ENUMERATION OF CHANDALAR RIVER FALL CHUM SALMON USING SPLIT-BEAM SONAR, 1996

Alaska Fisheries Technical Report Number 42

July 1997

Region 7
U.S. Fish and Wildlife Service • Department of the Interior

Enumeration of Chandalar River Fall Chum Salmon Using Split-beam Sonar, 1996

Alaska Fisheries Technical Report Number 42

Bruce M Osborne
David W Daum

U.S Fish and Wildlife Service
Fishery Resource Office
101 12th Avenue, Box 17
Fairbanks, Alaska 99701

July 1997

ABSTRACT

A five-year fixed-location, split-beam hydroacoustic study was initiated in 1994 to assess the population of adult fall chum salmon *Oncorhynchus keta* in the Chandalar River, a tributary of the Yukon River Objectives for the 1996 season were to continue developing site-specific operational methods, evaluate site characteristics, describe possible data collection biases, determine daily in-season counts, estimate total escapement, and quantify sex and age composition of the spawning population Elliptical transducers were sited on opposite river banks to optimize sonar beam coverage and aimed perpendicular to the river current. Both sonar units were operated, 24 hours per day, from August 8 through September 22

Background noise levels were low, ranging from −58 to −42 dB on the left bank and −60 to −36 dB on the right bank Throughout the season, *in situ* standard target strength measurements of a 38 1 mm tungsten carbide sphere were within 1 4 dB of factory values Variability (SD) of on-axis target strength measurements during *in situ* calibrations was low, ranging from 0 32 to 1 15 dB. Variability increased as the standard target moved off-axis

A total of 2,161 hours of digital echo processor data were "cleaned" and manually tracked, resulting in 210,998 fish written to file Ninety-eight percent of the season's available sample time was monitored Upstream traveling fish accounted for 97% of the total count. Acquired echoes per upstream fish averaged 19 2 on the left bank and 26 6 on the right bank

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 On both banks, average target strengths of upstream fish were larger than downstream fish

The adjusted 1996 fall chum salmon escapement count from August 8 through September 22 was 208,170 upstream fish This represented a conservative estimate of total escapement because the passage rate was 4,304 upstream fish on the last day of sonar operation (September 22) The 1996 total is 3 6 times the 1986-1990 average of 58,628 fish, but less than the 280,999 total in 1995 Precision of the estimate was high because few adjustments to the actual count were needed (98% of the run was manually tracked) Spatial distribution of upstream fish suggested that few fish were undetected by the sonar. Passage of upstream fish showed an increasing trend through August 31, peaking at 11,146 fish/d Counts dropped to approximately 4,000 fish/d by September 6, staying consistent throughout the remainder of the season Median passage date was September 2 The right bank accounted for 64% of the total adjusted escapement Chum salmon carcasses collected on the spawning grounds were used for sex and age composition data, males comprised 67% of the sample and age 0 4 fish predominated (54%)

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figure		Page

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 (USFWS), through Section 302 of the Alaska National Interest Lands Conservation Act, has a responsibility to ensure that salmon populations on refuge lands are conserved in their natural diversity, international treaty obligations are met, and subsistence opportunities are maintained An important component of this mandate is providing 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 (USFWS) used fixed-location hydroacoustics to enumerate adult fall chum salmon escapement in the Chandalar River in the Yukon Flats National Wildlife Refuge (Daum et al 1992) The results of this study showed that Chandalar River fall chum salmon was the second largest stock of fall chum salmon in the U S portion of the Yukon River drainage Because Chandalar River fall chum salmon are important as a refuge and subsistence resource, and due to 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 Overall project objectives were to

1) determine daily in-season counts for fishery managers,
2) describe annual variability in run size and timing, and
3) estimate total escapement of Chandalar River fall chum salmon

The initial year, 1994, although prematurely ended due to flooding, 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 chum salmon escapement and *in situ* target strength evaluations were added (Daum and Osborne 1996) The specific objectives for the 1996 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) determine daily in-season counts, describe run timing, and estimate escapement of fall chum salmon, and
7) quantify sex and age composition of the spawning population

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 and covered 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 Upstream from this area, the river becomes braided with many islands and multiple channels

The sonar site (at River Kilometer 21 5) was previously described by Daum et al (1992, Figure 2) Requirements for site selection include: 1) single channel; 2) uniform non-turbulent 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 1996 Systems were installed on opposite river banks to optimize sonar beam coverage of the river cross-sectional area Site locations were similar to 1995 and were operational from August 8 through September 22.

<u>Equipment description</u>

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 with optical disk drives having networking capabilities (Figure 3) Specific component descriptions and operations are detailed in HTI manuals (HTI 1994a, 1994b) Aiming the transducer was accomplished by using a Remote Ocean Systems underwater rotator attached to the transducer housing For each bank, sonar equipment was housed in a portable shelter and powered by a 3 5 kW gasoline-powered generator. Frequency modulation hardware (FM slide) was installed in the right bank echo sounder to reduce background noise levels (Ehrenberg 1995)

<u>Echo sounder settings</u>

Echo sounder settings differed between banks. Left bank settings were· 10 dB_W transmit power, −3 dB_V total receiver gain; *40* $\log_{10}(R)$ time-varied gain function, where R = target range (m); 0 2 ms pulse width; and 10 pings/s ping rate Right bank settings, using FM slide, were. 25 dB_W transmit power, −18 dB_V total receiver gain, *40* $\log_{10}(R)$ time-varied gain function; 1.17 ms pulse width, and 6 25 pings/s ping rate Echo sounder settings were influenced by background noise levels and signal cross-talk

Data acquisition

Three system components were used to record hydroacoustic data digital echo processor, chart recorder, and a 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 The processor was run continuously throughout the season, except 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) Pulse width criteria were widened from 1995 settings, allowing more returning echoes to be included in the data base 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 Throughout the season, voltage threshold values were set at -39 9 dB on-axis for both banks During rare noise events, right bank threshold was increased to -33.9 dB on-axis for data collection beyond approximately 30 m Acquisition range changed due to transducer redeployment as water levels varied Left bank acquisition range varied from 11-16 m and right bank acquisition range varied from 65-78 m All changes to processor settings were recorded in hourly files and log books A network, installed in 1995, allowed daily back-up and analysis without interrupting real-time data collection

Paper chart recordings (echograms) 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 to verify transducer aiming and confirm that fish were not being missed because of the processor's echo acceptance criteria Voltage threshold settings were kept at -39 9 dB throughout the season The acquisition range for echogram 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 1996 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 4.9 by 11 0° on the left bank and 2 0 by 9.5° on the right bank A narrower vertical beam transducer was installed in 1996 on the right bank to reduce background noise levels caused by surface and bottom acoustic reverberation. Low side-lobe transducers were used so the beam could be aimed close to the river bottom (−16 1 dB for the left bank and −23 1 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 calculated near-field values (MacLennan and Simmonds 1992) for each transducer, 1 3 m on the left bank and 7 2 m on the right bank Fish moving upstream and close to shore would encounter the weir, be forced offshore, and then pass through the sonar beam

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 decide 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 redeployment were recorded in log books

Hydrographic Conditions (Objective 2)

River profile and beam fit

Determining a site-specific river profile is essential before initiating sonar operations Transducer beam selection and bottom anomalies that may allow fish to go undetected can be determined from accurate river profiles Bottom-profile measurements were made July 31, 1996 A Lowrance chart recording depth sounder, with an 8° transducer, 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 of a sonar system 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

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

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)

A complete system calibration was performed preseason 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 1996) 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 with the FM slide frequency modulation hardware

In situ calibration data were collected three times per bank during the season using the 38 1 mm tungsten carbide sphere (standard target) The standard 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 aided in accurately positioning the standard target in the acoustic beam. When the target's location stabilized, 4 to 6 m from the transducer, acoustic data were electronically collected from the standard target With each bank's transducer aimed in the data acquisition position (lower edge of the beam on the river bottom), two measurements were taken of the standard target. One measurement was taken with the standard target positioned on the beam's acoustic axis allowing comparisons to factory calibration data. The second measurement was taken from the target positioned 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-axis and off-axis target positions were compared using an 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 18a 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 called 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. All upstream swimming fish were assumed to be chum salmon, based on five previous seasons of gill net catches consisting of 99% chum salmon (Daum and Osborne 1995) For each bank, hourly sample times and upstream/downstream fish counts were tabulated. Also, the number of acquired echoes per fish was 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, 42 days on the left bank and 45 days on the right bank Hourly passage rates were expressed as proportions (%) of the daily count so that 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 failing to detect fish that pass above, below, or beyond the detection range of the sonar beam Also, spatial information furnishes insight into behavioral differences between upstream and downstream swimming fish and between fish of different species Median range (horizontal distance from the transducer) values were calculated for all tracked fish and used for subsequent analyses Median vertical positions of tracked fish were calculated and converted to angle off-axis measurements before analyses,

$$V_a = \text{arcsine}\ (V_d / R_d), \qquad (2)$$

where V_a= vertical median angle off-axis (°), V_d = median vertical distance off-axis (m), R_d= median distance from transducer (m) For each bank, 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 by bank were plotted for the season Mean target strengths of upstream and downstream fish by bank and between banks were compared using a two-sample *t* test for means with unequal variances Also, daily mean values were calculated and plotted.

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 by bank were compared using a two-sample *t* test for means with unequal variances

Run Timing and Escapement Estimate (Objective 6)

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 the daily and seasonal totals were calculated Adjustments were made for partial and missing hours. Partial hourly counts (≥ 15 and < 60 min) were standardized to 1 h, using

$$C_e = (60 / T) \cdot C_a , \qquad (3)$$

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

$$C_m = [R_h / (100 - R_h)] \sum C_h , \qquad (4)$$

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 Daily counts were then generated by summing all the hourly counts with all the calculated estimates for missing hourly counts Adjusted daily and seasonal totals of upstream fish passage were tabulated and graphed.

Sex and Age Composition (Objective 7)

On September 17, 1996, sex and age composition data were collected from 144 chum salmon carcasses found on a spawning ground, 8 km above Venetie Village, by students from Venetie High School. Access to the sample site was by boat Carcasses were collected at various depths (shoreline to 1 5 m deep) with a 2 m long spear. Vertebrae from the carcass collection (three per fish) were used for age determination Vertebrae were cleaned, dried, and independently read twice under direct light with a magnifying glass Disagreements between readings were resolved with a third reading. Unreadable samples were discarded Ages were reported by the European method (Foerster 1968) - number of freshwater annuli followed by number of saltwater annuli Chi-square analysis with the Yates correction for continuity (Zar 1984) was used to test the hypothesis that sex ratios were 1 1 for the Chandalar River carcass sample

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 6 5° on the left bank and 3 2° on the right bank, corresponding to vertical transducer beam widths (echo acceptance criteria) of 6 1 and 3.0°, respectively 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 80 m distance from the transducer)

Hydrologic measurements

River depth and width varied considerably during the season River stage was highest on August 8 (4 4 m deep and 147 m wide) and lowest on September 19 (3 2 m deep and 121 m wide) For all but the first six days of the 1996 season, water levels were lower than the three previous seasons average (Figure 6) Water temperature remained steady for the first 12 days of the season then decreased as the season progressed from 12 to 4°C (Figure 7) Conductivity remained constant, ranging from 250 to 320 µS/cm

Background noise

Background noise levels on the left bank varied from −58 to −42 dB Noise was lowest 1-10 m out from the transducer Noise increased in the 10-16 m range, varying from −44 to −42 dB Passive noise level (no transmitting) was −63 dB at 75 m range

Background noise levels on the right bank varied from −60 to −36 dB Noise was lowest 1-30 m out from the transducer and increased with range beyond 30 m Passive noise level was −74 dB at 100 m range

System Calibration (Objective 3)

Mean target strength measurements of the standard target from factory calibrations were within 1 8 dB of the predicted value of −39 5 dB (MacLennan and Simmonds 1992), −38 71 dB for the left bank system and −37.75 dB for the right bank system

For the season, mean on-axis target strength measurements from *in situ* calibrations were within 1.4 dB of factory values (Table 2) For all three calibration periods, right bank mean on-axis target strength measurements were significantly less than off-axis values (*P* values <0.001). Left bank did not exhibit any trends Target strength variability was low during all on-axis calibrations, with standard deviations varying from 0 32 to 1 15 dB For each calibration period, the variability in target strength measurements for the standard target positioned near the bottom edge of the beam was 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 is presented in Tables 3 and 4 All data files for the entire season were manually tracked, resulting in 210,998 fish from 2,161 hours of "clean" processed data Of the season's available sample time, 98% was monitored Upstream traveling fish accounted for 97% of the total count, followed by 3% downstream, and 0 2% unknown The number of acquired echoes per upstream fish averaged 19 2 on the left bank (range of 4-169) and 26.6 on the right bank (range of 4-196), with medians of 17 and 22 echoes per fish, respectively (Figures 8 and 9) Downstream fish averaged 16 3 echoes per fish on the left bank (range of 5-108) and 29 2 on the right bank (range of 4-180), with medians of 14 and 26 echoes per fish, respectively On average, upstream fish on the left bank had significantly more acquired echoes per fish than downstream fish (*P* < 0 001). On the right bank, downstream fish had significantly more echoes than upstream fish (*P* < 0 001), due to their offshore position

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 previous two seasons (Daum and Osborne 1995, 1996)

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) Ninety percent of upstream fish were within 9 m of the left bank transducer and 26 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 less than downstream fish (*P* values < 0 001) Over the entire season, the daily mean ranges of upstream fish were closer to shore than the mean ranges of downstream fish (Figure 15)

Daily mean ranges of upstream fish on the left bank were constant throughout the season, varying from 5 to 8 m Daily mean ranges of upstream fish on the right bank were more variable, varying from 11 to 22 m. For both banks, upstream fish were consistently closer to shore during the later half of the season (September 3-22) Downstream daily ranges were highly variable for both banks

Vertical fish position data showed that upstream fish on both banks were bottom-oriented (Figures 16 and 17) Ninety-nine percent of upstream fish on the left bank and 98% of fish on the right bank passed 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 constant throughout the season, showing stability of transducer aim and vertical fish position on both banks

<u>Target strength distribution of tracked fish</u>

On both banks, upstream fish had mean target strengths significantly larger than downstream fish. Differences between upstream and downstream were 0 2 dB on the left bank and 2 6 dB on right bank (P values < 0 02, Figure 19 and 20) Target strengths from both upstream and downstream fish on the right bank were larger than fish on the left bank (P values < 0 001). Over the entire season, mean daily target strengths stayed fairly constant for upstream fish, while downstream fish were more variable (Figure 21) On the left bank, daily target strengths were similar for upstream and downstream fish Upstream fish on the right bank were acoustically larger than downstream fish throughout the season Mean within-fish target strength variability was similar (P > 0 5, Figure 22) between upstream and downstream fish on the left bank On the right bank, mean within-fish target strength variability was greatest for upstream fish (P < 0 001, Figure 23)

Run Timing and Escapement Estimate (Objective 6)

The adjusted 1996 fall chum salmon escapement count for the Chandalar River was 208,170 upstream fish (Table 5), the second highest estimate since sonar operations began in 1986 (Figure 24). The 1996 count was 3.6 times the 1986-1990 average of 58,628 fish (Daum et al 1992, Figure 25). Daily counts were more than 1,000 fish/d for 43 of the 46 counting days Passage of upstream fish showed an increasing trend through August 31, peaking at 11,146 fish/d. Counts dropped off to approximately 4,000 fish/d by September 6, remaining consistent throughout the rest of the counting season The median passage date was September 2 Run timing differed between banks, with right bank counts increasing earlier and dropping off later than left bank counts (Figure 26) The right bank accounted for 64% of the total adjusted escapement.

Few adjustments to the upstream fish count were needed, because more than 98% of the run was tracked (204,153 out of the final adjusted upstream count of 208,170 fish) Adjustments for partial hours made up only 10% of all hourly counts, with the majority of incomplete hours having sample times >0.75 h. Adjustments for missing hours made up less than 1% of all hourly counts, 0 49% for the left bank and 0.05% for the right bank

Sex and Age Composition (Objective 7)

Males (67%) predominated the fall chum carcass sample (N = 137) Of the 144 carcasses collected seven were not sexed The sex ratio of the Chandalar River fall chum carcass sample differed significantly from a 1·1 sex ratio (P < 0.001). Age 0 4 (53 5%) predominated, followed by age 0 3 (36 6%), age 0.5 (7.8%), and age 0 2 (2 1%) Vertebrae were unreadable from one female and one male The majority of males were age 0 4 (58%) and the majority of females were age 0 3 (48%)

DISCUSSION

High variability in target strength within and among fish could result in undercounting fish or cause elevated target strength calculations due to voltage threshold bias (MacLennan and Simmonds 1992) High target strength variability was noticed in the 1996 *in-situ* calibration data for the standard target when it was positioned near the bottom of the beam compared to an on-axis position Because Chandalar River chum salmon are bottom orientated, high variability in target strength would be expected Results from the 1995 *in-situ* target strength experiment on free-swimming fish confirmed the high variability found in target strength values, both within and among fish (Daum and Osborne 1996) In 1996, voltage thresholds were set substantially lower than predicted target strength values for fish of given lengths (Love 1977) to insure the data were not biased Increasing the right bank threshold, during rare high noise events past 30 m, could have resulted in undercounting fish at far greater ranges However, most upstream fish had target strengths substantially above the elevated threshold setting (-34 dB) and few fish traveled beyond 30 m offshore. Chart counts from the echogram recordings were compared daily to the electronic data to insure target strength thresholds did not affect target acquisition In addition, fish traces at range were closely scrutinized while visually tracking upstream targets to verify that off-axis echos were being collected. This evidence supports the assumption that few fish were missed due to voltage threshold settings

Fish position data suggest that most upstream fish passing the sonar site were within the ensonified zone during the 1996 season Upstream fish were found close to shore and near the bottom. As in the two previous years (Daum and Osborne 1995 and 1996), fish were found low in the beam and close to the transducers, with fewer fish near the top of the beam or in the outer range limit of acoustic detection Chart counts from the echogram recordings provided additional evidence that few fish passed beyond the acquisition range The shore/bottom orientation exhibited by 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)

Large numbers of non-target fish species on the Chandalar River could influence the ability to accurately estimate chum salmon passage using hydroacoustics Split-beam sonar can be used to detect changes in species composition due to behavioral differences among fish species A temporal change in either spatial distribution (range or vertical position), direction of travel, swimming behavior, or average target strength may show a shift in species composition, especially in species that migrate in high concentrations such as whitefishes. The 1996 acoustic data supports previous years findings that fish species, other than chum salmon, were not passing through the ensonified zone during sonar operation (Daum and Osborne 1996). Daily mean ranges, vertical positions, and target strengths were consistent for upstream fish throughout the 1996 season Also, the frequency distributions for these variables were all unimodal, suggesting that large numbers of fish species, other than chum salmon, were not present.

The 1996 escapement estimate of 208,170 fall chum salmon on the Chandalar River was consistent with escapement trends from other Yukon River enumeration projects (JTC 1996) The Sheenjek River, Fishing Branch River, and mainstem Yukon River projects all reported large numbers of returning fish relative to recent years The Sheenjek River, located 116 km upstream from the Chandalar River, had similar run characteristics. Both runs peaked around the end of August with the median passage date on the Sheenjek River (September 4) lagging two days behind the Chandalar River's median date of September 2 (L Barton, Alaska Department of Fish and Game, personal communication) A similar lag period in median passage dates was also found in 1995

The precision and accuracy of the 1996 Chandalar River escapement estimate was considered high because of the extensive run coverage (both in sample time and volume), few adjustments to the actual tracked fish count were needed, and species apportionment was not necessary. Acoustic data were collected for 98% of the available sample time and approximately 80% of the river width was ensonified Ninety-eight percent of the total adjusted count was visually evaluated before inclusion into the database Because of the assumed high level of precision, actual variances around the estimate were not calculated

Providing timely and accurate escapement counts to fishery managers is an overall objective of this project In 1996, daily in-season counts were provided throughout the season and an escapement estimate was determined for Chandalar River fall chum salmon. Data verification and fish tracking can be labor intensive due to large numbers of salmon and software limitations Considerable time would be saved if an automatic tracking system was developed that provided accurate counts of upstream traveling fish on the Chandalar River. Until that time, each target will be manually tracked to ensure data integrity During the 1997 season, daily in-season counts and a post-season escapement estimate will again be provided.

Sampling schedules for the 1997 season will attempt 24-h continuous acoustic monitoring from each bank However, sub-sampling may become necessary if in-season manual fish tracking falls behind schedule due to high passage rates

ACKNOWLEDGMENTS

Special appreciation is extended to the people that participated in the third year of this project and who are largely responsible for its success; James R. Massa and Amy S Ritchie for field assistance, and S. Johnston for on-site consulting and technical assistance We appreciate the assistance from R. King and R. Carroll for providing transportation, and C Michaud and the students of the Venetie High School Success of this project was also dependant on the support from M. Millard for assistance in computer programming and data analysis, R Simmons for editorial and project review, J. Millard and K Russell for editorial review

REFERENCES

Barton, L H 1995 Sonar enumeration of fall chum salmon on the Sheenjek River, 1988-1992. Alaska Department of Fish and Game, Commercial Fisheries Management and Development Division, Technical Fishery Report 95-06, Juneau, Alaska

Bergstrom, D. J., A. C. Blaney, K C Schultz, R R Holder, G. J. Sandone, D J Schneiderhan, and J H. Barton. 1995. Annual management report, Yukon Area, 1993. Alaska Department of Fish and Game, Commercial Fisheries Management and Development Division, AYK Region, Regional Information Report 3A95-10, Anchorage, Alaska.

Bergstrom, D., K Schultz, and B M Borba 1996 Salmon fisheries in the Yukon area, Alaska 1995 Alaska Department of Fish and Game, Commercial Fisheries Management and Development Division, Regional Information Report 3A96-03, Anchorage, Alaska

Craig, P. C., and J Wells 1975 Fisheries investigations in the Chandalar River region, northeast Alaska Canadian Arctic Gas Study Ltd Biological Report Series 33 1-105, Calgary, Alberta

Daum, D W., and B M Osborne 1995 Enumeration of Chandalar River fall chum salmon using split-beam sonar, 1994 U S Fish and Wildlife Service, Fishery Resource Office, Alaska Fisheries Progress Report 95-4, Fairbanks, Alaska

Daum, D W , and B M. Osborne. 1996. Enumeration of Chandalar River fall chum salmon using split-beam sonar, 1995. U. S. Fish and Wildlife Service, Fishery Resource Office, Alaska Fisheries Progress Report 96-2, Fairbanks, Alaska

Daum, D. W., R C Simmons, and K D Troyer 1992 Sonar enumeration of fall chum salmon on the Chandalar River, 1986-1990 U S Fish and Wildlife Service, Fishery Assistance Office, Alaska Fisheries Technical Report 16, Fairbanks, Alaska

Ehrenberg, J E 1983 A review of *in situ* target strength estimation techniques. FAO (Food and Agriculture Organization of the United Nations) Fisheries Report 300 85-90

Ehrenberg, J E. 1995. FM-slide/chirp signals. Report to Hydroacoustic Technology, Inc., Seattle, Washington.

Foerster, R E 1968 The sockeye salmon, *Oncorhynchus nerka* Fisheries Research Board of Canada, Bulletin 162, Ottawa, Canada

Foote, K G , and D N MacLennan 1984 Comparison of copper and tungsten carbide calibration spheres Journal of the Acoustical Society of America 75(2) 612-616.

Gaudet, D. M. 1990 Enumeration of migrating salmon populations using fixed-location sonar counters. Rapports et Procès-Verbaux des Réunions, Conseil International pour l'Exploration de la Mer 189 197-209.

Huttunen, D. C., and P. A Skvorc 1994. 1992 Yukon River border sonar progress report Alaska Department of Fish and Game, Commercial Fisheries Management and Development Division, Regional Information Report 3A94-16, Anchorage, Alaska

HTI (Hydroacoustic Technology, Inc). 1994a Model 240 split beam digital echo sounder operator's manual, version 1 2. Hydroacoustic Technology, Inc , Seattle, Washington

HTI (Hydroacoustic Technology, Inc). 1994b. Model 340 digital echo processor (split beam) operator's manual, version 1.04 D Hydroacoustic Technology Inc., Seattle, Washington

HTI (Hydroacoustic Technology, Inc) 1996 Transducer calibration for HTI Model 240 split-beam system. Report of Hydroacoustic Technology, Inc. to U S Fish and Wildlife Service, Fishery Resource Office, Fairbanks, Alaska

Johnston, S. V , B H. Ransom, and K K Kumagai 1993 Hydroacoustic evaluation of adult chinook and chum salmon migrations in the Yukon River during 1992 Report of Hydroacoustic Technology, Inc to U S Fish and Wildlife Service, Fisheries Assistance Office, Fairbanks, Alaska

JTC (United States/Canada Yukon River Joint Technical Committee) 1996 Yukon River salmon season review for 1996 and technical committee report. Prepared by the United States/Canada Yukon River Joint Technical Committee Whitehorse, Yukon Territory

Love, R H 1977. Target strength of an individual fish at any aspect Journal of the Acoustical Society of America 72(6).1397-1402

MacLennan, D N , and E. J Simmonds. 1992. Fisheries acoustics. Chapman and Hall, London.

Traynor, J J., and J E. Ehrenberg 1990. Fish and standard sphere target strength measurements obtained with a dual beam and split beam echo sounding system Rapports et Procès-Verbaux des Réunions, Conseil International pour l'Exploration de la Mer 189 325-335

U. S. Department of the Interior. 1964. A report on fish and wildlife resources affected by the Rampart dam and reservoir project, Yukon River, Alaska. U S Fish and Wildlife Service, Juneau, Alaska

Urick, R. J. 1983 Principles of underwater sound, 3rd edition McGraw-Hill Book Co , New York

Zar, J. H. 1984. Biostatistical analysis, second edition. Prentice and Hall, Englewood Cliffs, New Jersey

Table 1. Echo acceptance criteria used for digital echo processing, Chandalar River, 1996 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 0.38	-3.65 to 2.43	-5 49 to 5 49	-39 9	11 to 16
Right	0.10 to 0 38	-1.49 to 1.49	-4 75 to 4.75	-39.9[a]	65 to 78

[a]During rare noise events right bank threshold increased to -33 9 dB at ranges >30 m

Table 2. Target strength measurements of a 38 1 mm tungsten carbide sphere, Chandalar River, 1996.

Type of calibration	Date	Mean target strength (dB)	SD	N	Position of target
		Left bank			
Factory	Jul 10	-38 71	0 31	901	On-axis
In situ	Aug 7	-38.40	0.43	2,951	On-axis
In situ	Aug 7	-39 22	2 17	1,035	Bottom of beam
In situ	Aug 16	-38.28	0 32	3,022	On-axis
In situ	Aug 16	-38 81	1 73	2,039	Bottom of beam
In situ	Sep 5	-37 45	0 42	3,019	On-axis
In situ	Sep 5	-35 69	2 40	2,882	Bottom of beam
		Right bank			
Factory	Jun 7	-37 75	0 30	605	On-axis
In situ	Aug 6	-37 00	1 15	1,766	On-axis
In situ	Aug 6	-33 55	2 01	1,251	Bottom of beam
In situ	Aug 17	-36 40	1 10	1,816	On-axis
In situ	Aug 17	-34 58	2 74	861	Bottom of beam
In situ	Sep 5	-36 60	0 79	1,925	On-axis
In situ	Sep 5	-35.57	3 08	1,146	Bottom of beam

Table 3 Hydroacoustic data collected from the left bank, Chandalar River, 1996

Date	Sample time (h)	Upstream count	Downstream count	Unknown count	Total count
Aug 8	23.76	448	9	2	459
9	23 14	383	3	0	386
10	23.76	314	4	0	318
11	23 84	253	3	1	257
12	21 20	414	5	0	419
13	22 93	477	3	1	481
14	23.82	463	2	0	465
15	23 85	801	6	0	807
16	21 34	849	6	2	857
17	23.72	775	11	1	787
18	23.84	696	8	1	705
19	23 54	696	3	1	700
20	23 53	863	8	1	872
21	23 79	1,168	12	1	1,181
22	22 75	683	16	2	701
23	23 81	1,126	12	1	1,139
24	23 66	2,037	15	6	2,058
25	23.82	3,958	16	14	3,988
26	23 83	4,597	15	10	4,622
27	23.73	2,955	11	2	2,968
28	23 80	2,835	15	2	2,852
29	23 84	2,618	14	6	2,638
30	22.45	2,667	16	5	2,688
31	23.73	3,841	25	5	3,871
Sep 1	23 71	2,021	38	0	2,059
2	23 81	2,642	57	2	2,701
3	16 97	1,791	9	5	1,805
4	23 79	1,724	20	3	1,747
5	23 00	1,136	17	6	1,159
6	23.69	1,301	16	10	1,327
7	23 79	1,943	11	6	1,960
8	23.16	1,869	5	6	1,880
9	23 76	1,602	7	7	1,616
10	23 83	1,610	6	6	1,622
11	23 67	1,747	7	4	1,758
12	23 79	1,522	27	0	1,549
13	23 84	2,538	25	7	2,570
14	23 81	1,744	35	13	1,792
15	23 69	1,500	10	6	1,516
16	23 80	1,941	32	7	1,980
17	23.83	2,010	36	10	2,056
18	23.81	1,453	20	9	1,482
19	23 82	1,350	54	9	1,413
20	23 64	1,297	26	5	1,328
21	23 84	1,433	53	1	1,487
22	23 84	1,667	63	0	1,730
Total	1076 37	73,758	812	186	74,756

Table 4. Hydroacoustic data collected from the right bank, Chandalar River, 1996.

Date	Sample time (h)	Upstream count	Downstream count	Unknown count	Total count
Aug 8	23.58	708	102	0	810
9	23.14	515	43	0	558
10	23.69	536	75	0	611
11	23.93	583	47	0	630
12	23 59	814	48	0	862
13	22 27	825	40	1	866
14	23 77	1,124	30	2	1,156
15	23.80	1,061	48	0	1,109
16	23.56	833	37	0	870
17	22.24	824	30	0	854
18	22 67	992	23	5	1,020
19	23 74	1,113	37	1	1,151
20	23 82	1,403	40	1	1,444
21	23.73	1,535	39	4	1,578
22	23 67	1,241	48	2	1,291
23	23 80	1,436	109	3	1,548
24	22 39	4,410	85	5	4,500
25	23 78	4,512	71	4	4,587
26	23 69	4,960	64	6	5,030
27	23.70	3,369	72	1	3,442
28	23 78	4,833	104	4	4,941
29	23 79	4,192	93	1	4,286
30	23.79	5,383	80	10	5,473
31	23 77	7,223	90	9	7,322
Sep 1	23 70	5,122	94	7	5,223
2	23 65	5,642	290	7	5,939
3	23 32	5,755	104	7	5,866
4	23 70	4,346	68	9	4,423
5	23 27	3,075	75	2	3,152
6	23 67	2,634	73	4	2,711
7	23.60	3,314	96	4	3,414
8	23 79	3,820	139	4	3,963
9	23.73	2,212	98	2	2,312
10	23.66	3,423	166	5	3,594
11	23.67	2,031	205	1	2,237
12	23 79	2,162	462	0	2,624
13	23.79	3,184	265	6	3,455
14	23 77	1,898	351	2	2,251
15	23 75	2,200	273	1	2,474
16	23 58	4,069	190	6	4,265
17	23 80	5,009	114	8	5,131
18	23 77	3,592	187	3	3,782
19	23 79	4,418	179	2	4,599
20	23 80	2,844	257	1	3,102
21	23 68	2,611	355	3	2,969
22	23 73	2,609	206	2	2,817
Total	1,084.70	130,395	5,702	145	136,242

Table 5. Daily adjusted fall chum salmon count, Chandalar River, 1996.

Date	Left bank	Right bank	Combined	Cumulative	Cumulative (%)
Aug 8	451	721	1,172	1,172	0 56
9	391	537	928	2,100	1 01
10	317	544	861	2,961	1 42
11	254	602	856	3,817	1 83
12	439	830	1,269	5,086	2 44
13	483	844	1,327	6,413	3 08
14	466	1,134	1,600	8,013	3 85
15	807	1,069	1,876	9,889	4 75
16	909	852	1,761	11,650	5 60
17	783	889	1,672	13,322	6 40
18	701	1,040	1,741	15,063	7 24
19	723	1,128	1,851	16,914	8 13
20	887	1,410	2,297	19,211	9 23
21	1,174	1,555	2,729	21,940	10 54
22	725	1,263	1,988	23,928	11 49
23	1,143	1,453	2,596	26,524	12 74
24	2,060	4,833	6,893	33,417	16 05
25	3,997	4,543	8,540	41,957	20 16
26	4,630	5,036	9,666	51,623	24 80
27	2,983	3,405	6,388	58,011	27 87
28	2,853	4,870	7,723	65,734	31 58
29	2,625	4,217	6,842	72,576	34 86
30	2,772	5,440	8,212	80,788	38 81
31	3,858	7,288	11,146	91,934	44 16
Sep 1	2,053	5,176	7,229	99,163	47 64
2	2,664	5,726	8,390	107,553	51 67
3	2,775	5,933	8,708	116,261	55 85
4	1,741	4,395	6,136	122,397	58 80
5	1,153	3,155	4,308	126,705	60 87
6	1,313	2,678	3,991	130,696	62 78
7	1,955	3,399	5,354	136,050	65 36
8	1,927	3,868	5,795	141,845	68 14
9	1,621	2,238	3,859	145,704	69 99
10	1,623	3,464	5,087	150,791	72 44
11	1,769	2,056	3,825	154,616	74 27
12	1,539	2,189	3,728	158,344	76 06
13	2,553	3,211	5,764	164,108	78 83
14	1,759	1,913	3,672	167,780	80 60
15	1,515	2,224	3,739	171,519	82 39
16	1,958	4,146	6,104	177,623	85 33
17	2,022	5,041	7,063	184,686	88 72
18	1,464	3,625	5,089	189,775	91 16
19	1,361	4,458	5,819	195,594	93 96
20	1,318	2,868	4,186	199,780	95 97
21	1,441	2,645	4,086	203,866	97 93
22	1,675	2,629	4,304	208,170	100 00
Total	75,630	132,540	208,170		

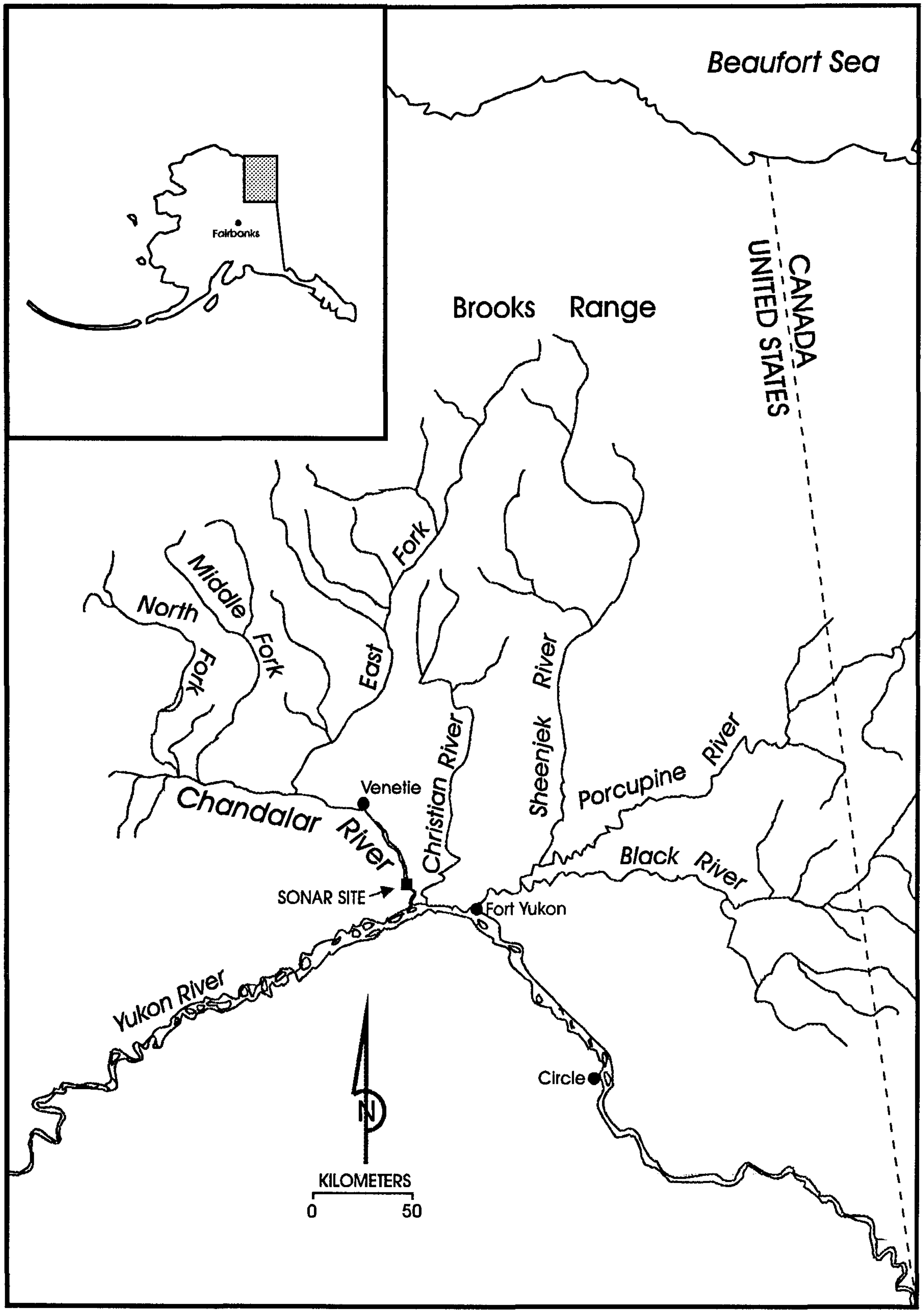

Figure 1. Major tributaries of the Yukon River near the U S /Canada border

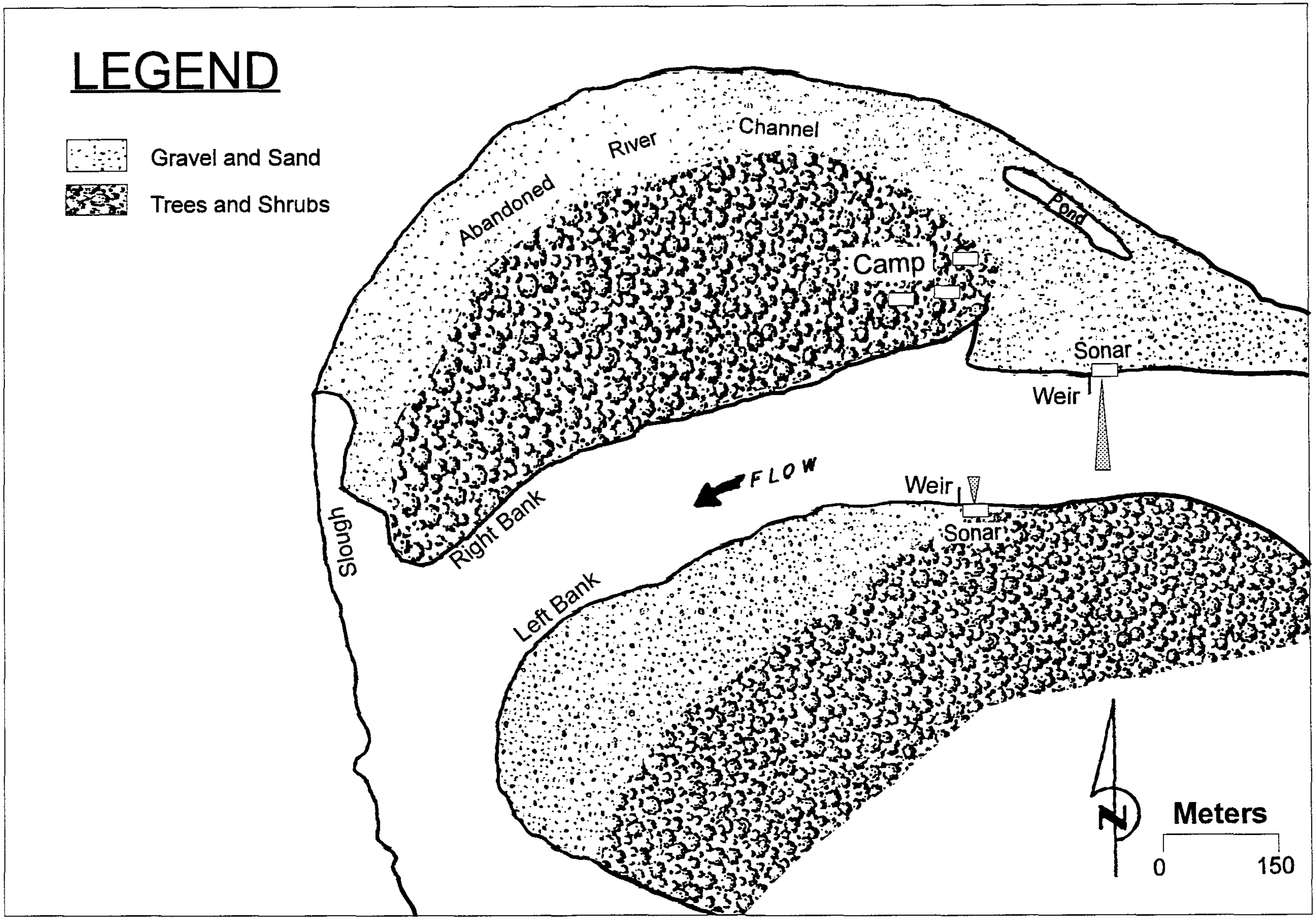

Figure 2. Site map of the Chandalar River sonar facilities, 1996.

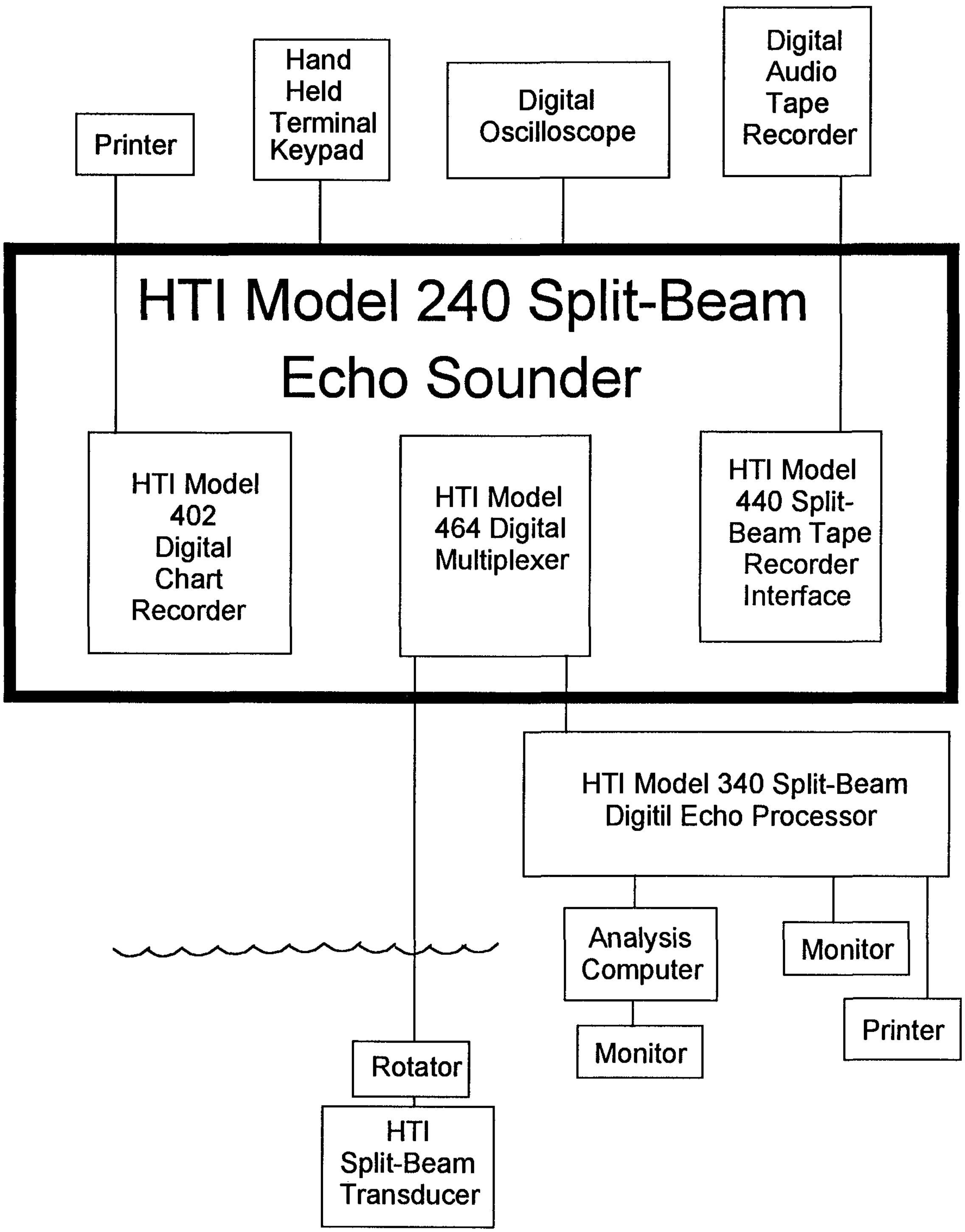

Figure 3 Split-beam hydroacoustic system, Chandalar River, 1996

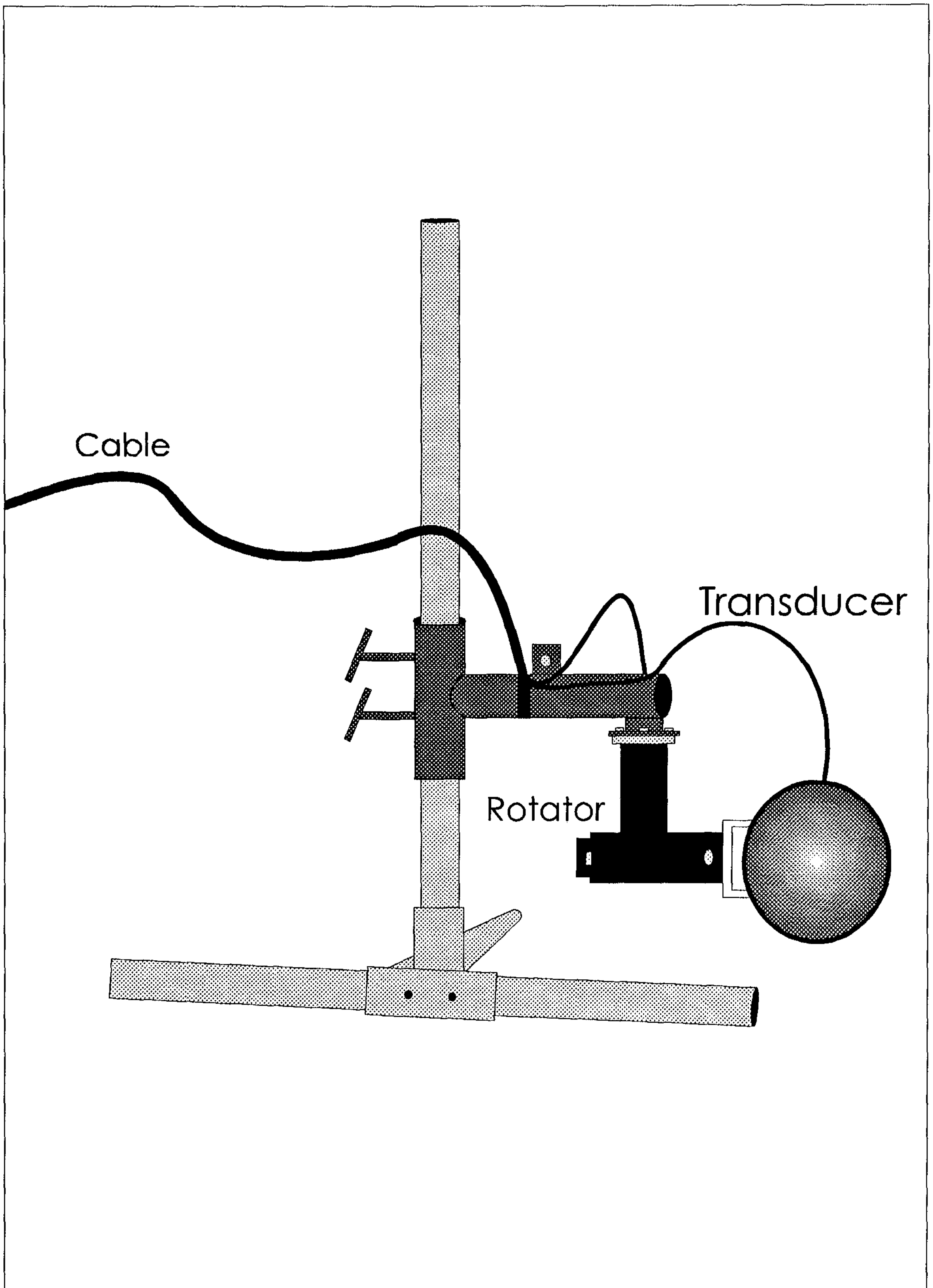

Figure 4 Split-beam transducer, remote rotator, and pod assembly, Chandalar River, 1996

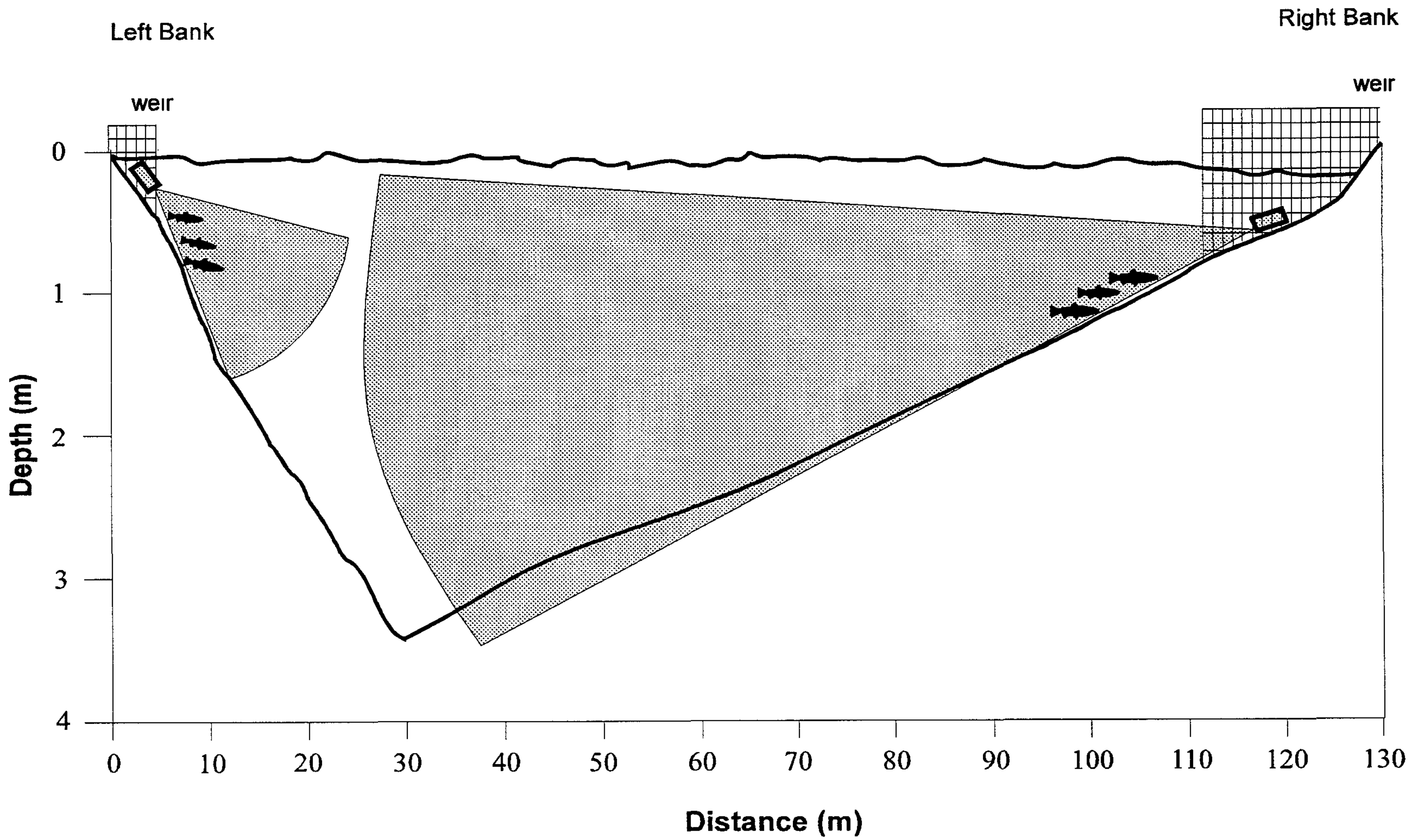

Figure 5 River channel profile and estimated ensonified zones of the left and right banks, Chandalar River, 1996. Different axis scales were used to enhance visibility

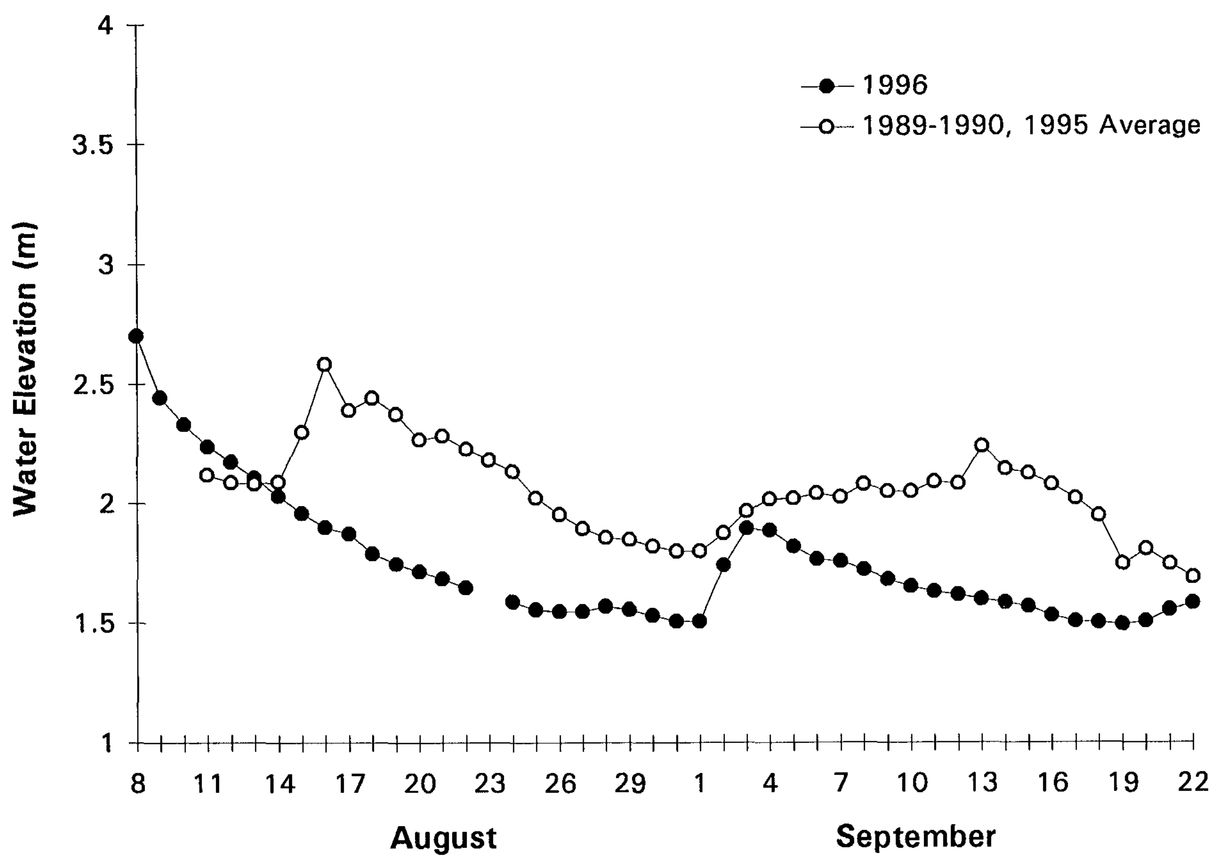

Figure 6 Daily water elevation during sonar operation, Chandalar River, 1996

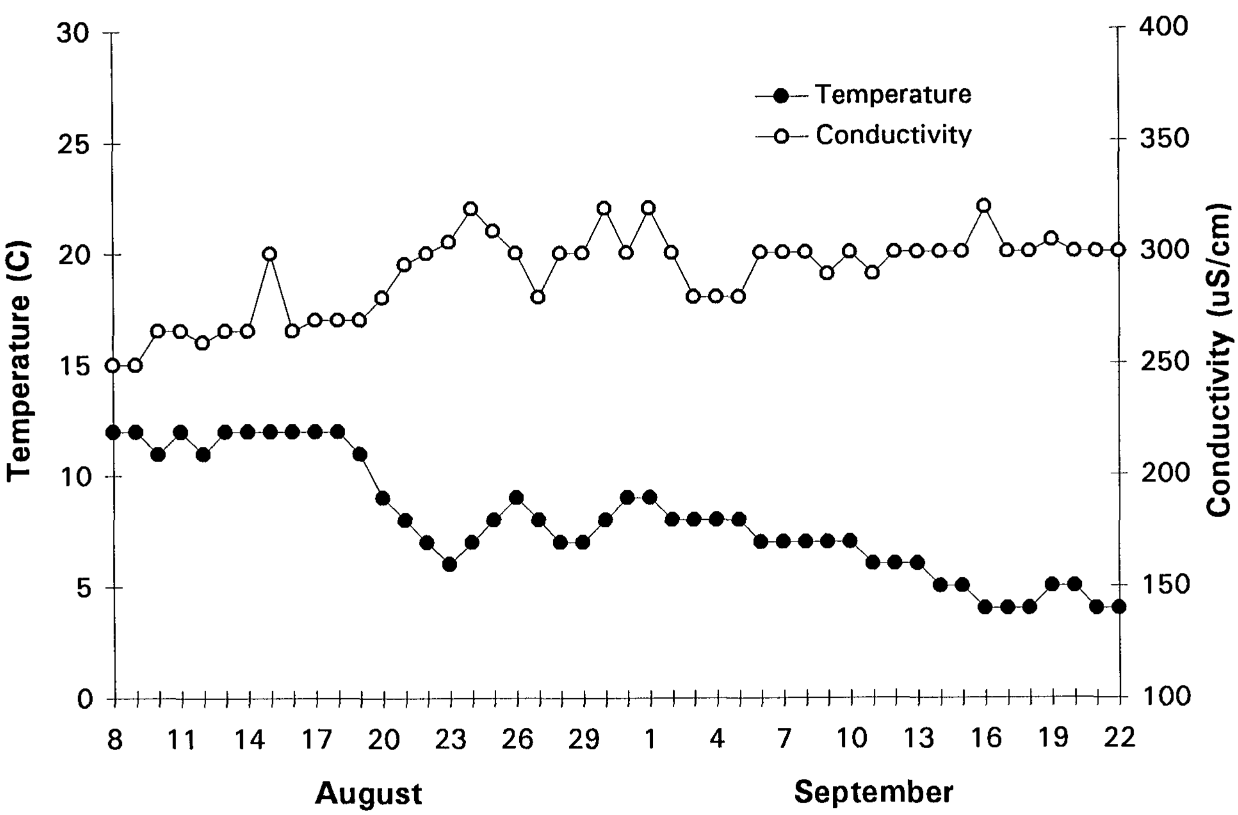

Figure 7 Daily water temperature and conductivity measurements, Chandalar River, August 8-September 22, 1996

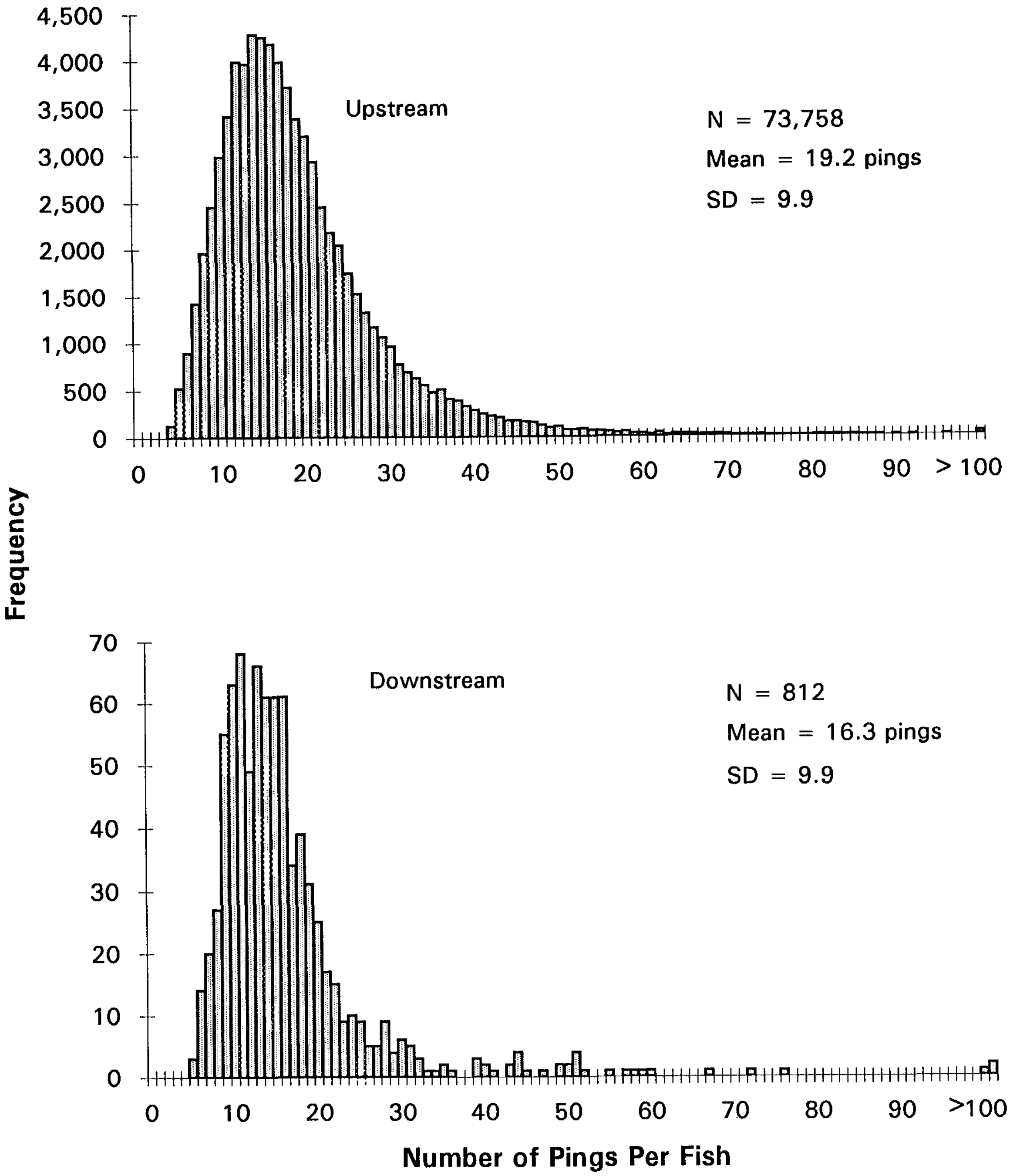

Figure 8 Number of acquired echoes per tracked fish, left bank, Chandalar River, August 8-September 22, 1996.

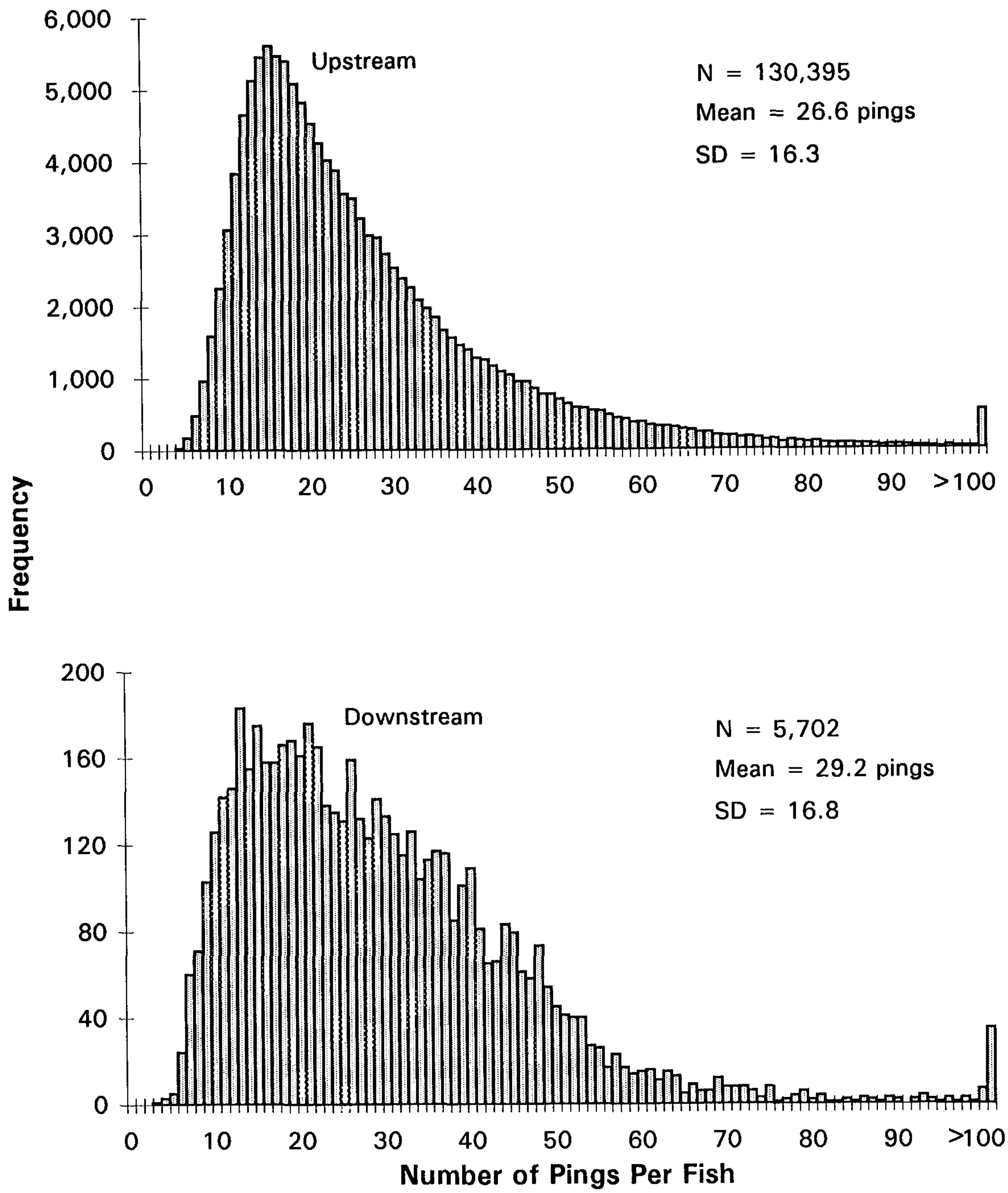

Figure 9. Number of acquired echoes per tracked fish, right bank, Chandalar River, August 8-September 22, 1996.

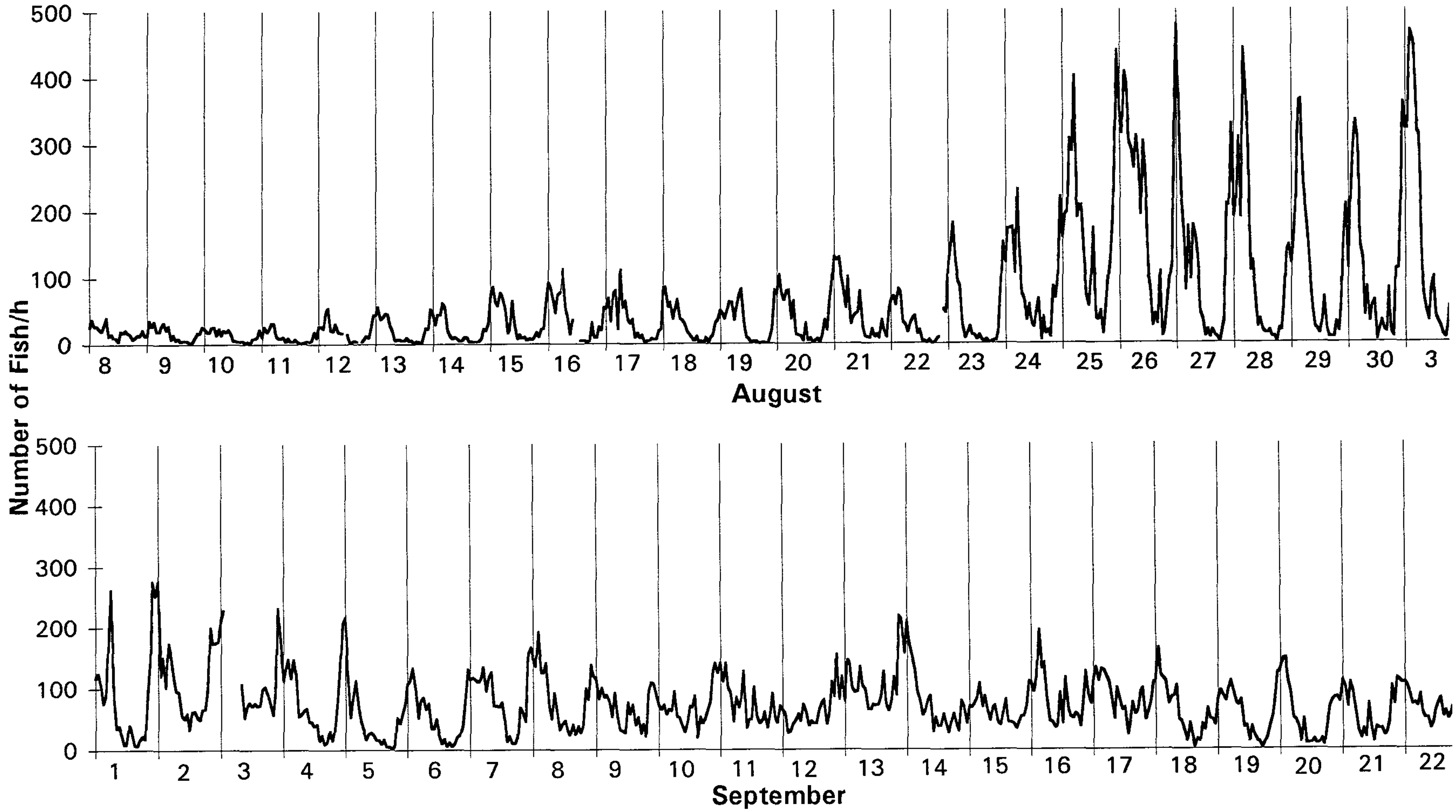

Figure 10 Diel distribution of upstream fish, left bank, Chandalar River, August 8-September 22, 1996.

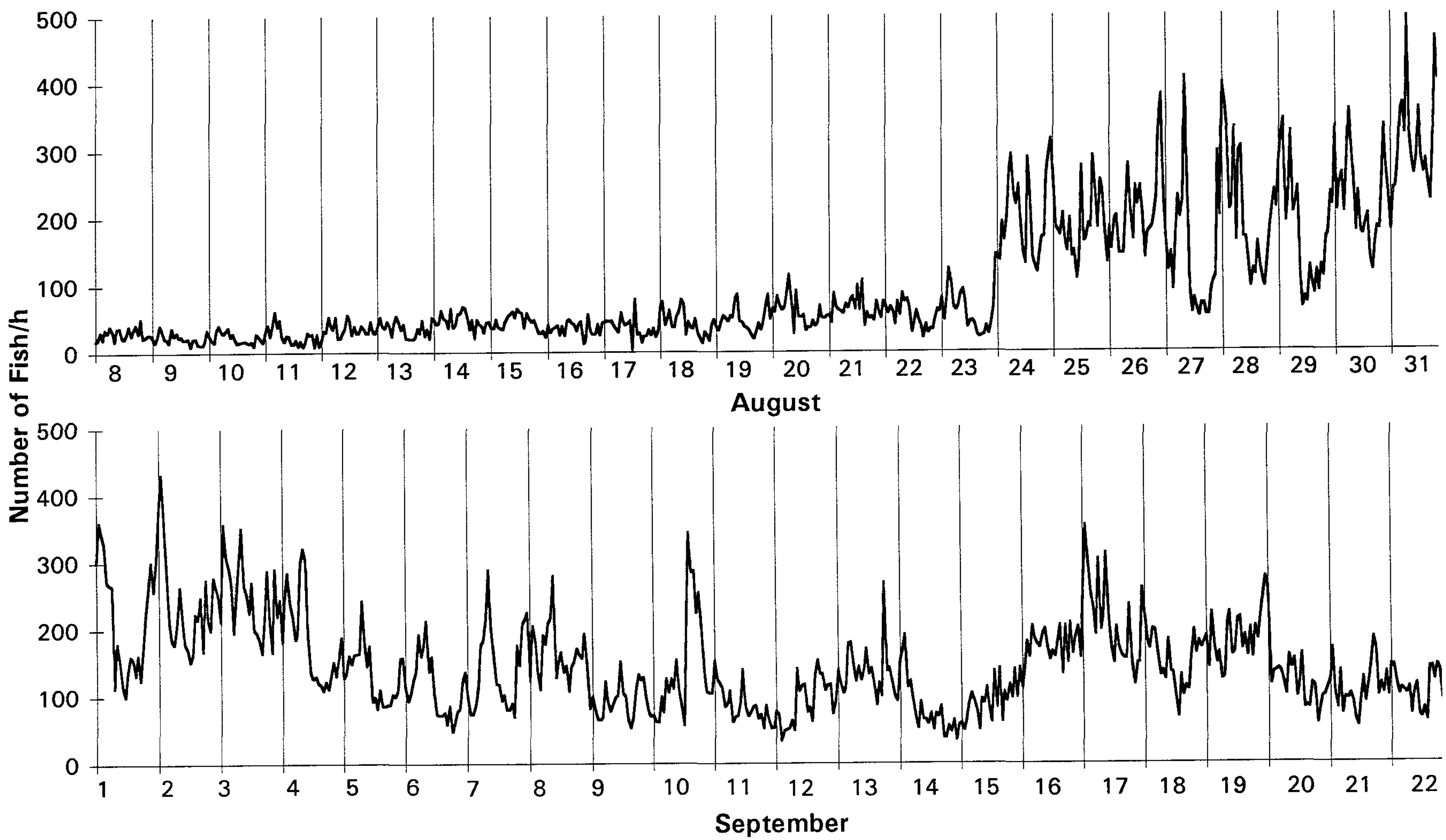

Figure 11 Diel distribution of upstream fish, right bank, Chandalar River, August 8-September 22, 1996.

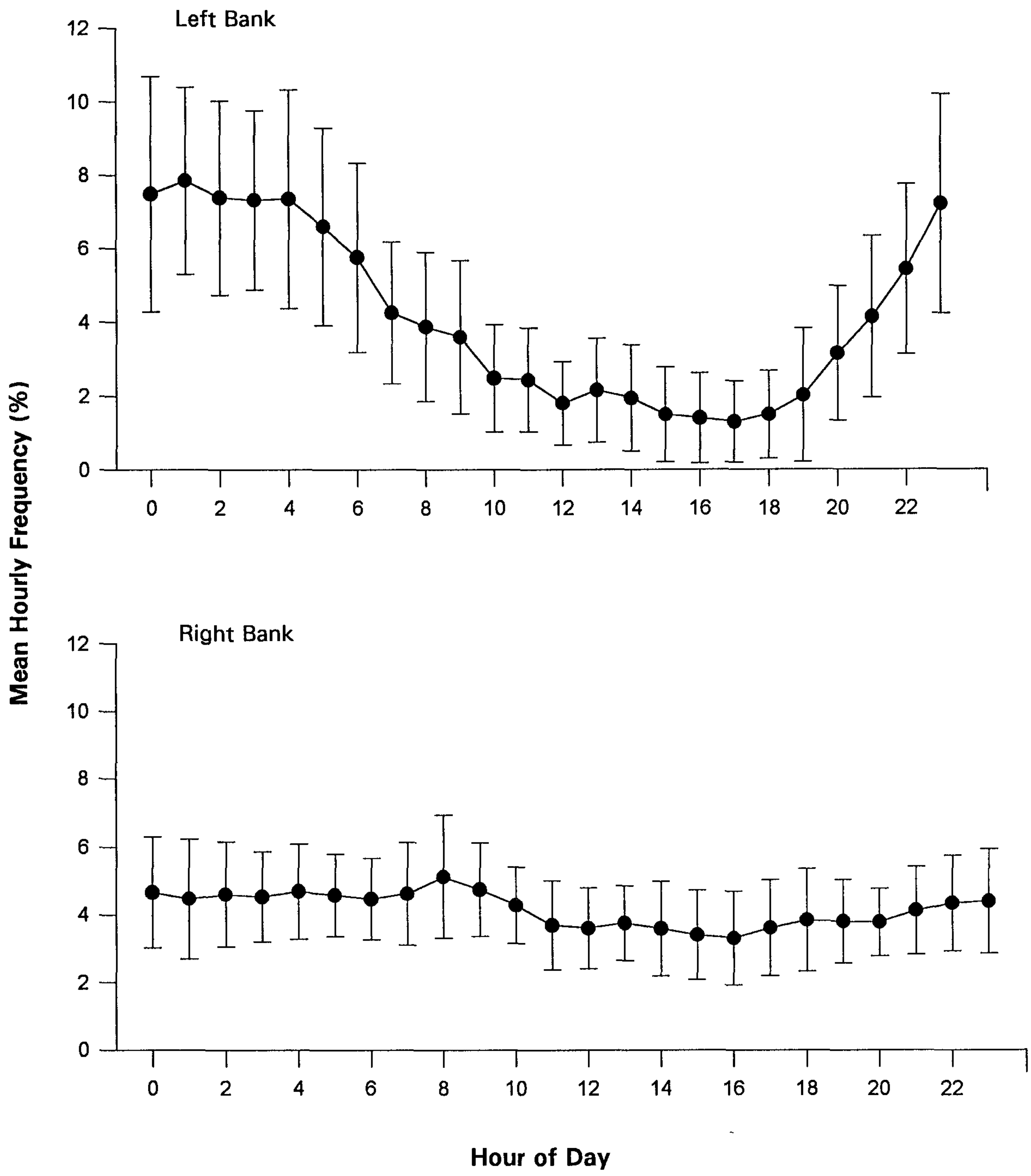

Figure 12. Mean (± SD) hourly frequency of upstream fish, Chandalar River, 1996 Data from 42 days of continuous 24 h data on the left bank and 45 days on the right bank

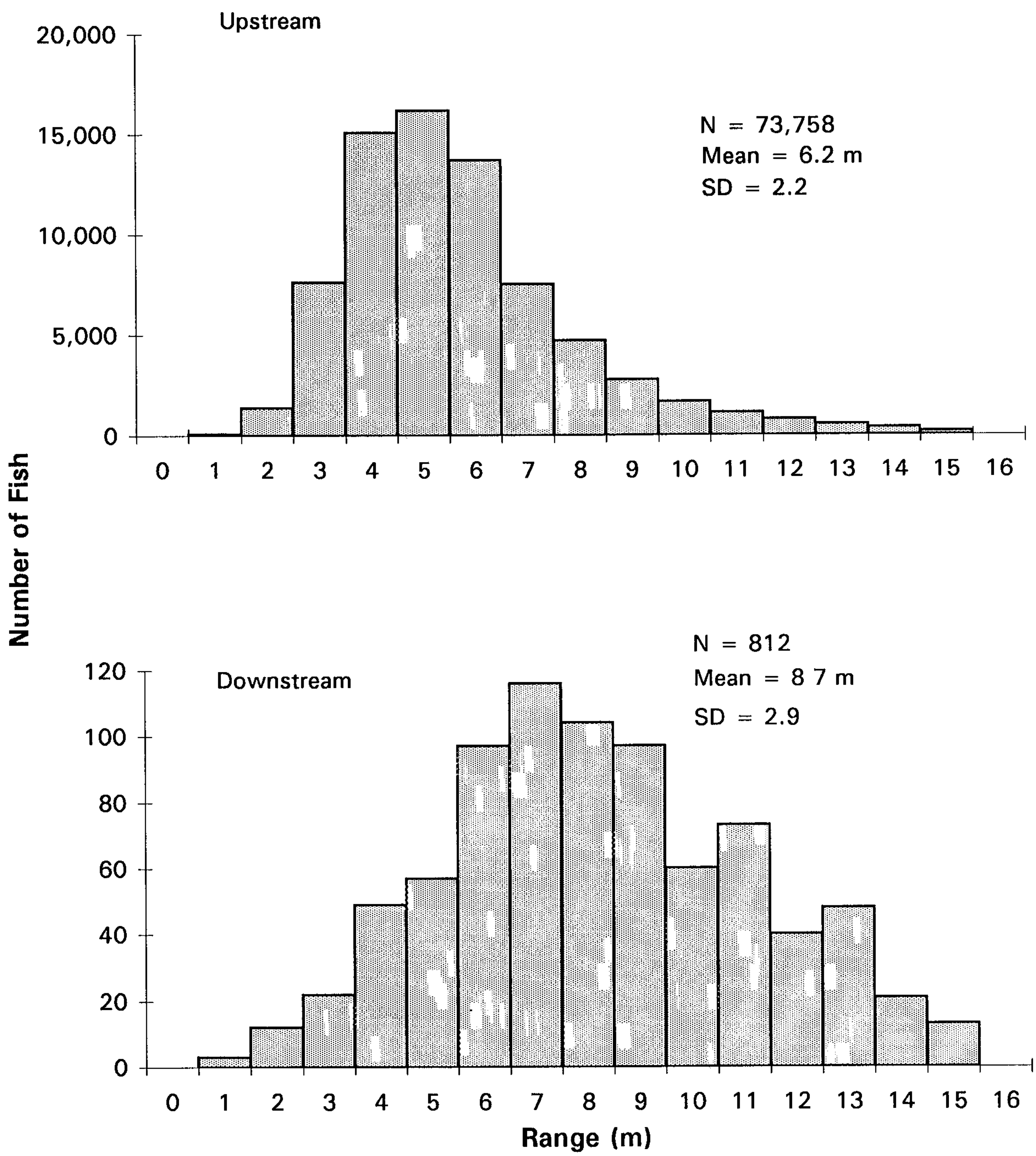

Figure 13 Range (horizontal distance from transducer) distribution of upstream and downstream fish, left bank, Chandalar River, August 8-September 22, 1996

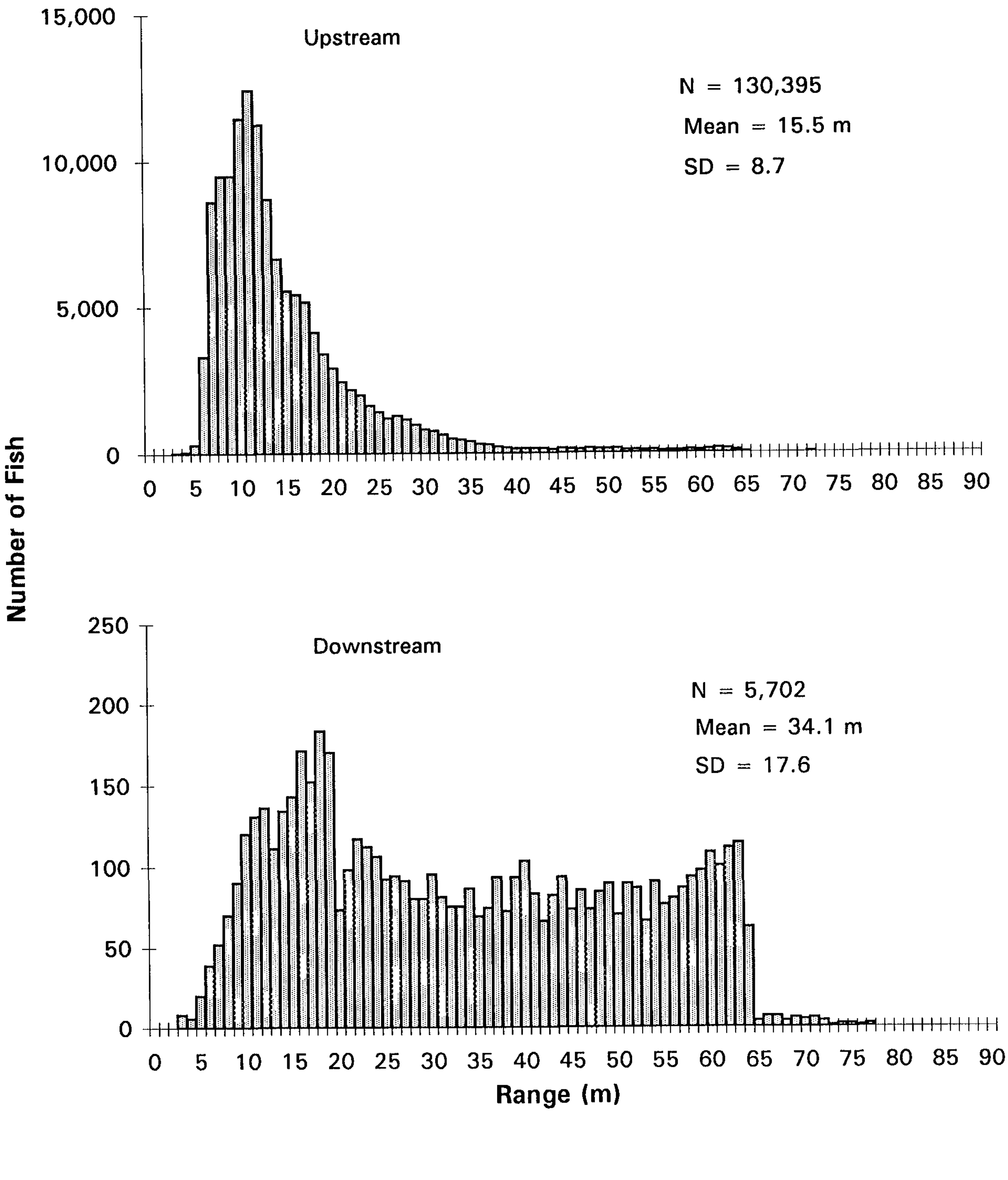

Figure 14 Range (horizontal distance from transducer) distribution of upstream and downstream fish, right bank, Chandalar River, August 8-September 22, 1996.

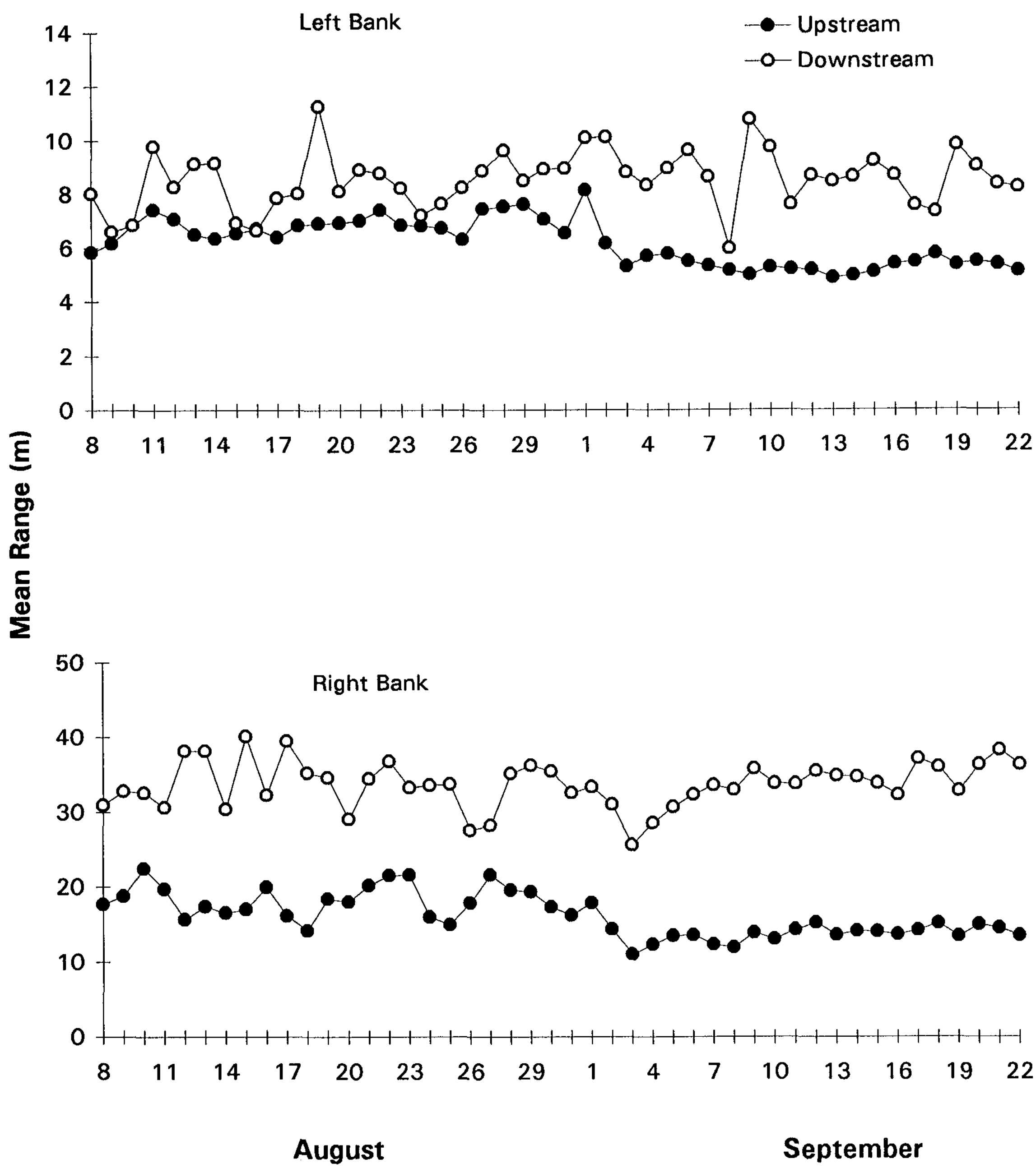

Figure 15 Mean daily range of upstream and downstream fish by bank, Chandalar River, August 8-September 22, 1996

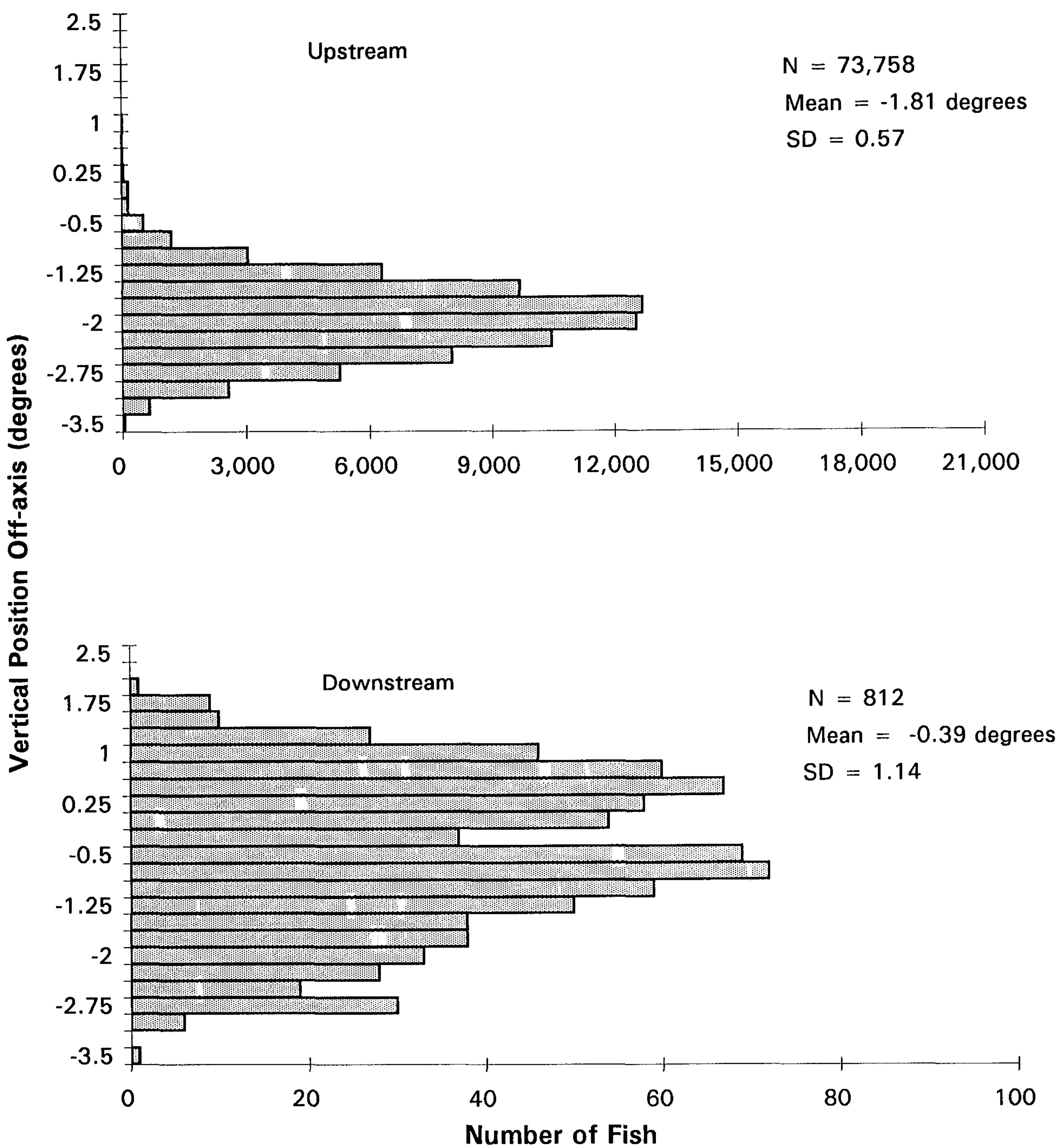

Figure 16. Vertical distribution of upstream and downstream fish, left bank, Chandalar River, August 8-September 22, 1996

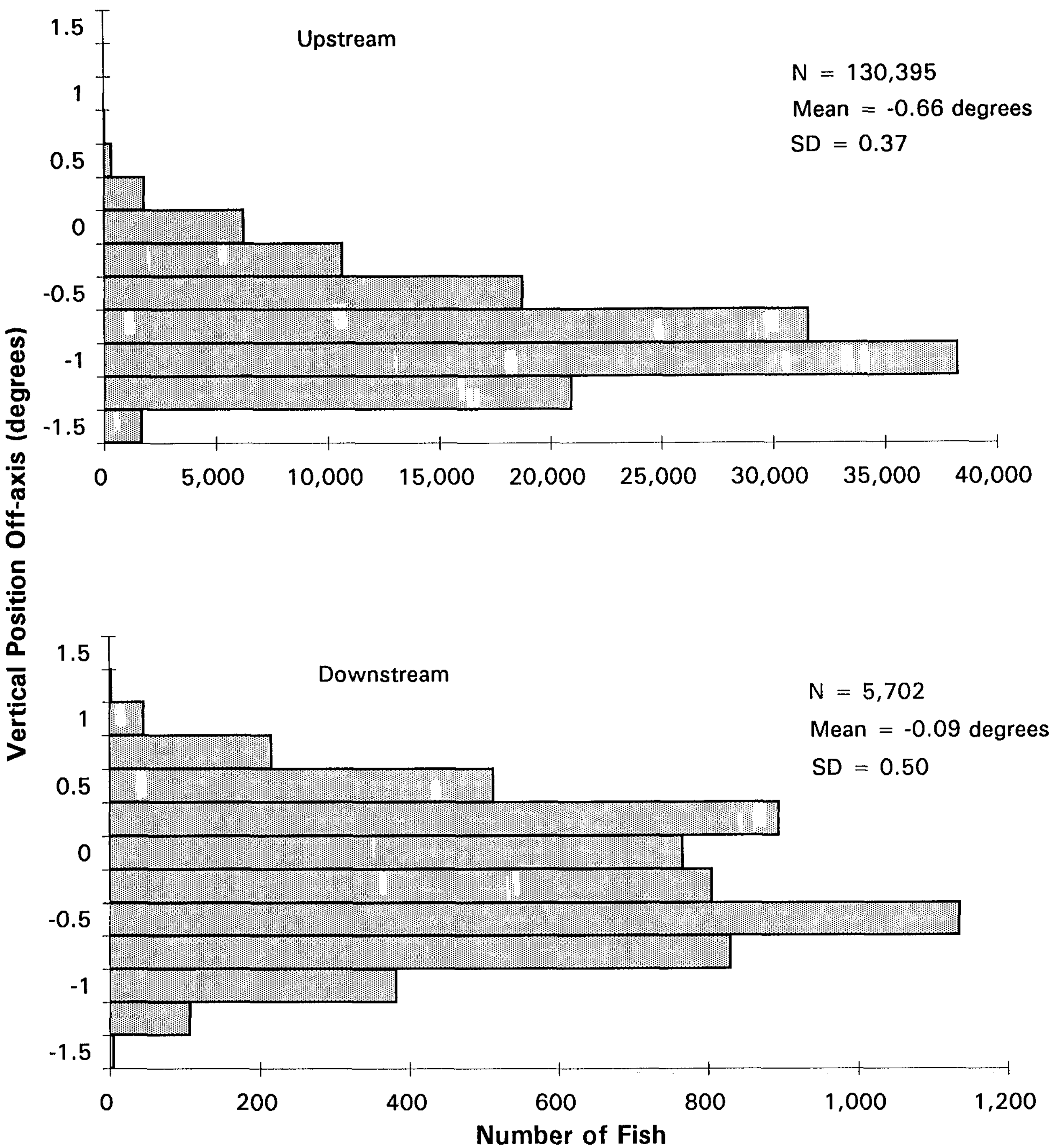

Figure 17 Vertical distribution of upstream and downstream fish, right bank, Chandalar River, August 8-September 22, 1996

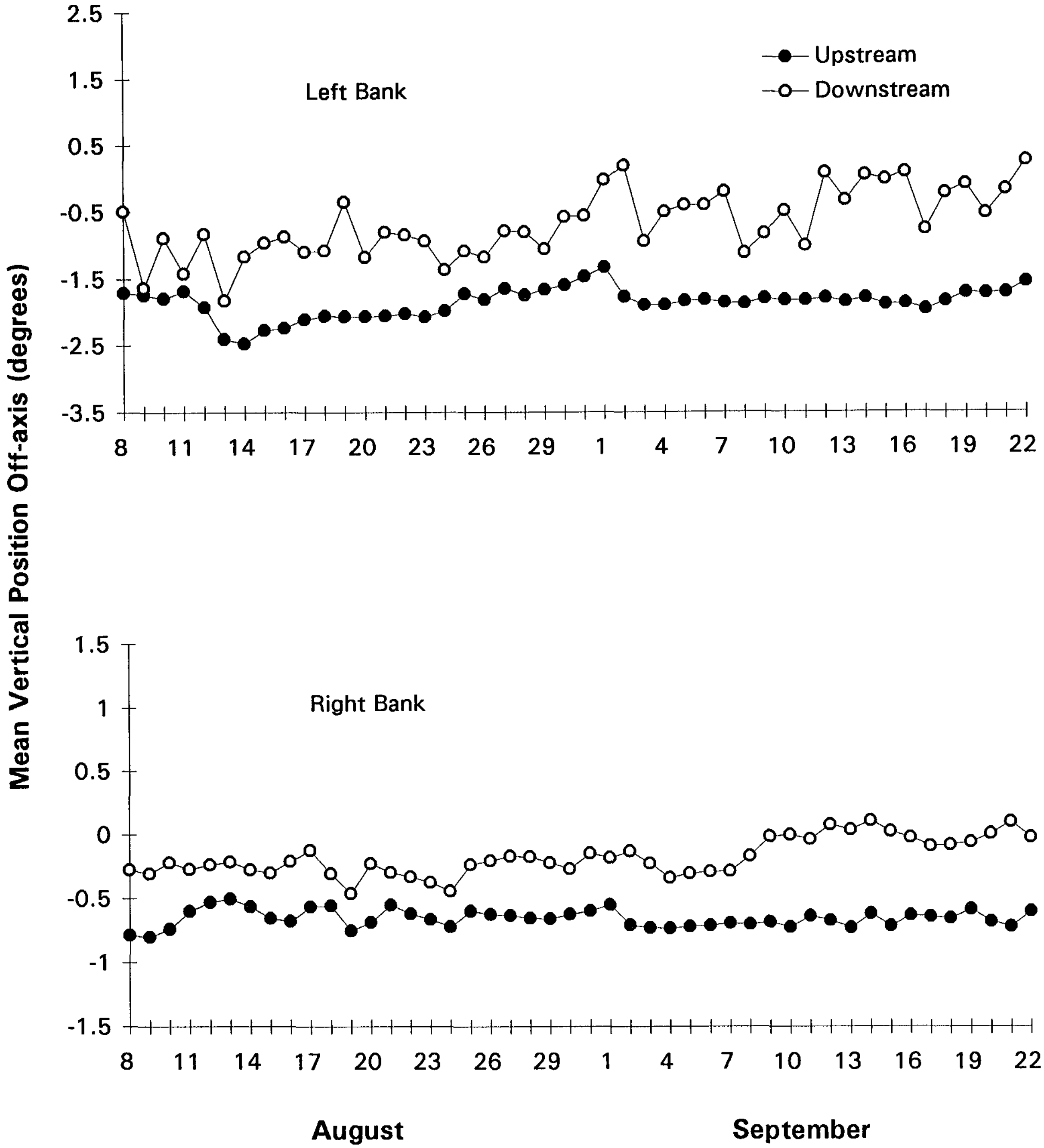

Figure 18 Mean daily vertical position of upstream and downstream fish by bank, Chandalar River, August 8-September 22, 1996

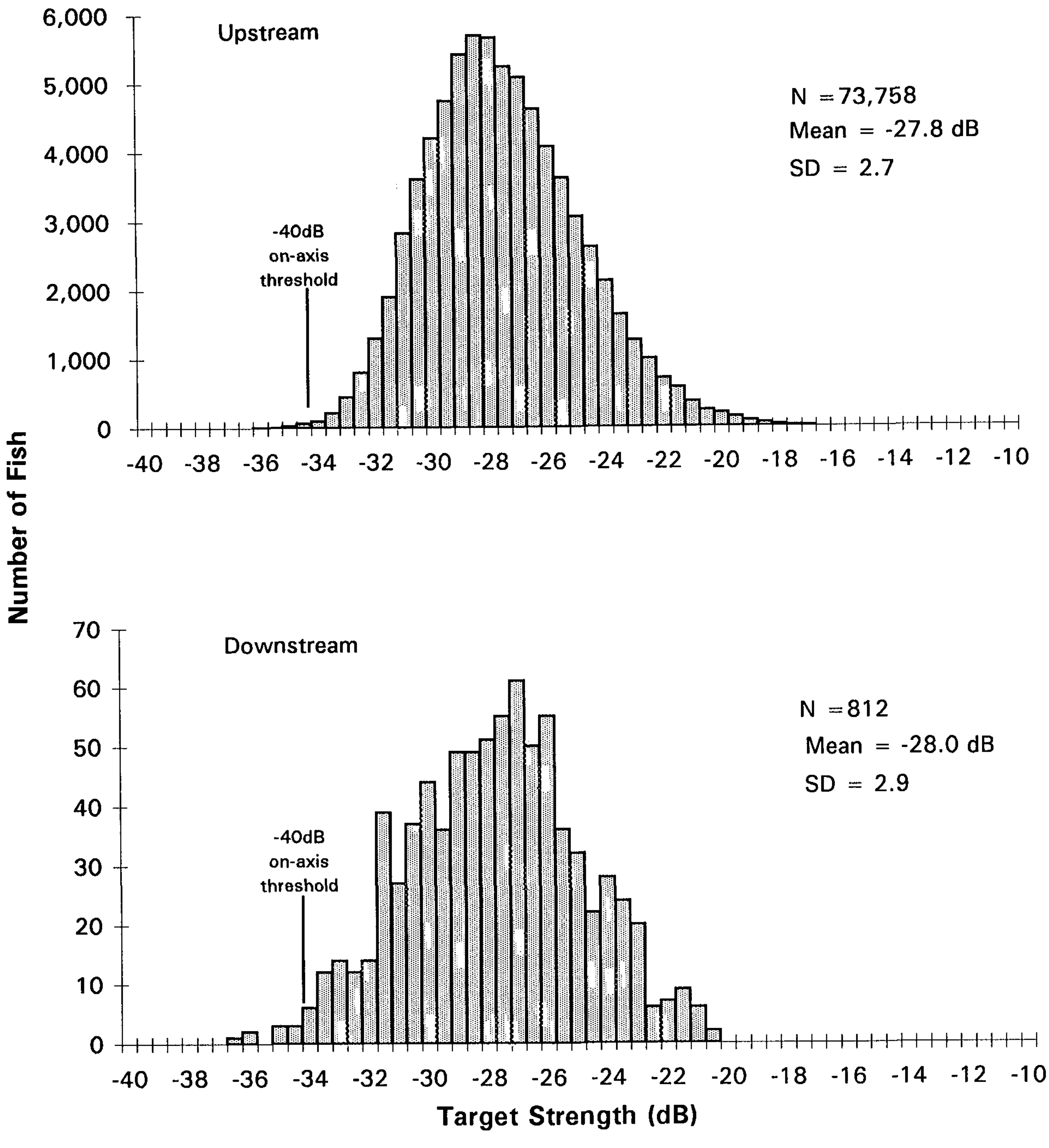

Figure 19. Target strength distribution of upstream and downstream fish, left bank, Chandalar River, August 8-September 22, 1996. Area of distribution potentially affected by signal threshold is indicated

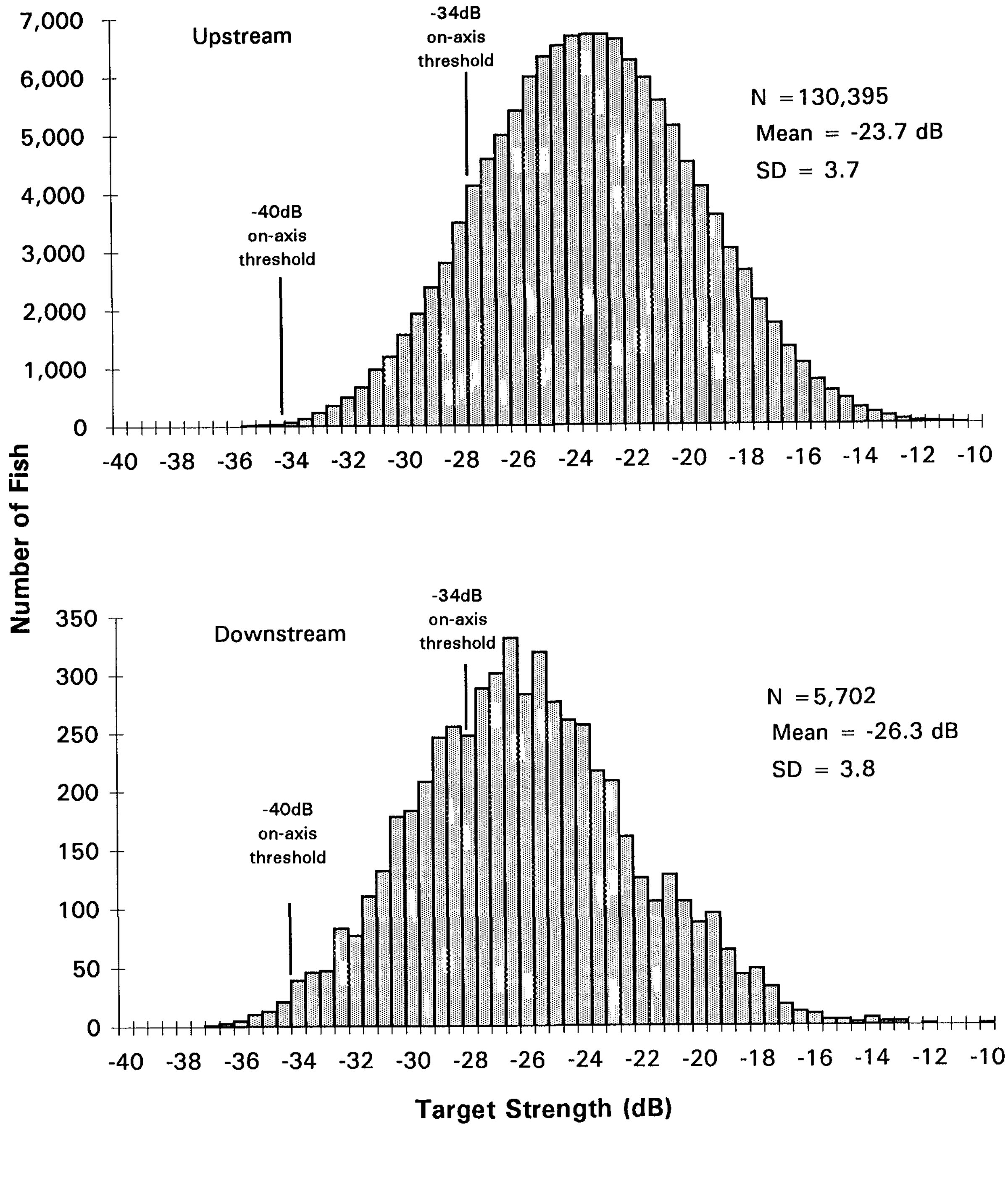

Figure 20 Target strength distribution of upstream and downstream fish, right bank, Chandalar River, August 8-September 22, 1996 Area of distribution potentially affected by signal threshold is indicated The -34 dB on-axis threshold was only used during rare noise events at ranges beyond 30 m

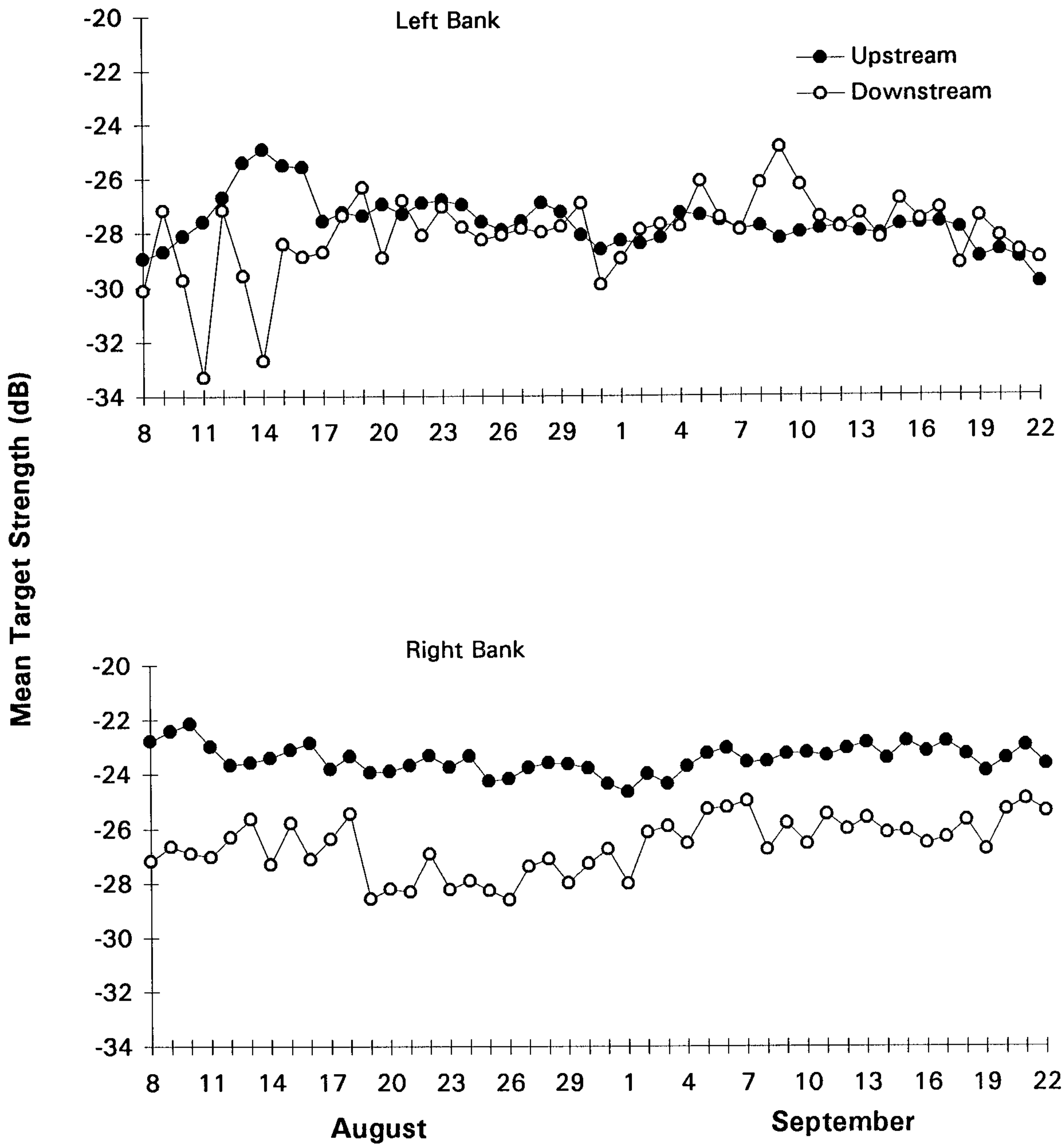

Figure 21 Mean daily target strength of upstream and downstream fish by bank, Chandalar River, August 8-September 22, 1996

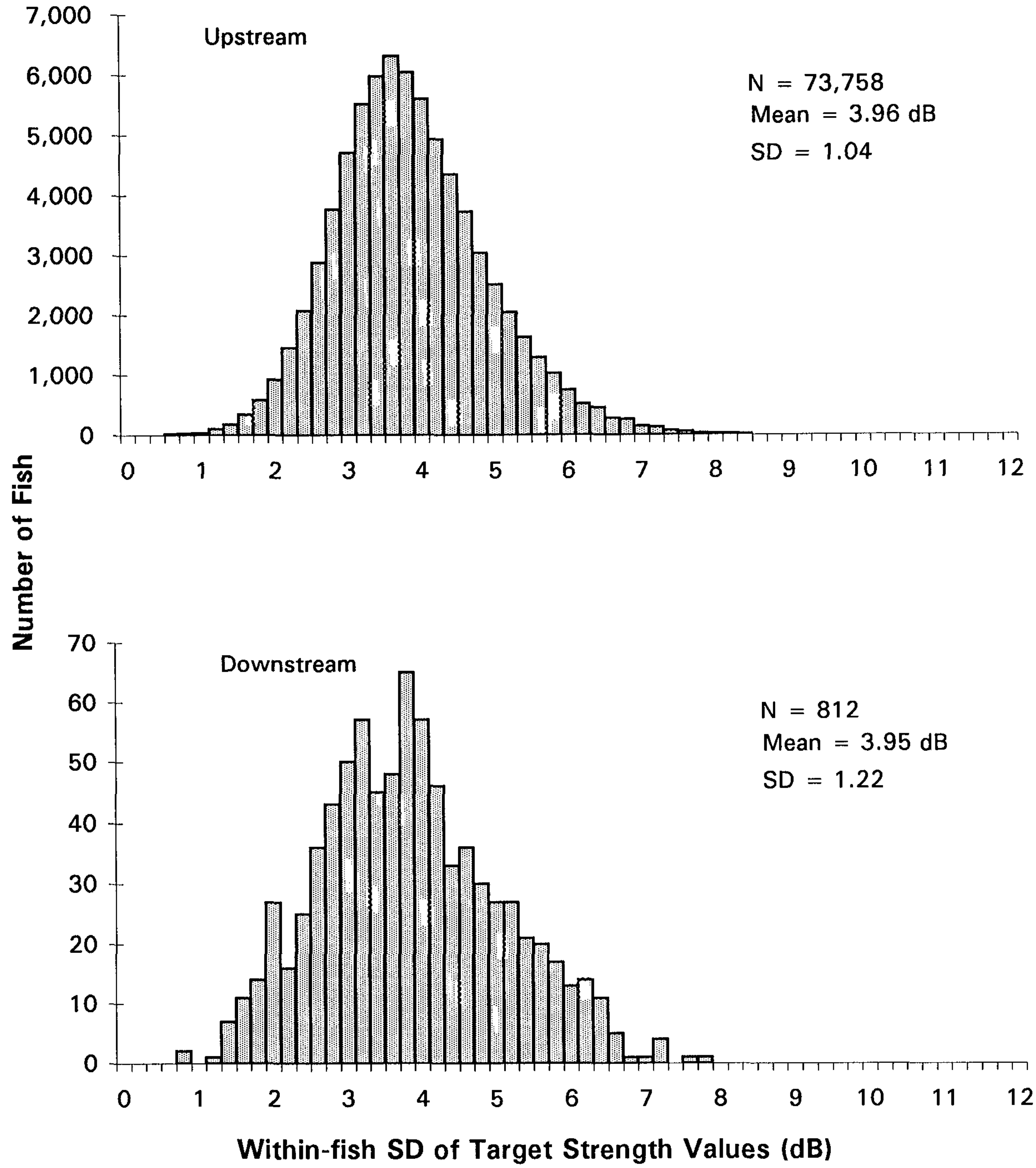

Figure 22 Within-fish target strength variability (SD) of upstream and downstream fish, left bank, Chandalar River, August 8-September 22, 1996

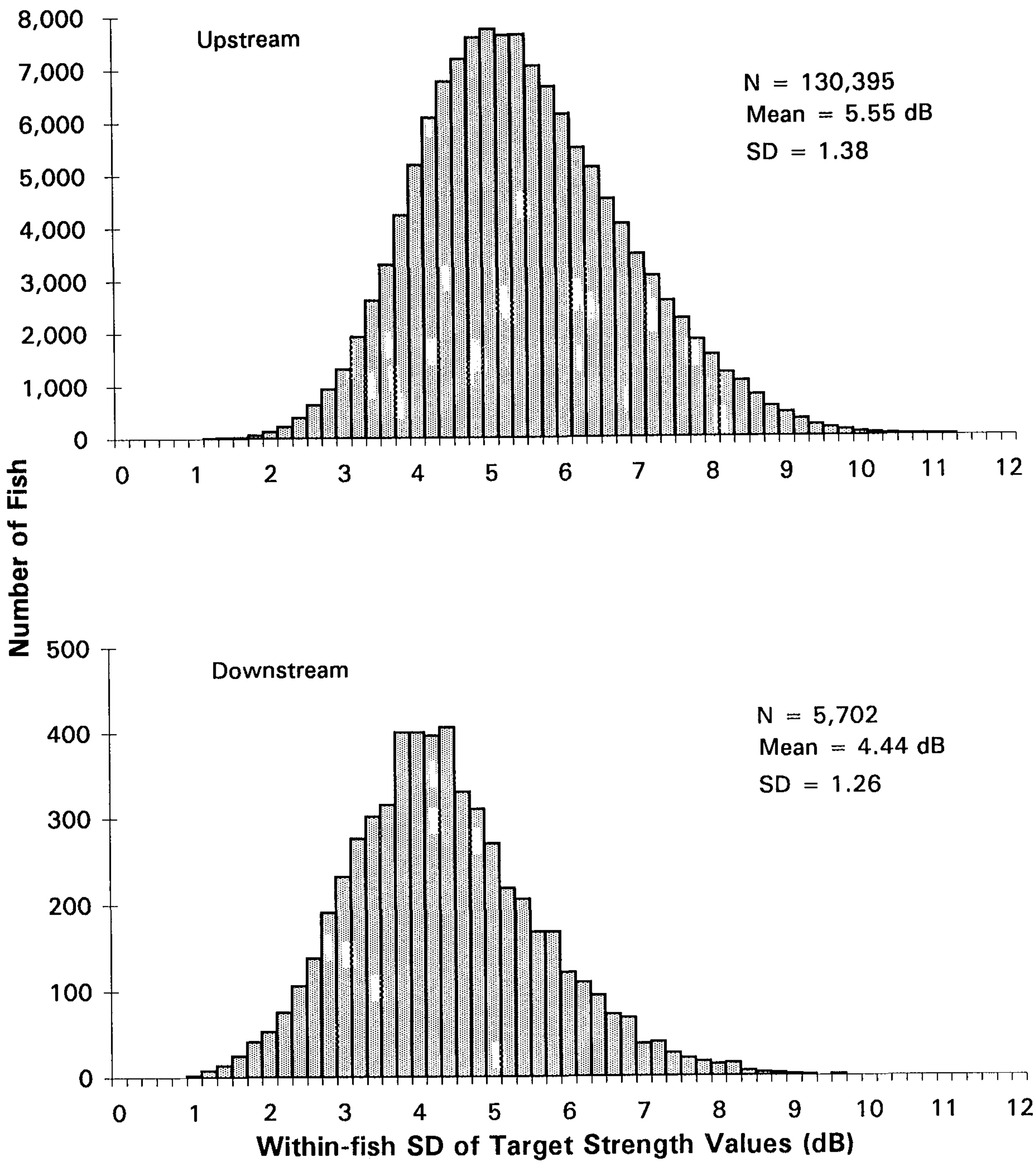

Figure 23 Within-fish target strength variability (SD) of upstream and downstream fish, right bank, Chandalar River, August 8-September 22, 1996

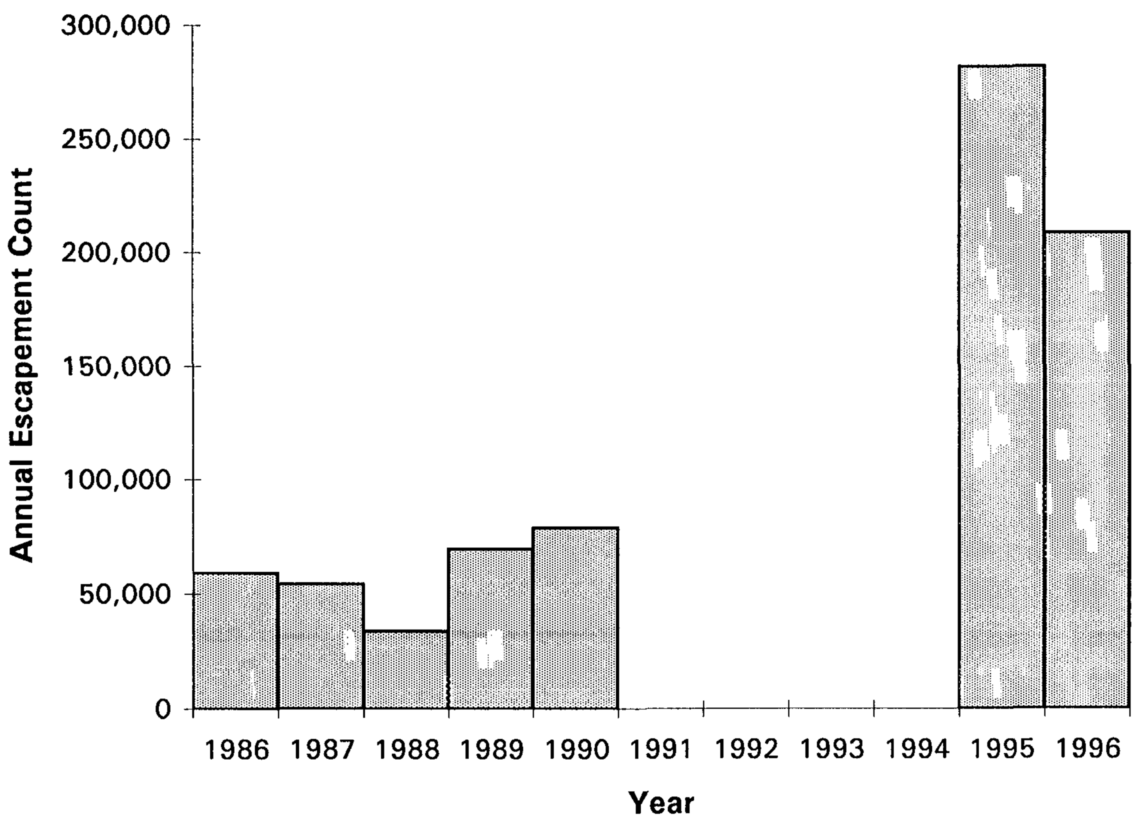

Figure 24 Annual sonar escapement counts of fall chum salmon, Chandalar River.

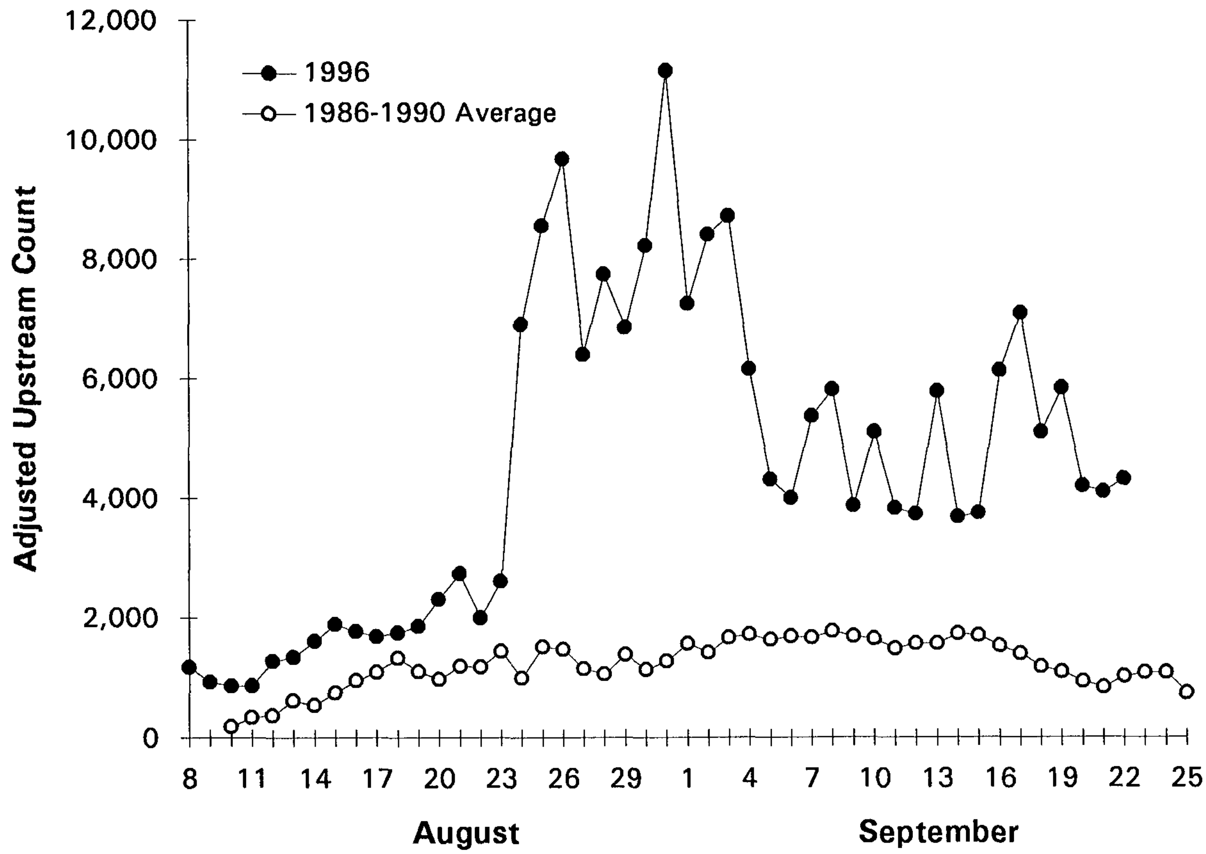

Figure 25 Adjusted daily counts of fall chum salmon, Chandalar River, August 8-September 22, 1996

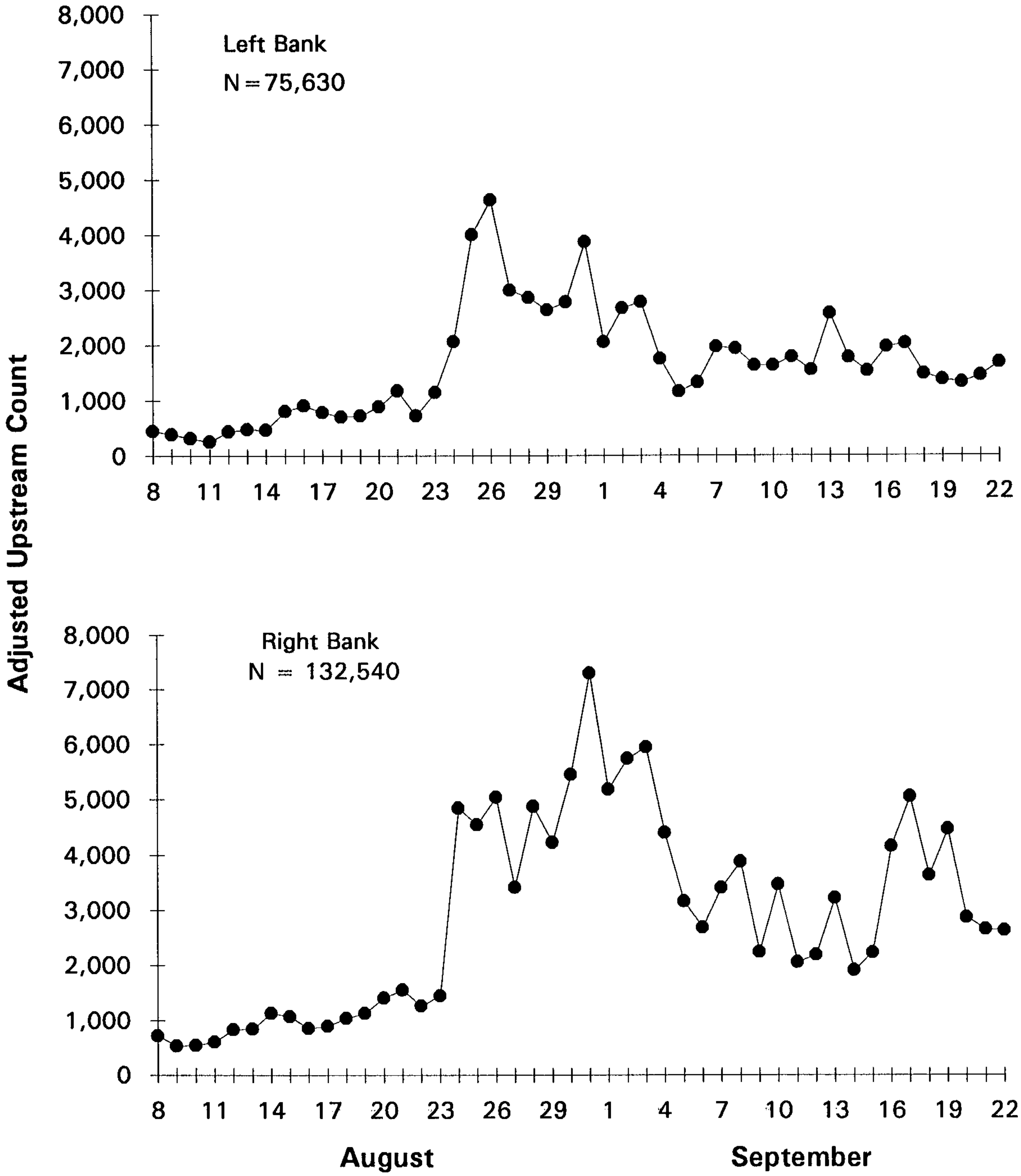

Figure 26. Adjusted daily counts of fall chum salmon by bank, Chandalar River, August 8-September 22, 1996.