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ENUMERATION OF CHANDALAR RIVER FALL CHUM SALMON USING SPLIT-BEAM SONAR, 1997

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ABSTRACT

A five-year, fixed-location, split-beam hydroacoustic study was initiated in 1994 to assess the population status of adult fall chum salmon *Oncorhynchus keta* in the Chandalar River, a tributary of the Yukon River Objectives for the 1997 season were to determine daily in-season passage rates of upstream swimming fall chum salmon, estimate total spawning escapement, and describe annual variability in run size and timing. Elliptical-beam transducers were installed on opposite river banks to optimize sonar beam coverage and aimed perpendicular to the river current. Both sonar units were operated continuously from August 8 through September 22, except for a high water event in late-August and early September which caused the right bank sonar to miss 11 complete days of sampling.

A total of 1,883 hours of digital echo processor data were collected and manually tracked, resulting in 120,234 fish written to file. Upstream traveling fish accounted for 98% of the total tracked targets. The median number of acquired echoes per upstream fish was 21 on the left bank and 19 on the right bank Downstream fish had medians of 12 echoes per fish on the left bank and 15 echoes per fish on the right bank.

The estimated 1997 fall chum salmon escapement count from August 8 through September 22 was 199,874 fish ± 5,664 (95% confidence interval) The right bank accounted for 67% of the total estimated escapement. The count represented a conservative estimate of total escapement because counts did not include fish that passed before or after the sonar was operated Fish passage was assumed low during the unmonitored tails of the run The passage rate was 619 upstream fish on the first day of sonar operation (0.3% of the total estimated count) and 2,326 on the final day of counting (1.2% of the total). The 1997 count was below the 1995 and 1996 levels of 280,999 and 208,170 fish, respectively, but had the highest escapement of all monitored populations in the Yukon River drainage

Precision of the 1997 estimate varied between banks On the left bank, the precision of the estimate was considered high because 98% of the season was acoustically sampled and 98% of the left bank's adjusted count was actually tracked The right bank monitored only 72% of the season and tracked fish represented 40% of the right bank's total adjusted count The largest potential source of error was in estimating right bank counts for the 11 missing days during high water

Daily passage rates indicated a bi-modal run. The second mode was over twice the magnitude of the first, with a peak daily count of 15,951 fish on September 6 Median passage date also occurred on September 6 Run timing was compressed compared to the previous two years, with 50% of the run passing in only 10 days The run also arrived later by three to four days, with the first 25% not passing until August 31 Hourly passage rates of upstream fish on the left bank exhibited a strong diel pattern with highest passage rates occurring during late night/early morning hours Right bank diel patterns were not evident

Migrating chum salmon were shore-oriented and traveled close to the river bottom Downstream fish exhibited a wider spatial distribution than upstream fish Positional data suggested that most fish were detected by the sonar because few targets were observed near the vertical or outer range limits of acoustic detection. Target strength distributions, spatial positioning, and chart/tracked fish comparisons corroborated the assumption that few fish were missed due to the voltage threshold settings used for processing acoustic data

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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. 1997).

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 These early "Bendix salmon counters" were not acoustically calibrated, used factory-set, echo-counting criteria to determine fish counts, had limited acoustic range (<33 m), and could not determine direction of target travel (upstream or downstream) 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) This sonar system was acoustically calibrated, had user-defined, echo-tracking techniques to count fish, and had extended acoustic range (>100 m) The split-beam sonar also provided three-dimensional positioning for each returning echo, allowing the determination of direction of travel and swimming behavior for each passing target

From 1986 to 1990, the USFWS used fixed-location, Bendix salmon counters to enumerate adult fall chum salmon escapement in the Chandalar River, located on the Yukon Flats National Wildlife Refuge (Daum et al 1992) The results of this study revealed that the Chandalar River fall chum salmon stock was the second largest population of fall chum salmon in the U S portion of the Yukon River drainage Annual sonar counts averaged 58,628 fish, ranging from 33,619 to 78,631.

Because Chandalar River fall chum salmon are important as a wildlife and subsistence resource, and due to the recent declining trend of some Yukon River salmon stocks (Bergstrom et al. 1995), a five-year study was initiated in 1994 to reassess the population status using newly developed, split-beam hydroacoustics. Overall project objectives were to

1) provide daily in-season counts of Chandalar River fall chum salmon to fishery managers;
2) estimate annual spawning escapement, and
3) describe annual variability in run size and timing

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, daily and seasonal estimates of spawning escapement were calculated in the post-season and *in situ* target strength evaluations were collected (Daum and Osborne 1996) The 1995 escapement estimate of 280,999 chum salmon was the highest since sonar enumeration began in 1986 (Appendix 1) In 1996, the project became fully operational (Osborne and Daum 1997). Daily run passage rates were tallied in-season with a post-season escapement estimate of 208,170 fish (Appendix 2) This report presents the escapement information from the 1997 season and describes annual variability in run size and timing

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 included: 1) single channel, 2) uniform non-turbulent flow; 3) gradually sloping bottom gradient; 4) absence of highly reflective river substrate; 5) downriver from known salmon spawning areas, and 6) active fish migration past the site (no milling behavior) A transducer deployment site for each bank was selected from cross-sectional river profiles constructed of the area (Figure 3), using a chart recording depth sounder and 8° transducer mounted below a boat's hull Transducer deployment locations were similar to 1995 and 1996. The left bank site, looking downstream, had a steeper bottom gradient and faster water velocity than the right bank River bottom slopes were approximately 7.3° on the left bank and 2 8° on the right bank River substrate consist of small rounded cobble/gravel on the left bank and sand/silt on the right bank During the 1997 season, river width at the site averaged 142 m (ranging from 131 to 185 m) and maximum depth averaged 4.5 m (ranging from 3 9 to 5 9 m, Figure 4) Water temperature decreased from 16 to 6°C as the season progressed and conductivity remained fairly constant, varying from 220 to 300 µS/cm (Figure 5) Specific methodology for constructing cross-sectional river profiles and measuring daily water elevation, temperature, and conductivity can be found in Osborne and Daum (1997)

METHODS

Data Collection

Fixed-location, split-beam hydroacoustics was used to monitor the upstream migration of adult fall chum salmon in the Chandalar River in 1997 Systems were installed on opposite river banks to optimize sonar beam coverage of the river cross-sectional area Both sonar units were operated continuously from August 8 through September 22, except for a high water event in late-August and early September which caused the right bank sonar to miss 11 complete days of sampling.

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, and data analysis computer with optical disk drives having network capabilities (Figure 6) 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 Frequency modulation hardware (FM slide) was installed in the right bank echo sounder to reduce background noise levels (Ehrenberg 1995)

A complete system calibration was performed pre-season by HTI (HTI 1997) using the comparison method referenced in Urick (1983), along with on-axis standard target measurements from a 38 1 mm tungsten carbide sphere (Foote and MacLennan 1984). During the season, *in situ* calibration data were collected three times per bank using the standard target to insure that the system electronics were functioning properly All on-axis, *in situ* calibrations were between 0 4 and 1 9 dB of factory calibrated values (Table 1) When the standard target was positioned near the bottom edge of the beam, *in situ* target strength values and variability (SD) increased

Echo sounder settings

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; 0.18 ms pulse width (compressed); and 6 25 pings/s ping rate Echo sounder settings were influenced by background noise levels and signal cross-talk.

Data acquisition

The digital echo processor and digital chart recorder were used to record hydroacoustic data The digital echo processor receives output from the echo sounder, processes and stores acoustic data, and provides real-time screen displays of fish passing through the beam The processor was run concurrently with the echo sounder, except during short periods used for transducer aiming and generator maintenance Processor-produced 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 2). A detailed description of file contents can be found in Johnston et al (1993) and HTI (1994b). On both banks, the vertical angle off-axis criteria were increased beyond the half-power beam widths so echoes from fish traveling very close to the river bottom were accepted into the echo processor data file. Throughout the season, target strength threshold values were set at -40 dB on-axis for both banks The on-axis target strength threshold was set 10 dB lower than the predicted target strength estimate (Love 1977) for the smallest chum salmon in the Chandalar River (50 cm in length, Daum et al 1992) to insure that passing fish were not being missed because of acoustic size or off-axis position. During high noise events, the threshold was increased to -34 dB on-axis to collect data at far ranges. For the season, average peak amplitude noise levels varied from -57 to -39 dB for the left bank and -58 to -34 dB for the right bank Noise increased with distance from the transducer The maximum acquisition range (distance from the transducer) changed throughout the season, primarily due to transducer re-deployment as water levels varied Left bank acquisition range changed from 11 to 20 m, the final 10 m distance to the thalweg was not ensonified due to an inflection in the river bottom. Right bank beam coverage was nearly complete for the majority of the season, at approximately 72 m. High noise levels during extremely high water caused acquisition ranges to be shortened after September 11, varying from 31 to 60 m All changes to processor settings were recorded in hourly files and log books. Networking between the echo sounder, echo processor, and analysis computer allowed daily file back-up and data analysis without interrupting real-time data collection.

Digital 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 Target strength threshold settings were kept constant for the season at -40 dB The maximum acquisition range for chart recordings was increased approximately 4 m beyond the echo processor settings to insure that fish were not traveling beyond the range of the echo processor Fish counts from charts were compared to tracked fish counts from the processed data to confirm that fish were not being missed due to the echo acceptance criteria settings of the processor, i e., pulse width, angle off-axis, range, or target strength threshold All chart recorder settings and changes were recorded on real-time echograms and in log books

Transducer deployment

Elliptical-beam transducers (one per bank) were used throughout the 1997 season Elliptical beams 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 half-power beam widths (measured at -3 dB down the acoustic axis) were 5 1 by 10.7° on the left bank and 2 1 by 9 8° on the right bank The transducers had low side-lobes which allowed the beam to be aimed close to the river bottom (-16 2 dB for the left bank and -23.3 dB for the right bank, measured on a one-way beam pattern plot)

The transducers and remote-controlled rotators were mounted on aluminum T-bar frames and secured in place with sandbags at a depth of 0.6-1 5 m (Figure 7). 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 remove foreign matter and air bubbles that could affect performance The transducer assembly was moved inshore or offshore during the season as water level changed A wire fence weir (5 x 10 cm mesh) was installed 1 m downstream and extended past 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 During aiming, a target was used to align the lower edge of the beam with the river bottom Chart recordings, oscilloscope readings, and real-time positional displays of passing fish from the digital echo processor were used to monitor transducer aiming The low acoustic reflectivity of right bank substrate (silt and sand) allowed the right bank transducer to be aimed slightly into the bottom, enhancing detection of bottom-oriented fish. Whenever the transducer assembly was moved, proper beam orientation was checked by horizontally sweeping the beam across a stationary standard target suspended in the water column All changes in transducer aiming and redeployment were recorded in log books

Acoustic Data Verification and Fish Tracking

Prior to acoustic data analyses, all hourly files from the digital echo processor were examined for completeness and data integrity Subsequently, data files were processed through target tracking software (HTI Trakman software, version 1 27) Non-fish echoes from boat motors, acoustic noise, and rocks were excluded from the database Echoes from boat motors and acoustic noise were visually identified by the random nature of individual echoes displayed on software-produced echograms Rock targets exhibited a stationary bottom position in the beam with no movement in the upstream or downstream direction. Suspected fish targets, represented by a contiguous series of echoes, were examined for upstream or downstream directional progression and written to hourly files A description of tracked fish files (**.ech* and **.fsh* files) can be found in Johnston et al. (1993) and HTI (1994b). All targets in these tracked fish files were classified as fish, although some downstream debris could not be differentiated from downstream 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 target was deleted from the data set All upstream swimming fish were assumed to be chum salmon; based on five previous seasons of gill net catches consisting of over 99% chum salmon (Daum and Osborne 1996) For each bank, hourly sample times, upstream/downstream tracked fish counts, and average number of acquired echoes per fish were calculated Only tracked fish data were used in all subsequent analyses contained in this report

Acoustic Data Analyses

Escapement estimate and run timing

Daily and seasonal estimates of upstream fish passage were calculated from the hourly tracked fish files. Time lapses in data acquisition (*see Methods, Data Collection*) required adjusting tracked fish counts before the daily and seasonal totals were calculated. Count adjustments were made for partial hours, missing hours, and missing days

Partial hourly counts (≥ 15 and < 60 min) were standardized to 1 h, using

$$E_h = (60 / T_h) \cdot C_h , \tag{1}$$

where E_h = estimated hourly upstream count for hour h, T_h = number of minutes sampled in hour h, and C_h = tracked upstream count during the sampled time in hour h Counts from hours with sample times < 15 minutes were discarded and treated as missing hours

Fish counts from missing hours were extrapolated from seasonal mean hourly passage rates. Seasonal mean hourly passage rates were calculated from days with 24 h of continuous data, i.e., 46 days on the left bank and 32 days on the right bank First, hourly passage rates (fish/h) were calculated for all hours in each day. These hourly passage rates were expressed as proportions (%) of the daily count so high passage days did not bias results. Then mean passage rates (%) by hour were calculated for the season (*see Results, Figure 14*). Estimated fish counts for missing hours were calculated, using

$$E_d = \sum R_{di} / (100 - \sum R_{di}) \cdot T_d \,, \qquad (2)$$

where E_d = estimated upstream fish count for missing hours in day *d*, R_{di} = seasonal mean hourly passage rate (%) for each missing hour *i* in day *d*, and T_d = adjusted upstream fish count for non-missing hours in day *d*.

Daily upstream fish counts for each bank were calculated by summing all hourly counts for that day During the high water event, 11 complete days of acoustic sampling were missed on the right bank Missing daily counts from the right bank were extrapolated from left bank counts using the ratio estimator method and associated variance calculation (Cochran 1977, Eggers et al. 1995) The 95% confident interval for the missing-days estimate was reported For the season, total escapement was calculated by summing all estimated daily counts. Also, hourly fish passage rates for each bank were plotted for the season and examined for diel patterns

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 The spatial positions of individually tracked fish were described in two dimensions, distance offshore from the transducer (range) and vertical position in the acoustic beam Median range values and vertical position in meters were calculated for all tracked fish (upstream and downstream) Median vertical positions of tracked fish were converted to angle off-axis measurements before analyses, using

$$V_a = \text{arcsine}\,(V_d / R_d)\,, \qquad (3)$$

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.

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 (Zar 1984).

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 (SD) for upstream and downstream fish. Standard deviations for each fish were plotted and mean values were calculated. Mean within-fish target strength variability between upstream and downstream fish by bank were compared using a two-sample *t* test for means with unequal variances

RESULTS

Acoustic Data Verification and Fish Tracking

For the season, over 1,880 hours of acoustic data were collected and 120,234 fish were manually tracked Daily summary information for all tracked echo processor files is presented in Tables 3 and 4 Upstream traveling fish accounted for 98% of the total tracked fish On the left bank, 98% of the season was monitored Right bank sample time was considerably less than the left bank due to down time from the high water event Approximately 72% of the season was sampled, with 291 hours missed during high water Generally, upstream fish had more echoes/fish than downstream fish (Figures 8 and 9) The median number of acquired echoes per upstream fish was 21 on the left bank (range of 4-316) and 19 on the right bank (range of 3-163) Downstream fish had medians of 12 echoes per fish on the left bank (range of 4-414) and 15 echoes per fish on the right bank (range of 4-120)

Acoustic Data Analyses

Escapement estimate and run timing

The adjusted 1997 fall chum salmon escapement count for the Chandalar River was 199,874 upstream fish ± 5,664 (95% confidence interval, Table 5) The right bank accounted for 67% of the total escapement The seasonal count represented a conservative estimate of total escapement because counts did not include fish that passed before or after the sonar was operated. Fish passage was assumed low during the unmonitored tails of the run. The passage rate was only 619 upstream fish on the first day of sonar operation (0.3% of the total estimated count) and 2,326 fish on the final day of counting (1 2% of the total) Daily counts were more than 2,000 fish/d for 30 of the 46 counting days The 1997 count was below the 1995 and 1996 levels of 280,999 and 208,170 fish, respectively

Of the final adjusted upstream count of 199,874 fall chum salmon, 59% were actually tracked (117,714 fish) Count 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 1% of all hourly counts, 3% for the right bank and no hours were missed on the left bank Missing days made up the largest block of adjusted counts The right bank missed 11 complete days of sampling during the high water event beginning August 29 This represented 24% of the entire 46 day sampling period on the right bank

Daily passage rates indicated a bi-modal run with peaks on August 29 and September 6 (Figure 10). The second mode was over twice the magnitude of the first, with a peak daily count of 15,951 fish. The median passage date also occurred on September 6 Run timing was compressed compared to the previous two years, with 50% of the run passing in only 10 days. The run also arrived later by three to four days, with the first 25% not passing until August 31. Run timing was similar between banks, though right bank counts were missing during the peak of the run (Figure 11).

Hourly passage rates of upstream fish on the left bank exhibited a strong diel pattern with highest passage rates occurring during late night/early morning hours (Figure 12). When daily passage was high, the strong diel pattern was not evident. Right bank fish did not show any trend in diel distribution through the season (Figure 13). Mean hourly passage rates for left bank fish also showed a strong diel tendency among upstream fish (Figure 14) These diel passage results were similar to findings from the previous three seasons (Daum and Osborne 1995, 1996, Osborne and Daum 1997)

Spatial distribution of tracked fish

Upstream migrating chum salmon were shore-oriented and appeared to be well within the range of acoustic detection for both banks (Figures 15 and 16) Ninety percent of upstream fish were within 9 m of the left bank transducer and 24 m of the right bank transducer Downstream fish were more spread out across the full detection range For the season, the median distance offshore was less for upstream fish than downstream fish

Vertical fish position data showed that upstream swimming chum salmon on both banks were bottom-oriented (Figures 17 and 18) Ninety-nine percent of upstream fish on the left bank and 98% of fish on the right bank passed below the acoustic axis Downstream fish were more widely distributed throughout the ensonified zone. For the season, the median vertical position of upstream fish was lower in the water column than downstream fish. These trends in spatial position of tracked fish were similar to results from the previous three years.

Target strength distribution of tracked fish

On both banks, upstream fish had mean target strengths significantly larger than downstream fish Differences between upstream and downstream fish averaged 1.3 dB on the left bank and 3.3 dB on the right bank (*P* values < 0 001, Figures 19 and 20). Average target strengths from both upstream and downstream fish on the right bank were larger than fish on the left bank (*P* values < 0 001) Trends in target strength between upstream and downstream fish and between fish from opposite banks were similar to 1994-1996 results. Within-fish target strength variability (SD) averaged 3 7 dB for upstream fish on the left bank and 5 0 dB for fish on the right bank (Figures 21 and 22). On the average, downstream fish had less within-fish target strength variability than upstream fish from the same bank (*P* values < 0.001).

DISCUSSION

In 1997, the Chandalar River had the highest escapement of fall chum salmon (199,874 fish) in the entire Yukon River drainage (Bergstrom et al. 1997). The high numbers of returning adult chum salmon to the Chandalar River in 1995 and 1996 continued into the 1997 season (Figure 23). Escapements to the other major spawning grounds in the drainage dropped substantially from their high levels in 1994-1996. The 1997 Chandalar River estimate equaled the combined total of all other upper Yukon River enumeration projects, i.e., Sheenjek, Fishing Branch, and Canadian mainstem Yukon rivers. The Sheenjek River, located 116 km upstream from the Chandalar River, had similar run characteristics to the Chandalar River. Both runs experienced peak counts around the first week of September with the median passage date on the Sheenjek River (September 7) occurring one day after the Chandalar River's median date of September 6 (L. Barton, Alaska Department of Fish and Game, personal communication). Median passage dates between the two rivers have been within 2 days of each other since 1995.

The precision of the 1997 Chandalar River escapement estimate varied between banks. On the left bank, the precision of the estimate was considered high. Acoustic data were collected for 98% of the season and few adjustments were made to the actual tracked fish count (98% of the left bank's adjusted count was actually tracked). The right bank monitored only 72% of the season and tracked fish represented 40% of the right bank's total adjusted count. The largest potential source of error was in estimating right bank counts for the 11 missing days due to high water. The ratio of right bank to left bank daily counts from the non-missing days was used to extrapolate the missing right bank counts. The left and right bank daily counts were highly correlated for the 35 non-missing days ($r = 0.85$, $P < 0.001$). In addition, the 95% confidence interval around the missing-days estimate was within 2.8% of the total seasonal count. However, the ratio, calculated during low passage days, was used to estimate right bank counts during the peak of the run (Figure 24). This may have introduced bias to the estimate.

Fish position data suggested that most upstream fish passing the sonar site were within the ensonified zone during the 1997 season. As in the previous three years (Daum and Osborne 1995, 1996; Osborne and Daum 1997), upstream fish were found close to shore and near the bottom. Few fish were found near the vertical or outer range limits 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).

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) *In-situ* calibration data from 1995-1997 showed higher target strength variability 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) For most of the 1997 season, the voltage threshold was set substantially lower than predicted target strength values for fish of given lengths (Love 1977) to insure that acoustic data were not biased; threshold set at -40 dB. During high noise events, the voltage threshold was increased to -34 dB at far ranges (beyond approximately 12 m on the left bank and 30 m on the right bank). This may have caused biased target strength values and undercounting of fish at these ranges However, most upstream fish had target strengths substantially above the elevated threshold setting (Figures 19 and 20) and few fish occurred at far ranges (Figures 15 and 16) Daily comparisons of chart counts from the echogram recordings to the electronic data set revealed that few fish were missed at the higher threshold setting In addition, fish traces at far ranges were closely scrutinized while visually tracking upstream targets to verify that off-axis echoes were being collected This evidence supports the assumption that few fish were missed due to the elevated voltage threshold setting

Providing timely and accurate escapement counts to fishery managers is an overall objective of this project In 1996 and 1997, daily in-season counts of Chandalar River fall chum salmon were provided throughout the season 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 upcoming 1998 season, daily in-season counts and a post-season escapement estimate will again be provided Sampling schedules for the 1998 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

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Table 1 Target strength measurements of a 38.1 mm tungsten carbide sphere, Chandalar River, 1997

Type of calibration	Date	Mean target strength (dB)	SD	N	Target range (m)	Position of target
		Left bank				
Factory	Jun 27	-39.56	0.62	1,000	5.5	On-axis
In situ	Aug 7	-38.99	0.46	2,666	5.2	On-axis
In situ	Aug 7	-36.70	3.21	1,628	5.2	Bottom of beam
In situ	Aug 22	-39.12	0.86	2,791	6.3	On-axis
In situ	Aug 22	-33.06	1.89	2,110	6.3	Bottom of beam
In situ	Sep 18	-38.86	0.71	2,624	5.9	On-axis
In situ	Sep 18	-35.47	1.51	2,063	6.0	Bottom of beam
		Right bank				
Factory	Jun 27	-38.15	0.43	1,000	6.0	On-axis
In situ	Aug 5	-38.60	1.05	1,939	6.1	On-axis
In situ	Aug 5	-36.84	3.43	1,758	6.1	Bottom of beam
In situ	Aug 22	-38.76	0.60	1,878	5.4	On-axis
In situ	Aug 22	-35.78	2.91	1,869	5.4	Bottom of beam
In situ	Sep 19	-36.29	1.43	1,876	6.4	On-axis
In situ	Sep 19	-33.03	3.52	1,163	6.4	Bottom of beam

Table 2. Echo acceptance criteria used for digital echo processing, Chandalar River, 1997. 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 (°)	Voltage threshold (dB)	Range (m)
Left	0.10 to 0.38	−3.80 to 2 53	−5.35 to 5.35	−40[a]	11 to 20
Right	0 10 to 0 38	−1.58 to 1 58	−4 90 to 4 90	−40[a]	31 to 85

[a] During high noise events, voltage threshold was increased to −34 dB at far ranges

Table 3. Hydroacoustic data collected from the left bank, Chandalar River, 1997

Date	Sample time (h)	Upstream count	Downstream count	Total count
Aug 8	23.64	218	13	231
9	23.74	156	8	164
10	23.78	212	5	217
11	23.60	151	3	154
12	23.76	243	9	252
13	23 80	216	7	223
14	23.80	278	9	287
15	23.83	263	22	285
16	23.02	220	11	231
17	23.77	225	16	241
18	23.79	140	8	148
19	23 83	115	8	123
20	23.79	148	7	155
21	23.73	185	5	190
22	22 29	305	6	311
23	23 78	489	9	498
24	23.80	546	5	551
25	23.78	625	10	635
26	23 80	1,172	9	1,181
27	23.79	1,569	13	1,582
28	22.59	2,360	18	2,378
29	23 79	2,343	21	2,364
30	23 77	2,161	50	2,211
31	23 80	1,955	26	1,981
Sep 1	23 77	1,836	29	1,865
2	23 44	2,305	33	2,338
3	23 17	3,086	31	3,117
4	23 77	3,397	21	3,418
5	23.82	4,244	31	4,275
6	23 81	5,182	24	5,206
7	23 63	4,977	40	5,017
8	22 86	4,059	16	4,075
9	23 77	2,877	45	2,922
10	23.59	2,448	53	2,501
11	23.79	2,025	54	2,079
12	23 65	1,266	65	1,331
13	23 79	1,174	55	1,229
14	23 19	906	15	921
15	23.00	827	4	831
16	23 26	1,244	12	1,256
17	23 82	1,286	14	1,300
18	23 19	1,067	16	1,083
19	23.90	1,210	17	1,227
20	23.79	826	34	860
21	23 73	933	22	955
22	23 88	951	16	967
Total	1,085 69	64,421	945	65,366

Table 4. Hydroacoustic data collected from the right bank, Chandalar River, 1997 Asterisks represent days when sampling was discontinued due to high water.

Date	Sample time (h)	Upstream count	Downstream count	Total count
Aug 8	23.65	392	14	406
9	23.76	363	20	383
10	23 81	464	12	476
11	23 14	275	11	286
12	23 67	500	16	516
13	23 69	506	24	530
14	23.44	435	28	463
15	23.72	567	28	595
16	23.64	389	34	423
17	23 62	405	19	424
18	23.67	277	14	291
19	23.63	268	22	290
20	23 73	213	36	249
21	23 63	344	31	375
22	22 86	468	18	486
23	23.64	1,103	20	1,123
24	23 75	1,698	29	1,727
25	23.71	2,444	38	2,482
26	23.71	2,266	28	2,294
27	23.37	4,380	103	4,483
28	15 23	2,338	39	2,377
29*	0	-	-	-
30*	0	-	-	-
31*	0	-	-	-
Sep 1	13.50	1,610	60	1,670
2	14 84	1,460	57	1,517
3*	0	-	-	-
4*	0	-	-	-
5*	0	-	-	-
6*	0	-	-	-
7*	0	-	-	-
8*	0	-	-	-
9*	0	-	-	-
10*	0	-	-	-
11	23 72	3,373	74	3,447
12	23.76	3,339	85	3,424
13	23 13	2,838	116	2,954
14	23 59	2,986	85	3,071
15	23 44	2,969	89	3,058
16	23 20	2,779	72	2,851
17	23.66	2,938	94	3,032
18	23 59	2,518	73	2,591
19	22.43	2,151	22	2,173
20	23.61	1,461	68	1,529
21	23 45	1,434	72	1,506
22	23 56	1,342	24	1,366
Total	796 55	53,293	1,575	54,868

Table 5. Daily adjusted fall chum salmon count, Chandalar River, 1997. Asterisks represent daily estimate by ratio estimator method due to high water.

Date	Left bank	Right bank	Combined	Cumulative	Cumulative (%)
Aug 8	222	397	619	619	0 31
9	157	365	522	1,141	0 57
10	214	468	682	1,823	0 91
11	153	282	435	2,258	1 13
12	244	508	752	3,010	1 51
13	218	511	729	3,739	1 87
14	281	442	723	4,462	2 23
15	264	574	838	5,300	2 65
16	224	395	619	5,919	2 96
17	227	412	639	6,558	3 28
18	141	282	423	6,981	3 49
19	116	272	388	7,369	3 69
20	149	216	365	7,734	3 87
21	187	353	540	8,274	4 14
22	313	480	793	9,067	4 54
23	500	1,117	1,617	10,684	5 35
24	552	1,711	2,263	12,947	6 48
25	630	2,495	3,125	16,072	8 04
26	1,175	2,283	3,458	19,530	9 77
27	1,588	4,515	6,103	25,633	12 82
28	2,489	3,453	5,942	31,575	15 80
29	2,364	4,853*	7,217	38,792	19 41
30	2,182	4,479*	6,661	45,453	22 74
31	1,972	4,048*	6,020	51,473	25 75
Sep 1	1,857	3,266	5,123	56,596	28 32
2	2,347	2,162	4,509	61,105	30 57
3	3,184	6,536*	9,720	70,825	35 43
4	3,429	7,039*	10,468	81,293	40 67
5	4,281	8,788*	13,069	94,362	47 21
6	5,225	10,726*	15,951	110,313	55 19
7	5,051	10,369*	15,420	125,733	62 91
8	4,243	8,710*	12,953	138,686	69 39
9	2,906	5,966*	8,872	147,558	73 83
10	2,490	5,112*	7,602	155,160	77 63
11	2,044	3,414	5,458	160,618	80 36
12	1,281	3,379	4,660	165,278	82 69
13	1,182	2,927	4,109	169,387	84 75
14	926	3,030	3,956	173,343	86 73
15	849	3,051	3,900	177,243	88 68
16	1,269	2,855	4,124	181,367	90 74
17	1,293	2,971	4,264	185,631	92 87
18	1,100	2,556	3,656	189,287	94 70
19	1,219	2,294	3,513	192,800	96 46
20	834	1,486	2,320	195,120	97 62
21	943	1,485	2,428	197,548	98 84
22	956	1,370	2,326	199,874	100 00
Total	65,471	134,403	199,874		

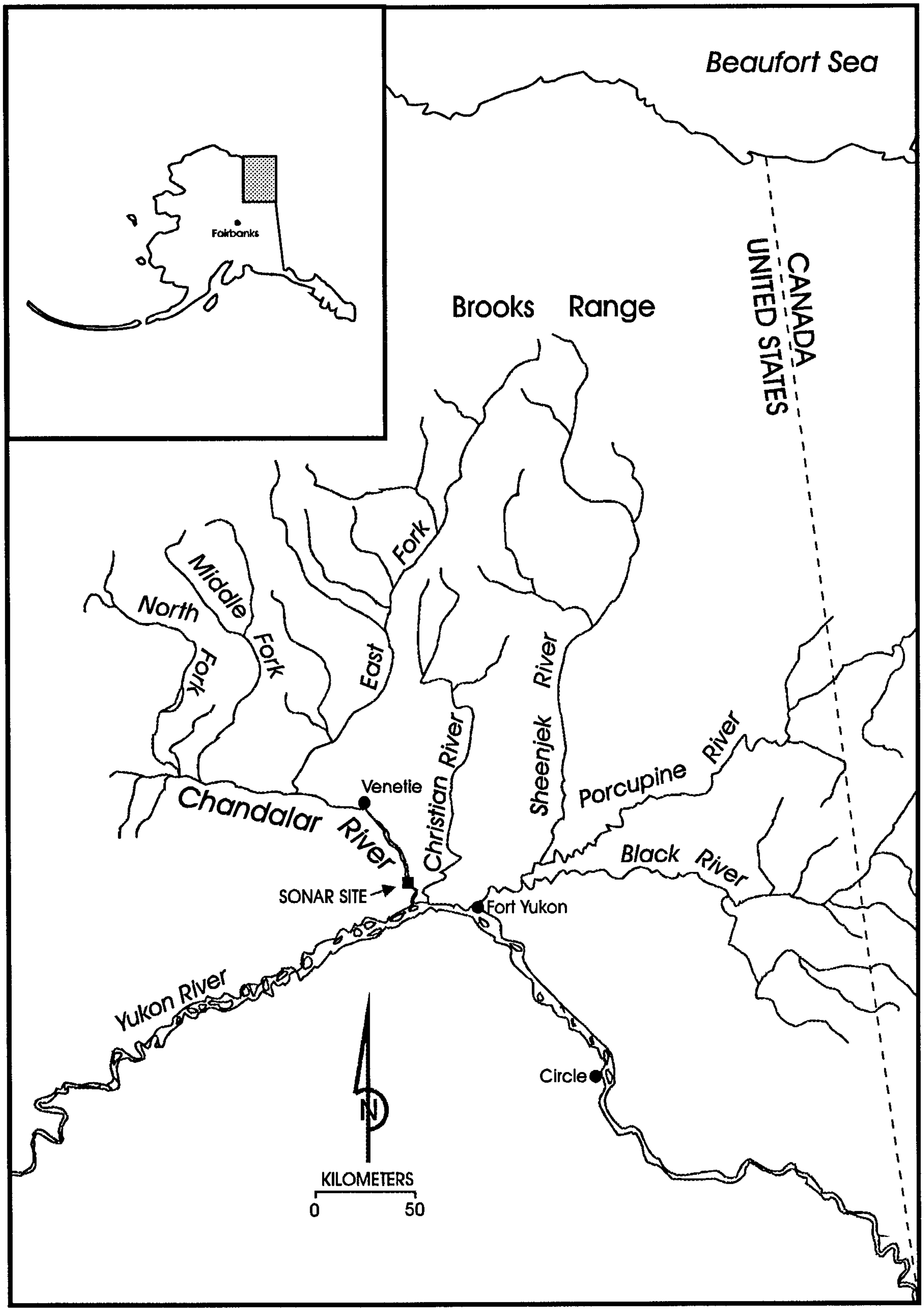

Figure 1 Major tributaries of the Yukon River near the U S./Canada border

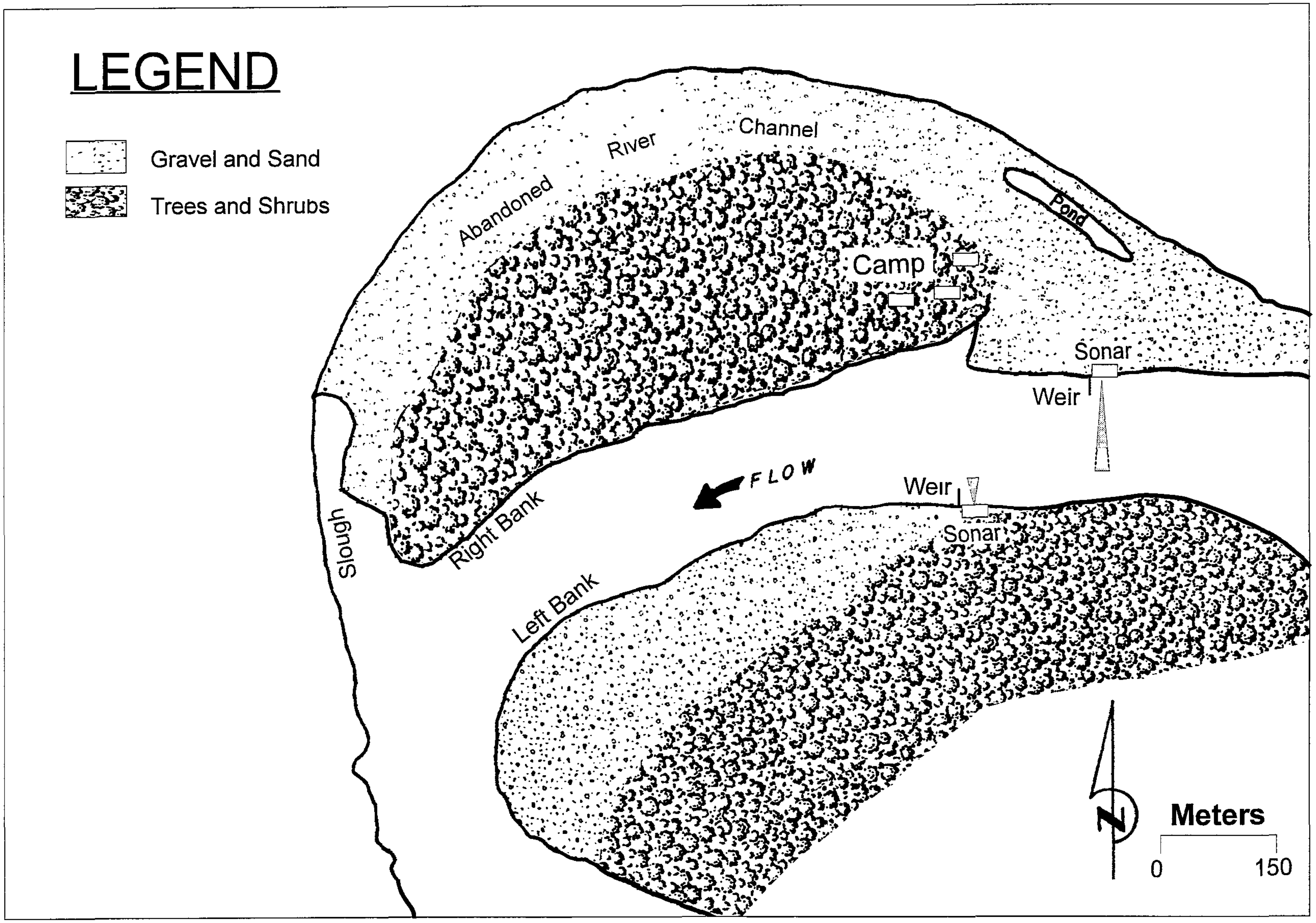

Figure 2. Site map of the Chandalar River sonar facilities, 1997

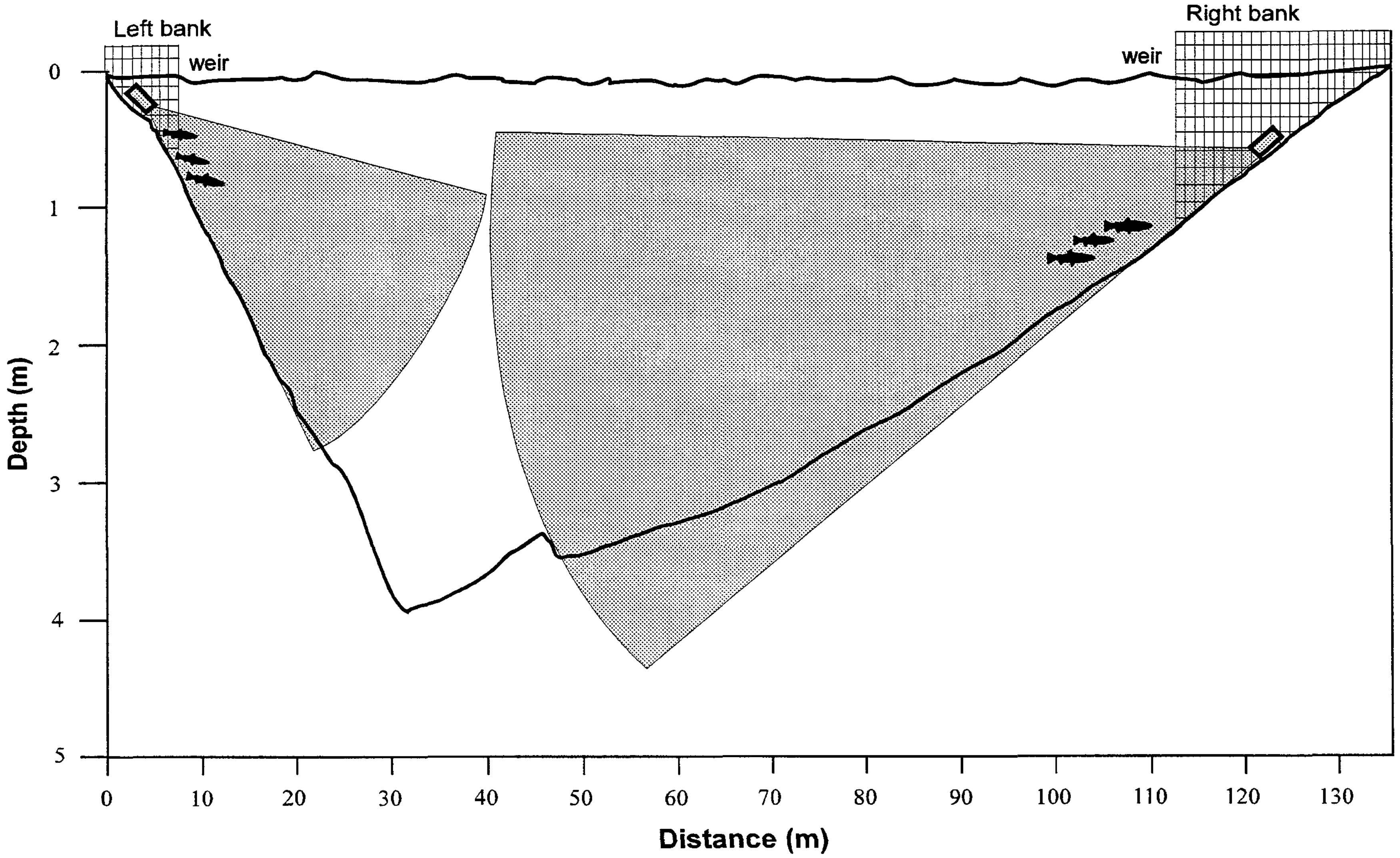

Figure 3 River channel profile and estimated ensonified zones of the left and right banks, Chandalar River, 1997 Different axis scales were used to enhance visibility

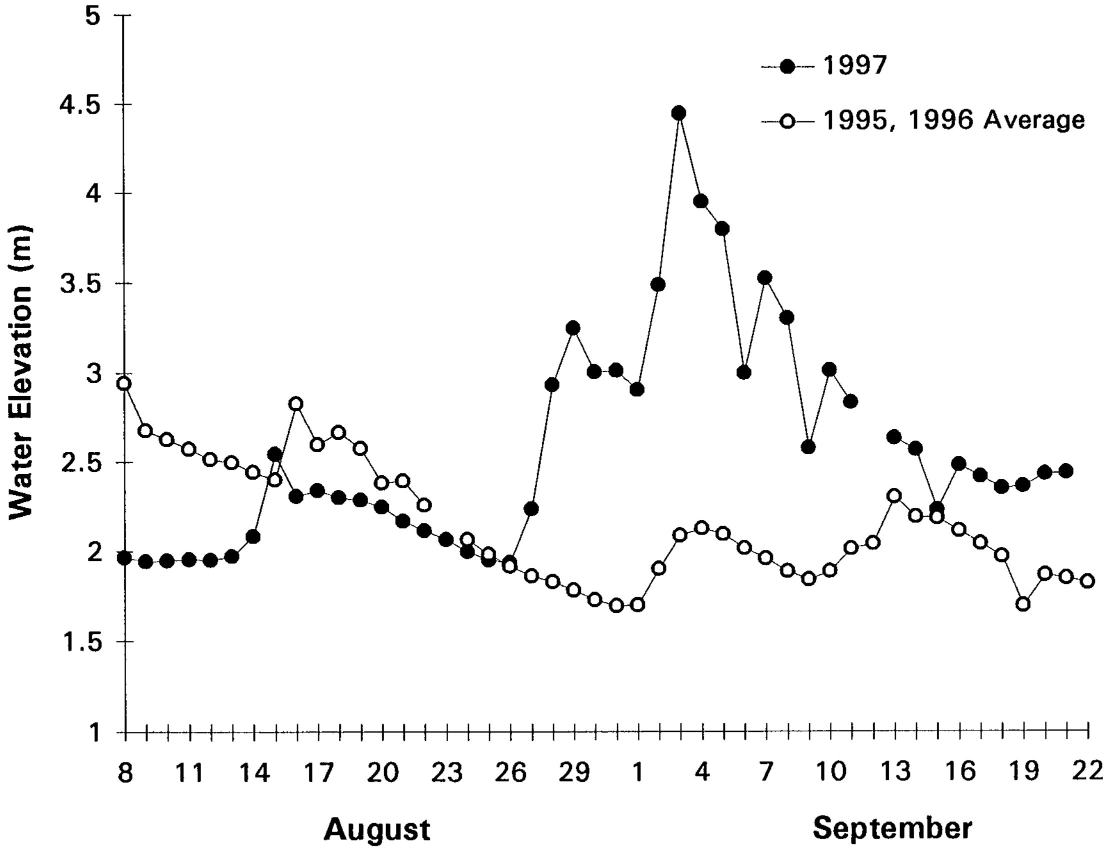

Figure 4. Daily water elevation during sonar operation, Chandalar River, 1997

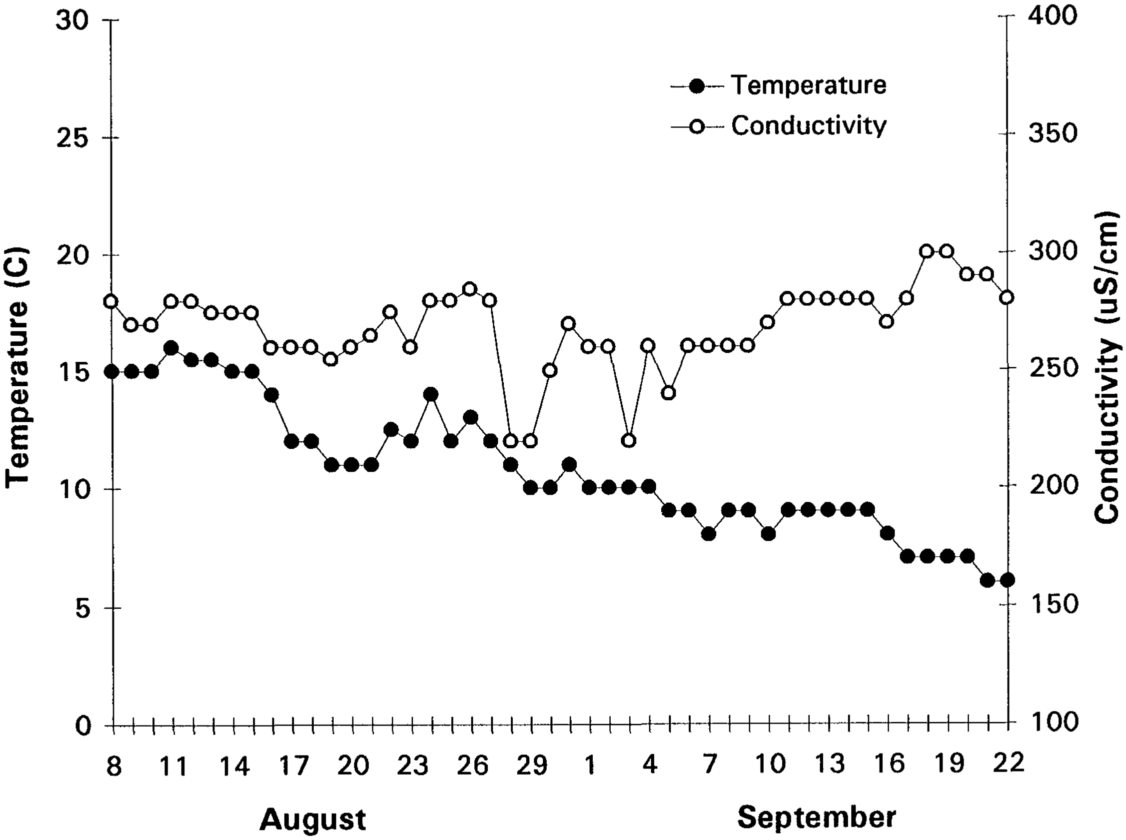

Figure 5 Daily water temperature and conductivity measurements, Chandalar River, August 8-September 22, 1997.

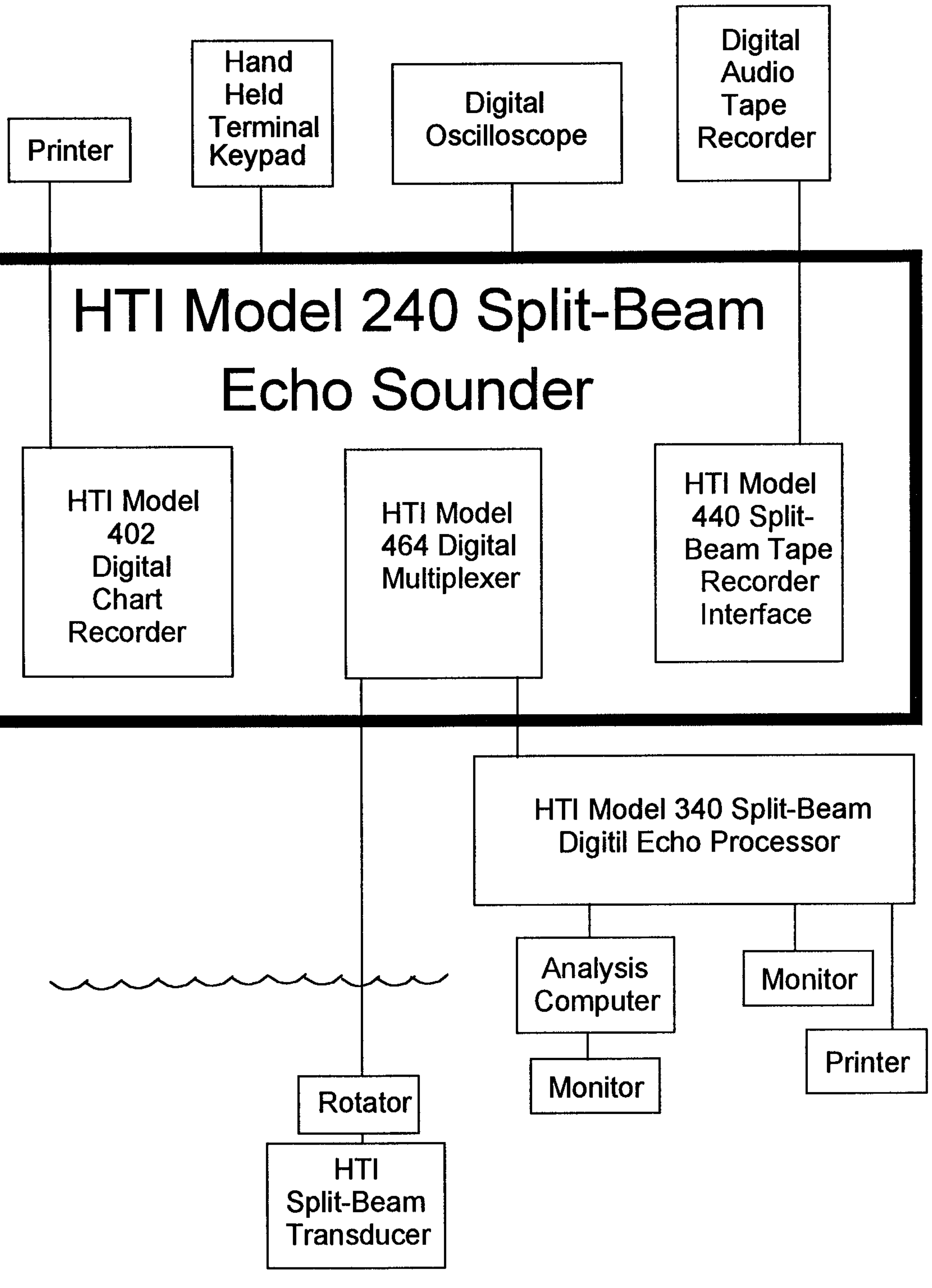

Figure 6. Split-beam hydroacoustic system, Chandalar River, 1997

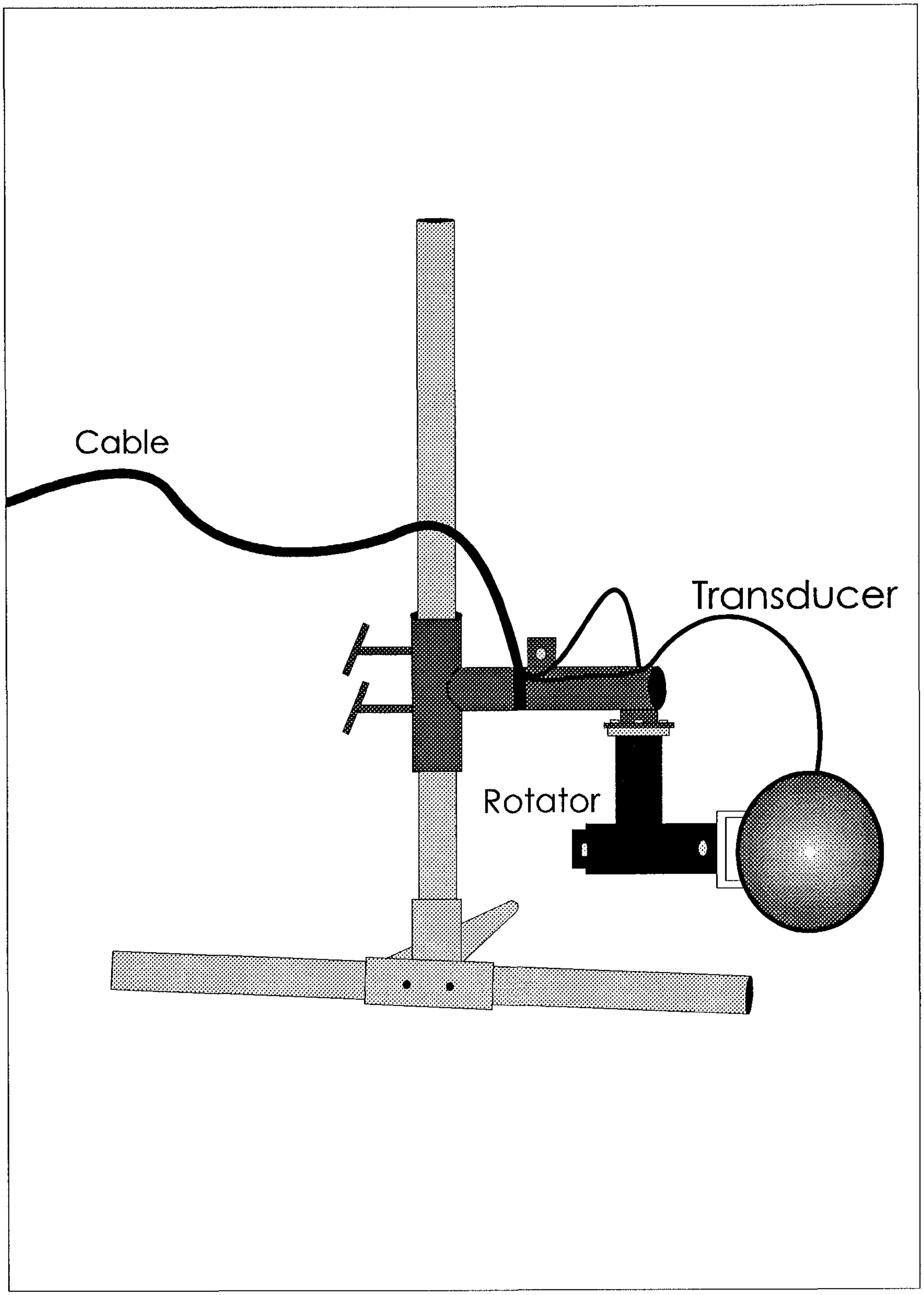

Figure 7 Split-beam transducer, remote rotator, and pod assembly, Chandalar River, 1997

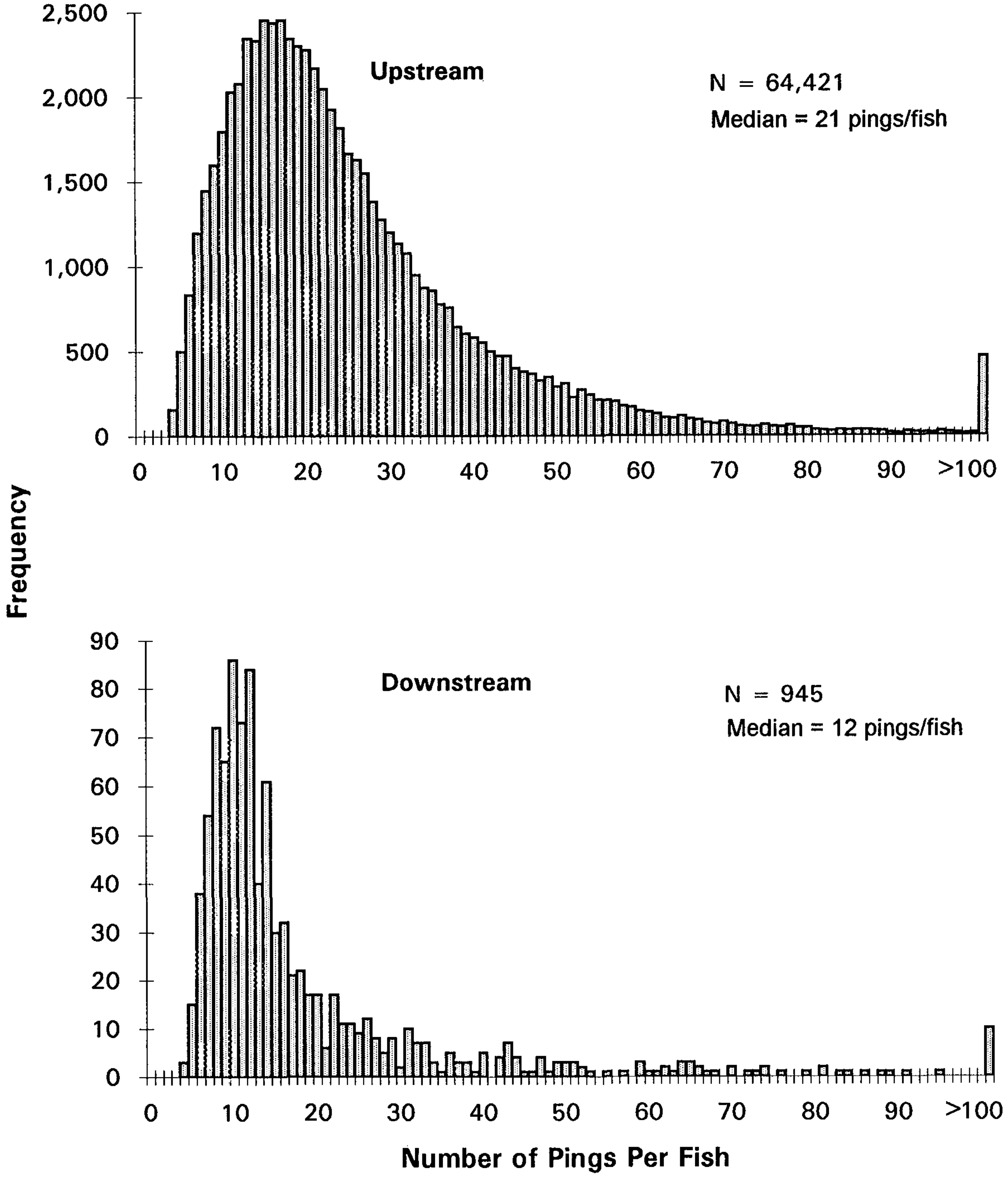

Figure 8 Number of acquired echoes per tracked fish, left bank, Chandalar River, August 8-September 22, 1997.

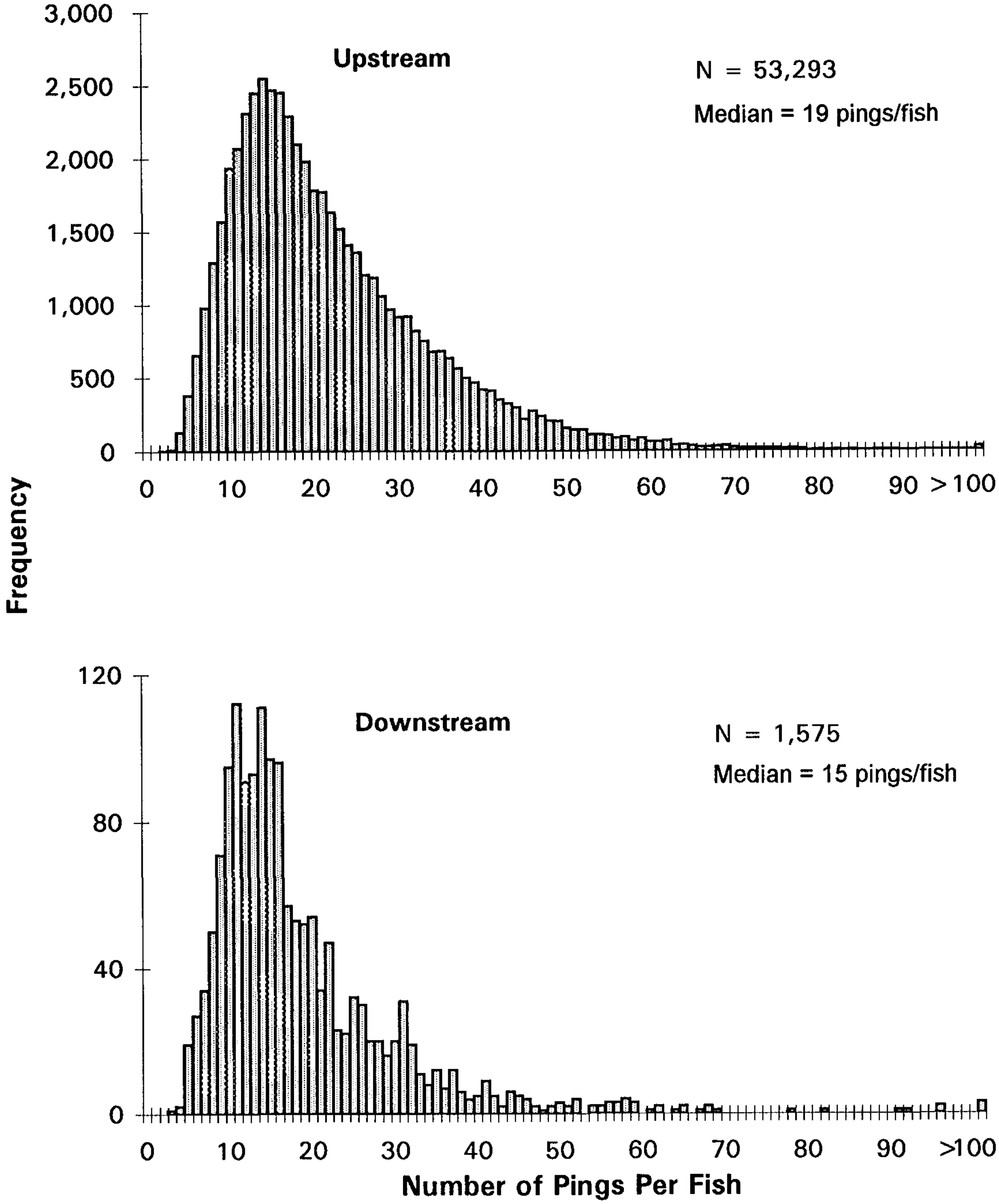

Figure 9. Number of acquired echoes per tracked fish, right bank, Chandalar River, August 8-September 22, 1997.

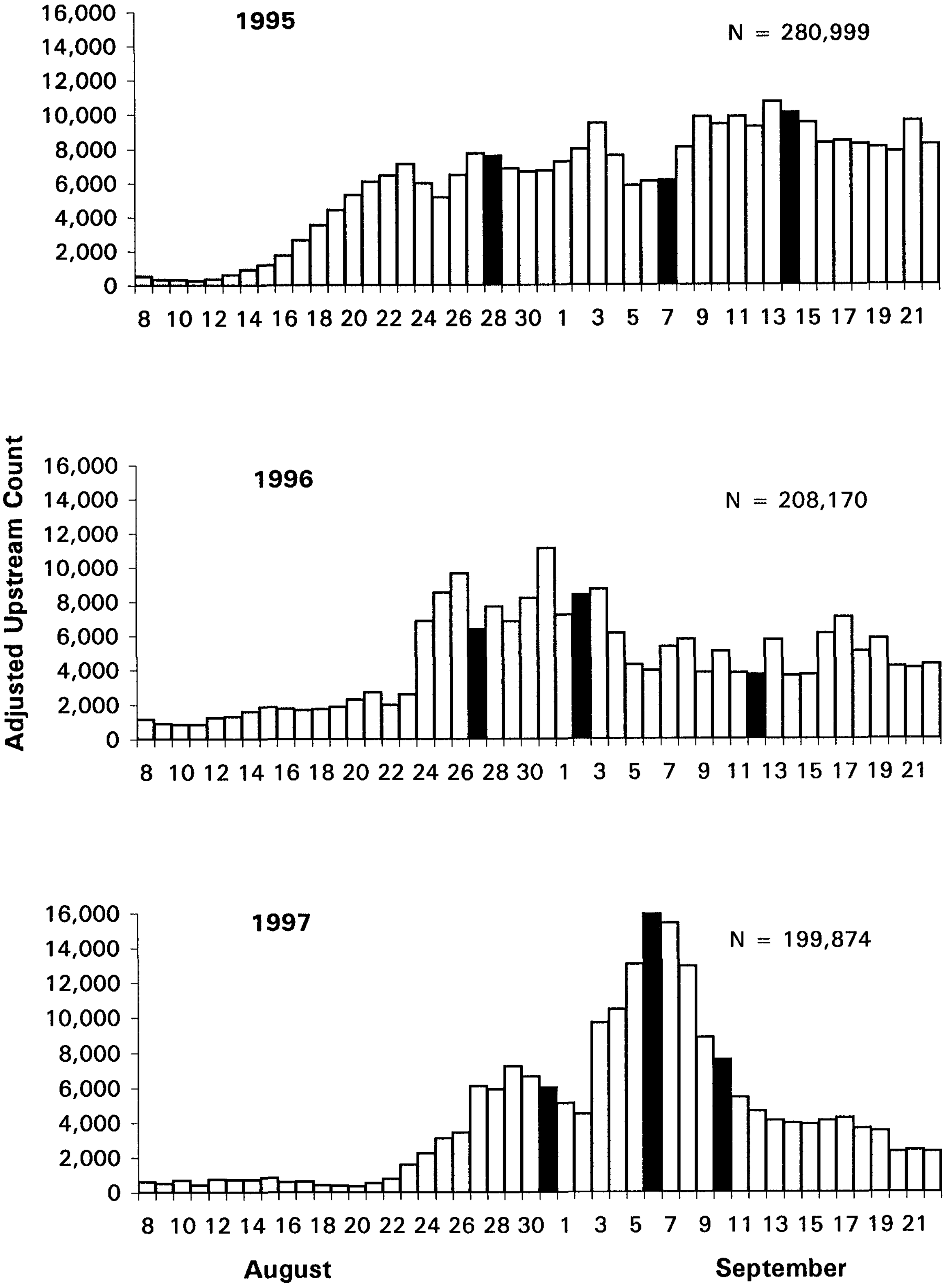

Figure 10. Adjusted daily counts of fall chum salmon, Chandalar River, 1995-1997. Shaded bars represent quartiles of the total count

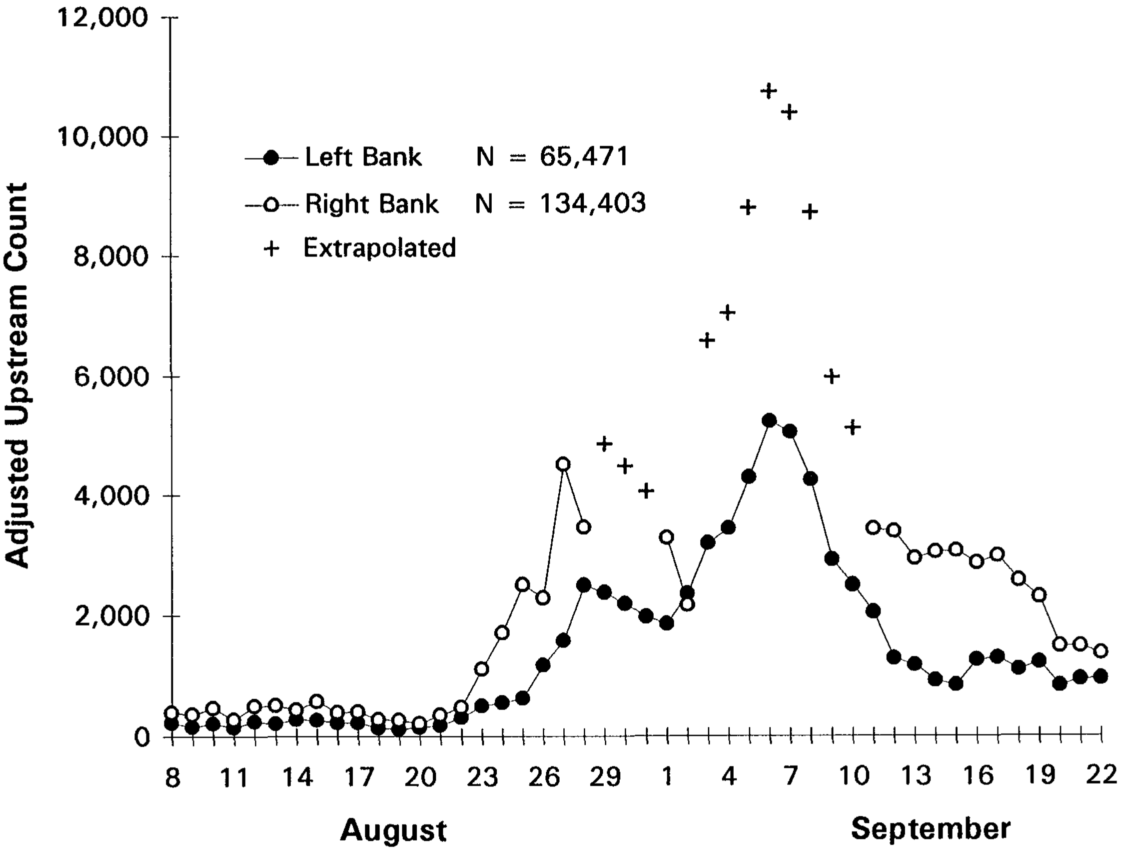

Figure 11. Adjusted daily counts of fall chum salmon by bank, Chandalar River, August 8-September 22, 1997 Daily counts were extrapolated for 11 days on the right bank due to high water.

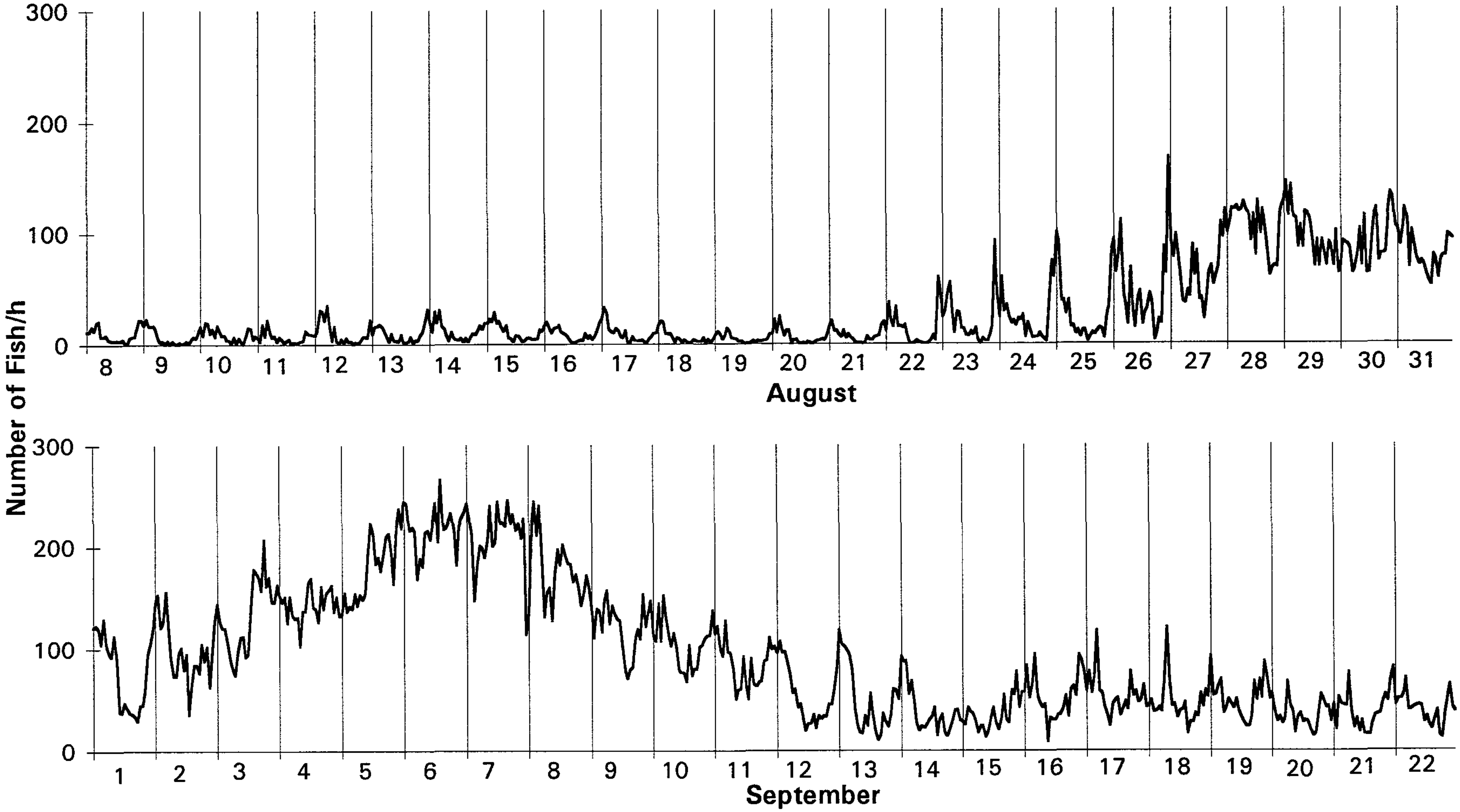

Figure 12. Diel distribution of upstream fish, left bank, Chandalar River, August 8-September 22, 1997.

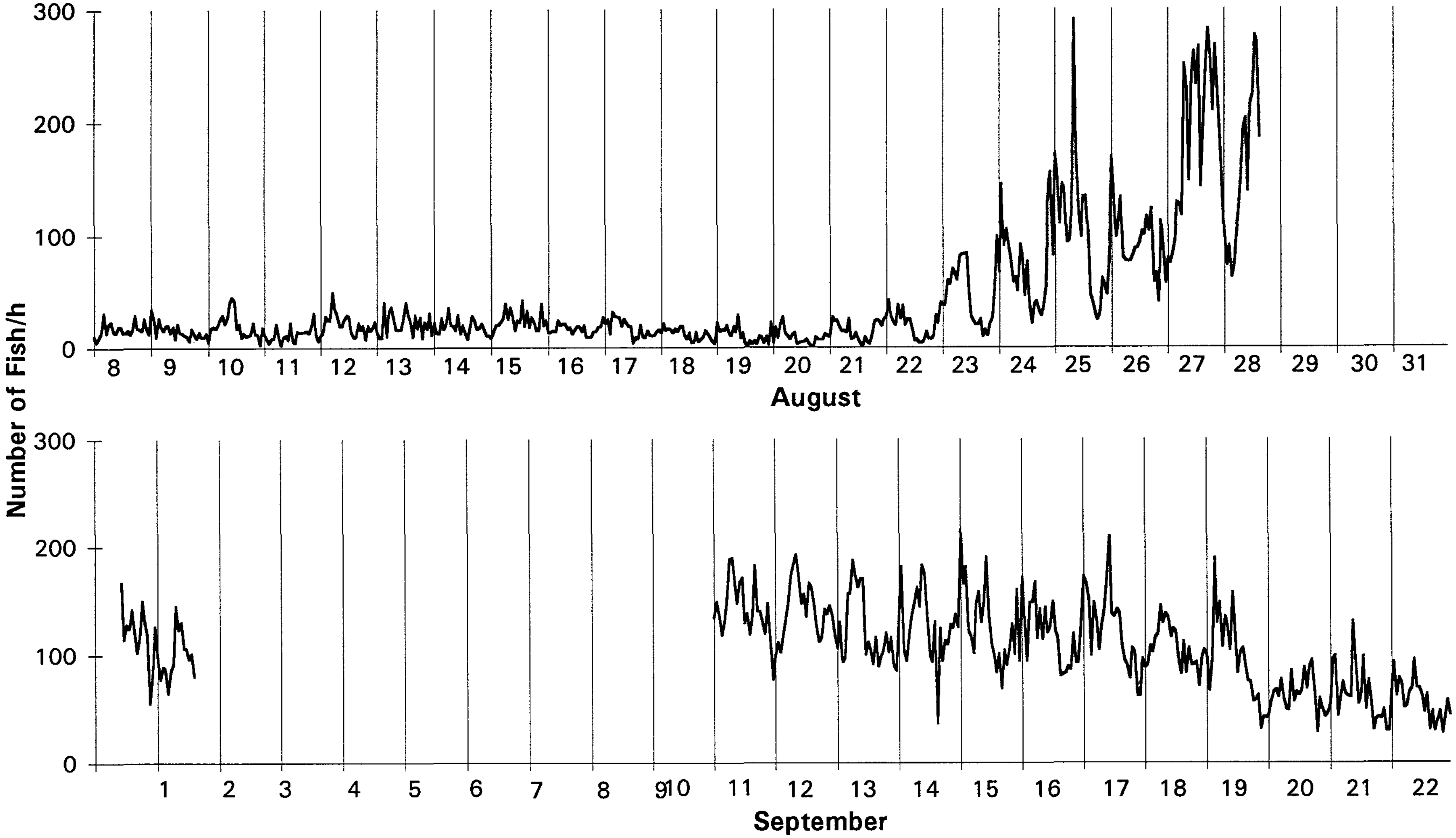

Figure 13. Diel distribution of upstream fish, right bank, Chandalar River, August 8-September 22, 1997.

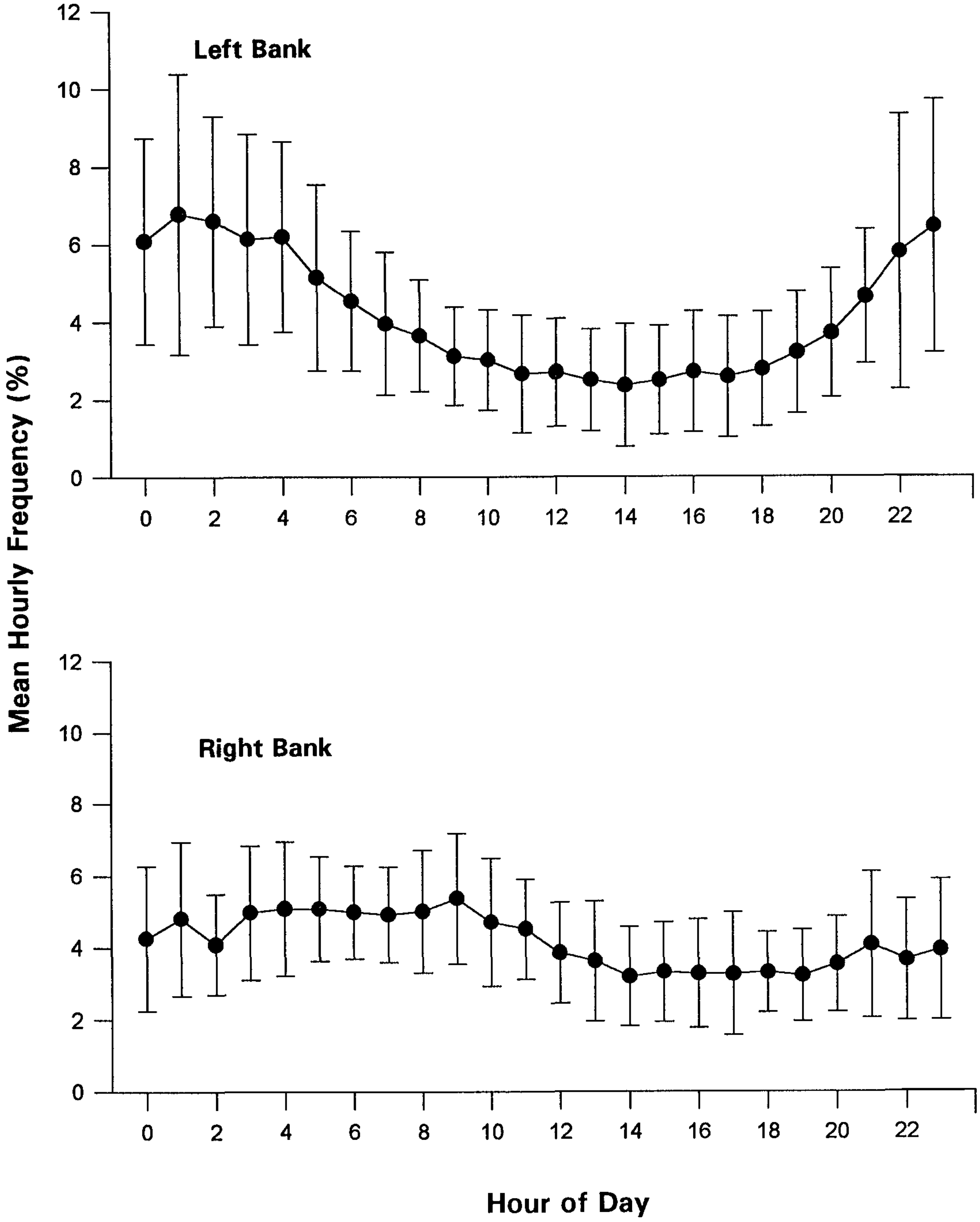

Figure 14. Mean (± SD) hourly frequency of upstream fish, Chandalar River, 1997 Data from 46 days of continuous 24 h data on the left bank and 32 days on the right bank.

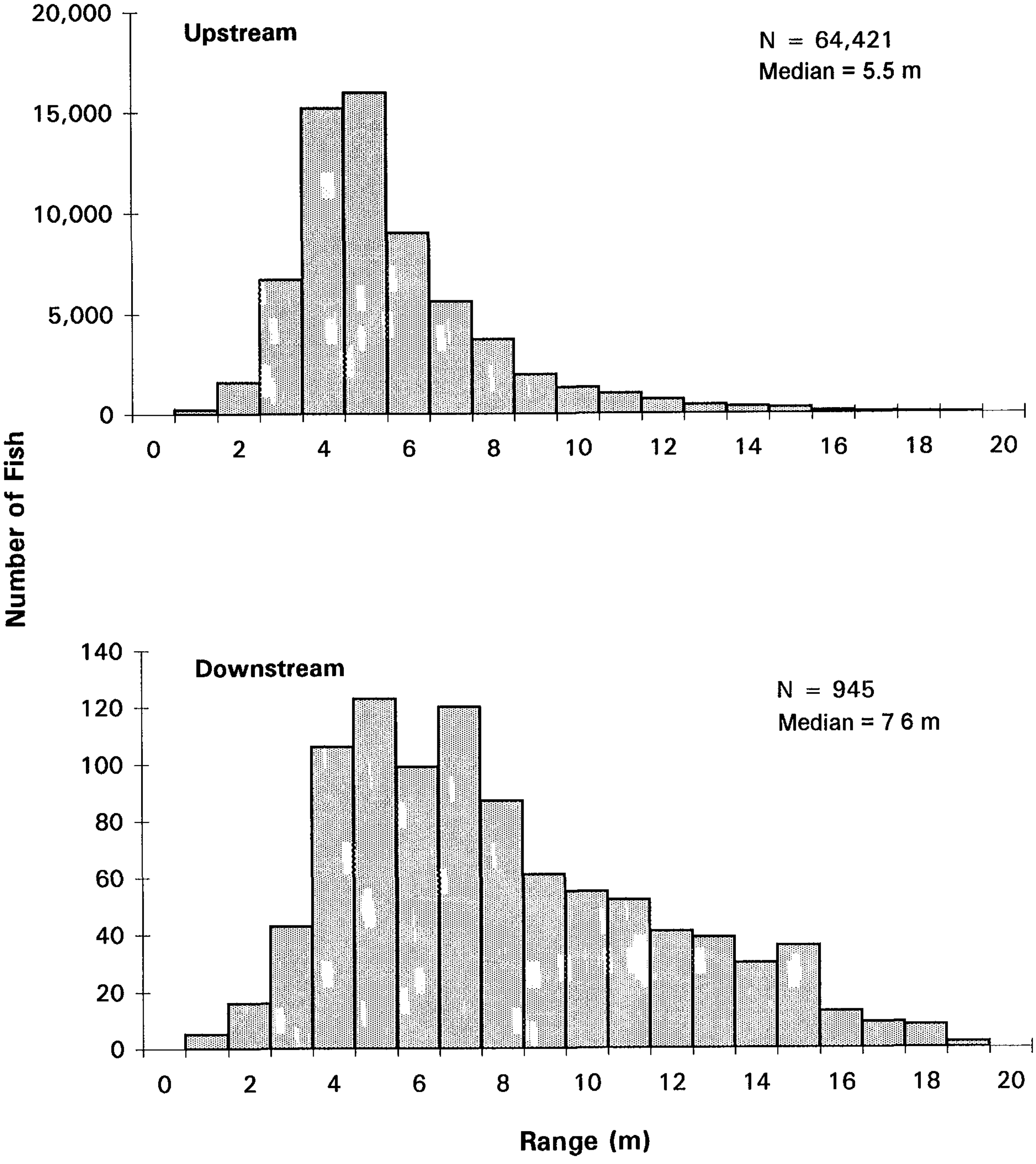

Figure 15. Range (horizontal distance from transducer) distribution of upstream and downstream fish, left bank, Chandalar River, August 8-September 22, 1997

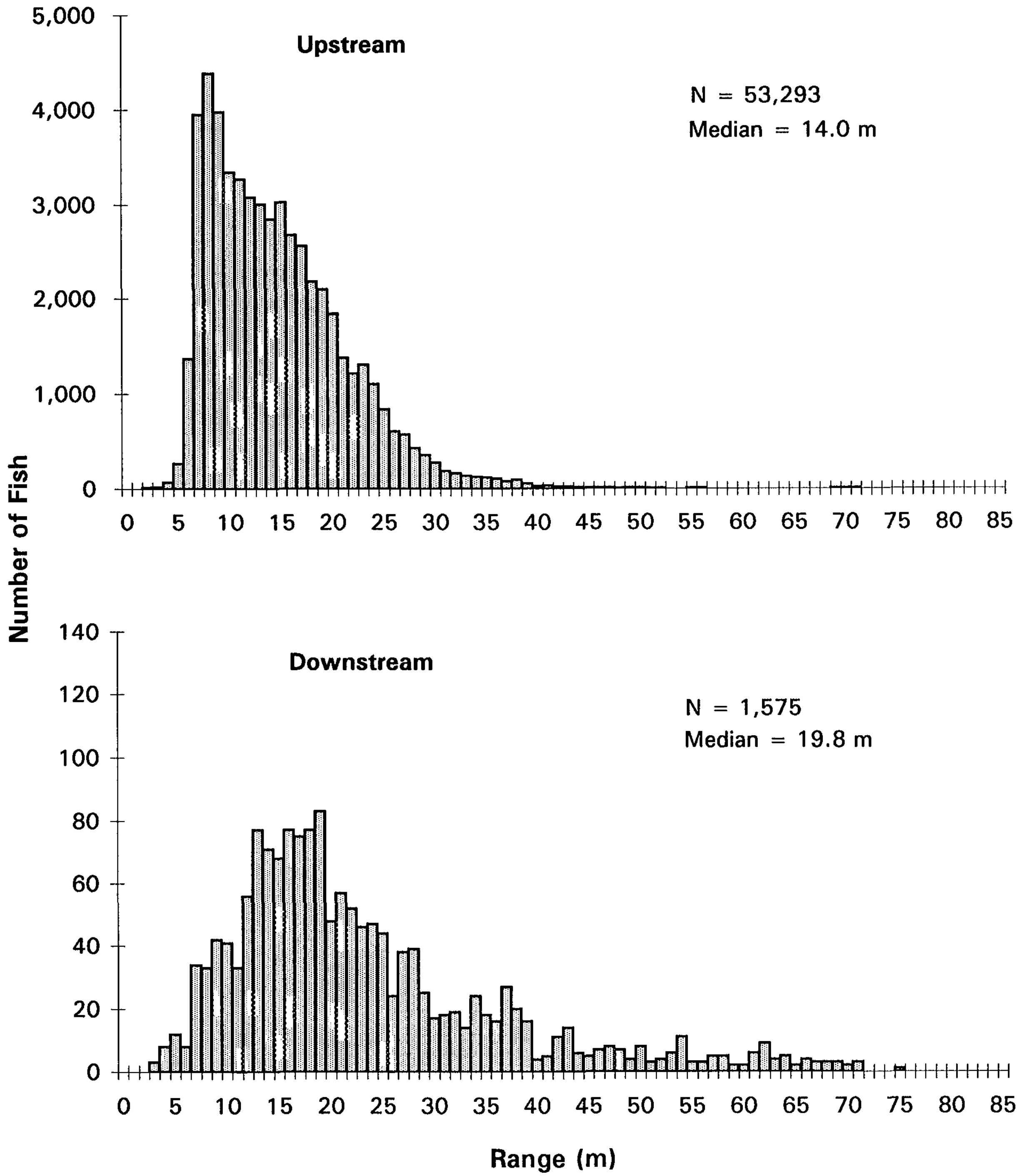

Figure 16 Range (horizontal distance from transducer) distribution of upstream and downstream fish, right bank, Chandalar River, August 8-September 22, 1997.

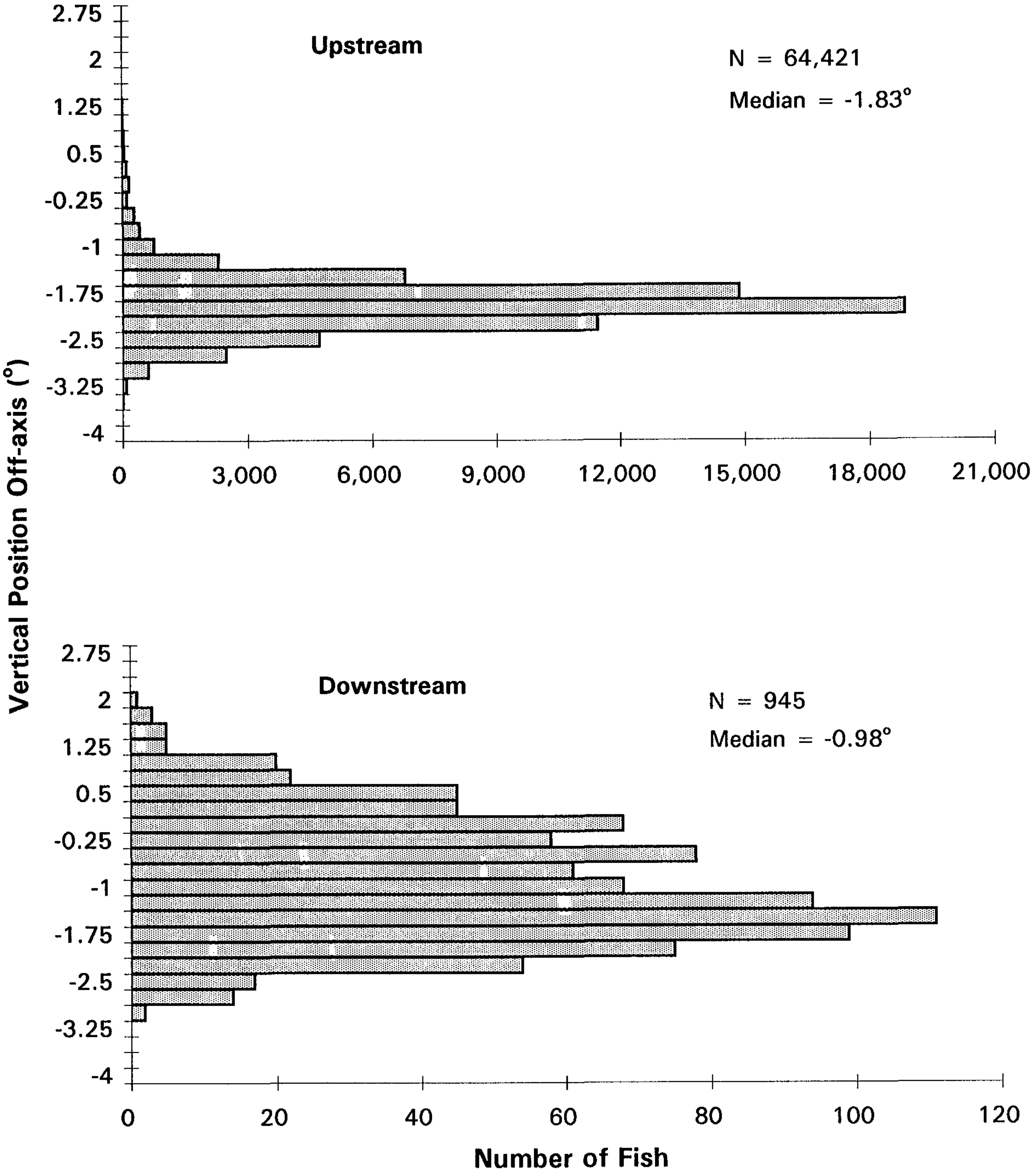

Figure 17. Vertical distribution of upstream and downstream fish, left bank, Chandalar River, August 8-September 22, 1997.

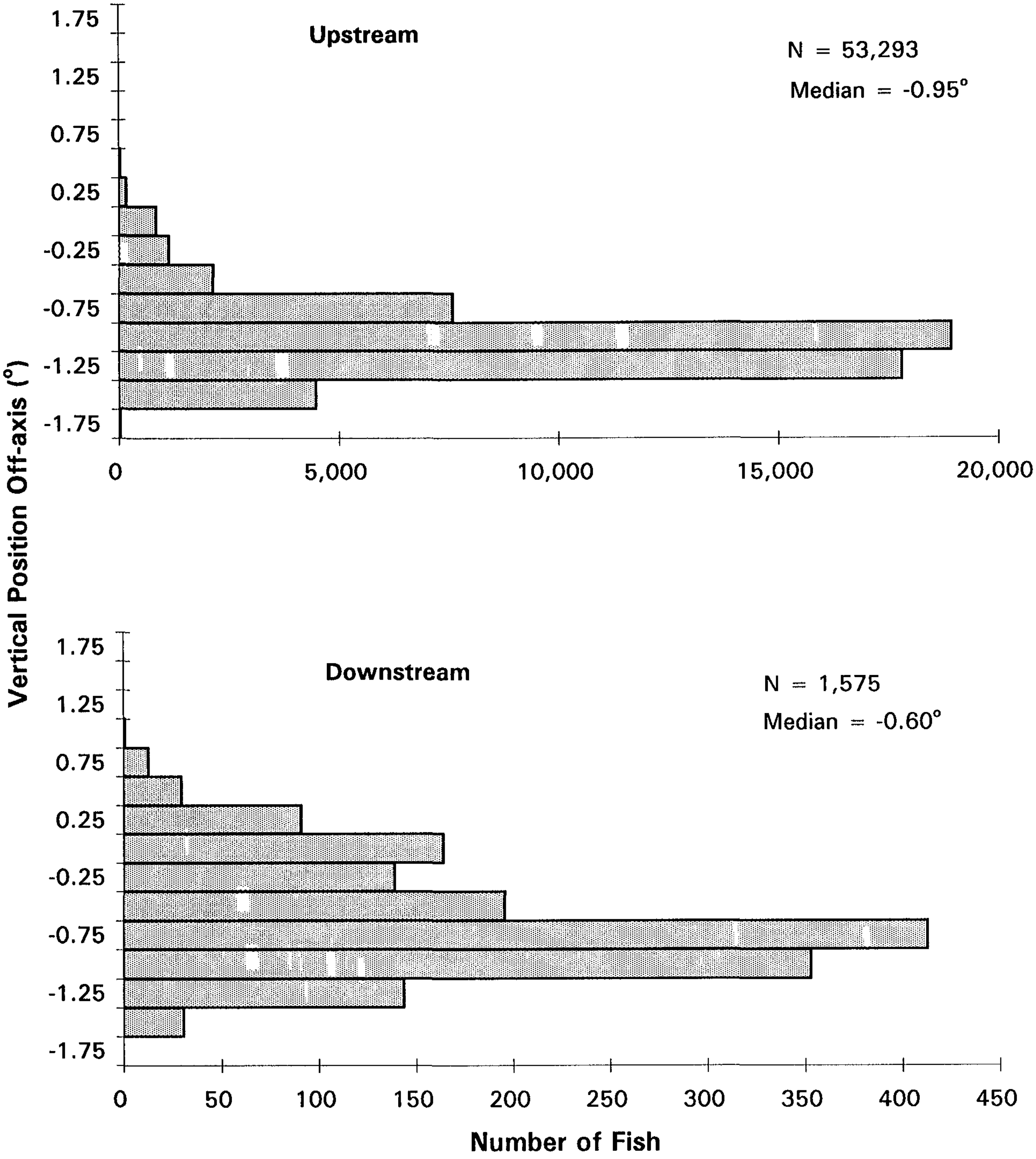

Figure 18. Vertical distribution of upstream and downstream fish, right bank, Chandalar River, August 8-September 22, 1997

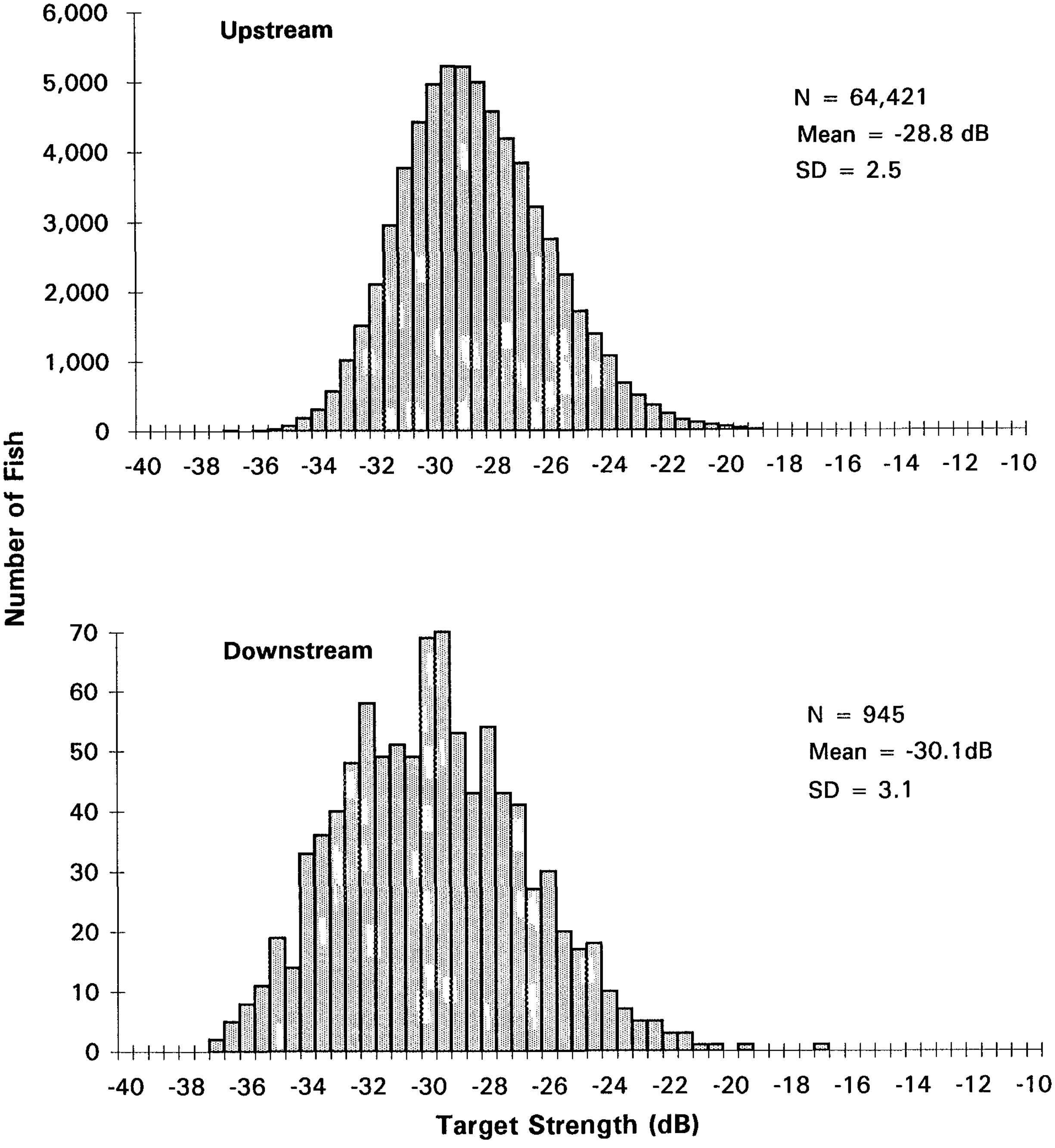

Figure 19 Target strength distribution of upstream and downstream fish, left bank, Chandalar River, August 8-September 22, 1997.

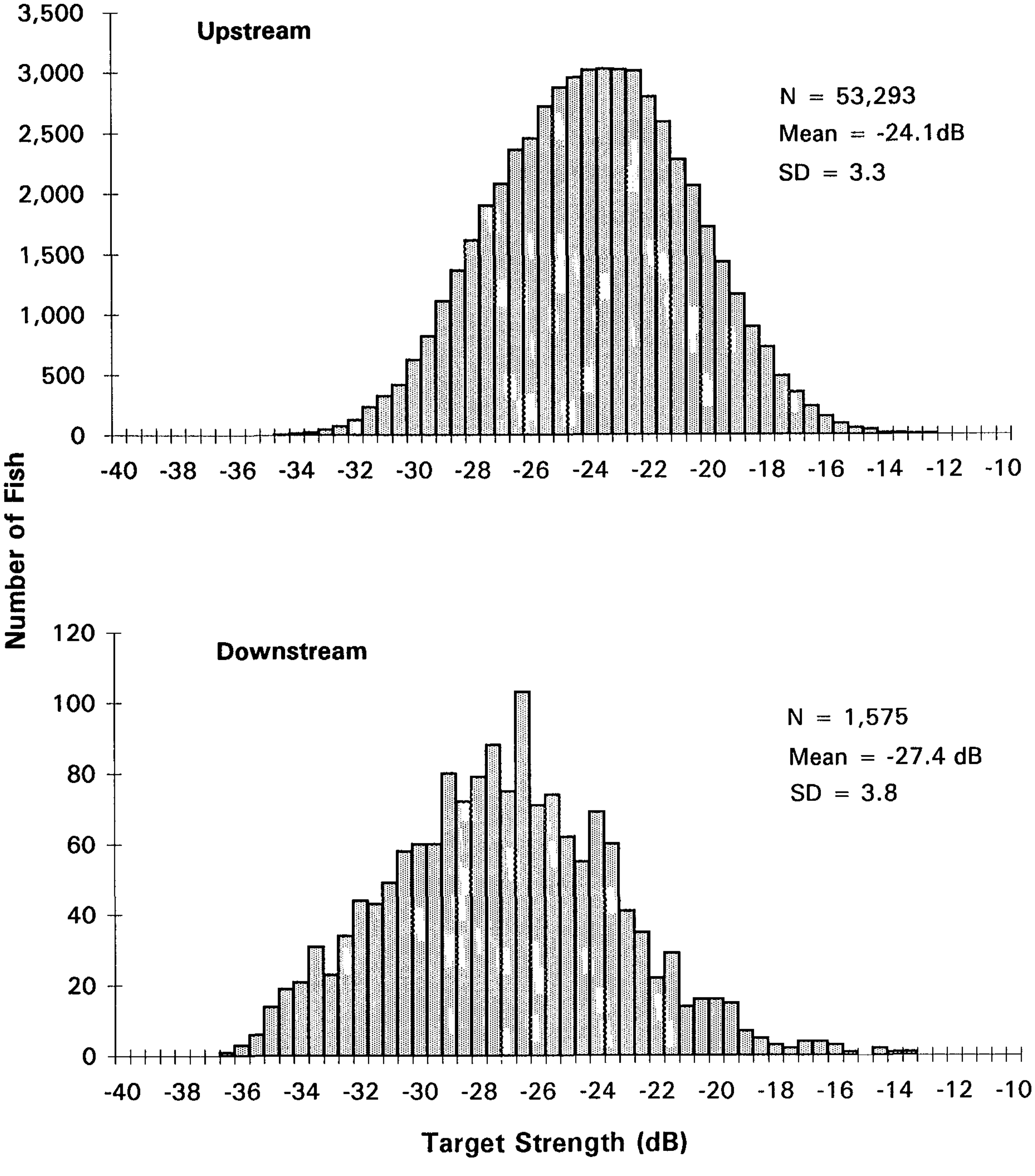

Figure 20. Target strength distribution of upstream and downstream fish, right bank, Chandalar River, August 8-September 22, 1997

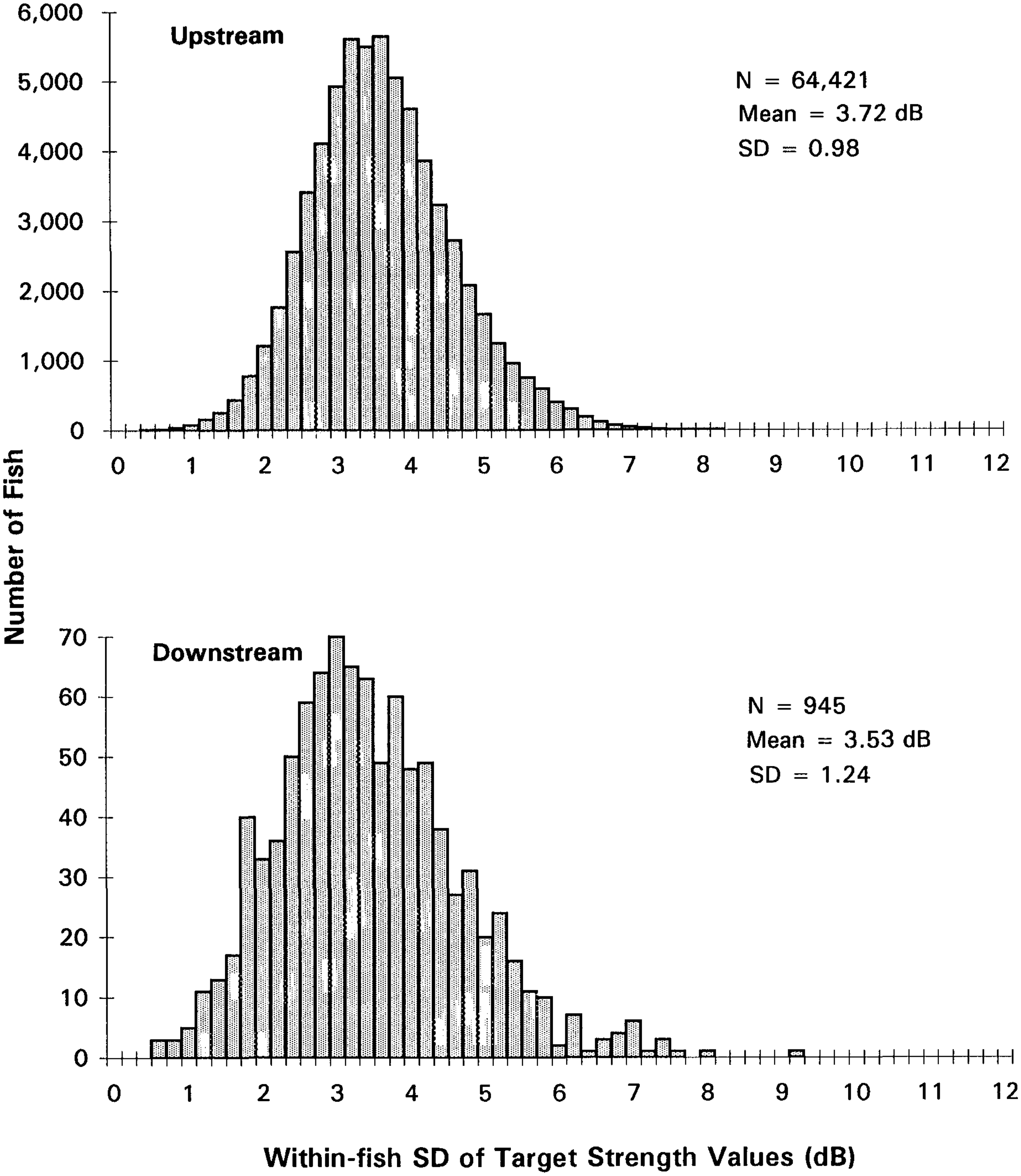

Figure 21 Within-fish target strength variability (SD) of upstream and downstream fish, left bank, Chandalar River, August 8-September 22, 1997.

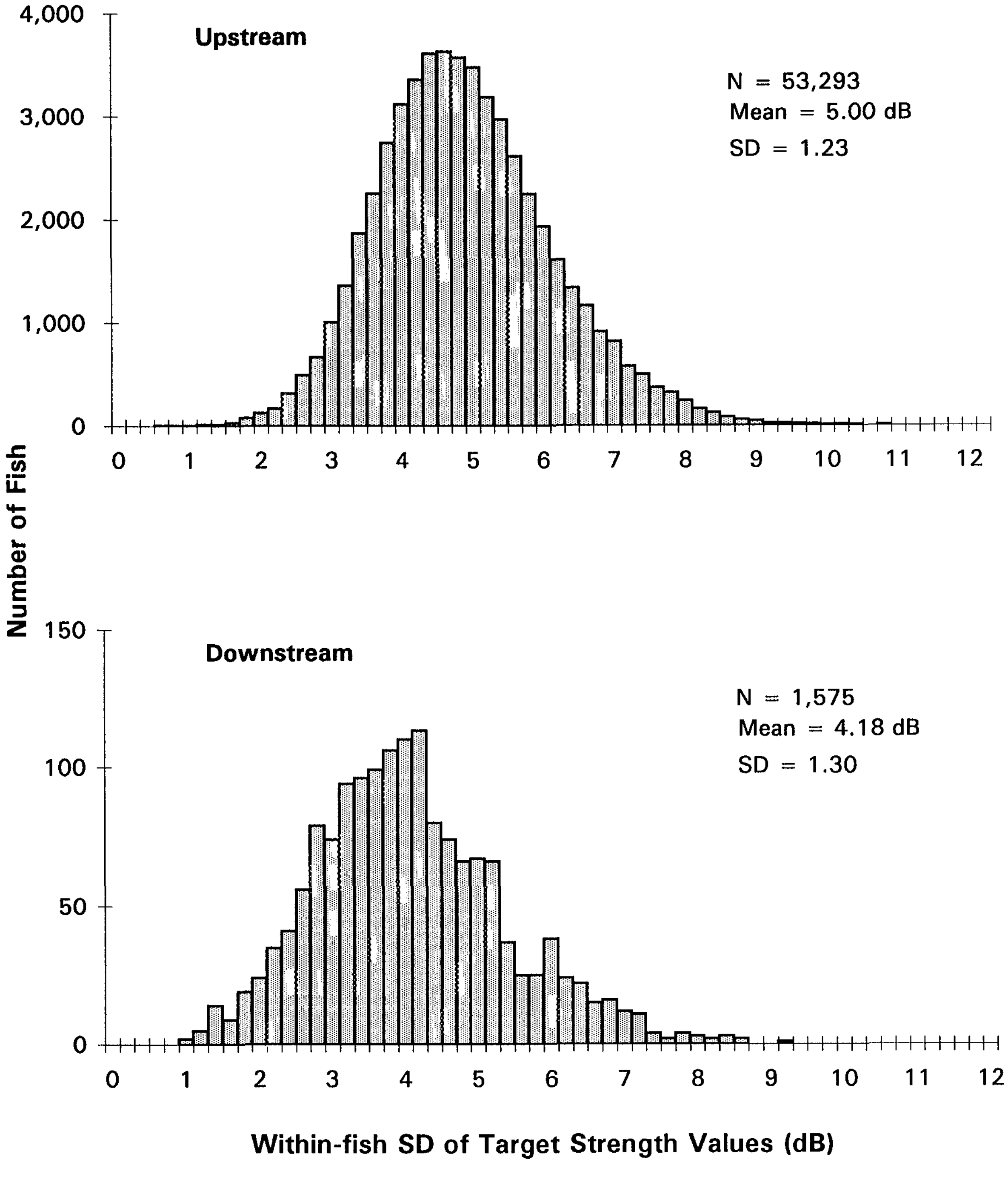

Figure 22 Within-fish target strength variability (SD) of upstream and downstream fish, right bank, Chandalar River, August 8-September 22, 1997.

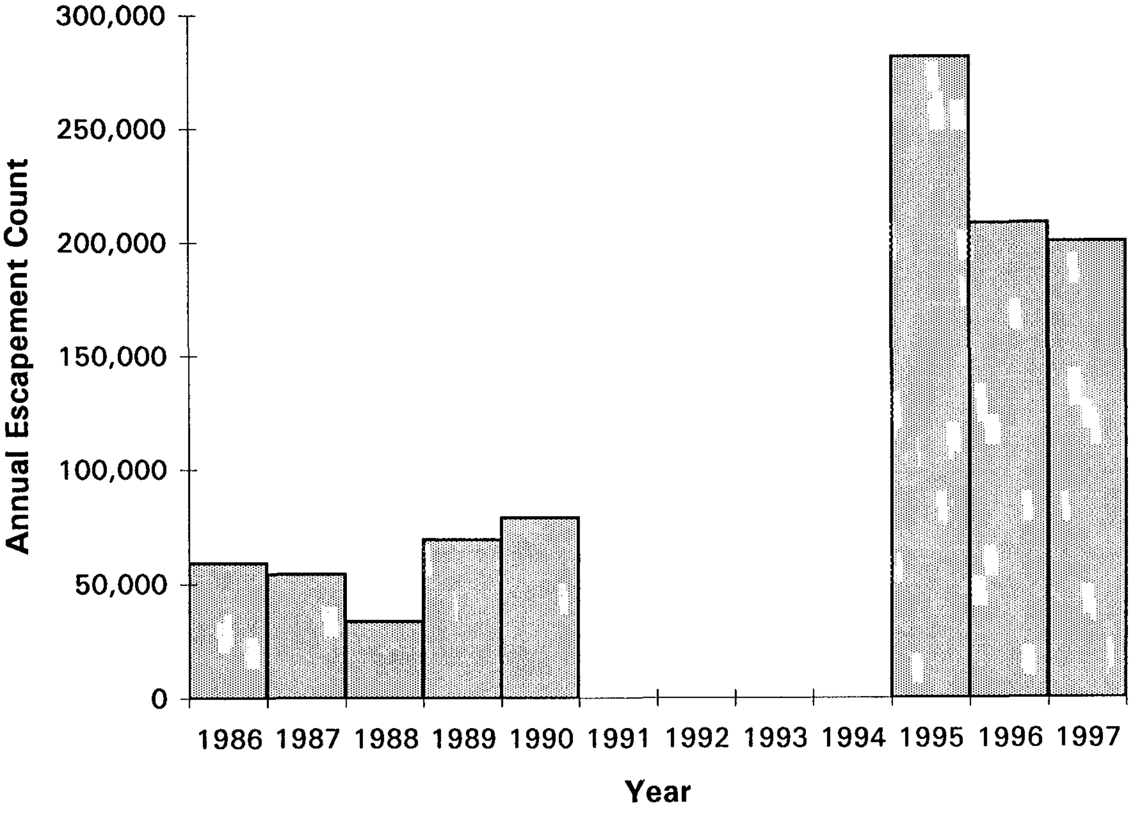

Figure 23. Annual sonar escapement counts of fall chum salmon, Chandalar River, 1986-1997.

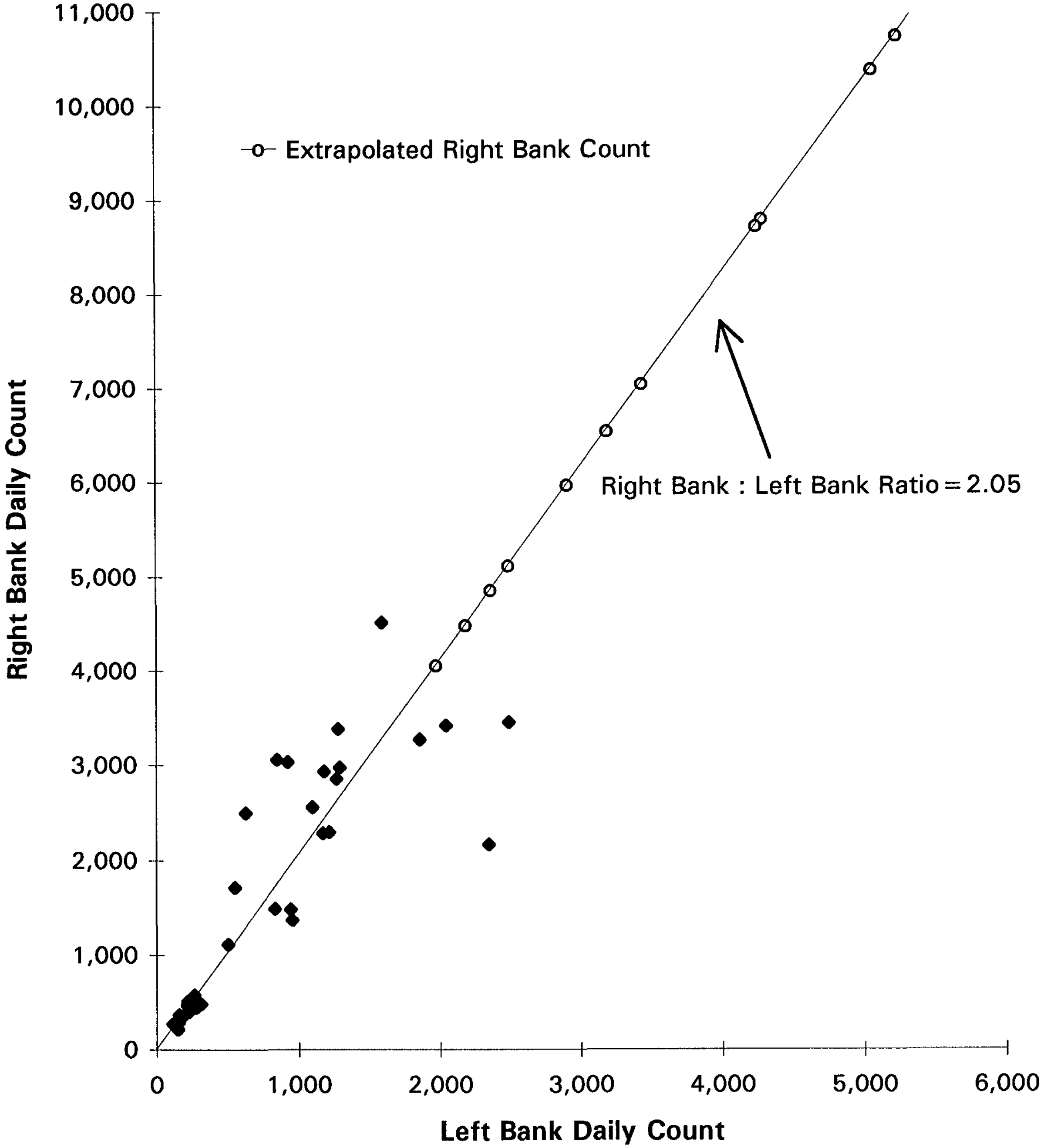

Figure 24. Relationship of right bank to left bank adjusted daily counts of fall chum salmon, Chandalar River, August 8-September 22, 1997 Missing right bank counts were extrapolated from left bank counts using the ratio estimator method (Cochran 1977)

Appendix 1 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		

Appendix 2. 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		