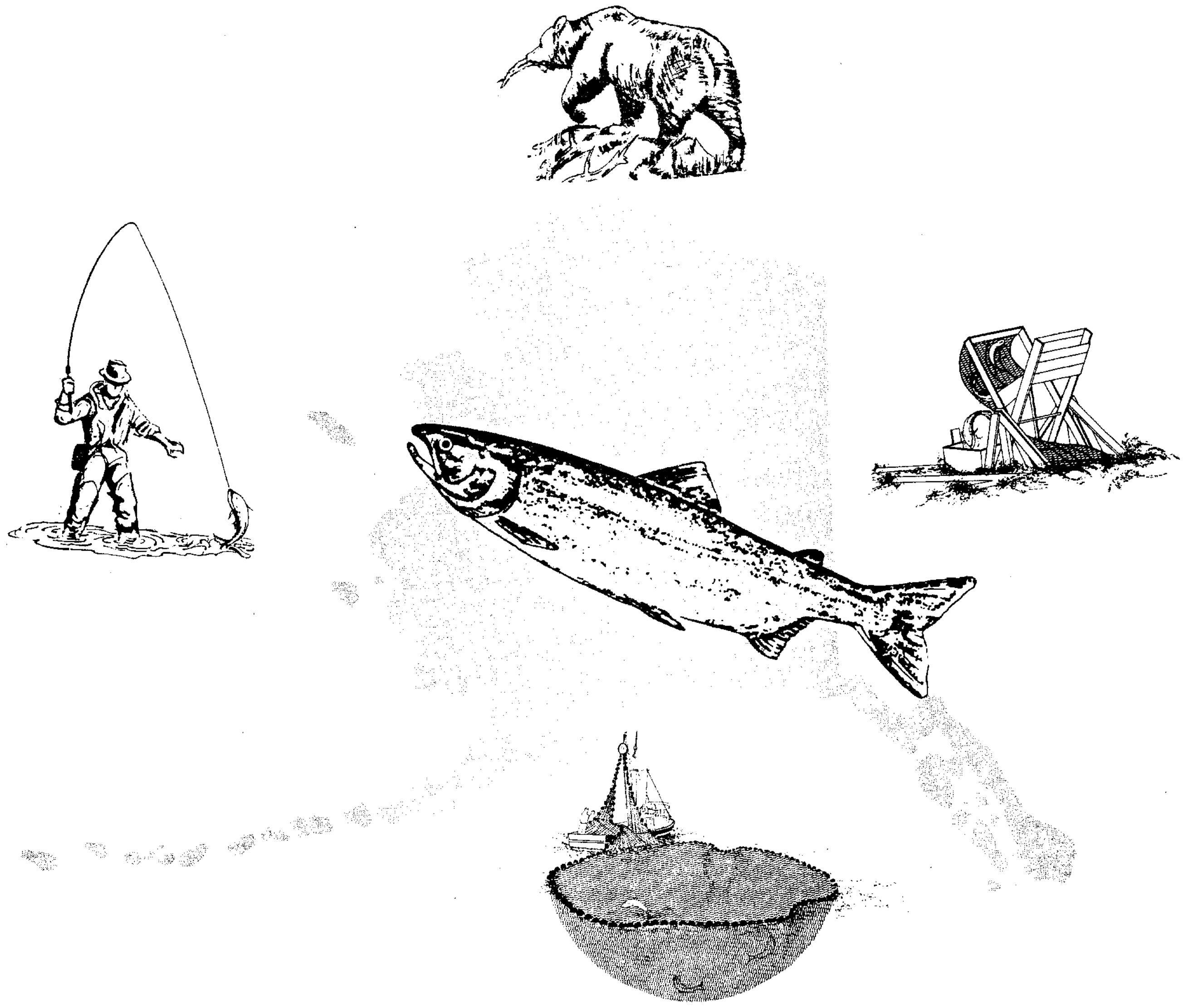
ENUMERATION OF CHANDALAR RIVER FALL CHUM SALMON USING SPLIT-BEAM SONAR, 1994

Alaska Fisheries Progress Report Number 95-4



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Enumeration of Chandalar River Fall Chum Salmon Using Split-beam Sonar, 1994

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ABSTRACT

A fixed-location split-beam hydroacoustic study was initiated in 1994 to assess the population status of adult fall chum salmon *Oncorhynchus keta* on the Chandalar River, a tributary of the Yukon River. This initial year of the five-year project was used to develop site-specific operational methods, evaluate site characteristics, and describe possible data collection biases. Sonar operation began on August 10 and ceased on August 27 due to river flooding. Elliptical transducers were sited on opposite river banks to optimize sonar beam coverage and aimed perpendicular to the river current.

Standard target deployment methodology proved to be very quick and accurate. *In situ* standard target strength measurements were within 1.6 dB of the predicted value for a 38.1 mm tungsten carbide sphere. Target strength variability was low, ranging from 0.65 to 0.86 SD.

Over 704 hours of digital echo processor data were re-tracked, resulting in 22,386 upstream traveling fish. Downstream fish accounted for only 6.5% of the total count. Over 70% of upstream fish were counted from 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 weak and exhibited highest mean hourly counts during morning hours when left bank passage rates were low. Chart recordings were collected for 710 hours. Hourly chart counts did not accurately reflect upstream tracked fish counts on the Chandalar River.

Acoustic data analyses of re-tracked targets revealed that Chandalar River fall chum salmon were shore oriented and traveled close to the river bottom. During daylight hours, upstream fish on the left bank moved further offshore and closer to the bottom. Right bank fish exhibited a similar trend in vertical position, with fish generally decreasing in vertical position during daylight hours. Acoustic fish size increased with range on the left bank, while right bank fish exhibited the opposite trend. On both banks, upstream fish increased in acoustic size as vertical position in the beam decreased. Average fish velocities were greater for right bank fish.

The acoustic size of fall chum salmon was larger than previously reported. Target strength of Chandalar River fall chum salmon averaged -25.3 dB on the left bank and -22.8 dB on the right bank. High threshold settings on the right bank due to high background noise levels may have biased results. Mean target strengths for upstream fish were larger than downstream fish. Mean hourly target strengths of upstream fish were greatest during daylight hours. Within-fish target strength variability (SD) was greatest for upstream fish, averaging 3.83 dB on the left bank and 4.34 dB on the right bank.

Chum salmon were the only fish species captured in 37 h of gill netting. Total catch was 62 salmon with males accounting for 62% of the total catch.

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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 (Schultz et al. 1993).

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

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

From 1986 to 1990, the U.S. Fish and Wildlife Service used side-scan hydroacoustics to enumerate adult fall chum salmon escapement on the Chandalar River, located in the Yukon Flats National Wildlife Refuge (Daum et al. 1992). The results of this study indicated that Chandalar River fall chum salmon were the second largest stock of fall chum salmon in the U.S. portion of the Yukon River drainage. Since 1991, declines in some Yukon River salmon stocks have led to reduced harvest, fishery closures, and, in some cases, poor spawning escapement (Schultz et al. 1994).

Because of the importance of Chandalar River fall chum salmon as refuge and subsistence resources, and the recent declining trend of some Yukon River salmon stocks, this five-year study was initiated in 1994 to reassess the population status using split-beam hydroacoustics. The overall objectives of the Chandalar River sonar project are to (1) estimate total escapement of Chandalar River fall chum salmon using split-beam sonar, (2) describe annual variability in run size and timing, and (3) provide accurate and timely escapement estimates to fishery management agencies.

The initial year was used to develop site-specific operational methods, evaluate site characteristics, and describe possible data collection biases. More specifically, the objectives 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 re-track all raw files so only suspected fish targets are included in the data set;
5) analyze acoustic data to describe fish behavior and possible sampling biases; and
6) collect species composition data to assess the need for species apportionment.

STUDY AREA

The Chandalar River is a fifth order tributary of the Yukon River, drains from the southern slopes of the Brooks Range, and 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. Breakup is typically in early June and freezeup occurs in late September to early October.

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

The sonar site was located at River Kilometer 21.5 which was previously described by Daum et al. (1992; Figure 2). Site selection requirements included: 1) single channel; 2) moderate laminar flow; 3) gradually sloping bottom gradient; 4) absence of highly reflective bottom substrate; 5) downriver from known salmon spawning areas; and 6) active fish migration. The left bank (looking downstream) bottom gradient was steeper and water velocity higher than the right bank. Bottom substrate consisted 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 passage of adult fall chum salmon on the Chandalar River in 1994. Systems were sited on opposite river banks to optimize sonar beam coverage of the river cross-sectional area. Sonar operations were initiated for the right bank system on August 10 and left bank on August 11. Monitoring ceased on August 27 due to river flooding.

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, 150 m transducer cable, elliptical-beam transducer, oscilloscope, chart recorder, digital audio tape recorder, digital echo processor, and data analysis computer (Figure 3). Specific component descriptions and operations are detailed in HTI manuals (HTI 1994a, 1994b). A Remote Ocean Systems underwater rotator was attached to the transducer housing to facilitate remote aiming. For each bank, sonar equipment was housed in a portable shelter and powered by a 3.5 kW gasoline powered generator.

Echo sounder settings

Echo sounder settings were similar for both banks. Transmit power was 25 dB_W, total receiver gain was -18 dB_V, and time-varied gain function was $40 \cdot \log_{10}(R)$, where R = target range (m). Settings were influenced by the desire to transmit the highest power into the water (transmit power) while using the lowest amplification (receiver gain) to receive returning echoes. Pulse width was 0.4 ms for the left bank and 0.2 ms for the right bank. Ping rate was 10/s for the left bank and 6.25/s for the right bank. Pulse widths and ping rates were different between banks to avoid recording signal cross-talk from the opposing echo sounders.

Data acquisition

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

Processor data files were created once per hour and consisted of three types: *raw*; *echo*; and *fish* files. *Raw* 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). The minimum vertical angle off-axis value for left bank data was decreased from -2.3 to $-3.5°$ after determining that some fish echoes were being excluded because fish were traveling very close to the rocky bottom substrate. Threshold and range values were not constant. Threshold levels were increased during high noise events to keep computer buffers and available disk space free. Threshold settings varied from 0.15 - 0.20 V (−43.1 to−40.6 dB on-axis) for the left bank and 0.40 - 0.70 V (−38.2 to −33.3 dB on-axis) for the right bank. Acquisition range changed due to transducer re-deployment as water levels varied; left bank varied from 13-17 m and right bank from 63-75 m. All changes to processor settings were recorded in hourly files and log books. *Echo* and *fish* output files were then created by tracking the filtered echoes in three-dimensional space using HTI Tracker software, version 1.04D. User-controlled tracking criteria determined how targets were tracked through the beam. Detailed descriptions of file types and HTI Tracker can be found in Johnston et al. (1993) and HTI (1994b). Files were backed-up daily; data were compressed onto high-density 2.0 megabyte diskettes and transferred to a computer for future data analyses.

Permanent chart recordings were collected throughout the season and run concurrently with the digital echo processor. Echograms were used for data back-up, transducer aiming, and visual evaluation of the echo sounder and fish tracking performance. Threshold settings varied from 0.15 - 0.20 V (−43.1 to−40.6 dB on-axis) for the left bank chart recorder and 0.40 - 0.55 V (−38.2 to −35.4 dB on-axis) for the right bank. Acoustic noise limited the ability to lower thresholds on the right bank. Unlike digital echo processor data files, echogram recordings were not filtered by pulse width or angle off-axis criteria. All changes to chart recorder settings were recorded on real-time echograms and log books.

Digital audio tape recordings were made at the beginning of the season to collect permanent records of background noise levels. Recordings were direct outputs from the echo sounder so incoming signals were not filtered for threshold, pulse width, or angle off-axis.

Approximate echo acceptance thresholds were determined pre-season for the digital echo processor and chart recorder. Chandalar River fall chum salmon range in length from 50 - 70 cm (Daum et al. 1992). A derivation of Love's (1977) side aspect equation was used to calculate expected fish target strength values corresponding to these lengths,

$$TS_S = 10 \cdot \log_{10}\left((0.0075\ m/cycle)^2 \cdot 0.074 \cdot (L/0.0075\ m/cycle)^{1.9} / 4\pi\right), \qquad (1)$$

where TS_S = side aspect target strength (dB) ± 15° and L = fish length (m). From equation (1), the side aspect target strength of the smallest fish of interest should be −30.2 dB. Using calibration data for the system, maximum threshold settings of 0.35 V (left bank) and 0.50 V (right bank) would be required to detect the smallest chum salmon across the entire beam. Since equation (1) was derived from entrained, anesthetized non-salmonids, biases may be introduced when applying the formula to free-swimming, sexually ripe salmon. Thus, calculated target strength values should be used only as approximations.

Transducer deployment

One elliptical-beam transducer per bank was used throughout the 1994 season. Elliptical-beam transducers increased 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 2.9 by 11.5° on the right bank and 4.6 by 10.9° on the left bank. Low side-lobe transducers were used so the beam could be aimed close to the river bottom (−20.1 dB for the right bank and −13.7 dB for the left 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. Transducers were oriented perpendicular to river flow and positioned approximately 10 cm off the bottom. Before deployment, the transducer face was washed with soap solution to eliminate foreign matter and air bubbles that could affect performance. A wire fence weir (5 x 10 cm mesh) was installed 1 m downstream and extended beyond the transducer face. Fish moving upstream and close to shore would encounter the weir, be forced to move offshore, and then pass through the sonar beam. Weirs were extended roughly twice the distance past calculated near-field distance values (MacLennan and Simmonds 1992) for each transducer, 1.3 m on the left bank and 3.2 m on the right bank.

Transducers were aimed using dual-axis remote rotators, allowing vertical and horizontal adjustments. Precise aiming was critical because most fish traveled close to the bottom. A small rise in vertical aim could allow fish to pass undetected under the beam. Chart recordings, oscilloscope readings, and real-time displays from the digital echo processor were used to determine proper aiming. The low acoustic reflectivity of right bank substrate (silt and sand) required the use of a target (≈ −24 dB in acoustic size) placed on the bottom during transducer aiming. During high noise events, the right bank transducer was partially aimed down into the bottom substrate to decrease sample volume which in turn lowered the amount of recorded noise. All changes in transducer aiming and re-deployment were recorded in log books.

Hydrographic Conditions (Objective 2)

River profile and beam fit

Determining a site-specific river profile is essential before initiating sonar operations. Transducer beam selection and bottom irregularities that may allow fish to go undetected can be determined from accurate river profiles. Bottom profile measurements were made from August 4-8, 1994. A Lowrance chart recording depth sounder, with a 20° transducer mounted below a river boat's hull, was used for recording water depth. Transect markers were spaced along each bank at 15 m intervals. Transects were run perpendicular to river flow from each marker to the thalweg, keeping boat speed as constant as possible. Buoys were placed at known distances from shore and used as reference points when performing transects. Charts were redrawn, adjusting horizontal distances from buoy location data. These bathymetric maps were used to select the best beam fit and transducer deployment site for each bank.

Hydrologic measurements

A river elevation gauge was installed by the right bank sonar site and monitored throughout the season. Water elevation was recorded daily to the nearest 0.6 cm. A permanent gauging site was established in 1989 so water levels between years could be compared (Daum et al.

1992). Water temperature (°C) and conductivity (μS/cm) were measured daily using a mercury-filled thermometer and Hach mini-conductivity meter.

Background noise

Noise can affect the ability to detect acoustic targets (MacLennan and Simmonds 1992). Peak amplitude noise levels at range were recorded in the active (transmitting/receiving) and passive (receiving) condition using a digital oscilloscope. Permanent recordings of noise levels were stored on digital audio tapes. Noise measurements were expressed in similar units to signal strength (dB), using

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

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

System Calibration (Objective 3)

Complete system calibration was performed pre-season by HTI using the comparison method referenced in Urick (1983). Transducer calibration data (power output and receiving sensitivity) and beam pattern plots were provided (HTI 1994c). Current calibration data were entered into the digital echo processor before data collection began and 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.

In situ calibration data were collected from both banks using a 38.1 mm tungsten carbide sphere as a standard target (Foote and MacLennan 1984). The expected target strength value for the tungsten carbide sphere using a 200 kHz sounder in freshwater is −39.5 dB (MacLennan and Simmonds 1992). The target was washed in soap solution and suspended in the middle of the water column with a fiberglass pole and monofilament line. The target was kept 7 m beyond the transducer face, exceeding the near-field distance for each transducer by two-fold. The standard target was positioned in the center of the beam by aiming the transducer while viewing the real-time echo position display from the digital echo processor. When the target's location stabilized, echoes were collected from the standard target and recorded to a data file for analysis. Also, an examination of target strength stability across the full beam cross-section was done by collecting echoes off a stationary standard target while changing the transducer aim. Target strength data were collected from all areas of the beam and plotted by horizontal and vertical position.

Acoustic Data Verification and Re-tracking (Objective 4)

Before analyses of acoustic data began, tracked files from the digital echo processor (*echo* and *fish* files) were examined to ensure that tracking parameters accurately selected passing fish targets. Tracked targets in the data files included passing debris, rocks, motor boat wake, acoustic noise, and fish. Individual fish targets sometimes appeared as multiple fish in the data set due to tracking settings, noise, and variations in fish behavior. Since the originally produced data set included erroneous data, all processor-produced *raw* files were manually re-tracked using HTI Trakman software, version 1.00. 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, the new *echo* and *fish* files included only suspected fish targets, although some downstream debris could not be differentiated from downstream fish. For clarity, all re-tracked targets will be referred to as "fish". Fish were grouped into upstream and downstream categories based on direction of travel values reported in the re-created *fish* files. If the total distance traveled in the upstream/downstream direction was <0.1 m, that fish was excluded from any directional analyses. For each bank, hourly sample times and upstream/downstream fish counts were tabulated. Re-tracked data were used in all subsequent analyses contained in this report.

Chart recordings for the entire sampling period were interpreted independently by three experienced readers. Hourly chart counts by bank were tallied and averaged between readers. Sample times by bank were recorded.

Acoustic Data Analyses (Objective 5)

Temporal distribution of tracked fish

Descriptions of diel fish passage rates are needed before future sampling schedules and daily count adjustments can be made. Hourly passage rates (fish/h) for upstream and downstream fish were calculated for all *fish* files with sample times ≥ 15 min. *Fish* files with sample times <15 min were not included. Also, mean hourly passage rates for the season were determined by averaging hourly rates from all days with 24 h of continuous data, ten days on the left bank and seven days on the right bank. All days were equally weighted so high passage days did not bias results.

Hourly passage rates from processor data were compared to chart counts. Similar to *fish* file data, hourly passage rates (fish/h) from chart counts were calculated for sample times ≥ 15 min. Chart counts with sample times <15 min were not included. Ratios of hourly chart counts to upstream tracked fish counts were calculated. Also, daily and seasonal mean ratios by bank were determined. To assess the reliability of substituting hourly chart counts for missing upstream tracked fish counts, differences between hourly ratios and daily and seasonal mean ratios were described by counting the number of hourly ratios that fell within 10% of the daily and seasonal ratio.

Spatial distribution of tracked fish

Fish position data provide an assessment of the likelihood of not detecting fish that pass above, below, or beyond the detection range of the sonar beam. Midpoint range (distance from transducer) values were calculated for all tracked fish and used for subsequent analyses,

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

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

$$V_m = arcsine\ (V_s + (D_v/2)/R_m\ ),$$

where V_m=vertical midpoint angle off-axis (°), V_s=starting vertical coordinate (m), D_v=distance traveled in vertical direction (m), and R_m=midpoint range (m). Range and vertical distributions of upstream and downstream fish were plotted for the season. Also, daily mean values were calculated and plotted.

In addition, diel changes in spatial distribution of upstream fish by bank were examined. A subset of each bank's data set was chosen for this analysis. Data from August 11-19 on the left bank and August 14-16 on the right bank were used. Data represented time periods when threshold settings and transducer aim were constant. Hourly means were calculated and plotted for each bank.

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 data collection threshold settings. Mean target strength values for each fish were calculated. Target strength distributions of upstream and downstream fish were plotted for the season. Mean target strengths of upstream and downstream fish were compared using a two-sample *t* test for means with unequal variances (Zar 1984). Also, daily mean values were calculated and charted.

In addition, diel changes in mean target strengths of upstream fish by bank were examined. A subset of each bank's data set was chosen for this analysis (see *Methods, Spatial distribution of tracked fish*). Hourly means were calculated and plotted for each bank.

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

Velocity distribution of tracked fish

Fish velocity was calculated as the three-dimensional distance traveled by a tracked fish divided by total time in the beam. Velocity distributions of upstream and downstream fish were plotted for the season. Mean fish velocities of upstream and downstream fish were compared using a two-sample *t* test for means with unequal variances. Daily mean velocities were calculated and charted.

In addition, diel changes in mean velocities of upstream fish by bank were examined. A subset of each bank's data set was chosen for this analysis (see *Methods, Spatial distribution of tracked fish*). Hourly means were calculated and plotted for each bank.

Relationships between behavioral characteristics of upstream tracked fish

Understanding the relationships between fish position in the beam, acoustic size, and swimming speed provides insight useful in sonar project design. A subset of each bank's data set was chosen for this analysis (see *Methods, Spatial distribution of tracked fish*). Simple linear regression analysis (Zar 1984) was used to examine the relationship between these variables.

Species Composition (Objective 6)

Gill nets were used periodically throughout the season to determine fish species composition. Nets were 30.5 m long and 3.7 m deep, with stretch mesh sizes of 11.4 and 14.9 cm. Nets were set from shore on both banks and drifted near-shore on the left bank. Nets were checked frequently to minimize fish mortality. Fishing effort, fish species captured, and fish lengths were recorded. Salmon were measured to the nearest 0.5 cm, from mid-eye to the fork in the caudal fin. Fish were caudal fin marked for recapture identification.

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 4. River bottom slopes were ≈3.4° on the right bank and ≈7.0° on the left bank, corresponding to vertical transducer beam widths (echo acceptance criteria) of 2.9 and 5.8°, respectively. The left bank beam was range limited due to a decrease in bottom slope at ≈16 m from the transducer.

Hydrologic measurements

River depth and width varied considerably during the season. On Aug 8, the river was 127 m wide and 4.0 m deep, increasing to 160 m wide and 6.0 m deep by Aug 28. Before the flood event beginning on August 27, water levels were in ranges reported from previous years (Figure 5). Water temperature decreased from 17 to 9°C and conductivity remained fairly constant, ranging from 200 to 280 μS/cm (Figure 6).

Background noise

Background noise levels on the left bank varied from −53 to −41 dB. Noise was lowest 0-8 m out from the transducer with levels varying from −53 to −43 db. Noise increased in the 8-16 m range with levels fluctuating between −43 and −41 dB. Passive noise level (no transmitting) was −59 dB at 100 m range.

Right bank noise levels ranged from −50 to −33 dB. Noise was lowest 0-20 m out from the transducer and varied from −50 to −38 dB. Noise increased in the 20-75 m strata with levels ranging from −38 to −33 dB. Passive noise level was −62 dB at 100 m range.

System Calibration (Objective 3)

The method of standard target deployment proved to be very quick and accurate. Under calm conditions, the target's position in the beam was kept very stable. *In situ* mean target strength measurements of the standard target were within 1.6 dB of the predicted value of −39.50 dB, −37.91 dB (N = 1,739) on the left bank and −38.21 dB (N = 2,113) on the right bank. Target strength variability was low, with SD of 0.86 on the left bank and 0.65 on the right bank. Examination of target strength stability data revealed that target strength values for the standard target increased near the outer edges of the beam, especially for the right bank sonar system (Figures 7 and 8).

Acoustic Data Verification and Re-tracking (Objective 4)

Summary information for all re-tracked processor data and chart counts are presented in Table 2. Over 704 hours of processor data were manually re-tracked, representing 89% of total time sampled. Upstream fish accounted for 92.5% of the total count, followed by 6.5% downstream and 1% undetermined. Over 70% of upstream fish were counted from the right bank. The number of acquired echoes per upstream fish ranged from 4-200 on the left bank and 4-387 on the right bank, with modes of 10 echoes per fish for both banks.

Chart recordings were collected for 710 hours, accounting for 90% of total time sampled. Variability among the three reader's counts was low, with individual seasonal totals within 5% of each bank's mean total count.

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 values occurring during late night/early morning hours (Figure 9). Downstream fish did not show any diel differentiation. Mean hourly passage rates for left bank fish also showed this strong diel tendency among upstream fish (Figure 10).

Right bank fish did not show a strong trend in diel distribution for the season (Figure 11). Mean hourly passage rates for upstream fish tended to be higher during morning hours (Figure 12).

Hourly chart counts were poor estimators of upstream tracked fish counts. The mean seasonal ratio of hourly chart counts to upstream tracked fish counts was 1.19 (N = 319) for the left bank and 1.22 (N = 371) for the right bank. Only 34% of hourly left bank ratios and 47% of right bank ratios were within 10% of the seasonal mean. Compared to mean daily ratios, only 42% of hourly left bank ratios and 59% of right bank ratios were within 10% of the daily mean (Table 3).

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). Downstream fish were more evenly distributed across the full range spectrum. The average daily range of upstream fish were generally closer to shore than downstream fish, especially on the right bank (Figure 15).

Vertical distribution of upstream fish was different between banks. Upstream fish on the left bank were bottom oriented (Figure 16). Upstream fish on the right bank were vertically positioned throughout the beam, averaging near the acoustic axis (Figure 17). This anomaly was caused by transducer aiming constraints due to high background noise levels on the right bank (*see Methods, Transducer deployment*). The majority of upstream fish were located near the bottom of the beam during periods of proper beam positioning. On both banks, downstream targets were found throughout the ensonified zone.

On the left bank, the average daily vertical position of upstream fish was consistent throughout the season, indicating stability of transducer aim and fish position (Figure 18). Downstream fish were oriented higher in the beam. On the right bank, daily vertical means for upstream and downstream targets rose substantially after August 19, due to the above mentioned transducer aim change. During this period some fish passed over the beam undetected.

A diel trend in spatial positioning of upstream fish on the left bank was apparent (Figure 19). During daylight hours, fish were farther from shore and closer to the bottom. Upstream fish on the right bank exhibited a similar trend in vertical position, with fish generally decreasing in vertical position during daylight hours. There was no noticeable trend in range positioning for upstream fish from the right bank.

Target strength distribution of tracked fish

For each bank, mean target strengths were significantly different between upstream and downstream fish (*P* values <0.001; Figures 20 and 21). Mean target strengths for upstream fish were ≈ 4 dB larger than downstream fish. Also, mean target strengths between banks were significantly different for upstream and downstream fish (*P* values <0.001). On the average, target strengths from fish on the left bank were ≈ 2.5 dB smaller than those from the right bank. High threshold settings on the right bank may have biased results; echoes smaller than -27.3 dB would not be detected across the full beam width at a 0.7 V threshold setting (Figure 21).

For both banks, average daily target strengths of upstream and downstream fish followed the same trend; upstream fish were larger than downstream fish throughout the season (Figure 22). The tendency for upstream and downstream fish from the left bank to be acoustically smaller than their right bank counterparts was not apparent at the end of the season, when both banks had similar mean daily target strengths.

Diel changes in mean target strength values of upstream fish were similar for both banks (Figure 23). Mean target strengths were largest from 0500 to 2100, with the smallest mean size passing in the late night/early morning period.

For each bank, mean within-fish target strength variability (SD) was greatest for upstream fish (*P* values <0.001), averaging 3.83 dB on the left bank and 4.34 dB on the right bank (Figures 24 and 25).

Velocity distribution of tracked fish

As expected, average velocities (by bank) of downstream fish were significantly faster than upstream fish (*P* values <0.001; Figures 26 and 27). Velocities of downstream fish on the right bank were highly variable (SD=1.17). Mean velocities between banks for upstream and downstream fish were significantly greater on the right bank (*P* values <0.001). Also, differences in mean velocities between upstream and downstream fish were greater on the right bank, even though right bank water velocities were lower. Daily mean velocities showed similar trends to the seasonal distributions; downstream fish generally swam faster and had more variation in mean velocities than upstream fish (Figure 28). Diel changes in velocity of upstream fish did not show any apparent trends (Figure 29).

Relationships between behavioral characteristics of upstream tracked fish

Significant relationships existed between all tested behavioral characteristics of upstream tracked fish: fish position, acoustic size, and swimming speed (Table 4). All *P* values were <0.001. Large sample sizes contributed to the statistical significance of the results.

On the left bank, acoustic fish size increased with range; as range increased from 2 to 13 m, predicted acoustic size increased from −29.1 to −22.8 dB. Acoustically larger fish were also found nearer to the bottom of the beam; as vertical position decreased from 1.5 to −3.5°, predicted acoustic size increased from −34.5 to −23.5 dB. Also, fish velocity increased with acoustic fish size; as acoustic size increased from −35 to −20 dB, predicted fish velocity increased from 0.7 to 1.1 m/s.

On the right bank, acoustic fish size decreased with range; as range increased from 10 to 65 m, predicted target strength decreased from −21.8 to −24.3 dB. Large acoustic size fish swam lower in the beam than small fish; as vertical position decreased from 1.5 to −1.5°, predicted acoustic size increased from −26.2 to −20.2 dB.

Species Composition (Objective 6)

Chum salmon were the only fish species captured in 37 h of gill netting (Table 5). Total catch was 62 salmon with an average length of 56 cm; lengths ranged from 45-65 cm. Males made up 62% of the catch. None of the 62 marked fish were recaptured.

DISCUSSION

Most upstream fish were within the ensonified zone of detection during the 1994 season. On the left bank, vertical and horizontal fish position in the beam remained fairly constant throughout the season. Upstream fish were shore oriented and traveled close to the river bottom. This was consistent with previous observations of Yukon River fall chum salmon on the Chandalar (Daum et al. 1992), Sheenjek (Barton *in press*), and mainstem Yukon rivers (Johnston et al. 1993). However, the river bottom inflection, ≈16 m offshore from the left bank transducer, did not allow the final 14 m distance to the thalweg to be ensonified. Some fish probably passed undetected in this unensonified zone, though numbers were assumed small because of the exhibited shore orientation of upstream tracked fish. On the right bank, fish position remained fairly constant relative to the beam from August 10-19, with few fish assumed missed. After August 19, high background noise levels causing transducer aim changes resulted in some fish passing undetected above the beam. It is believed that high noise levels on the right bank were due to surface and bottom acoustic reverberation from the shallow bathymetry. For the 1995 season, transducer deployment sites will be re-mapped and evaluated. The goal is to eliminate the left bank bottom inflection point and reduce the right bank background noise level.

Providing timely escapement counts to fishery managers is an overall objective of this project. Verification and re-tracking of the acoustic data base is essential before accurate daily and seasonal counts can be determined for Chandalar River fall chum salmon. However, tracking software is not presently available that will provide accurate daily escapement counts in-season. Data verification and re-tracking is labor intensive, but new developments in fish tracking software may make in-season daily enumeration possible. In 1995, an attempt will be made to provide post-season counts of seasonal and daily escapement of Chandalar River fall chum salmon.

The temporal distribution of upstream fish influences acoustic sampling schedules and procedures used to estimate hourly passage rates. The strong diel trend of Chandalar River upstream fish on the left bank was similar to fall chum salmon passage patterns on the Sheenjek (Barton *in press*) and mainstem Yukon rivers (Johnston et al. 1993). However, right bank diel patterns were weak and exhibited the highest mean hourly counts during morning hours when left bank passage rates were low. Because of the differences in diel distribution patterns between banks in 1994 and the annual variability in fish distribution between banks shown in 1986-1990 (Daum et al. 1992), hourly counts from one bank are poor estimators of passage rates for the opposite bank. As in 1994, sampling schedules for the 1995 season will attempt 24-hour continuous acoustic monitoring from each bank.

Hourly chart counts did not accurately reflect upstream tracked fish counts on the Chandalar River. This disparity may have resulted from the different selection criteria used by the chart recorder and digital echo processor to generate data. Unlike digital echo processor data files, echogram recordings were not filtered by pulse width or angle off-axis criteria. Also, at close range (<20 m), most downstream targets could not be differentiated from upstream fish on the chart. Because of the inconsistency between chart and tracked fish counts, chart counts should not be used to estimate missing hourly passage rates for upstream fish on the Chandalar River. In 1995, bank-specific re-tracked acoustic data will be used to estimate missing hourly counts. As a cautionary note, upstream/downstream ratios from re-tracked processor data should not be used to estimate upstream/downstream fish passage rates from chart recording counts since data collection criteria are not comparable.

The acoustic size of Chandalar River fall chum salmon was larger than expected. The mean target strength of Chandalar River fall chum salmon was 7.5 dB larger than mainstem Yukon River fall chum salmon (Johnston et al. 1993) and 3 dB larger than Love's equation (1977) would predict for a side-aspect target with mean fork length of 63 cm (mean fork length estimated from 1994 mid-eye length data). Left bank Chandalar River acoustic data were used for these comparisons because of assumed unbiased target strength estimates due to low background noise levels and threshold settings. Right bank target strength measurements may have been biased from high background noise levels (Figure 21). High signal threshold settings used to reduce noise on the right bank may cause the smaller acoustic signals to be ignored, resulting in elevated target strength calculations for some fish (MacLennan and Simmonds 1992). Also, mean target strength values are raised if fish of smaller acoustic size are excluded from analysis. Additionally, right bank fish that pass through the outer edges of the beam may incorporate additional bias, since standard target measurements revealed an increase in target strength values in these areas (Figure 8).

Large numbers of non-target fish species on the Chandalar River could influence the ability to accurately estimate chum salmon passage using hydroacoustics. If fish species could not be acoustically differentiated, species apportionment techniques would be required. Preliminary results suggest that chum salmon are the dominant fish species in the Chandalar River during sonar operation. In 1994, only chum salmon were captured using gill nets. Similar results were obtained in 1986, when chum salmon made up 99% of the catch (Daum et al. 1992). Gill netting will be continued during the 1995 season.

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REFERENCES

Barton, L. H. *in press*. 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 Fisheries Report 93-3005, Juneau, 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., 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.

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, II. 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.

Hydroacoustic Technology, Inc. 1994a. Model 240 split beam digital echo sounder operator's manual, version 1.2. Hydroacoustic Technology, Inc., Seattle, Washington.

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

Hydroacoustic Technology, Inc. 1994c. 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.

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.

Schultz, K. C., R. R. Holder, L. H. Barton, D. J. Bergstrom, C. Blaney, G. J. Sandone, and D. J. Schneiderhan. 1993. Annual management report for subsistence, personal use, and commercial fisheries of the Yukon River, 1992. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 3A93-10, Anchorage, Alaska.

Schultz, K., D. Bergstrom, R. Holder, and B. Borda. 1994. Salmon fisheries in the Yukon area, Alaska 1994. Alaska Department of Fish and Game, Division of Commercial Fisheries Management and Development, Regional Information Report 3A94-31, Anchorage, Alaska.

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, 1994. Threshold and range values represent the range of individual settings during the season.

Bank	Pulse width (ms) at −6 dB	Vertical angle off-axis (°)	Horizontal angle off-axis (°)	Threshold (V)	Range (m)
Left	0.35 to 0.45	−3.50 to 2.30	−5.43 to 5.43	0.15 to 0.20	13 to 17
Right	0.15 to 0.25	−1.44 to 1.44	−5.75 to 5.75	0.40 to 0.70	63 to 75

Table 2. Hydroacoustic data collected from both banks, Chandalar River, 1994.

	Chart recorder		Processor fish file			
August date	Sample time (h)	Total count	Sample time (h)	Upstream count	Downstream count	Total[a] count
			Left bank			
11	22.92	517	23.33	485	22	517
12	13.72	185	23.33	395	9	407
13	22.92	337	22.02	308	13	325
14	23.75	313	23.33	295	9	307
15	23.65	285	23.23	261	19	282
16	12.10	208	23.13	287	14	303
17	16.70	203	23.37	312	8	324
18	23.70	376	23.37	329	34	366
19	23.65	620	23.20	528	41	576
20	18.12	359	19.72	299	14	326
21	15.35	503	21.78	607	3	629
22	14.85	424	21.10	558	7	580
23	23.58	723	23.08	559	14	580
24	22.15	492	20.30	426	12	442
25	22.38	358	20.98	283	25	310
26	13.52	672	12.92	581	18	607
Total	313.06	6,575	348.19	6,513	262	6,881
			Right bank			
10	23.52	809	21.89	761	70	837
11	22.90	1,433	17.99	1,026	70	1,103
12	23.82	1,622	21.06	1,251	90	1,343
13	22.23	1,107	9.68	414	50	465
14	23.05	1,141	23.01	1,013	89	1,104
15	23.70	980	22.85	877	49	927
16	23.60	908	23.10	852	54	908
17	23.62	956	22.88	753	85	841
18	23.23	1,310	23.05	1,017	128	1,149
19	22.35	991	21.63	688	116	809
20	22.92	891	21.54	613	57	680
21	23.72	481	22.02	339	77	424
22	23.70	853	23.26	815	80	898
23	23.52	1,517	22.93	1,329	84	1,420
24	23.53	1,699	22.26	1,483	64	1,559
25	23.53	1,517	22.79	1,360	117	1,490
26	23.57	2,045	14.16	1,282	36	1,324
Total	396.51	20,260	356.10	15,873	1,316	17,281

[a] includes upstream, downstream, and unknown fish.

Table 3. Comparisons between daily mean and hourly ratios of chart counts to upstream manually tracked fish counts by bank, Chandalar River, 1994.

August date	Mean hourly ratio	Number of hourly ratios inside 10% of mean	Number of hourly ratios outside 10% of mean	N	SD
Left bank					
11	1.11	17	7	24	0.15
12	1.11	8	6	14	0.19
13	1.16	8	16	24	0.28
14	1.13	6	18	24	0.42
15	1.37	6	16	22	0.56
16	1.04	7	7	14	0.21
17	1.15	4	14	18	0.24
18	1.33	5	19	24	0.41
19	1.21	15	9	24	0.22
20	1.28	6	12	18	0.30
21	1.11	8	8	16	0.17
22	1.35	5	9	14	0.06
23	1.31	10	14	24	0.22
24	1.10	11	11	22	0.27
25	1.22	8	14	22	0.22
26	1.11	11	4	15	0.12
Total		135	184	319	
Right bank					
10	1.07	11	12	23	0.31
11	1.08	9	9	18	0.14
12	1.17	19	3	22	0.09
13	1.16	7	4	11	0.13
14	1.13	19	5	24	0.11
15	1.08	19	4	23	0.08
16	1.15	13	11	24	0.61
17	1.90	1	22	23	2.06
18	1.30	20	4	24	0.15
19	1.54	6	17	23	0.67
20	1.32	8	14	22	0.43
21	1.43	11	12	23	0.39
22	1.03	21	3	24	0.09
23	1.11	15	8	23	0.12
24	1.11	13	11	24	0.16
25	1.11	15	9	24	0.20
26	0.95	12	4	16	0.12
Total		219	152	371	

Table 4. Relationships between behavioral characteristics of upstream fish by bank using simple linear regression analysis, Chandalar River, 1994.

Behavioral characteristic					
Dependent variable	Independent variable	Relationship $P < 0.001$	Intercept	Slope	r^2
		Left bank, *N* = 3,200			
Target strength	Range	Positive	−30.292	0.579	0.192
Fish velocity	Range	Positive	0.530	0.065	0.175
Vertical position	Range	Negative	−1.847	−0.035	0.021
Fish velocity	Target strength	Positive	1.652	0.027	0.052
Target strength	Vertical position	Negative	−31.174	−2.193	0.160
Fish velocity	Vertical position	Positive	1.095	0.075	0.014
		Right bank, *N* = 2,742			
Target strength	Range	Negative	−21.353	−0.045	0.016
Fish velocity	Range	Positive	0.515	0.043	0.438
Vertical position	Range	Positive	−0.763	0.012	0.048
Fish velocity	Target strength	Positive	1.517	0.012	0.004
Target strength	Vertical position	Negative	−23.228	−2.006	0.103
Fish velocity	Vertical position	Positive	1.303	0.094	0.007

Table 5. Total catch, effort, and length of chum salmon captured by 11.4 and 14.9 cm mesh gill nets, Chandalar River, 1994. Asterisk denotes one fish included in total catch but not measured.

Mesh size and fishing method	Total catch	Effort (h)	Mean length (cm)	Length range (cm)
<u>11.4 cm</u>				
Set	31*	14.60	54.8	45.0 - 63.5
<u>14.9 cm</u>				
Set	30	21.75	56.8	50.0 - 64.5
Drift	1	0.73	----	65.0
Total	31	22.48	57.0	50.0 - 65.0
<u>All</u>	62	37.08	55.9	45.0 - 65.0

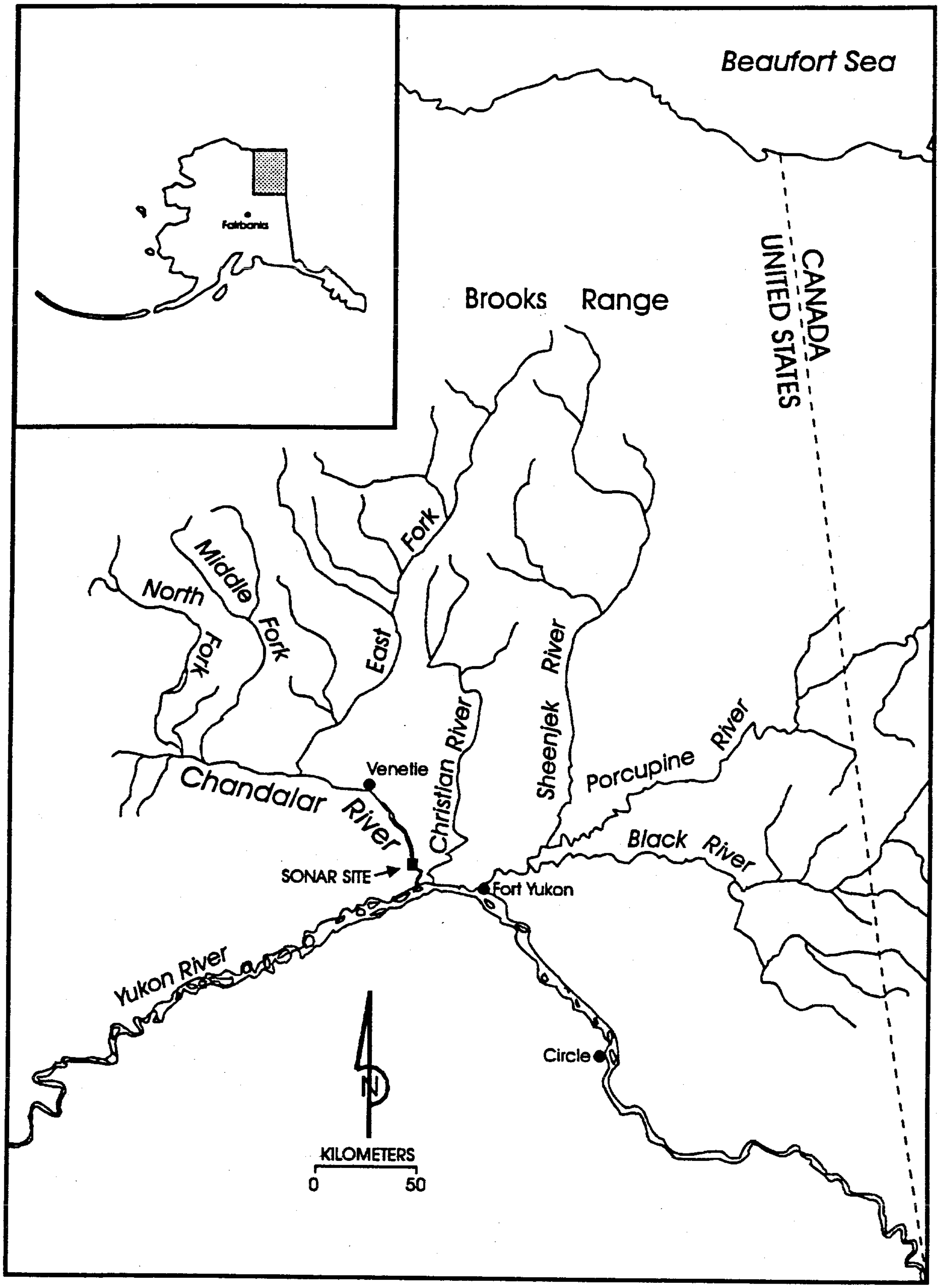

Figure 1. Major tributaries of the Yukon River near the U.S./Canada border.

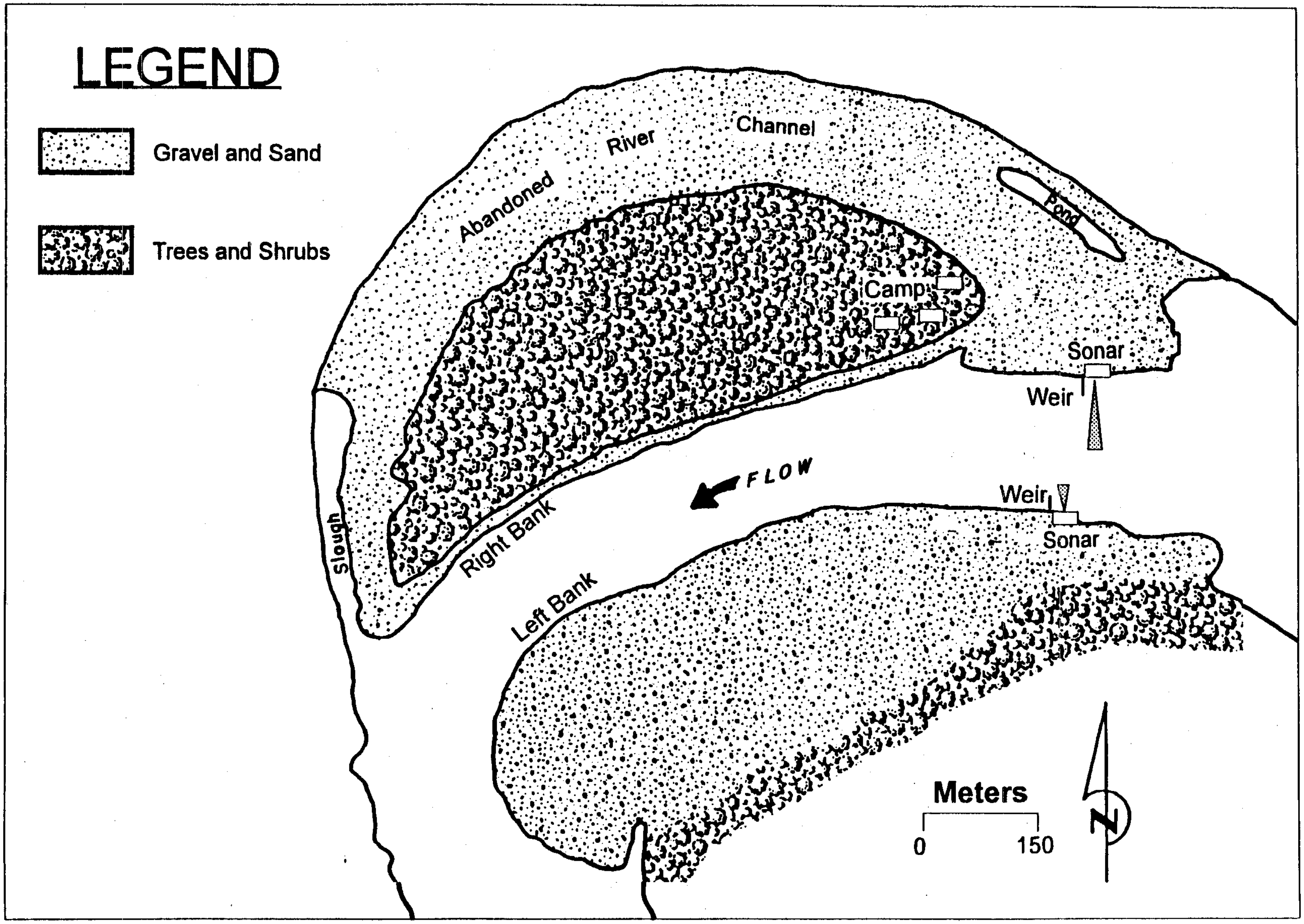

Figure 2. Site map of the Chandalar River sonar facilities, 1994.

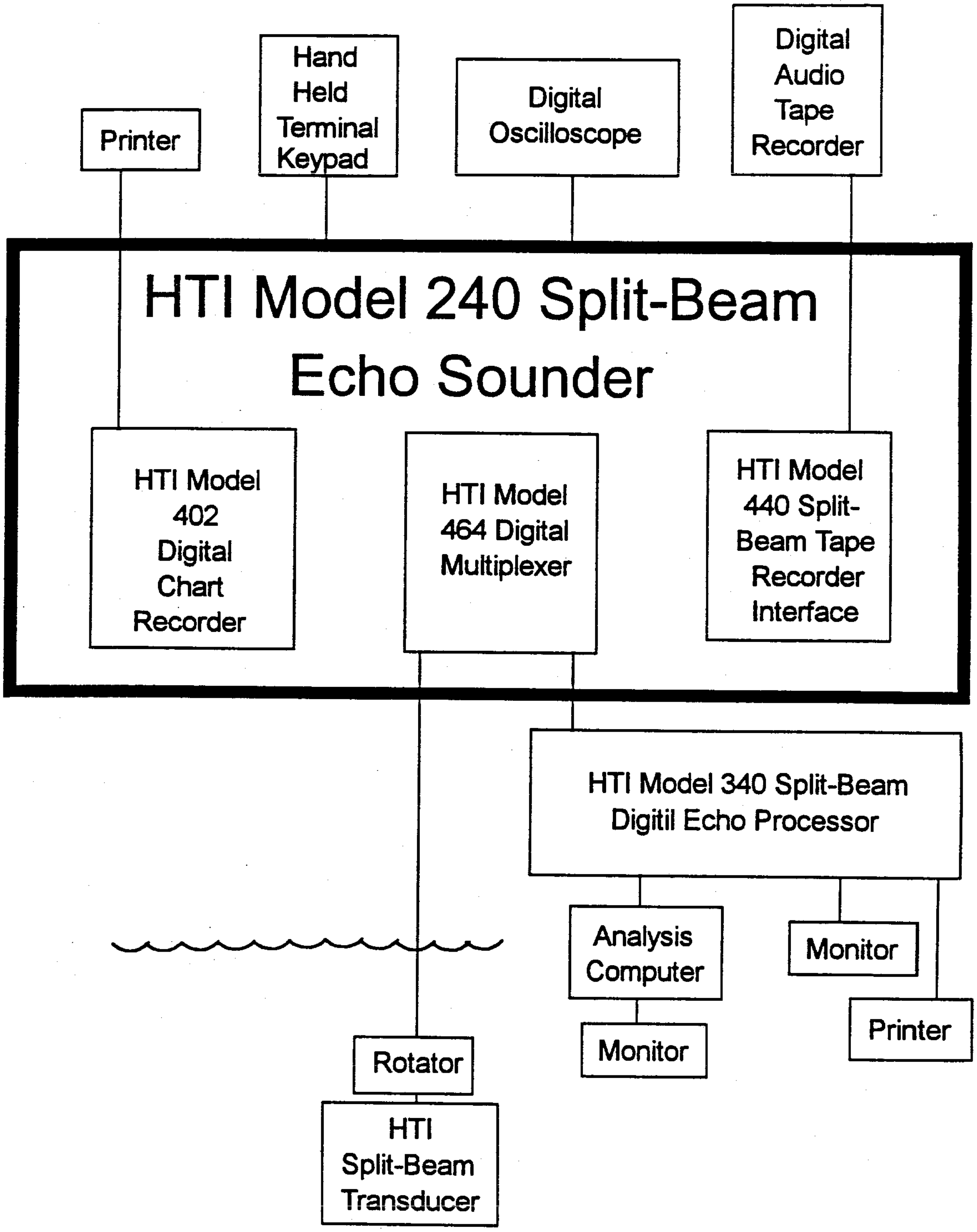

Figure 3. Split-beam hydroacoustic system, Chandalar River, 1994.

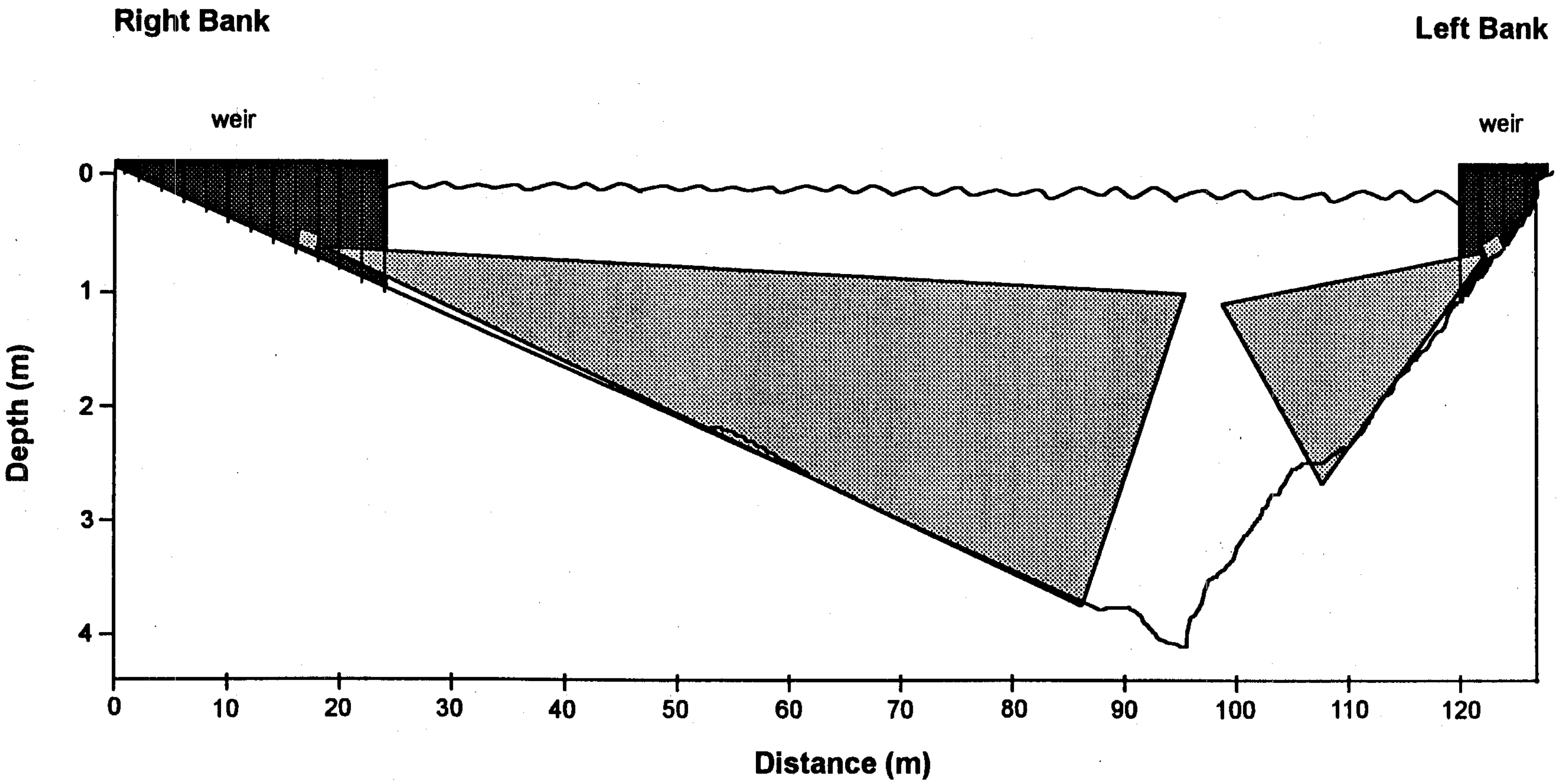

Figure 4. River channel profiles and estimated ensonified zones of the left and right banks, Chandalar River, 1994. Different axis scales were used to enhance visibility.

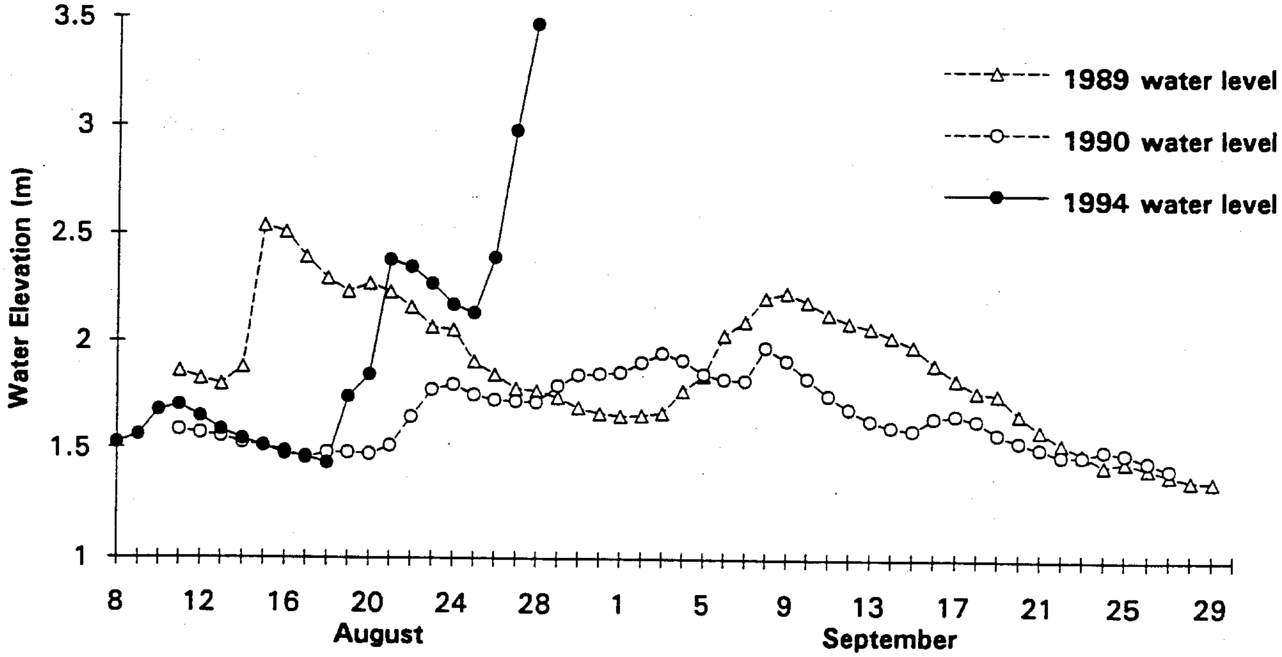

Figure 5. Daily water elevation during sonar operation, Chandalar River, 1989, 1990, and 1994.

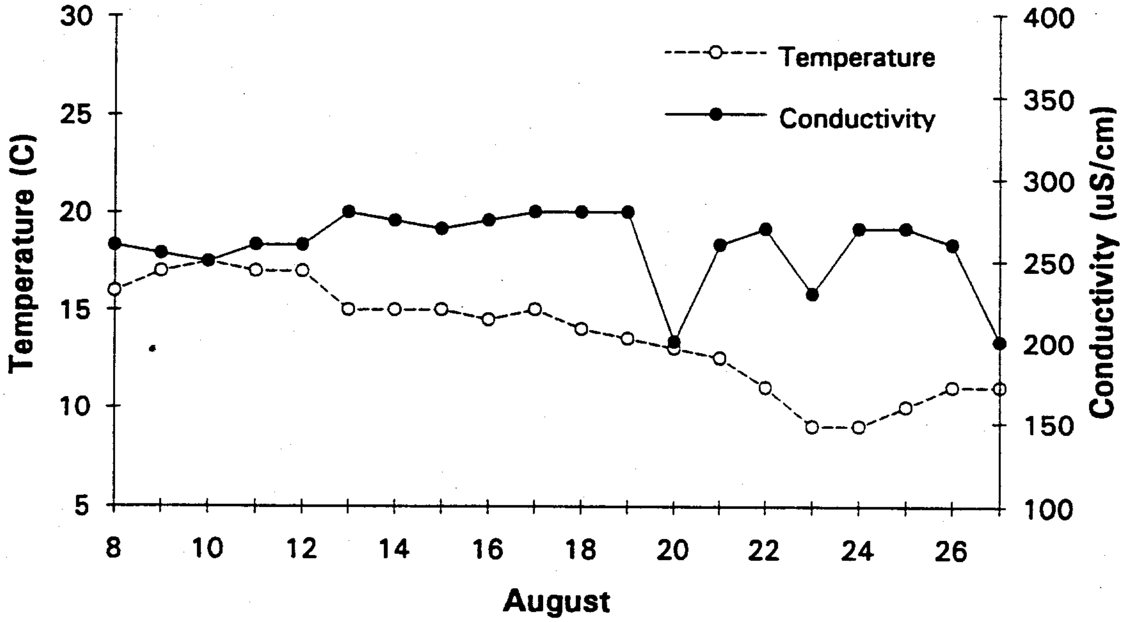

Figure 6. Daily water temperature and conductivity measurements, Chandalar River, August 8-27, 1994.

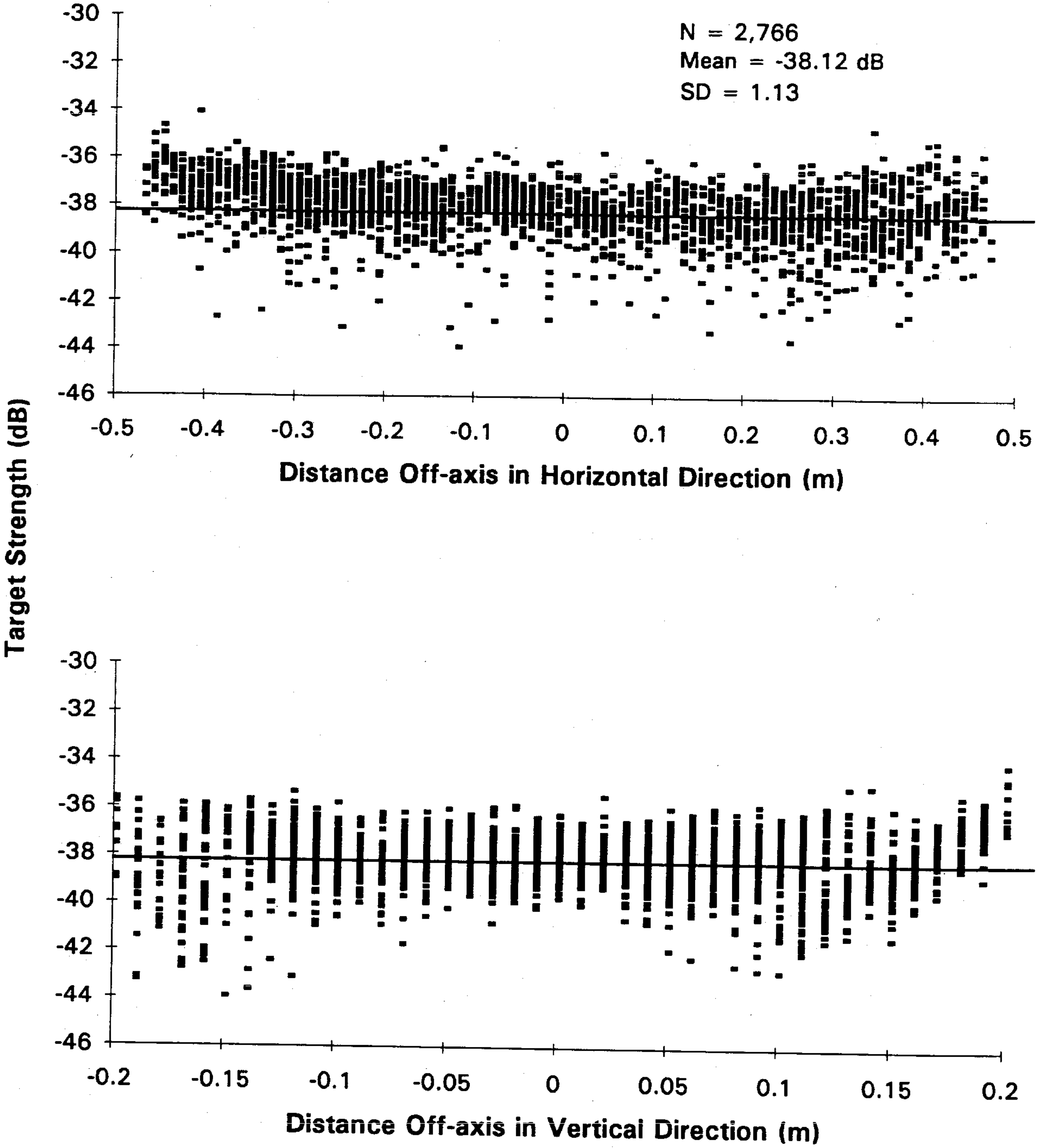

Figure 7. Target strength values of a standard target (38.1 mm tungsten carbide sphere) collected across the full beam cross-section and plotted in the horizontal and vertical direction, left bank, Chandalar River, August 8, 1994.

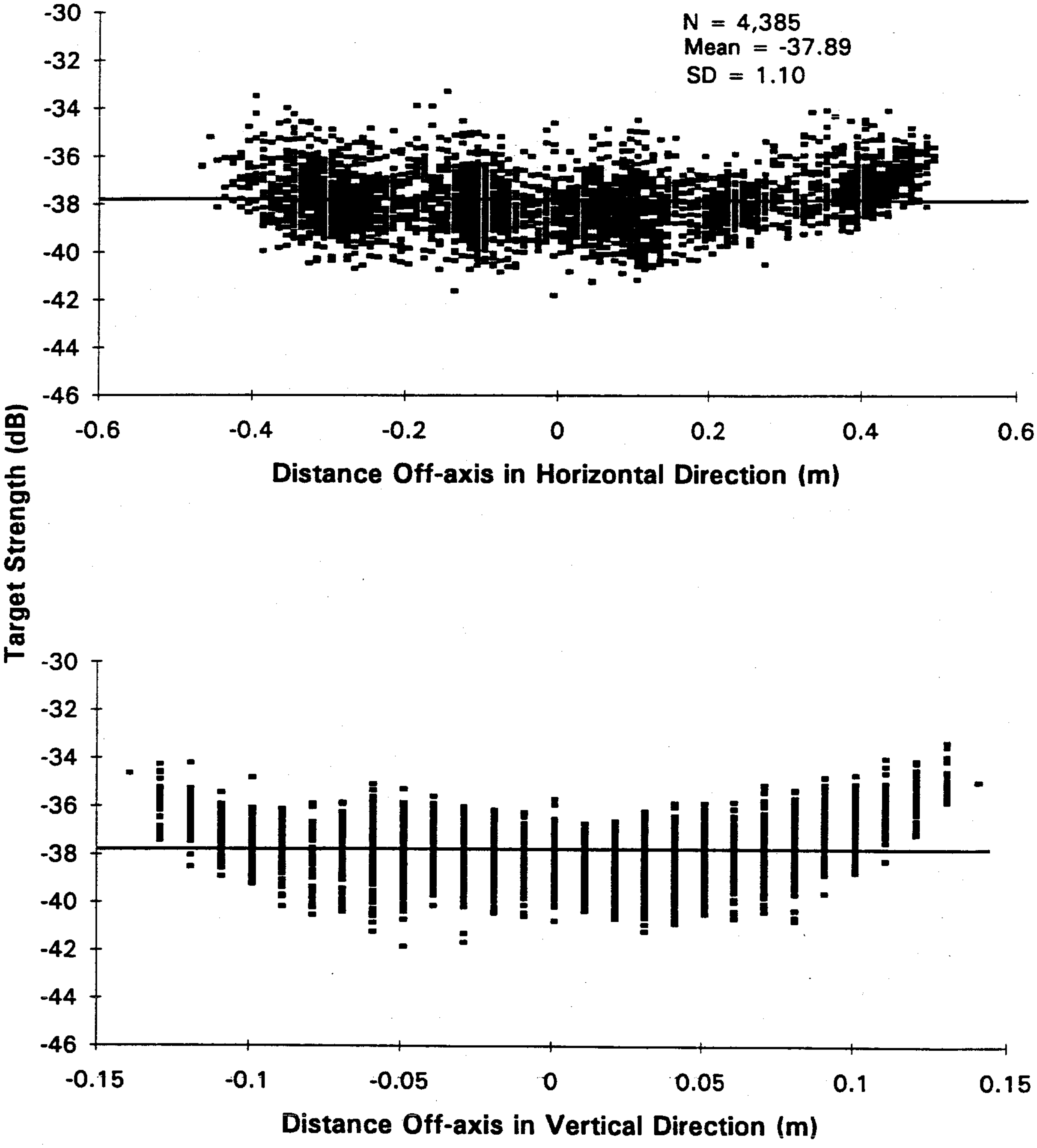

Figure 8. Target strength values of a standard target (38.1 mm tungsten carbide sphere) collected across the full beam cross-section and plotted in the horizontal and vertical direction, right bank, Chandalar River, August 7, 1994.

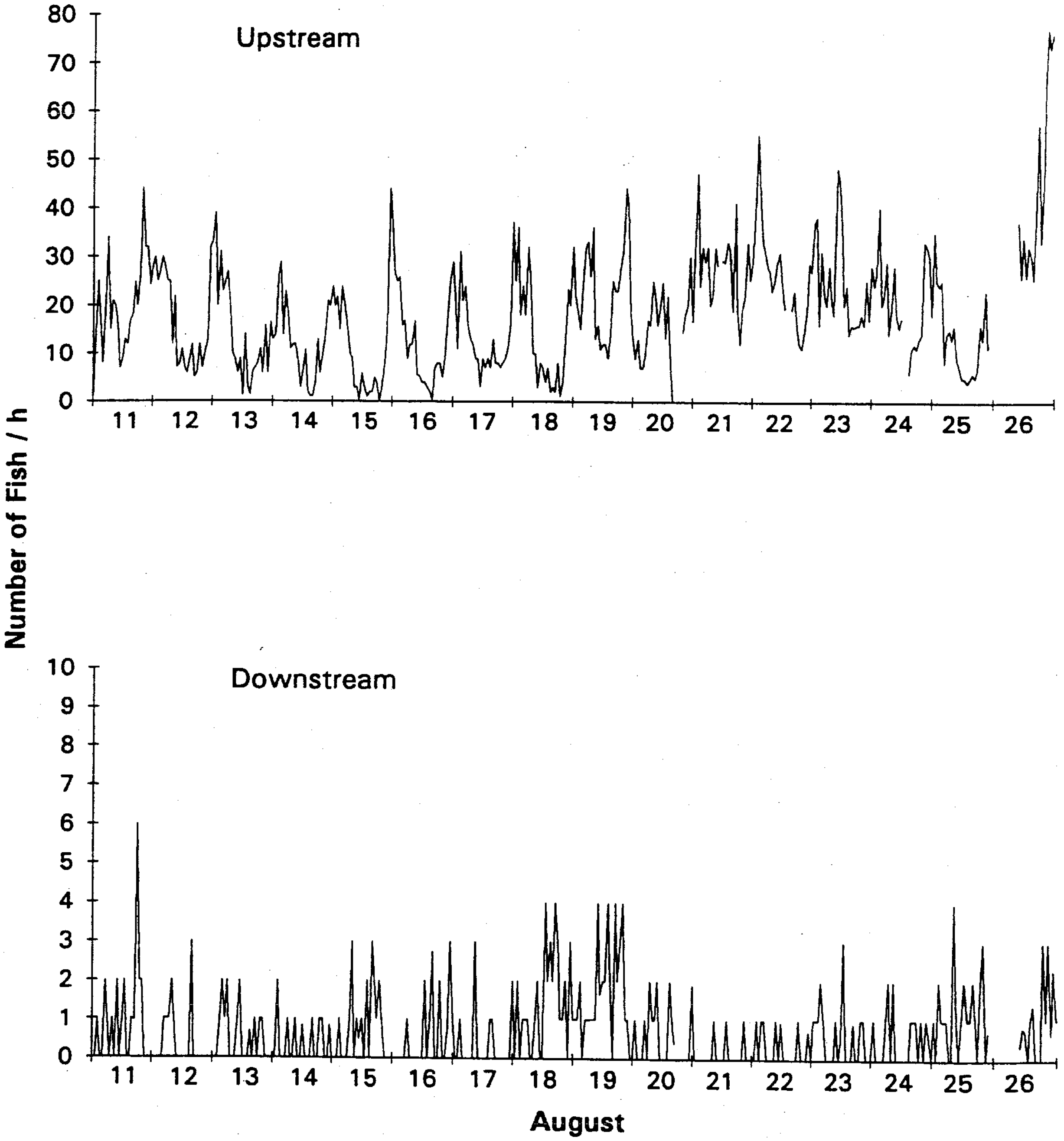

Figure 9. Diel distribution of upstream and downstream fish, left bank, Chandalar River, August 11-26, 1994.

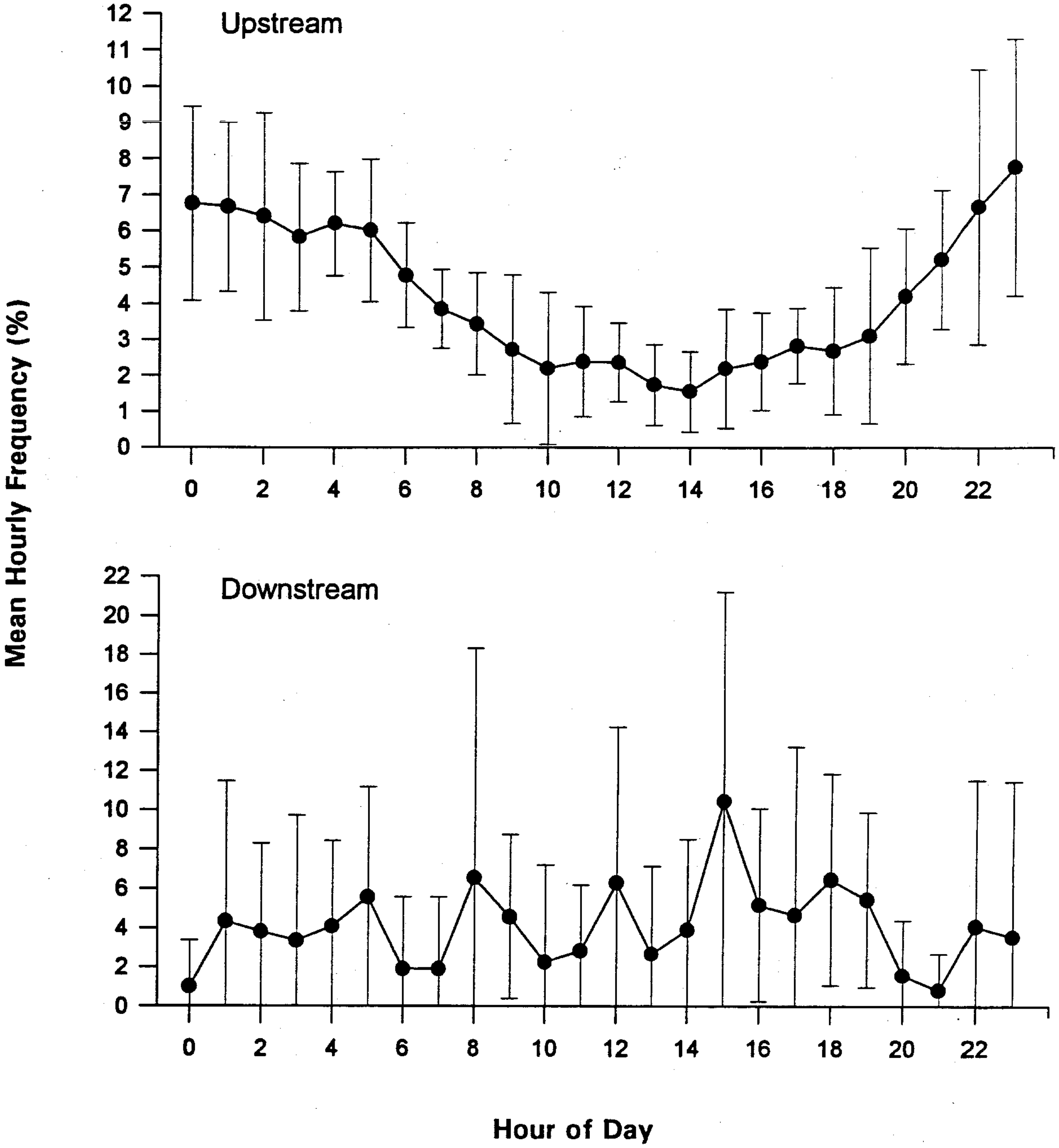

Figure 10. Mean (± SD) hourly frequency of upstream and downstream fish from ten days of continuous 24 h data, left bank, Chandalar River, 1994.

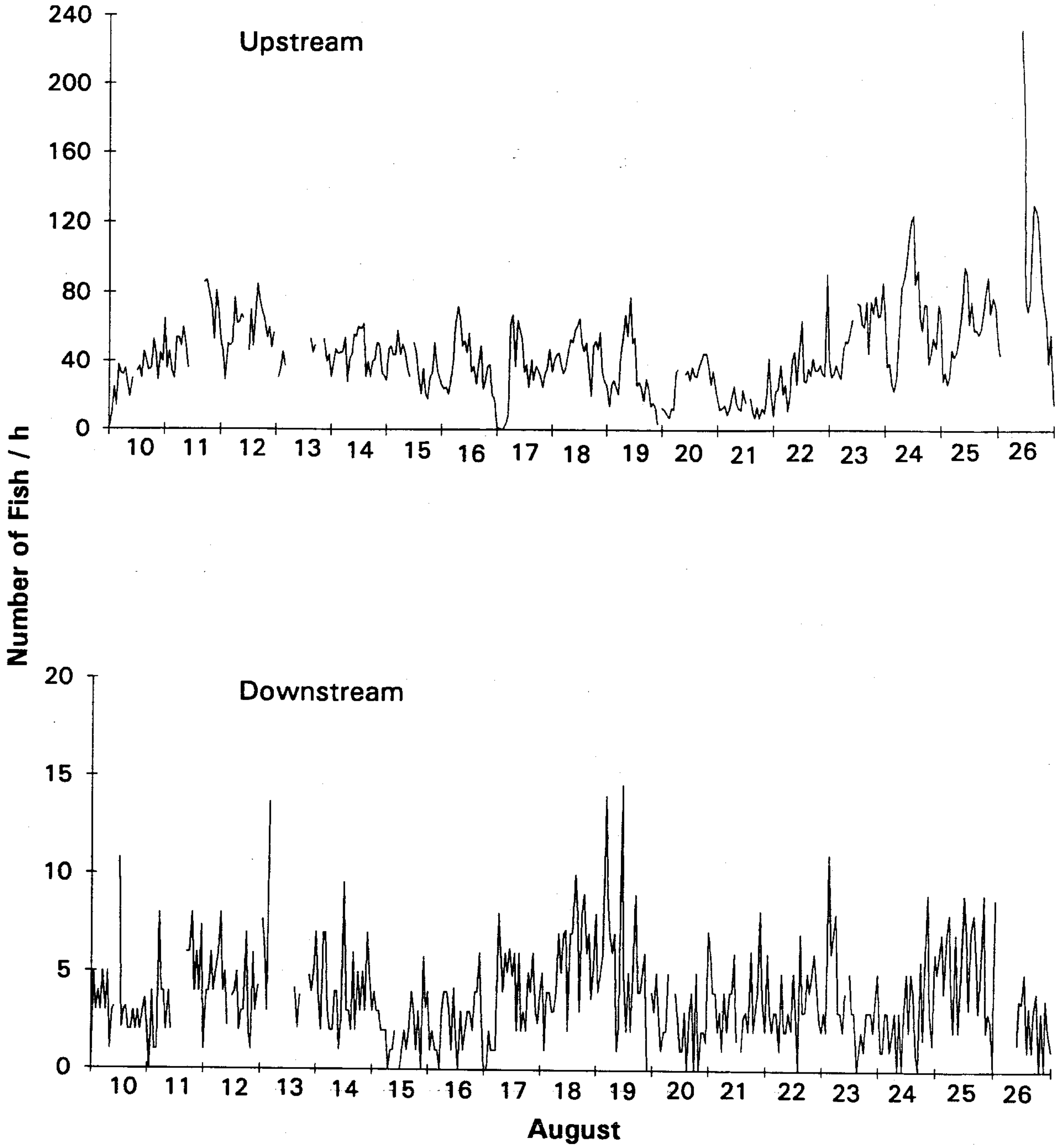

Figure 11. Diel distribution of upstream and downstream fish, right bank, Chandalar River, August 10-26, 1994.

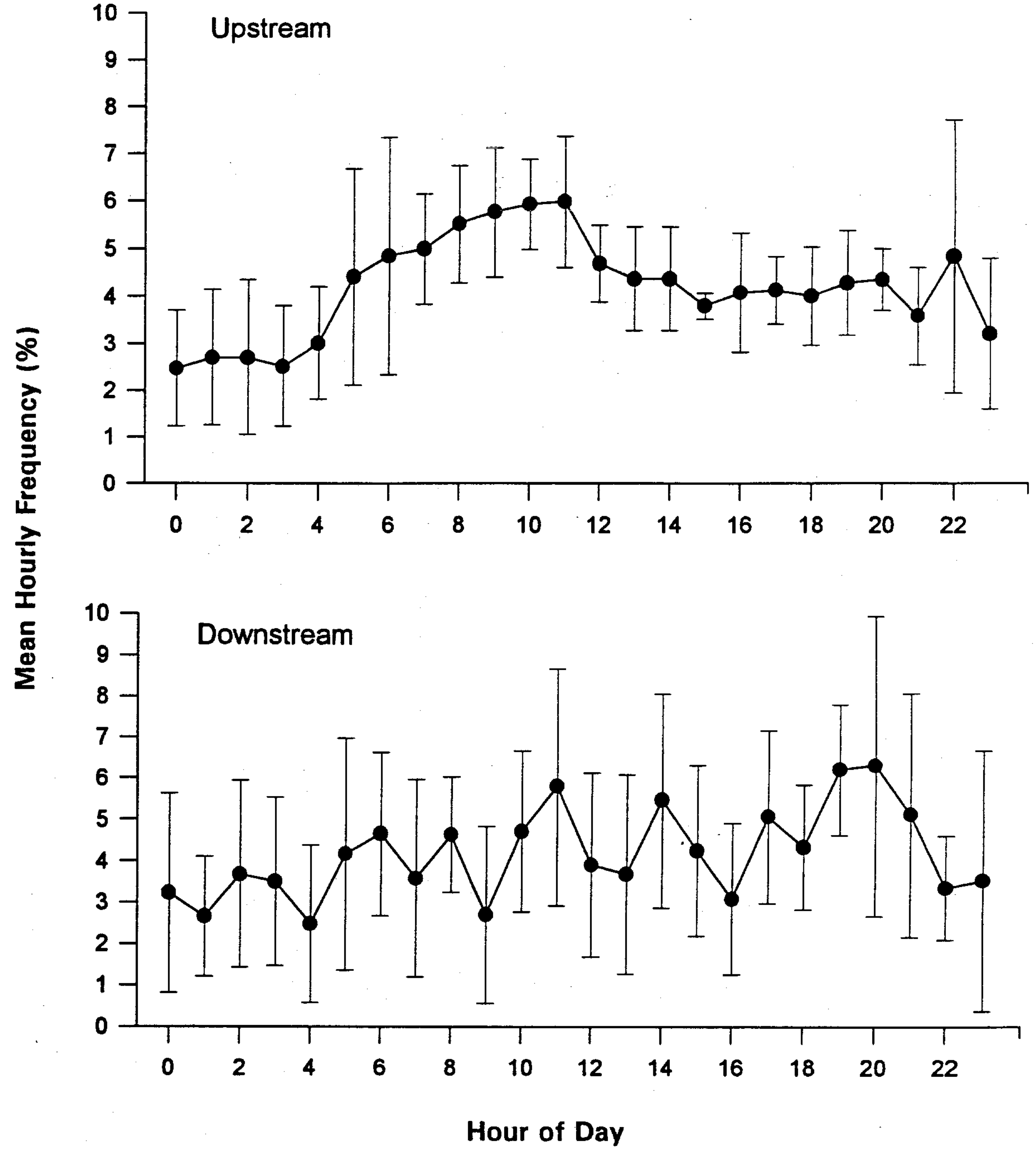

Figure 12. Mean (± SD) hourly frequency of upstream and downstream fish from seven days of continuous 24 h data, right bank, Chandalar River, 1994.

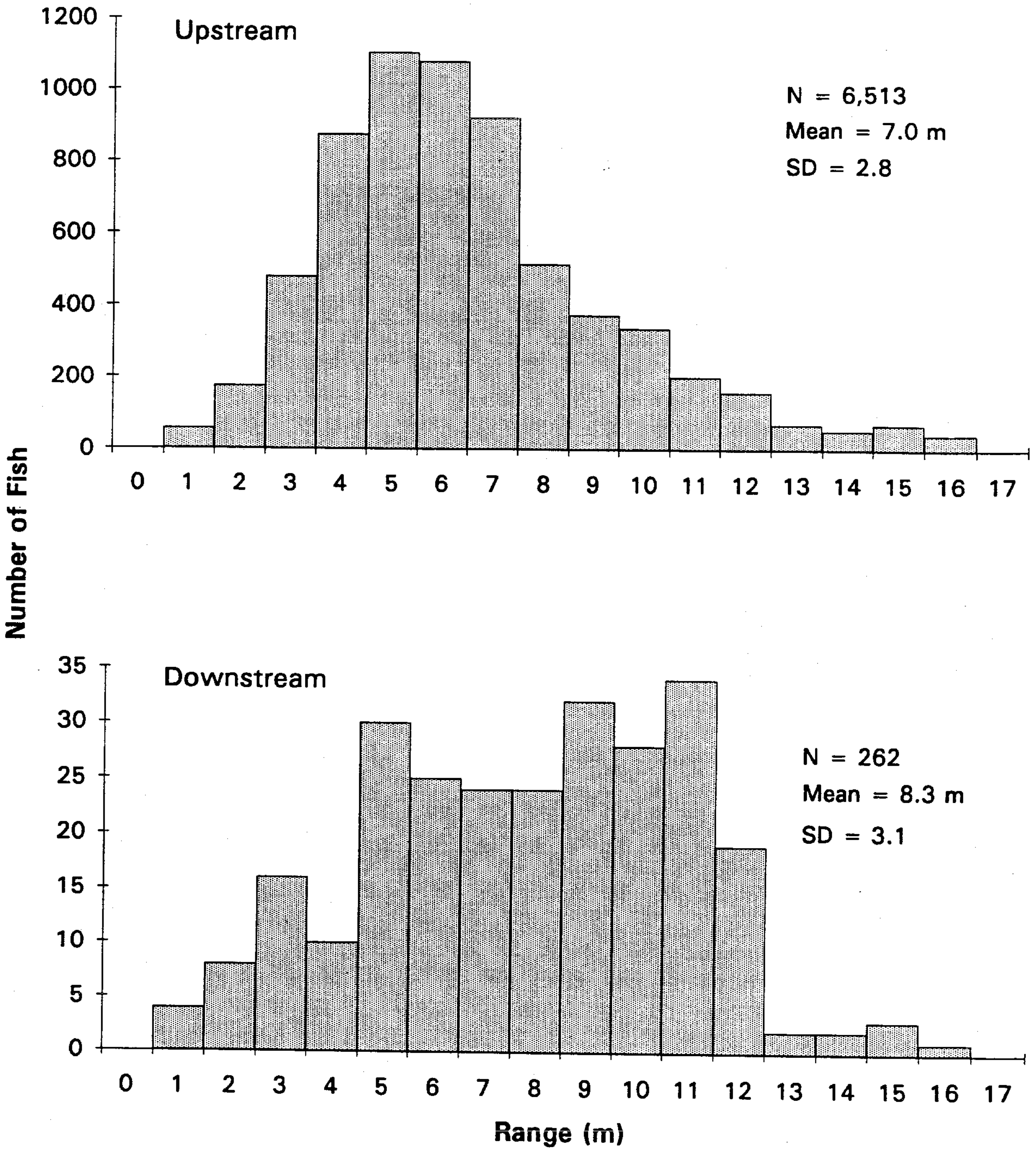

Figure 13. Range (distance from transducer) distribution of upstream and downstream fish, left bank, Chandalar River, August 11-26, 1994.

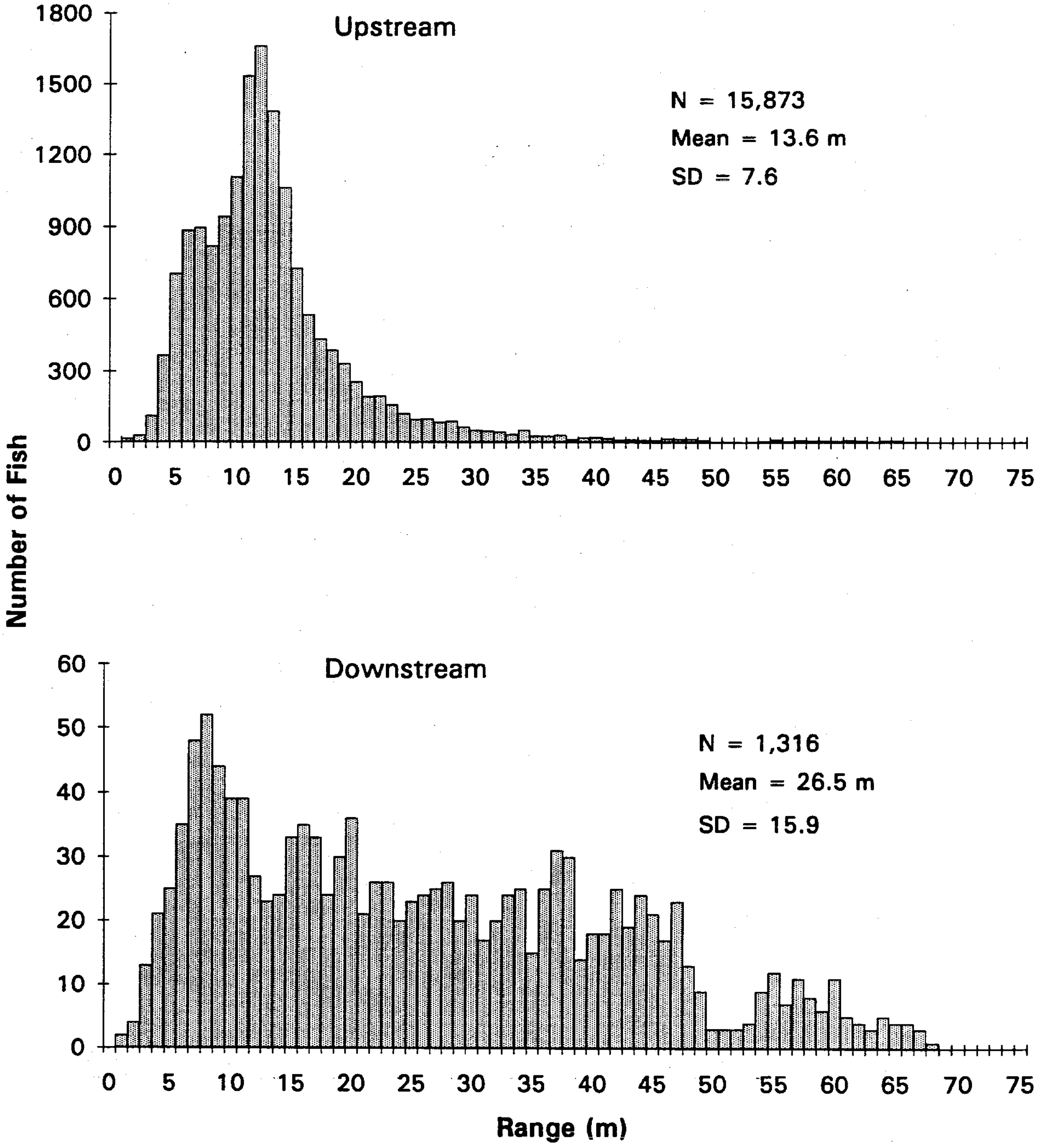

Figure 14. Range (distance from transducer) distribution of upstream and downstream fish, right bank, Chandalar River, August 10-26, 1994.

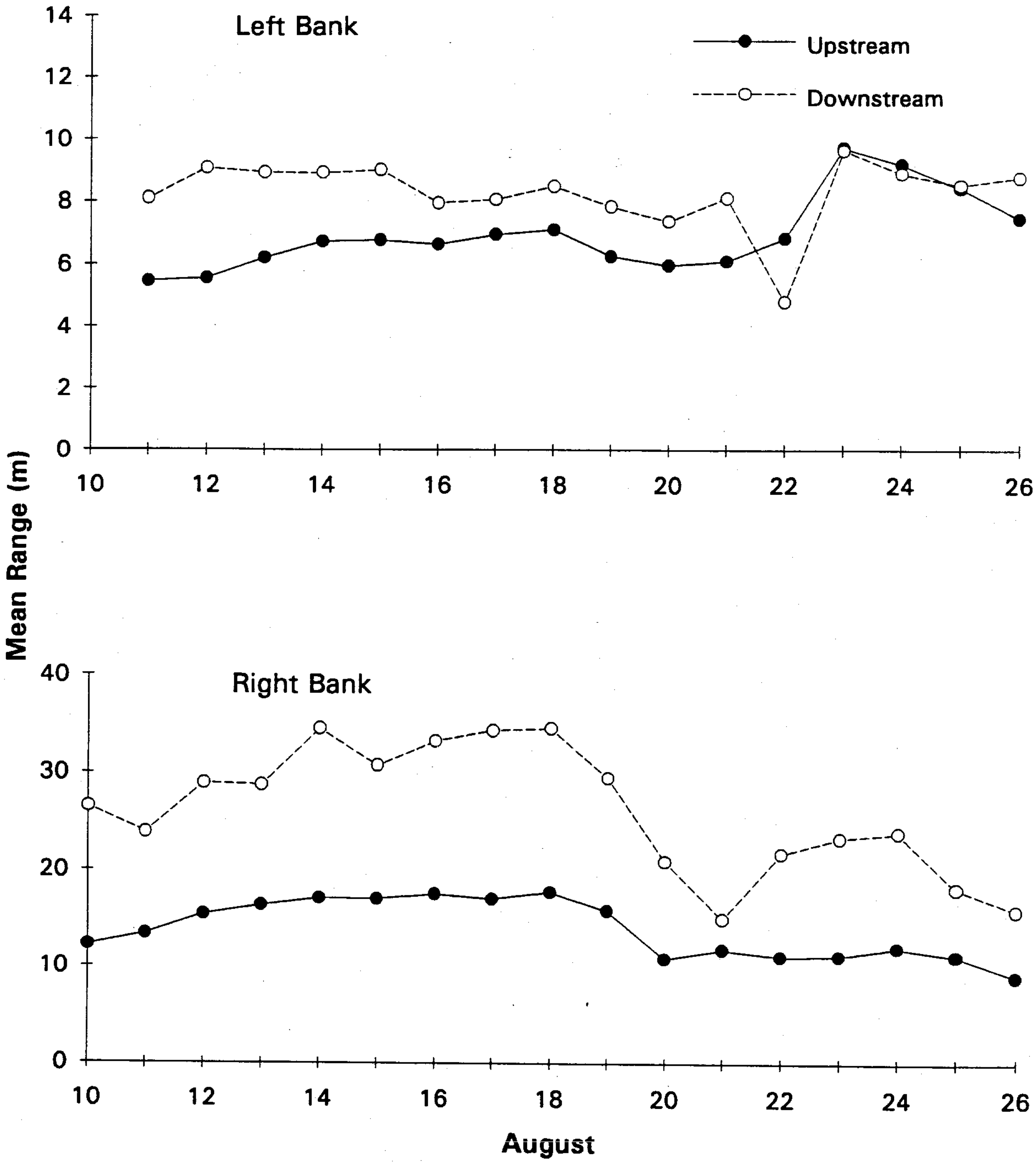

Figure 15. Mean daily range of upstream and downstream fish by bank, Chandalar River, 1994.

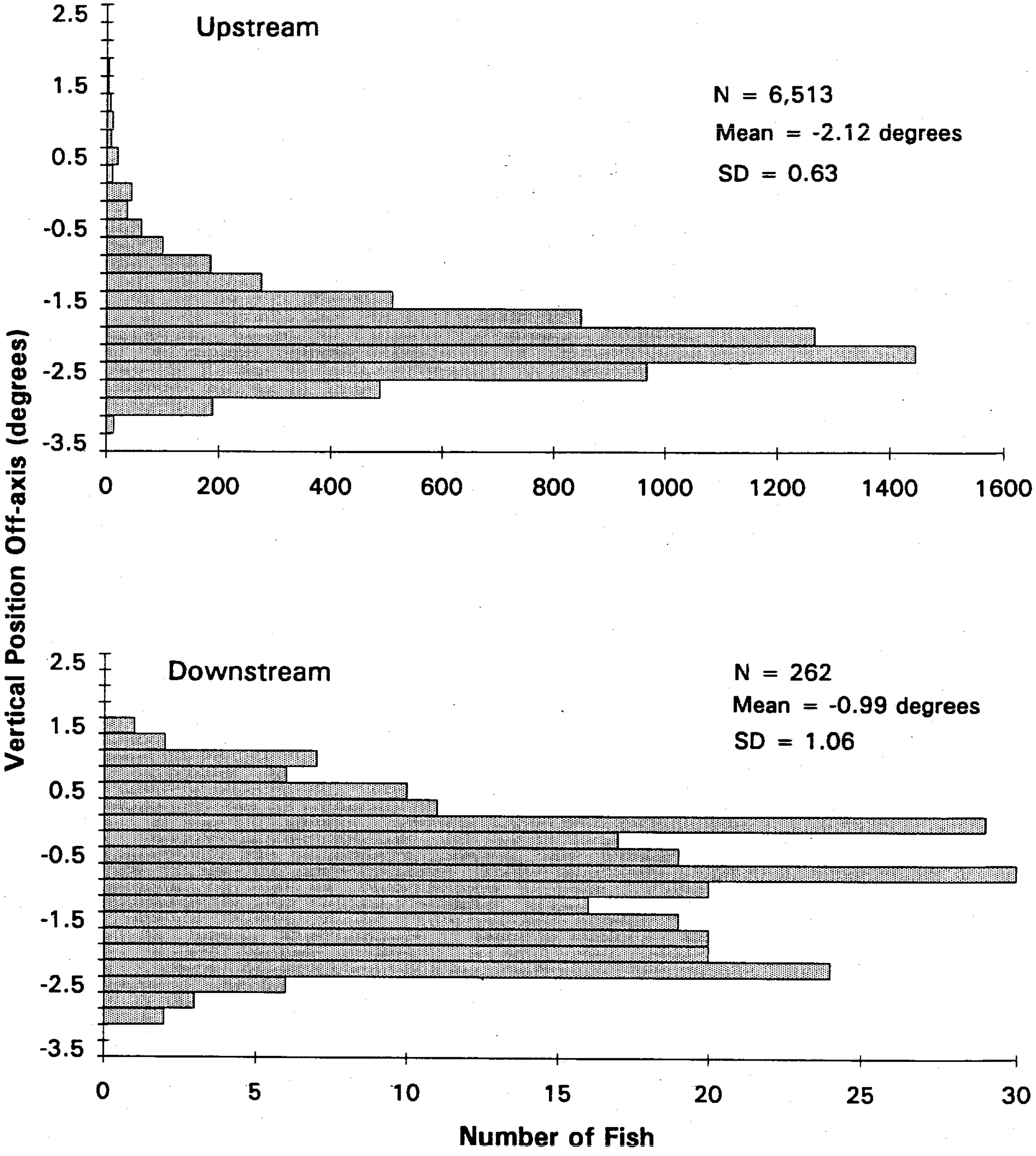

Figure 16. Vertical distribution of upstream and downstream fish, left bank, Chandalar River, August 11-26, 1994.

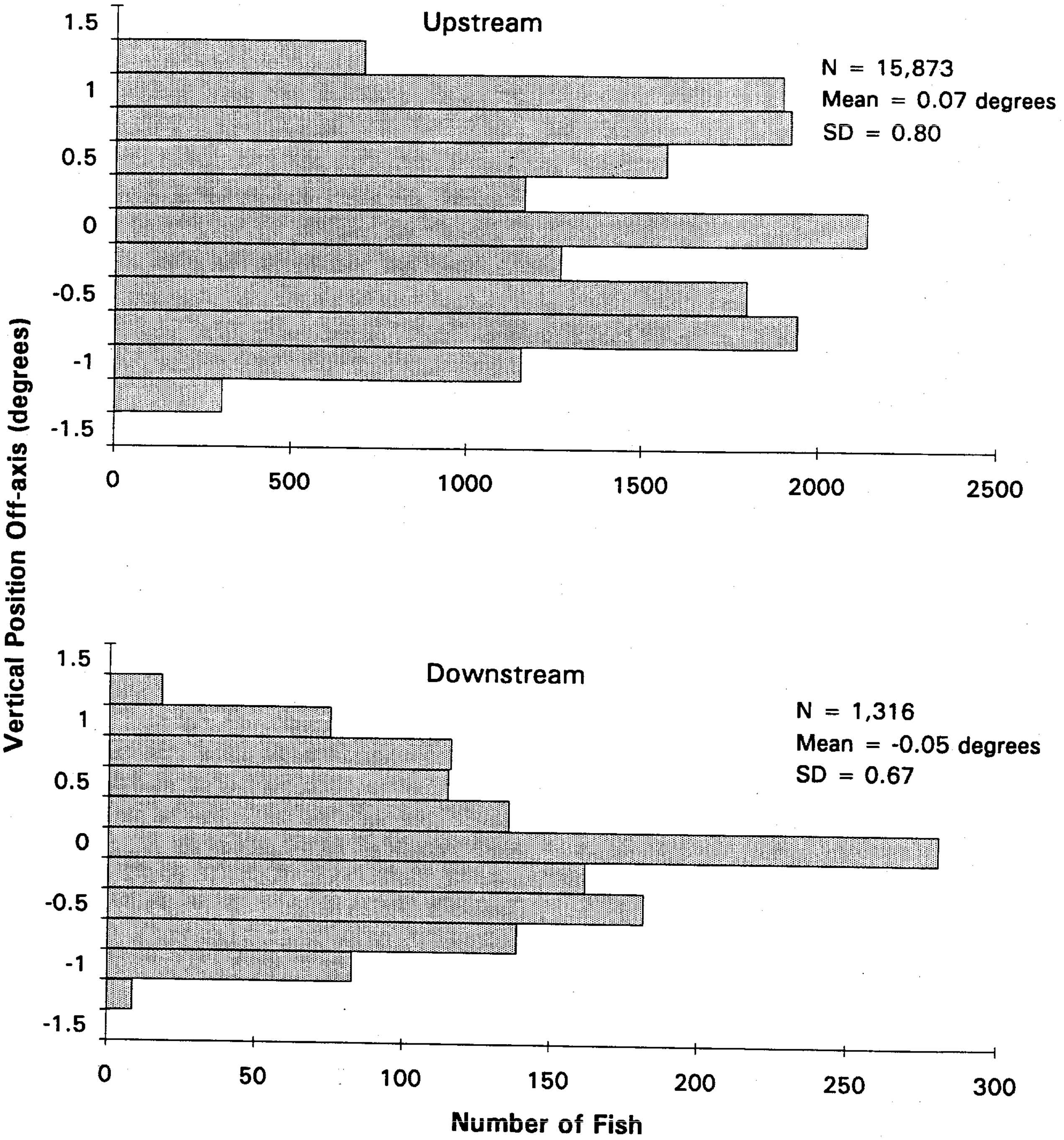

Figure 17. Vertical distribution of upstream and downstream fish, right bank, Chandalar River, August 10-26, 1994.

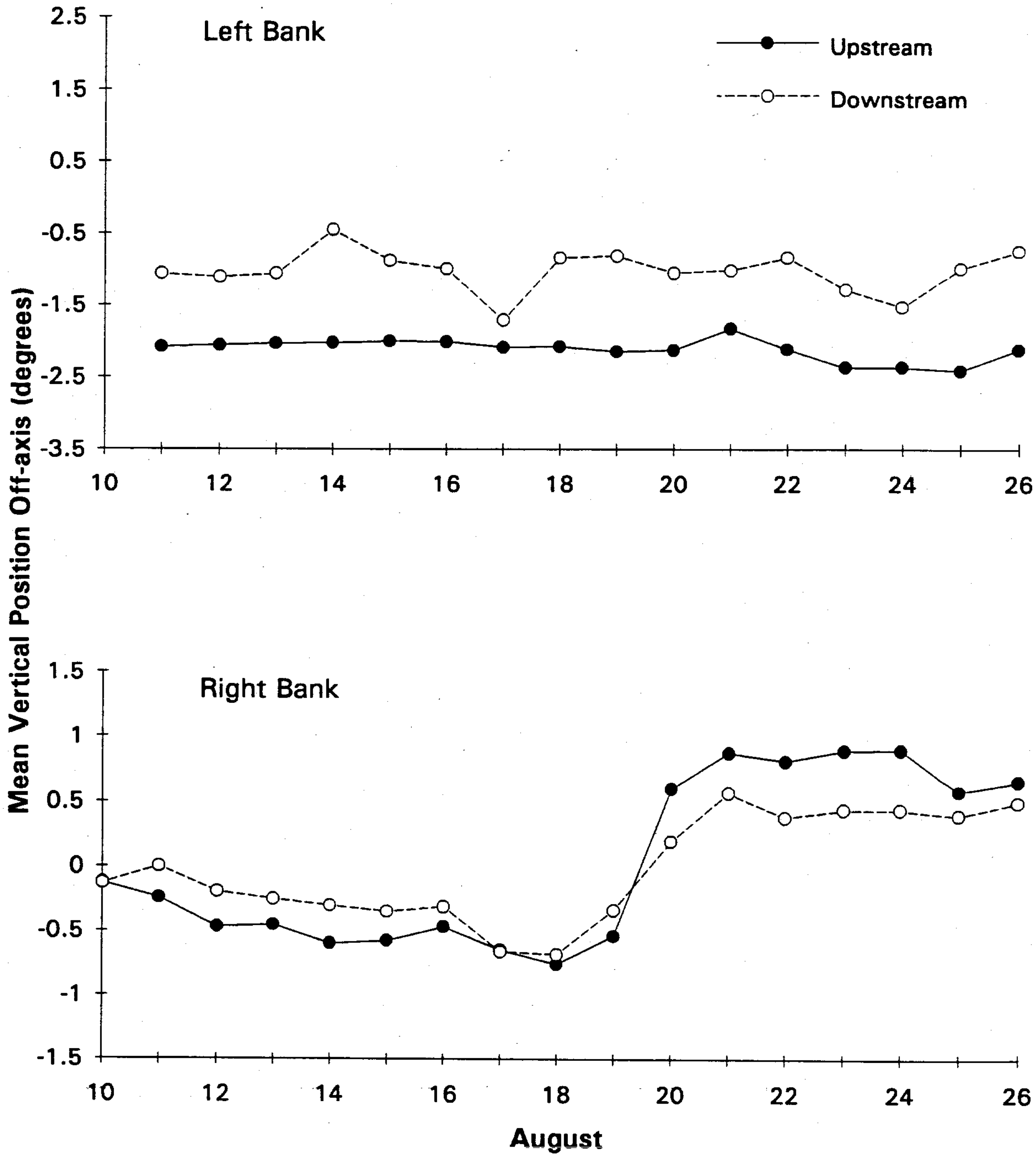

Figure 18. Mean daily vertical position of upstream and downstream fish by bank, Chandalar River, 1994.

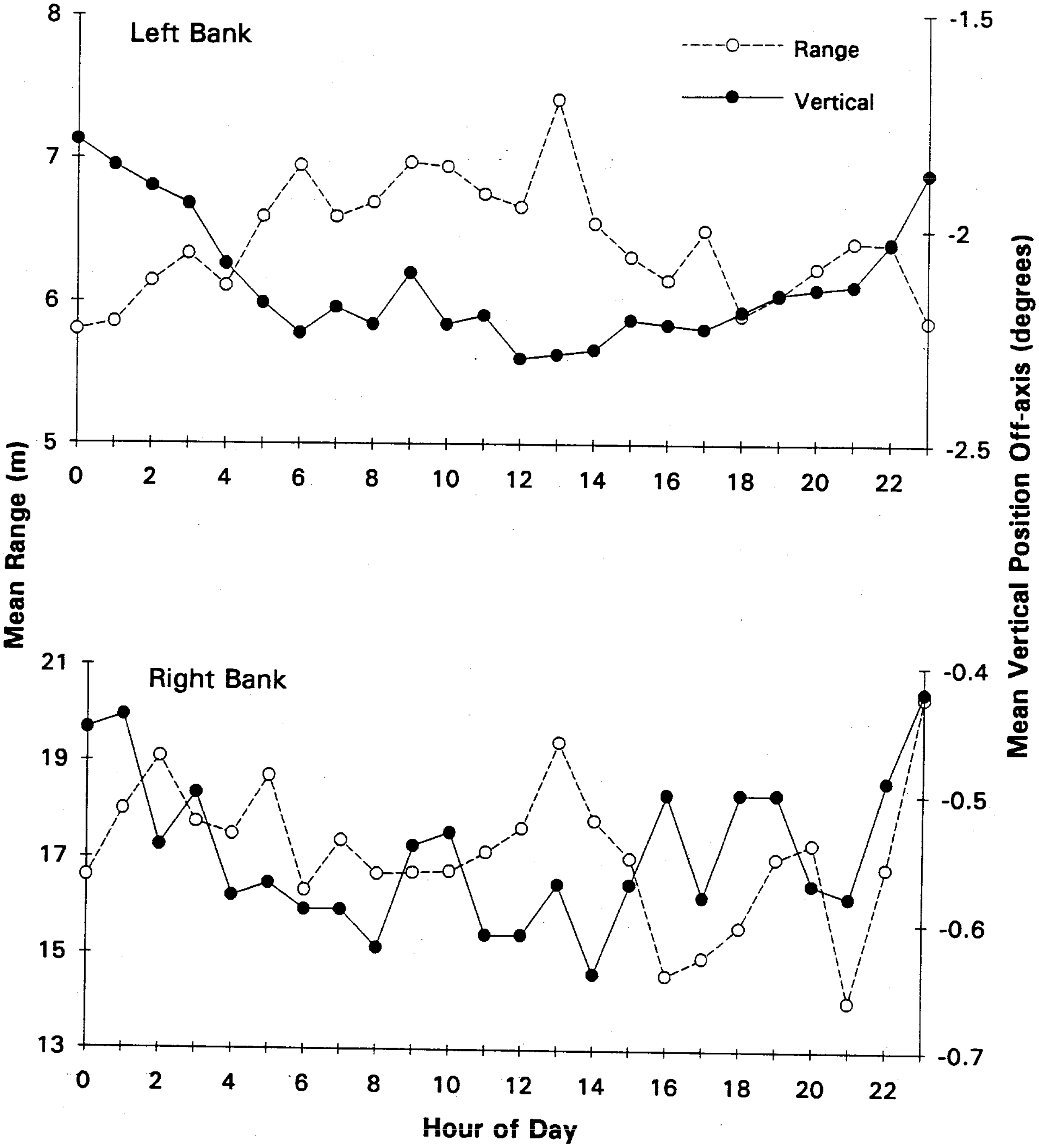

Figure 19. Mean hourly range and vertical position of upstream fish by bank, Chandalar River, August 11-19 (left bank) and August 14-16 (right bank), 1994.

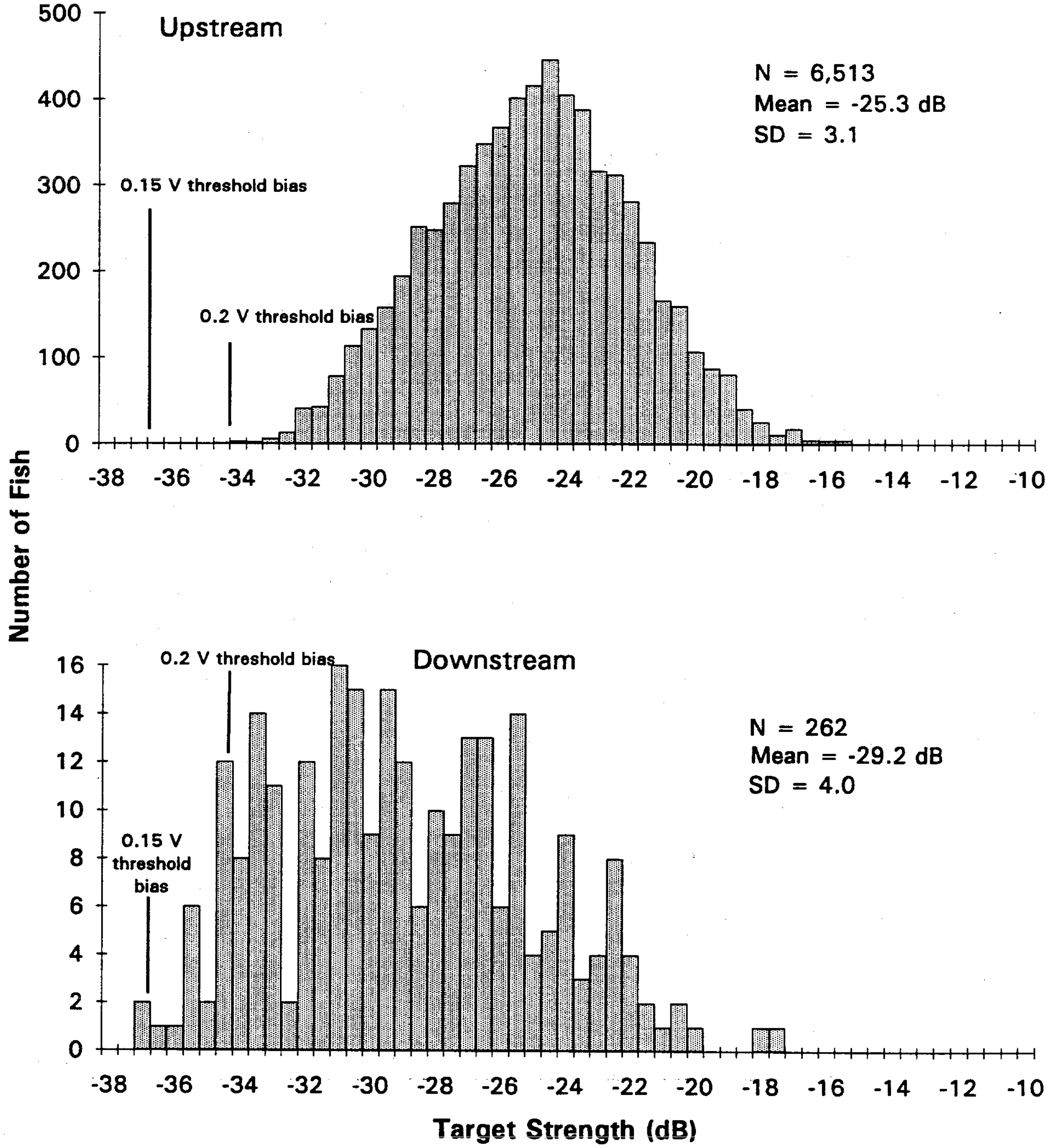

Figure 20. Target strength distribution of upstream and downstream fish, left bank, Chandalar River, August 11-26, 1994. Area of distribution potentially affected by signal threshold bias is indicated.

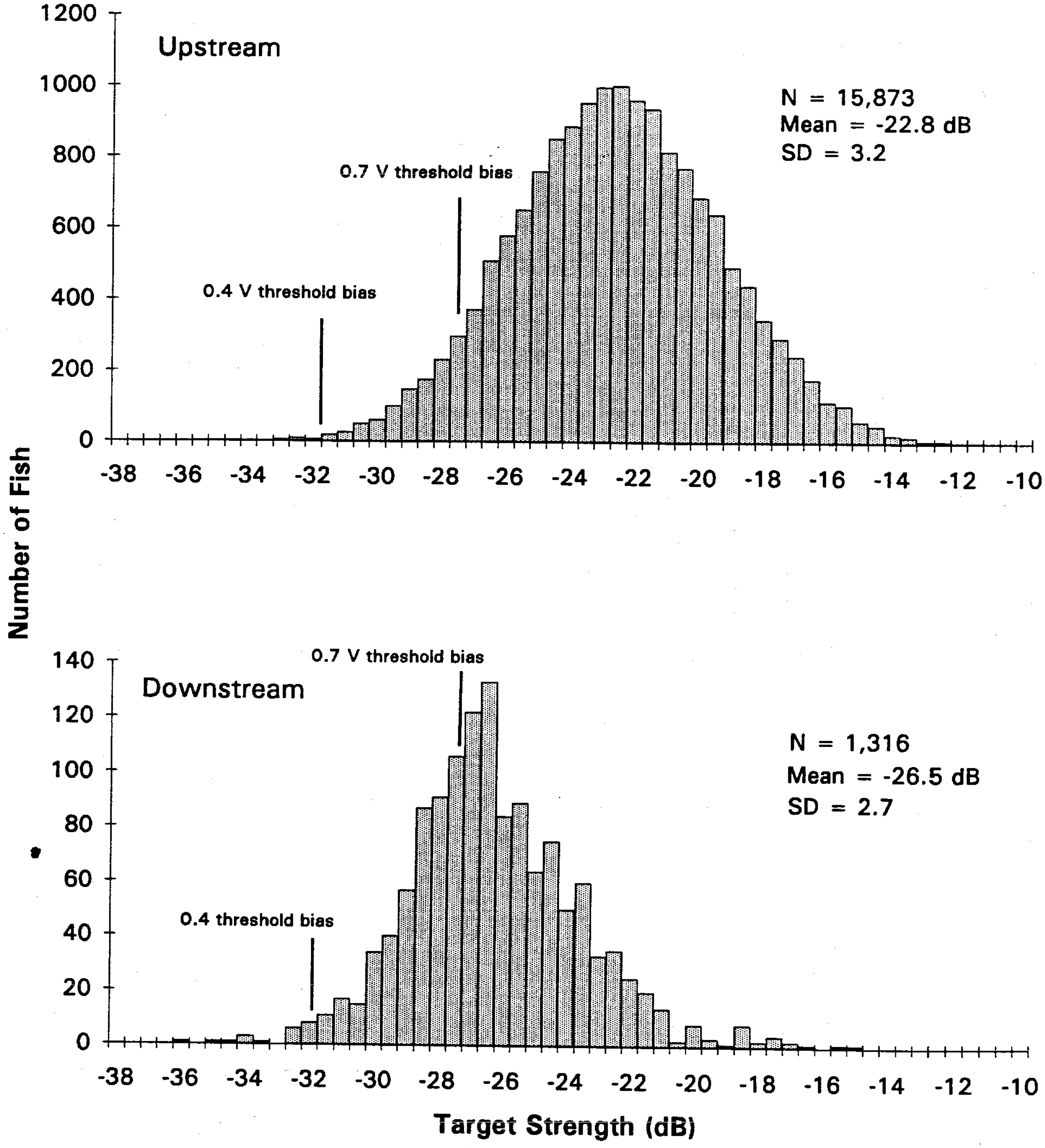

Figure 21. Target strength distribution of upstream and downstream fish, right bank, Chandalar River, August 10-26, 1994. Area of distribution potentially affected by signal threshold bias is indicated.

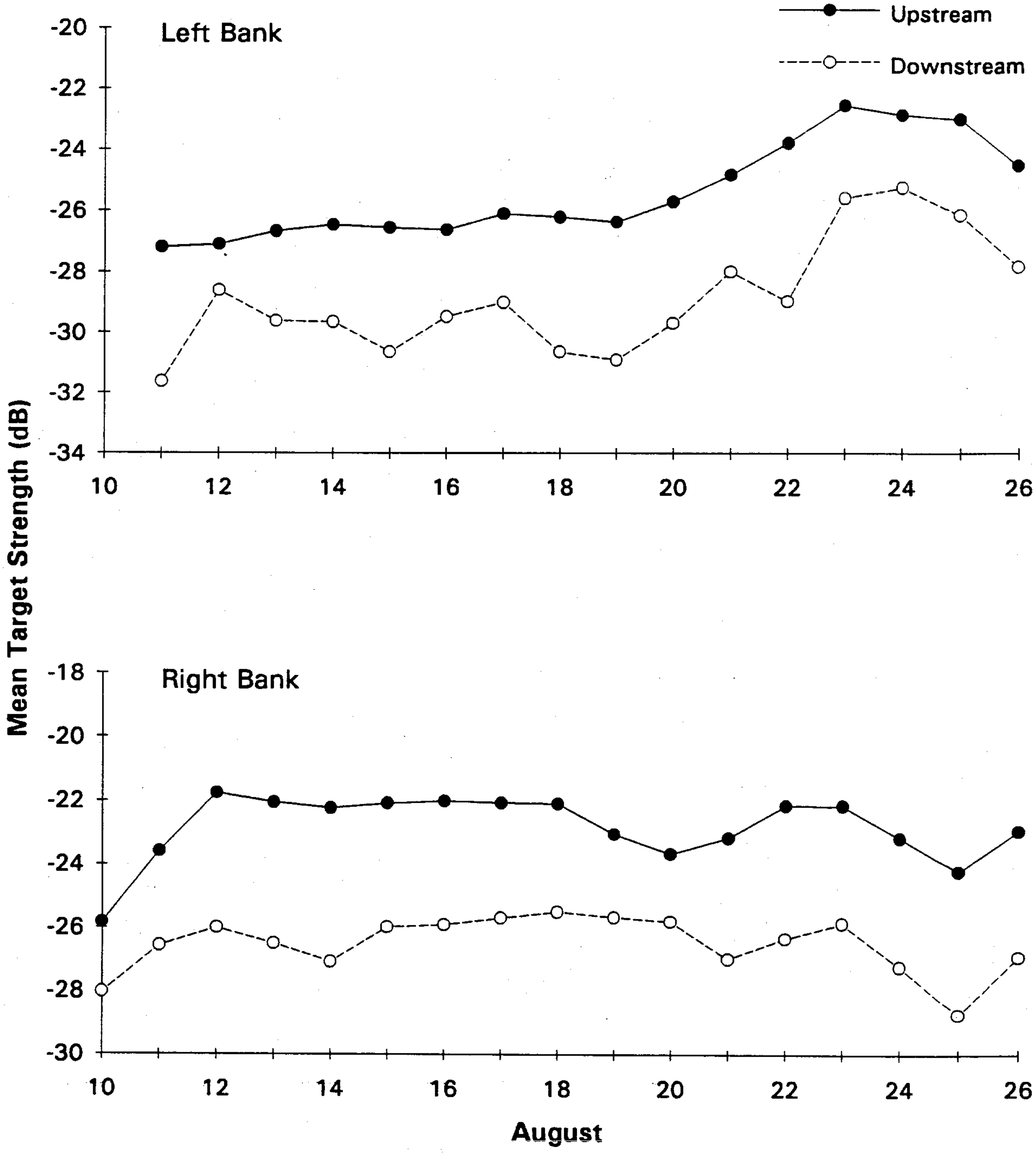

Figure 22. Mean daily target strength of upstream and downstream fish by bank, Chandalar River, 1994.

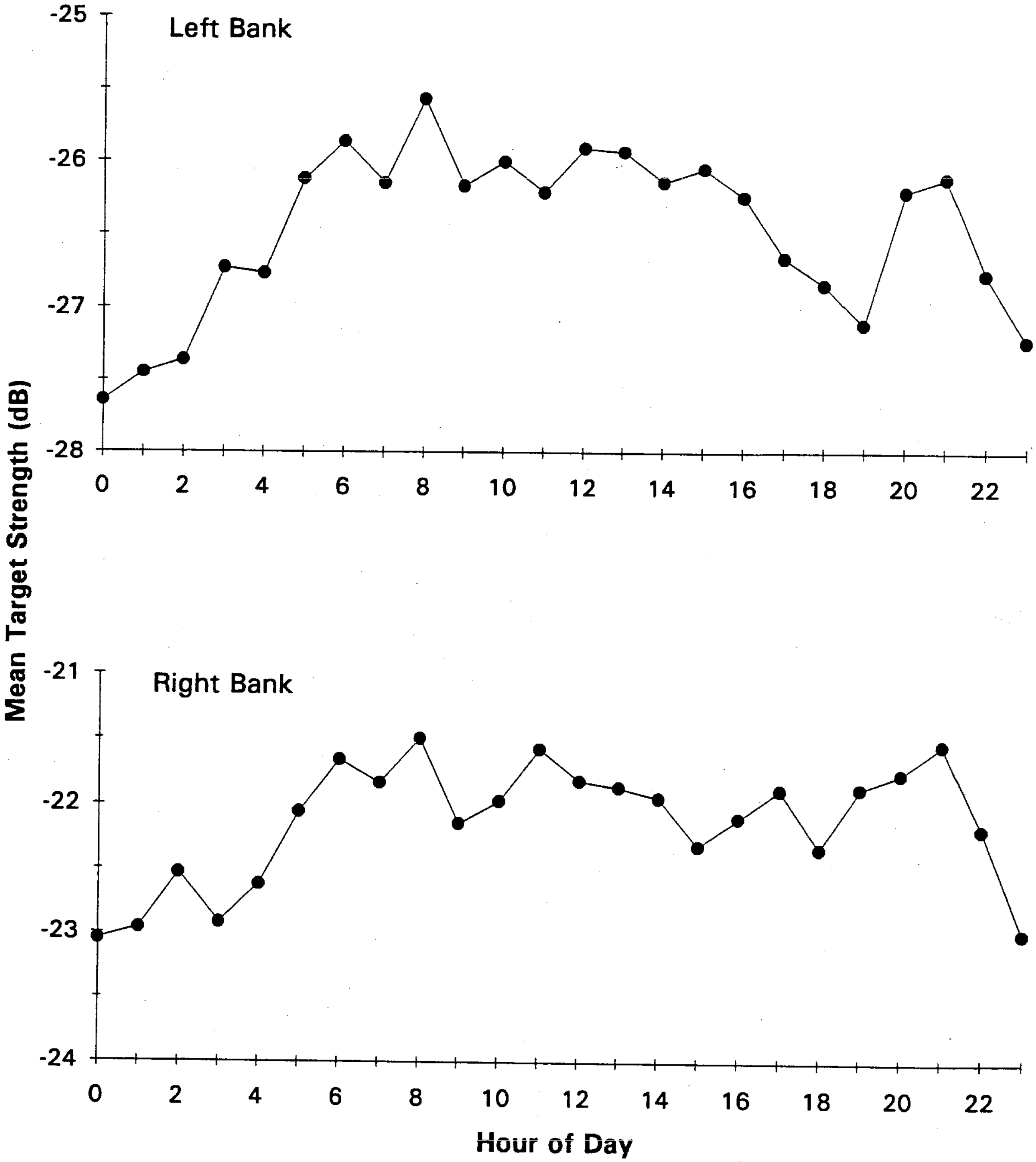

Figure 23. Mean hourly target strength of upstream fish by bank, Chandalar River, August 11-19 (left bank) and August 14-16 (right bank), 1994.

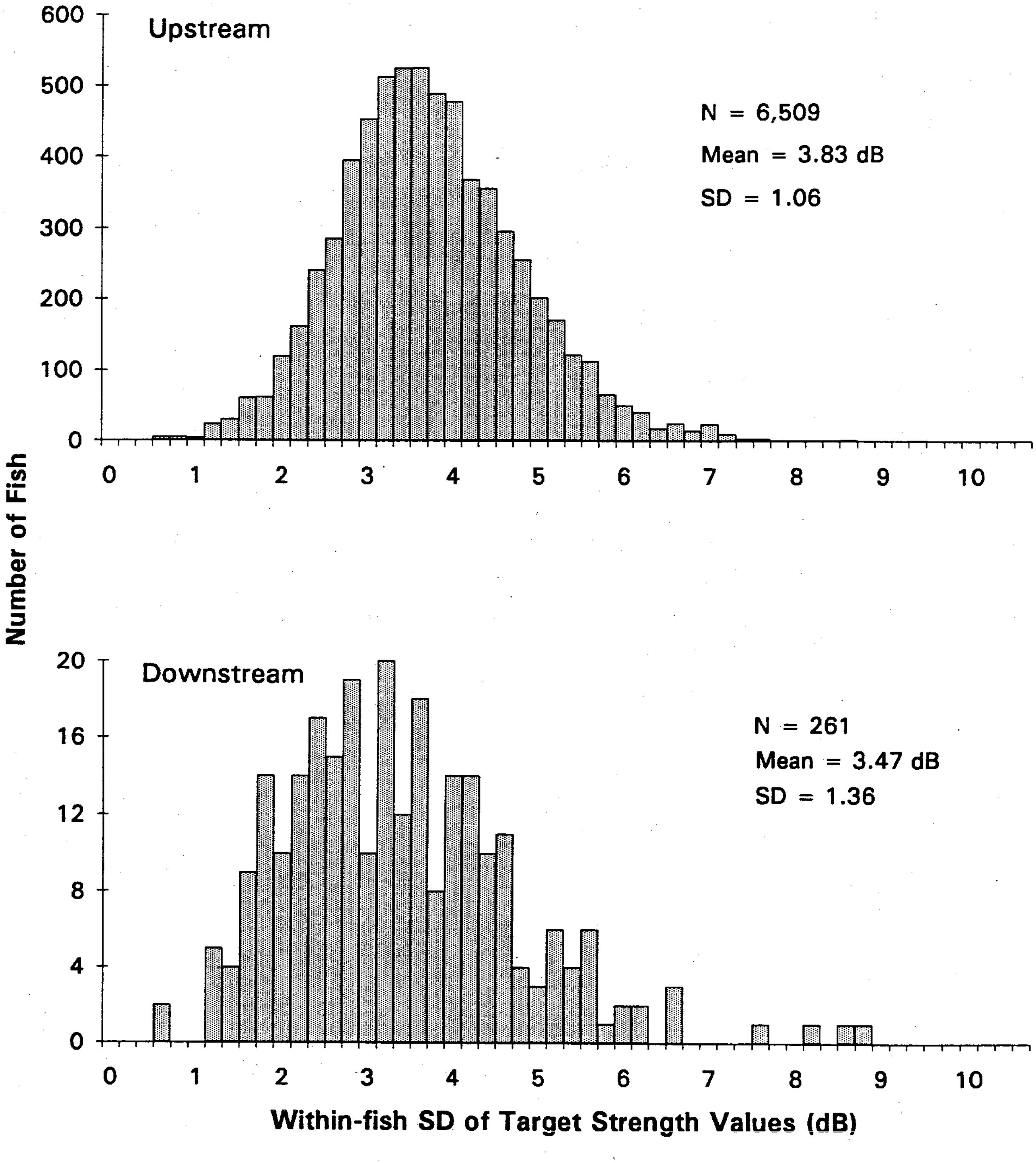

Figure 24. Within-fish target strength variability (SD) of upstream and downstream fish, left bank, Chandalar River, August 11-26, 1994.

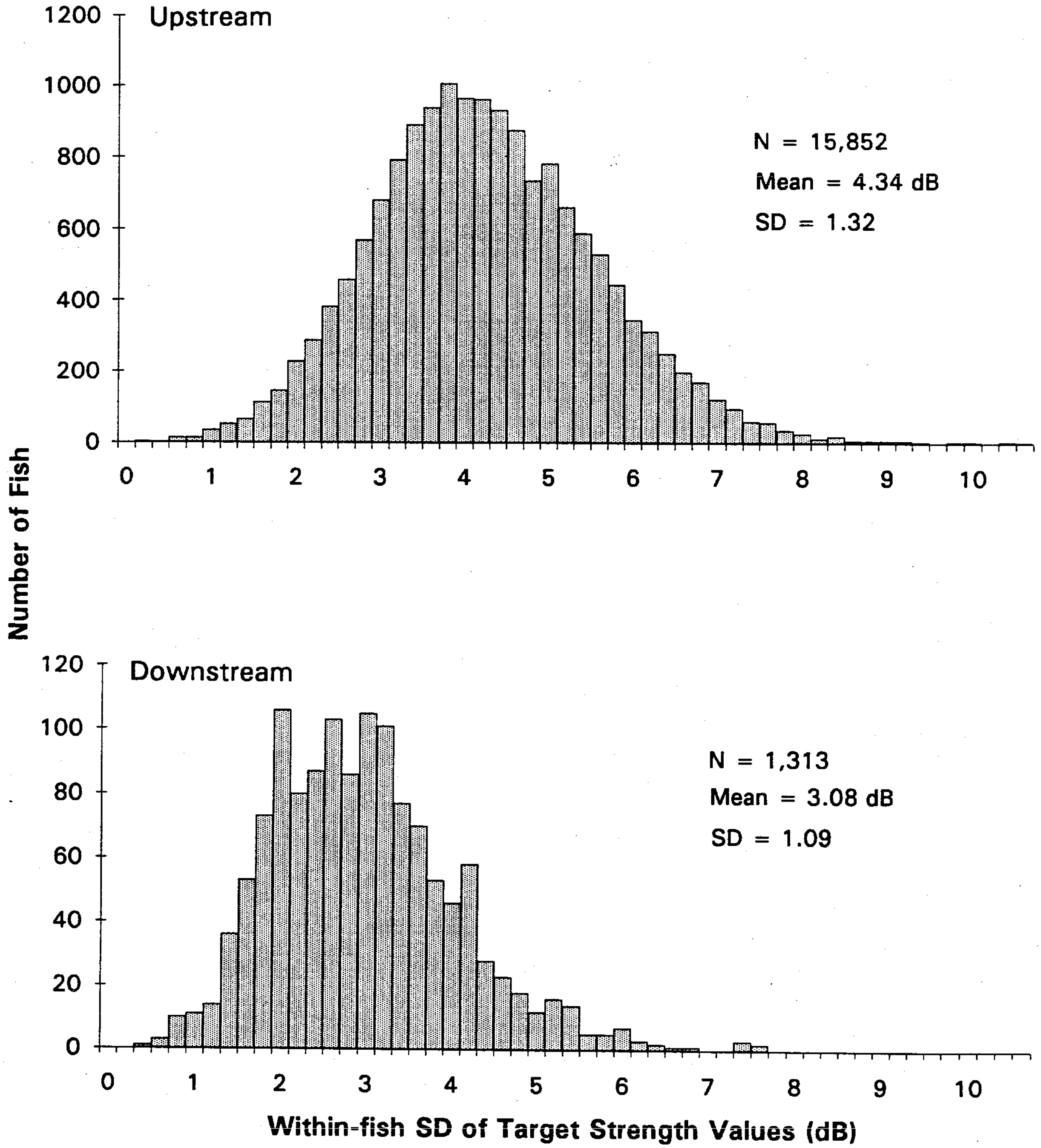

Figure 25. Within-fish target strength variability (SD) of upstream and downstream fish, right bank, Chandalar River, August 10-26, 1994.

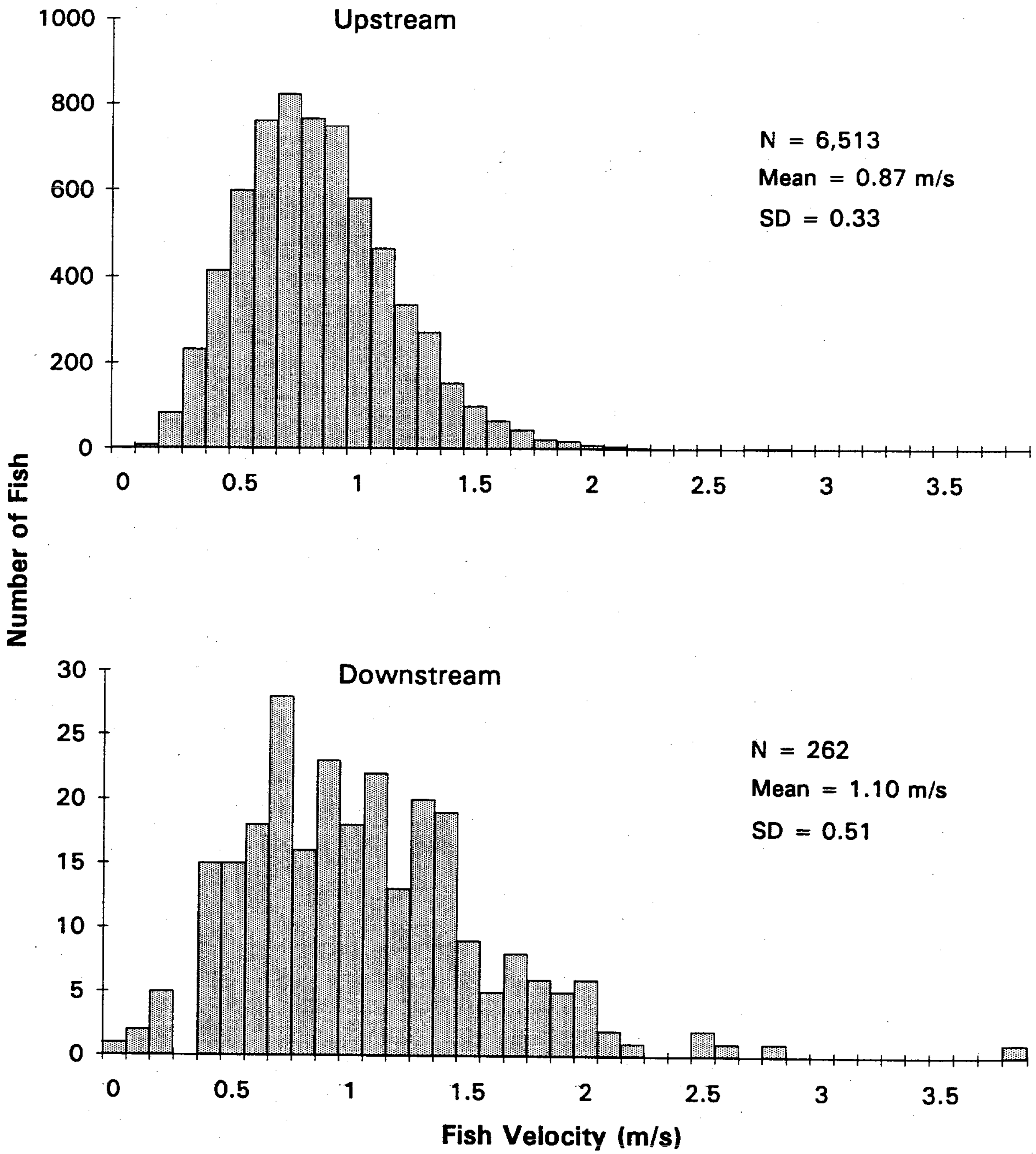

Figure 26. Fish velocity distribution of upstream and downstream fish, left bank, Chandalar River, August 11-26, 1994.

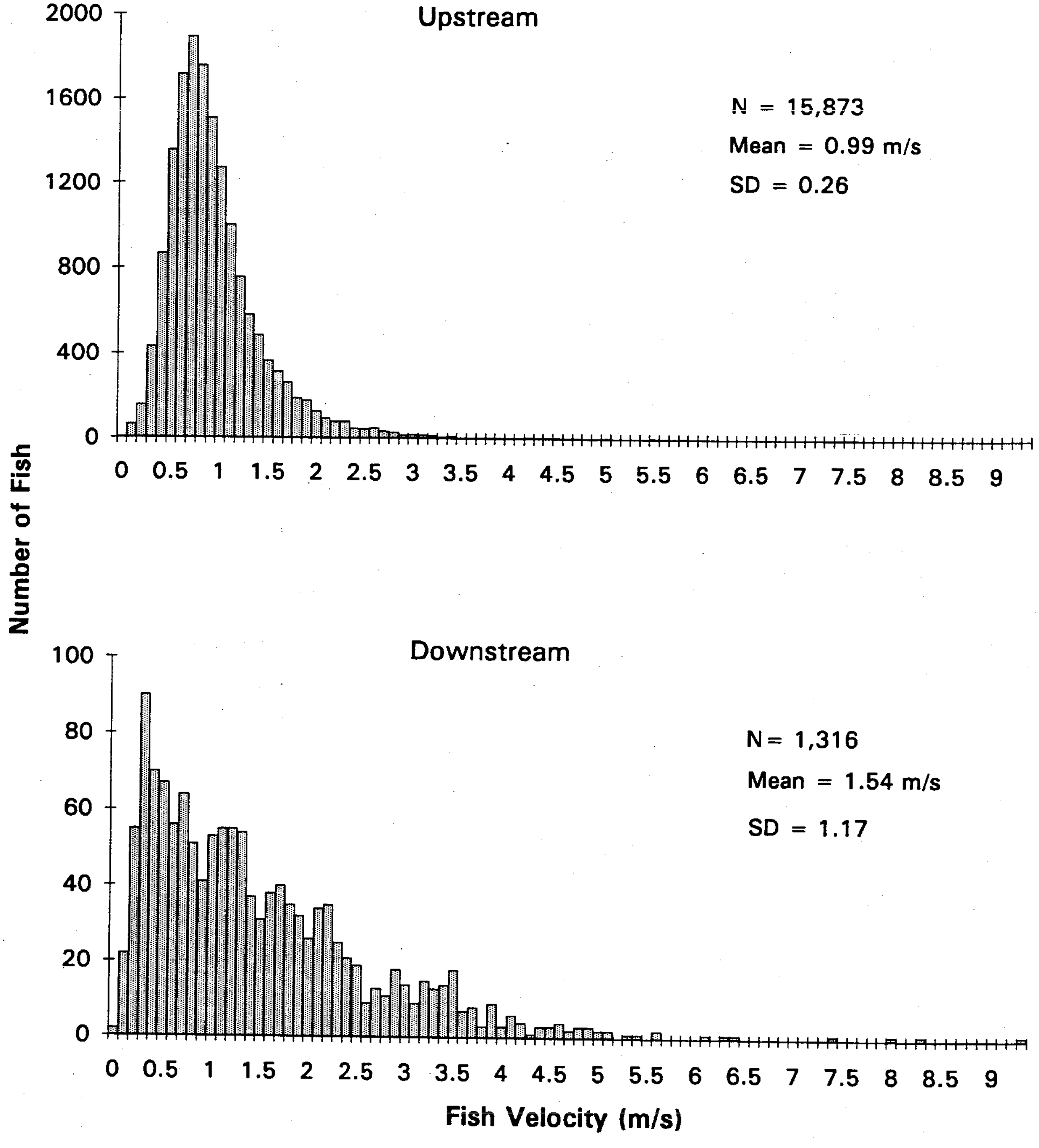

Figure 27. Fish velocity distribution of upstream and downstream fish, right bank, Chandalar River, August 10-26, 1994.

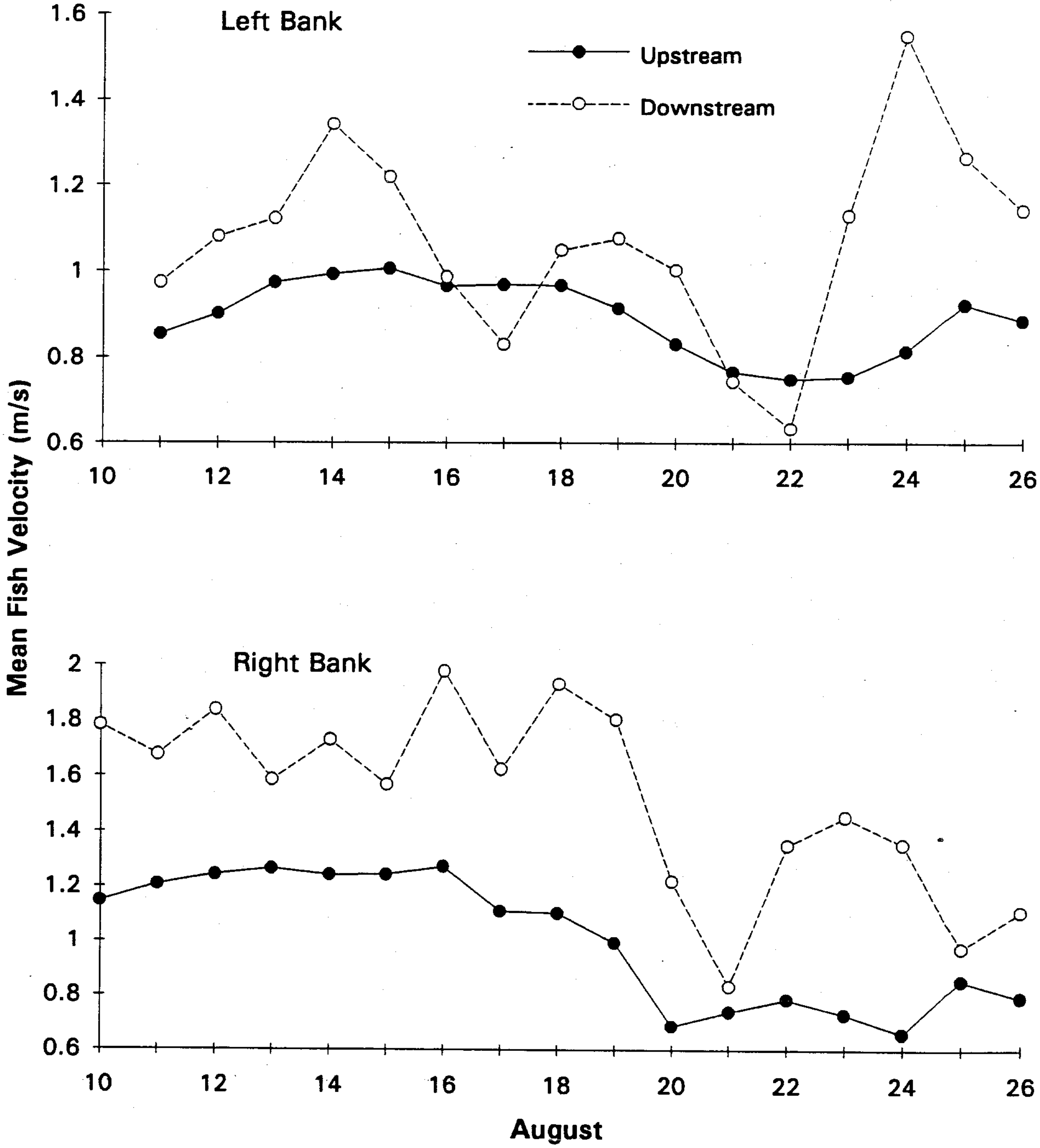

Figure 28. Mean daily fish velocity of upstream and downstream fish by bank, Chandalar River, 1994.

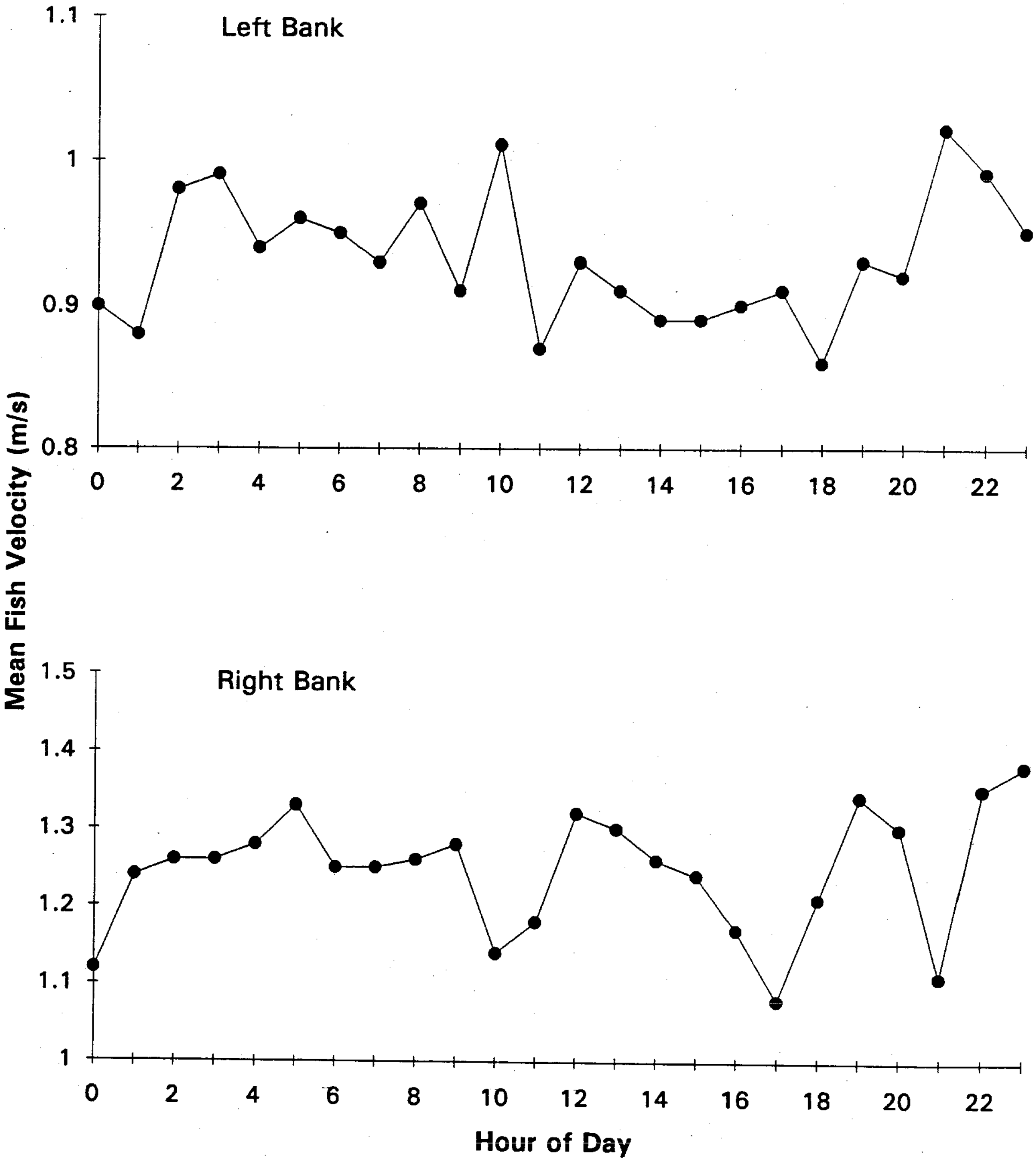

Figure 29. Mean hourly fish velocity of upstream fish by bank, Chandalar River, August 11-19 (left bank) and August 14-16 (right bank), 1994.