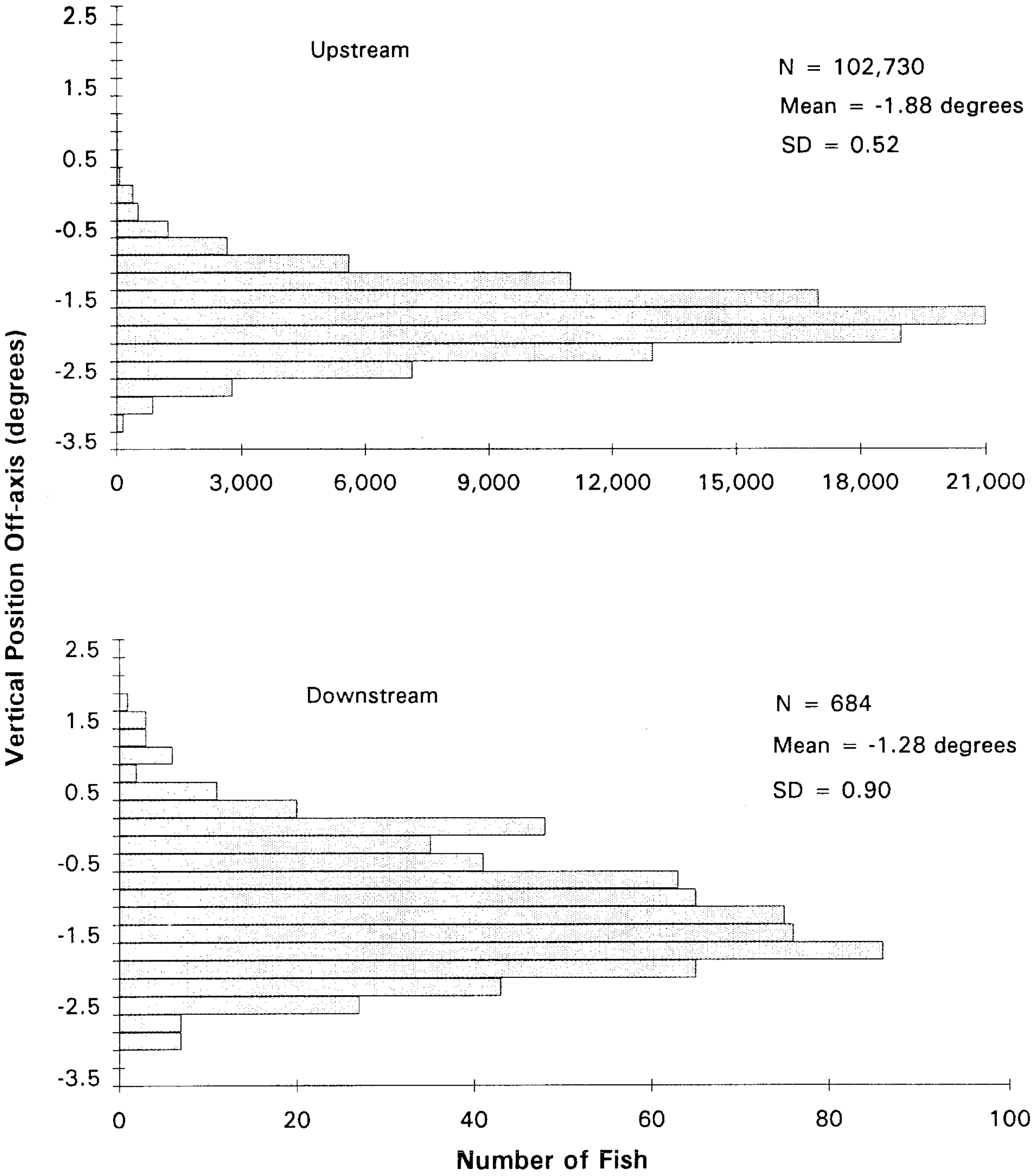

Figure 16. Vertical distribution of upstream and downstream fish, left bank, Chandalar River, August 8-September 22, 1995.

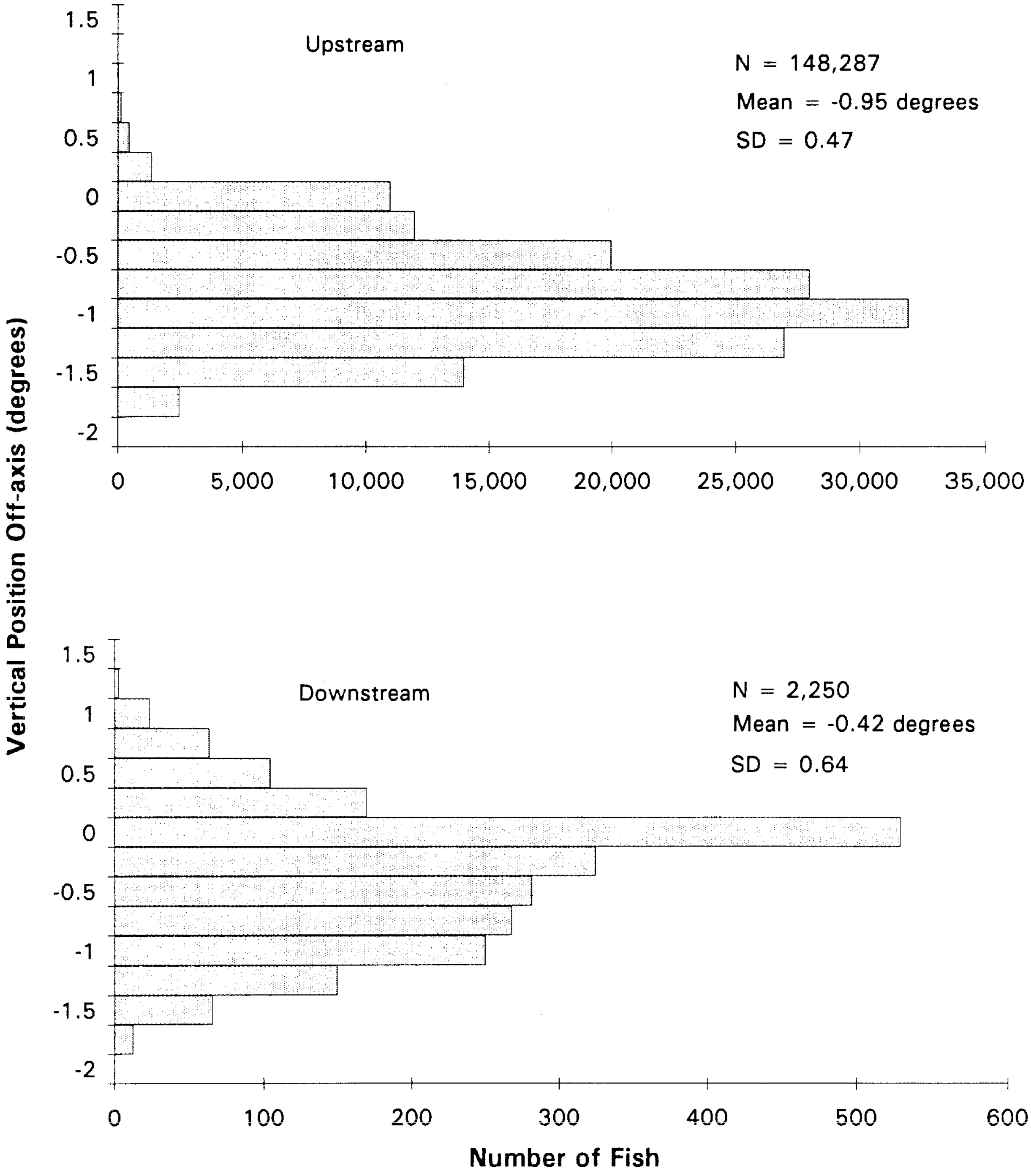

Figure 17. Vertical distribution of upstream and downstream fish, right bank, Chandalar River, August 8-September 22, 1995.

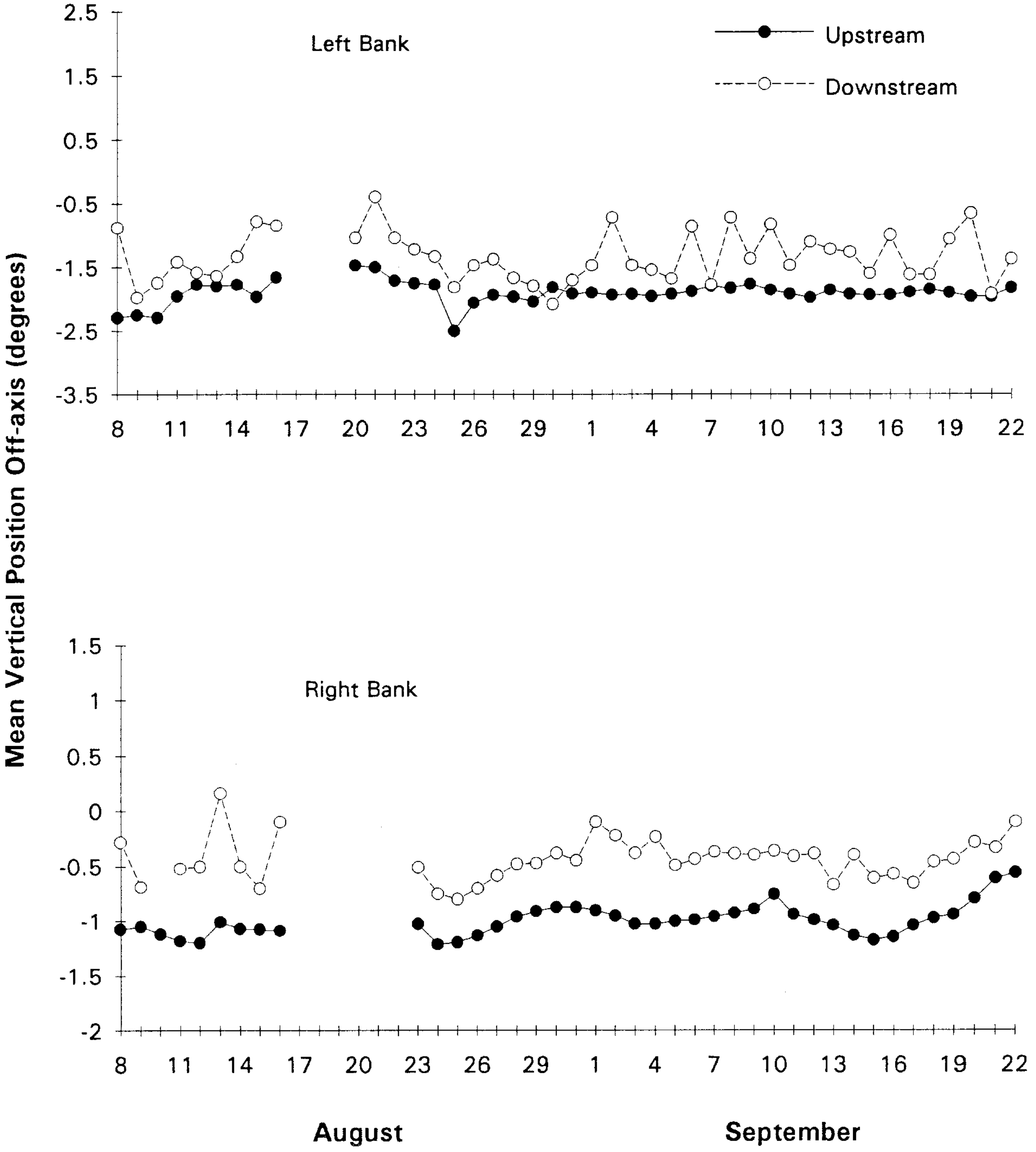

Figure 18. Mean daily vertical position of upstream and downstream fish by bank, Chandalar River, August 8-September 22, 1995.

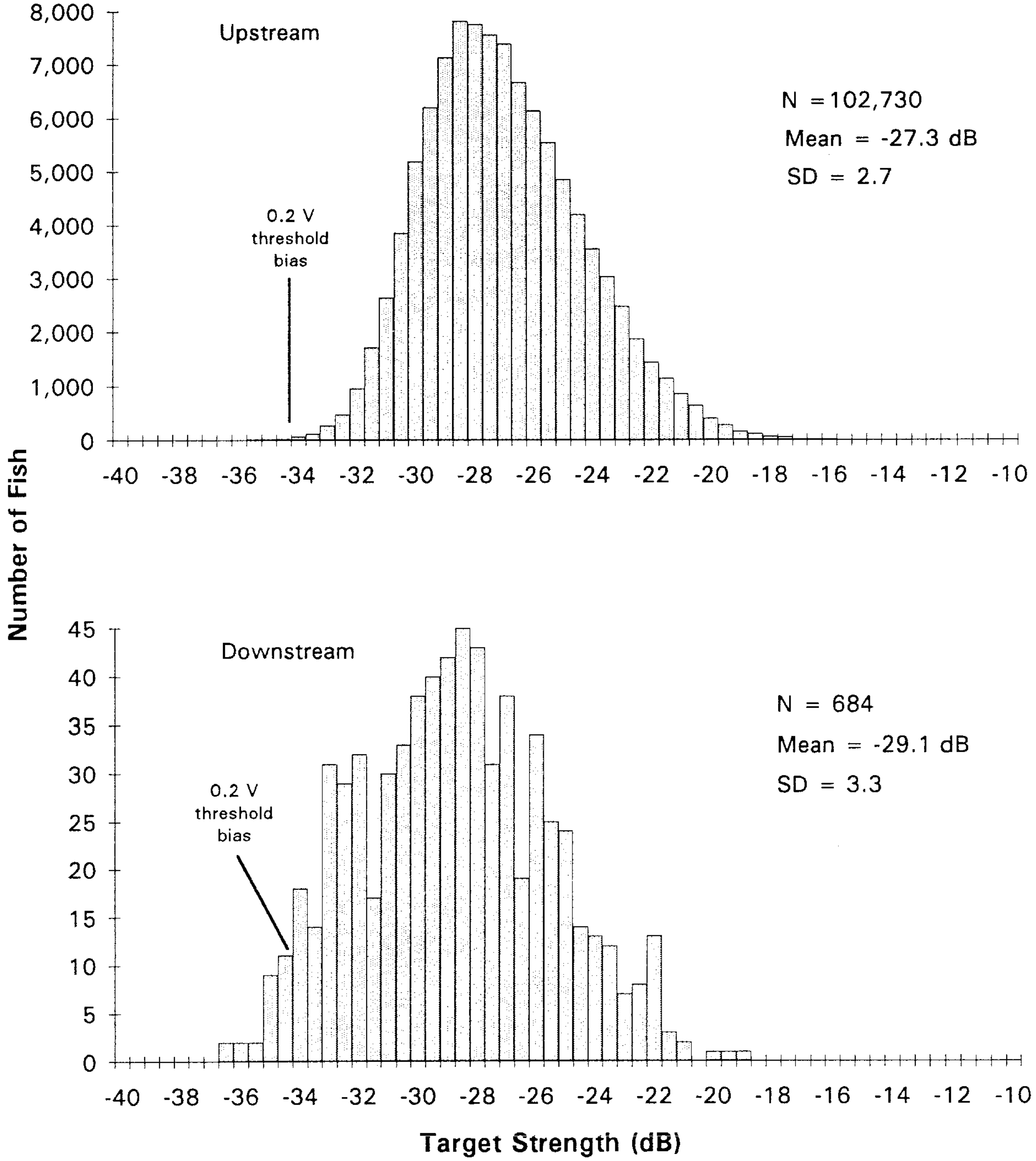

Figure 19. Target strength distribution of upstream and downstream fish, left bank, Chandalar River, August 8-September 22, 1995. Area of distribution potentially affected by signal threshold bias is indicated.

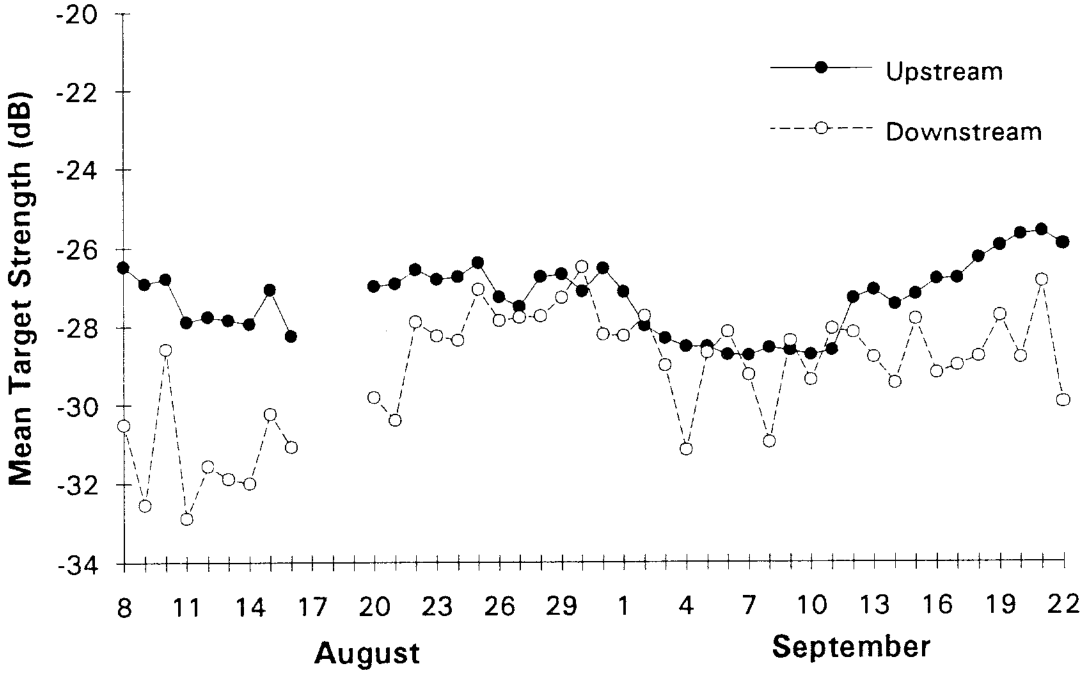

Figure 20. Mean daily target strength of upstream and downstream fish, left bank, Chandalar River, August 8-September 22, 1995.

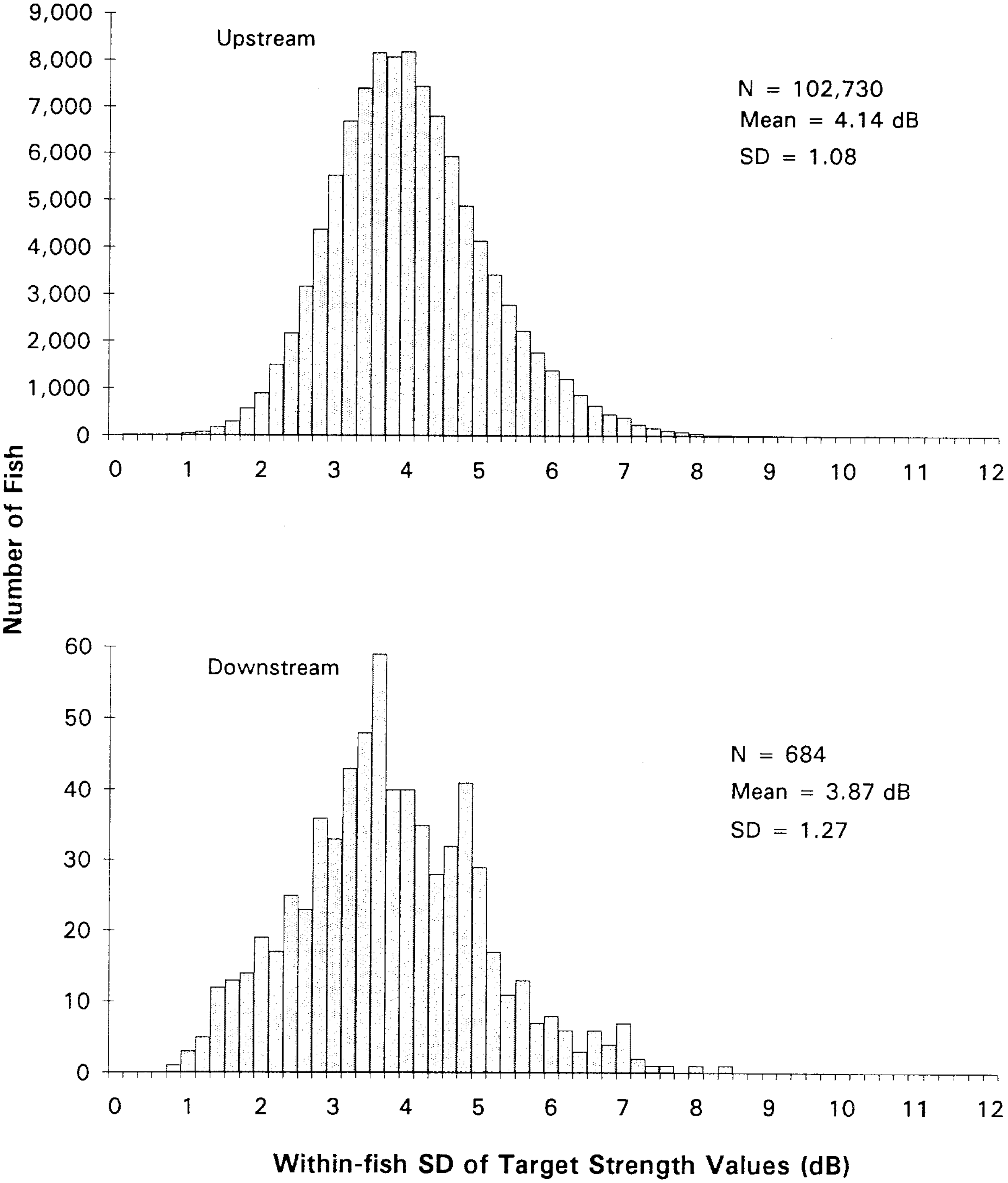

Figure 21. Within-fish target strength variability (SD) of upstream and downstream fish, left bank, Chandalar River, August 8-September 22, 1995.

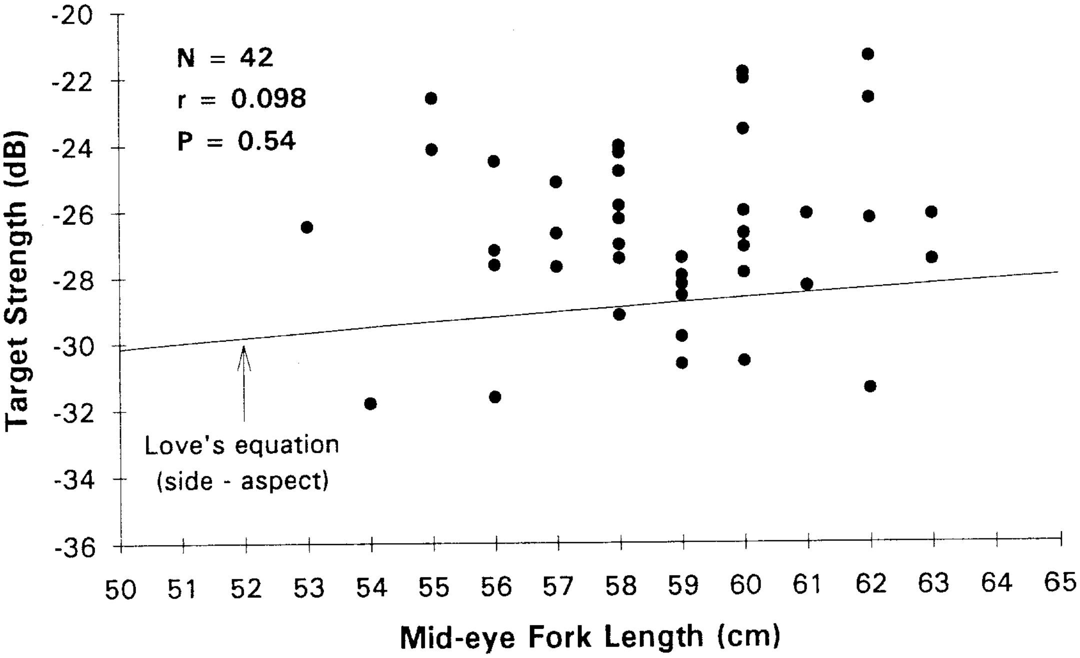

Figure 22. On-axis target strength measurements for free-swimming fall chum salmon, left bank, Chandalar River, August 8-September 22, 1995. The theoretical equation (Love 1977) for side-aspect fish position is also depicted.

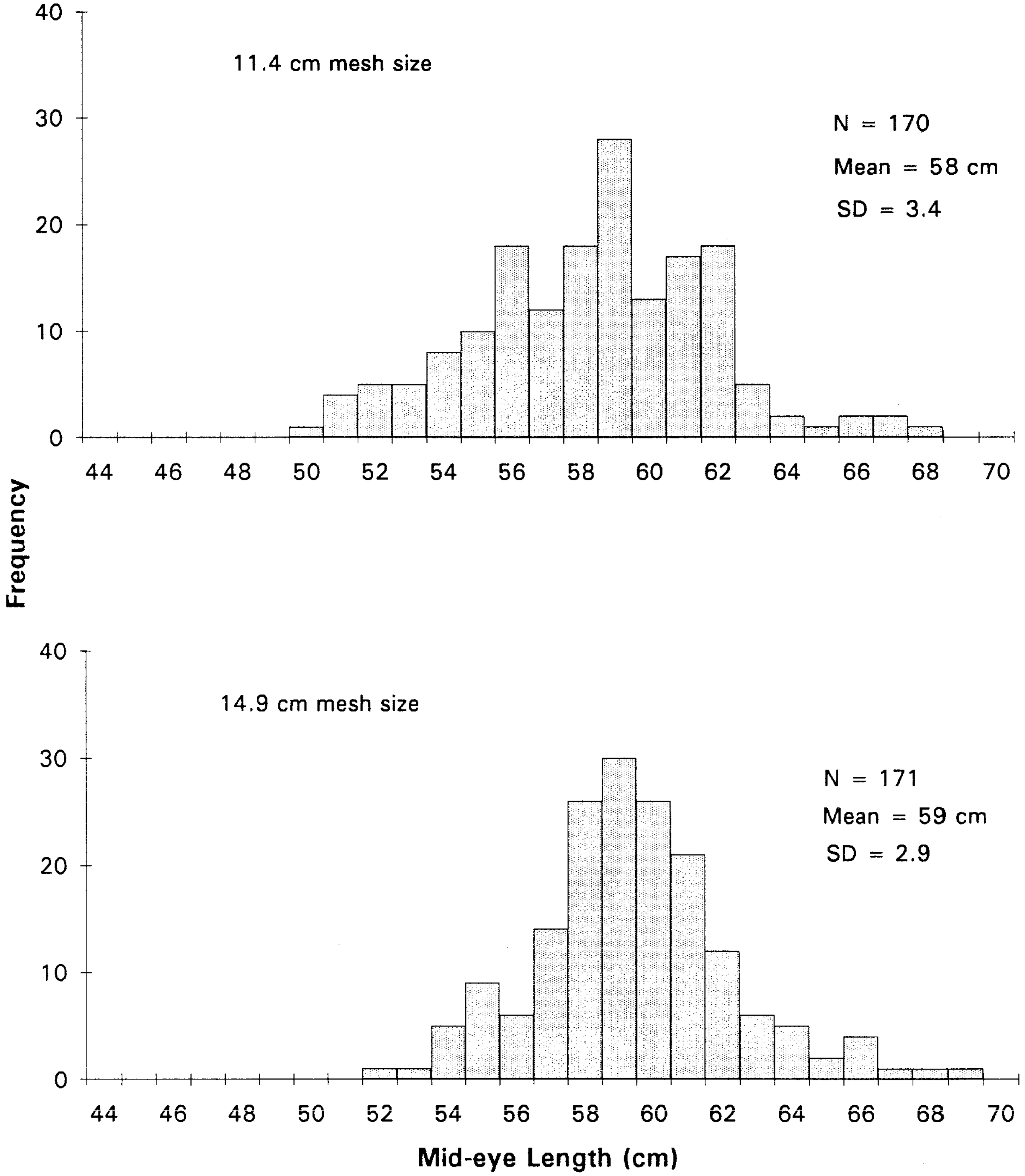

Figure 23. Lengths of fall chum salmon captured using gill nets with 11.4 and 14.9 cm stretch mesh sizes, Chandalar River, August 9-September 15, 1995.

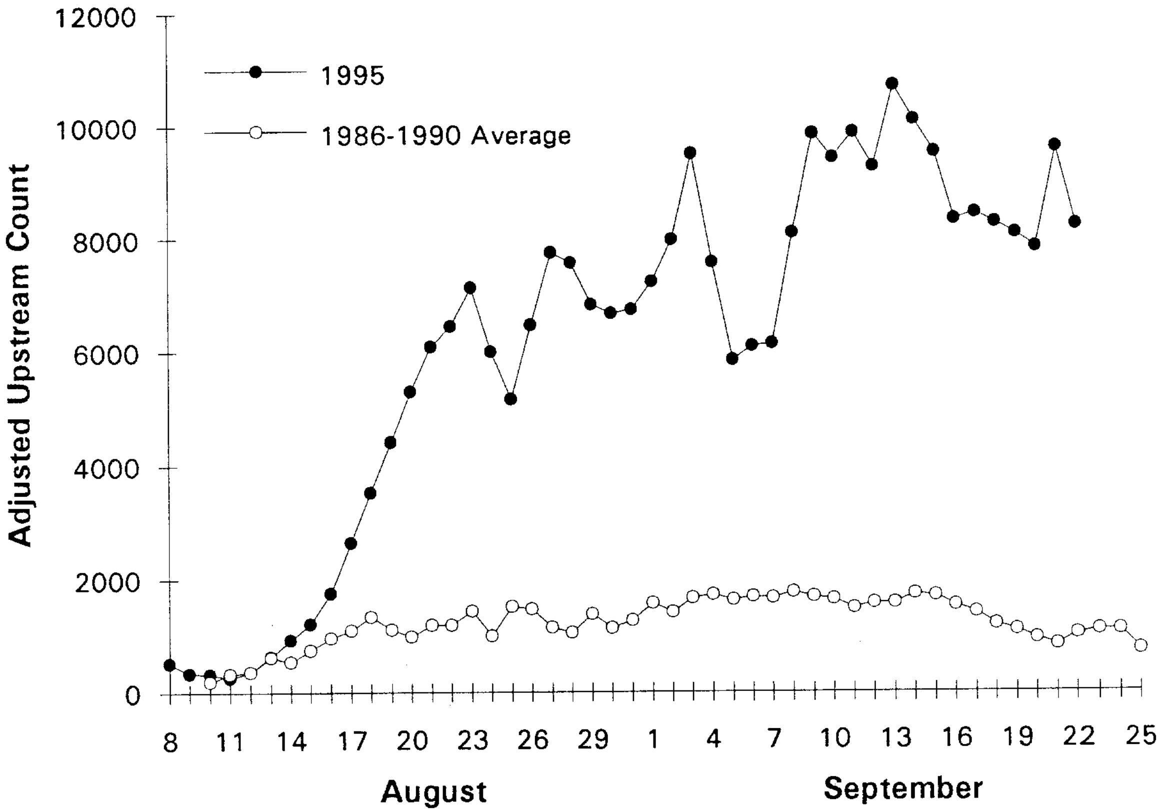

Figure 24. Adjusted daily counts of fall chum salmon, Chandalar River, August 8-September 22, 1995.

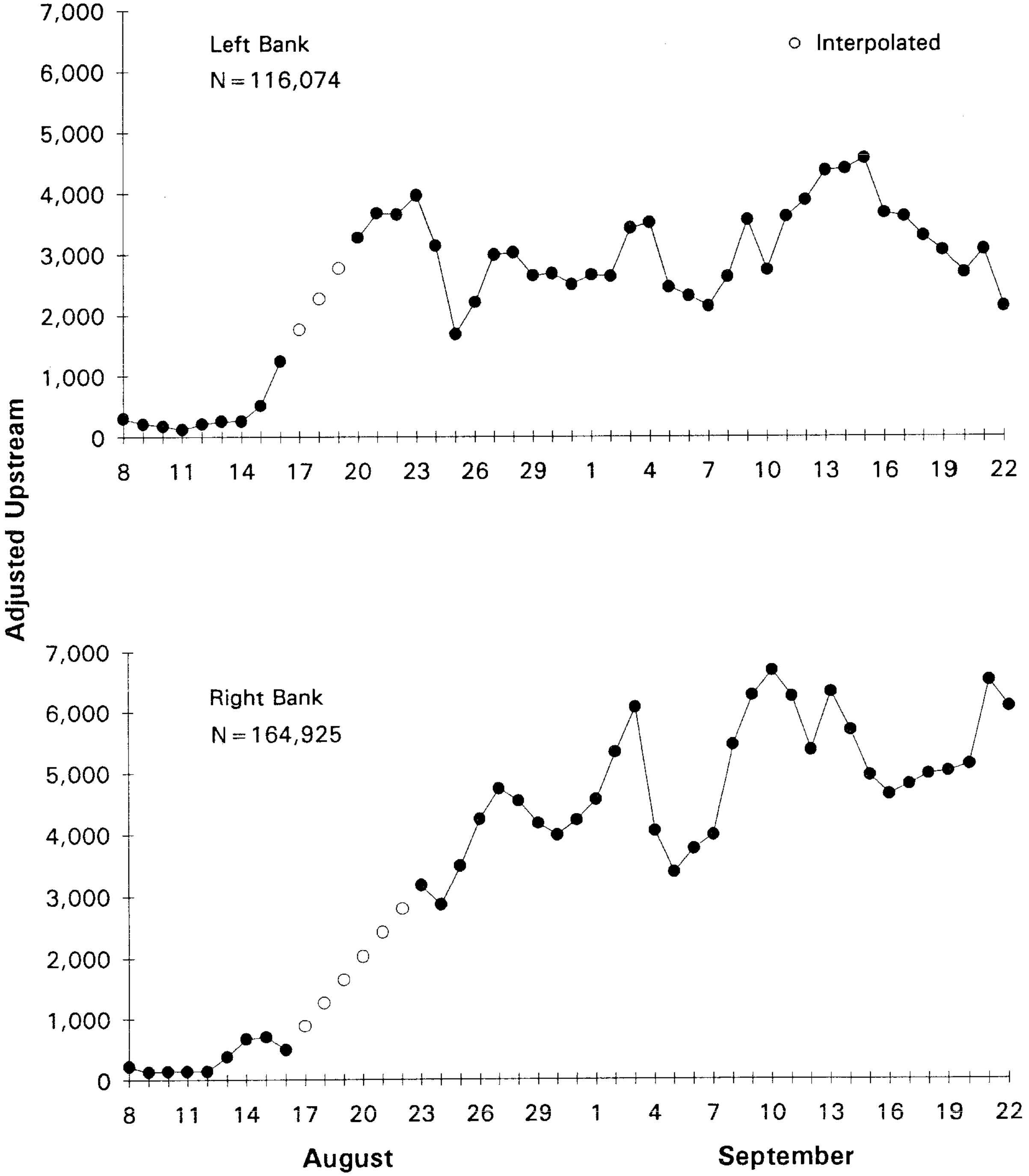

Figure 25. Adjusted daily counts of fall chum salmon by bank, Chandalar River, August 8-September 22, 1995.