Alaska Fisheries Technical Report Number 58

Enumeration of Chandalar River Fall Chum Salmon Using Split-beam Sonar, 1999

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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* in the Chandalar River, a tributary of the Yukon River. Annual escapement estimates have been made since 1995 and daily in-season counts provided since 1996. Operational methods and procedures for generating escapement counts from the acoustic data have been developed and finalized. This report presents the results for the 1999 season and describes the 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 from August 8 through September 26, except for a prolonged period of high water from mid-August to mid-September. The right bank sonar missed 29.5 days of sampling and the left bank missed 3.5 days during the high water period.

A total of 1,556 hours of digital echo processor data were collected and manually tracked, resulting in 52,471 fish written to file. Upstream-traveling fish accounted for 99% of the total tracked targets. The median number of acquired echoes per upstream fish was 27 on the left bank and 22 on the right bank. Downstream fish had medians of 16 echoes per fish on the left bank and 25 echoes per fish on the right bank.

The estimated 1999 fall chum salmon escapement count from August 8 through September 26 was 88,662 fish ± 2,934 (95% confidence interval). The right bank accounted for 57% of the total estimated 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. The fish passage rate was only 149 upstream fish on the first day of counting (0.2% of the total estimated count) and 1,046 fish on the final day (1.2% of the total). The 1999 count was 46% of the 1995-1998 average of 191,214 fish and only 39% of the high escapement levels from 1995-1997. In 1999, the Chandalar River had the highest escapement of all monitored populations of fall chum salmon in the Yukon River drainage.

Precision of the 1999 estimate varied between banks. On the left bank, the precision of the estimate was considered high because 90% of the season was acoustically sampled and 95% of the left bank's final adjusted count was actually tracked. The right bank monitored only 39% of the season and tracked fish represented 31% of the right bank's total adjusted count. The largest potential source of error was in estimating daily right bank counts for 28 missing 24-h periods during high water.

Daily passage rates indicated a bi-modal run, with the peak daily counts of 3,928 and 4,767 fish occurring on August 28 and September 6, respectively. The median passage date was September 3, two days earlier than the 1995-1997 average. The run arrived approximately four days earlier than in 1995-1997, with the first 25% passing by August 25. The 1998 run was not included in annual run timing averages since it was substantially later than in other years, i.e.,11 days later in both median and first quartile passage dates. In 1999, hourly

passage rates of upstream fish did not show any strong diel patterns. During the high escapement years of 1995-1997, the left bank exhibited a strong diel trend, with highest passage rates occurring during late night/early morning hours.

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. In 1999, the vertical position of upstream swimming fish on the right bank was more spread out across the full acoustic beam width than in previous years. The irregular, near-shore bottom contour on the right bank in 1999 required aiming the transducer in a more downward-looking aspect than previous years to attain complete bottom coverage. This, in turn, caused fish to be positioned higher in the beam at far ranges. 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 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. 1999).

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 fisheries 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 1960s (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 (Daum and Osborne 1998b).

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 one of the largest populations of fall chum salmon in the entire 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 in view of the declining trend of some Yukon River salmon stocks (Bergstrom et al. 1995), a 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 on record (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). In 1997, the escapement estimate was 199,874 fall chum salmon (Appendix 3), the highest escapement of all monitored populations in the Yukon River drainage for that year (Daum and Osborne 1998a). The 1998 estimate was 75,811 fish, only 33% of the 1995-1997 average (Appendix 4; Daum and Osborne 1999). This report presents the escapement information from the 1999 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 greater amount 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) location 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 previous years. The left bank site, looking downstream, had a steeper bottom gradient and higher water velocity than the right bank. River bottom slopes were approximately 7.6° on the left bank and 3.5° on the right bank. The consistent linear appearance of the bottom on the right bank (1994-1997) had changed in 1998 and 1999. The bottom was bumpy and uneven past 57 m offshore, due to sediment deposited from severe bank erosion during an early summer flood in 1998. In 1999, the near-shore bottom contour on the right bank was also non-linear. River substrate consisted of small rounded cobble/gravel on the left bank and sand/silt on the right bank. During the 1999 season, river width at the site averaged 148 m (ranging from 138 to 186 m) and maximum depth averaged 4.8 m (ranging from 4.1 to 6.6 m). In-season water levels were higher than in previous years, except when the site flooded in 1994. Water temperature decreased from 16 to 4°C as the season progressed. Daily water conductivity measurements were discontinued in 1999 because of the consistent readings from past years (ranging from 220 to 320 μS/cm). Specific methodology for constructing cross-sectional river profiles and measuring daily water elevation and temperature 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 1999. 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 26, except for a prolonged period of high water from mid-August to mid-September. The right bank sonar missed 29.5 days of sampling and the left bank system missed 3.5 days during the high-water event. As in 1998, the 1999 counting period was extended four days beyond the 1995-1997 termination date of September 22.

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. 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 1999) 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 using the standard target to insure that the system electronics were functioning properly. All on-axis, *in situ* calibrations were less than 1.9 dB of factory calibrated values.

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 1). 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 that predicted from Love's equation (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 up to -34 dB on-axis for data collected at far ranges. For the season, average peak amplitude noise levels varied from -57 to -34 dB for the left bank and -57 to -37 dB for the right bank. Noise increased with distance from the transducer. The maximum acquisition range (distance from the transducer) changed throughout the season on the left bank, primarily due to transducer redeployment as water levels varied. The left bank acquisition range changed from 10 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 57 m throughout the season, with approximately 30 m left unensonified due to reverberation from the irregular bottom. 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 backup and data analysis without interrupting real-time data collection.

Digital chart recordings were collected for 2 h/d throughout the season and run concurrently with the digital echo processor. Unlike digital echo processor data files, chart recordings were not filtered by pulse width or angle off-axis criteria. On the left bank, target strength threshold settings were kept constant for the season at -40 dB. For the right bank, the setting varied between -40 and -38 dB due to high noise levels. 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 1999 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 4.8 by 10.8° on the left bank and 2.0 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 (−16.3 dB for the left bank and −23.1 dB for the right bank, measured on a one-way beam pattern plot).

The transducers and remote-controlled rotators were mounted on frames and deployed at depths of 0.6-1.5 m (see Daum and Osborne 1999 for specific description of pod assembly). Transducers were oriented perpendicular to river flow and positioned as close to the river bottom as substrate and contour allowed, usually within 5 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 into the bottom, enhancing detection of bottom-oriented fish. Because of the irregular, near-shore bottom contour on the right bank in 1999, the transducer was aimed lower in the water column than in previous years. Bottom coverage was verified by dragging a target through the beam at various ranges. 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 1.31a). Echoes from boat motors, acoustic noise, and rocks were excluded from the database. Boat motor and acoustic noise echoes were visually identified by the random nature they displayed on software-produced echograms. Returning echoes from rocks exhibited a stationary bottom position in the beam with no movement in the upstream or downstream direction. Suspected fish targets, represented by a series of contiguous 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 more than 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

$$E_h = (60 / T_h) \cdot C_h , \quad (1)$$

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., 43 days on the left bank and 17 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 8). Estimated fish counts for missing hours were calculated, using

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

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, 26 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 two days, when both banks were inoperable, the daily counts were estimated by linear interpolation between the daily count before and after the event. 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

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

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).

RESULTS

Acoustic Data Verification and Fish Tracking

For the season, 1,556 hours of acoustic data were collected and 52,471 fish were manually tracked. Daily summary information for all tracked echo processor files is presented in Tables 2 and 3. Upstream-traveling fish accounted for 99% of the total tracked fish. On the left bank, 90% of the season was monitored, with 3.5 days missed during high water. Right bank sample time was considerably less than that on the left bank due to down time from the high-water event. Approximately 39% of the season was sampled, with 29.5 days missed during high water. The median number of acquired echoes per upstream fish was 27 on the left bank (range of 4-380) and 22 on the right bank (range of 4-257). Downstream fish had medians of 16 echoes per fish on the left bank (range of 4-207) and 25 echoes per fish on the right bank (range of 7-119).

Acoustic Data Analyses

Escapement estimate and run timing

The adjusted 1999 fall chum salmon escapement count for the Chandalar River was 88,662 upstream fish ± 2,934 (95% confidence interval; Table 4). The right bank accounted for 57% 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. The passage rate was only 149 upstream fish on the first day of sonar operation (0.2% of the total seasonal count), whereas 1,046 fish passed on the final day of counting (1.2% of the total). Daily counts were more than 2,000 fish/d for 18 of the 50 counting days. The 1999 count was only 46% of the 1995-1998 average of 191,214 fish (Figure 4).

Of the final adjusted upstream count of 88,662 fall chum salmon, 59% were actually tracked (51,870 fish). Missing days made up the largest block of estimated counts. The right bank missed 28 24-h sampling periods during the high-water event beginning August 10 and the left bank missed two complete days. This represented 56% of the entire 50-day sampling period on the right bank and 4% of the left bank total. Counts were also estimated for 96 missing hours for the season, 48 h on each bank. Count adjustments for partial hours made up only 11% of all hourly counts (counts ≥ 0.25 h), with the majority of incomplete hours having sample times ≥ 0.75 h.

Daily passage rates indicated a bi-modal run with the peak daily counts of 3,928 and 4,767 fish occurring on August 28 and September 6, respectively (Figure 4). The median passage date was September 3, two days earlier than the 1995-1997 average. The run arrived approximately four days earlier than 1995-1997, with the first quartile passing on August 25. The 1998 run was not included in annual run timing averages since it was substantially later than in other years, i.e.,11 days later in both median and first quartile passage dates (Figure 4). Run timing was similar between banks during the later part of the run (Figure 5). The beginning of the run could not be compared because of missing right bank counts.

In 1999, hourly passage rates of upstream fish did not exhibit any strong diel patterns throughout the season (Figure 6). During the high escapement levels in 1995-1997, the left bank exhibited a strong diel trend, with highest passage rates occurring during late night/early morning hours. As in previous seasons, right bank fish did not show any trend in diel distribution through the season.

Spatial distribution of tracked fish

Upstream migrating chum salmon were shore-oriented and most fish were well within the range of acoustic detection for both banks (Figures 7 and 8). More than 92% of upstream fish were within 11 m of the left bank transducer and 26m of the right bank transducer. Downstream fish were distributed more across the full detection range. For the season, median range values for upstream fish were 3 m closer to shore than downstream fish on the left bank and 5 m closer to shore on the right bank.

Vertical fish position data showed that most upstream-swimming chum salmon were bottom-oriented. On the left bank, more than 99% of upstream fish passed below the acoustic axis (Figure 9). On the right bank, 54% of upstream fish passed below the acoustic axis (Figure 10). The lower percentage of right bank fish found below the acoustic axis in 1999 compared to previous years (ranging from 91 to 99%) was an artifact of transducer aim due to a irregular bottom contour (see Discussion). On both banks, 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 that of downstream fish. These trends in spatial position of tracked fish were similar to results from the previous four years.

Target strength distribution of tracked fish

For the season, the average target strength of upstream-swimming fall chum salmon was -27.2 dB on the left bank and -24.7 dB on the right bank (Figures 11 and 12). Downstream fish had significantly smaller target strengths than upstream fish (*P* values < 0.001), averaging -29.5 dB on the left bank and -26.0 dB on the right bank. Mean target strengths for 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 1995-1998 results.

DISCUSSION

In 1999, the Chandalar River had the second lowest escapement of fall chum salmon since split-beam sonar enumeration began in 1995 (Figure 13). The low returns of the 1998 season continued into 1999. The 1999 count of 88,662 fish was only 37% of the average annual returns during the high-escapement years, 1995-1997. Also, escapements to other major spawning grounds in the upper Yukon River drainage dropped substantially from the 1994-1997 levels (Alaska Department of Fish and Game, in press). The Sheenjek River, located 116 km upstream from the Chandalar River, had a total run failure in 1999 (L. Barton, Alaska Department of Fish and Game, personal communication). A preliminary count of 14,229 fish represented only 8% of the 1994-1997 average annual escapement. In four of the last five years, the Chandalar River has had the highest escapement of all monitored spawning streams in the Yukon River drainage. The 1999 Chandalar River estimate was 45% of the combined total for all upper Yukon River enumeration projects, i.e., Chandalar, Sheenjek, Fishing Branch, and Canadian mainstem Yukon rivers.

The precision of the 1999 Chandalar River escapement estimate varied between banks. On the left bank, the precision of the estimate was considered high. Acoustic data were collected for 90% of the season and few adjustments were made to the actual tracked fish count (95% of the left bank's final count was actually tracked). The right bank monitored only 39% of the season and tracked fish represented 31% of the right bank's total adjusted count. The largest potential source of error was in estimating daily right bank counts for the 28 missing 24-h periods 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 (Figure 14). The left and right bank daily counts were highly correlated for the 22 non-missing days ($r = 0.83$, $P < 0.001$). In addition, the 95% confidence interval around the missing-days estimate was within 3.3% of the total seasonal count. However, the ratio, calculated during low passage days, was used to estimate unknown right bank counts during high-passage periods. This may have introduced bias to the estimate, especially if the ratio changed when passage rates increased.

Fish position data suggested that most upstream fish passing the sonar site were within the ensonified zone during the 1999 season. As in the previous four years, 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 echogram recordings provided additional evidence that few fish passed beyond the acquisition range. However, the vertical position of upstream-swimming fish on the right bank was more spread out across the full acoustic beam width than in previous years. In 1999, the non-linear, near-shore bottom contour required aiming the transducer in a more downward-looking aspect than in previous years to attain complete bottom coverage near the transducer. This, in turn, raised the acoustical position of fish at far ranges since the lower edge of the beam was down in the sand/silt substrate (Figure 3). 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).

For most of the 1999 season, the voltage threshold was set substantially lower (10 dB) than predicted target strength values for fish of chum salmon length (Love 1977) to insure that acoustic data were not biased; threshold set at -40 dB. During high-noise events, the voltage threshold was increased up to -34 dB at far ranges (beyond approximately 10 m on the left bank and 11 m on the right bank). This may have caused biased target strength values and undercounting of fish past these ranges. However, most upstream fish had target strengths substantially above the elevated threshold setting (Figures 11 and 12) and the majority of fish were close to shore (Figures 7 and 8). Daily comparisons of chart counts to the electronic data set confirmed that few fish were missed at the higher voltage threshold settings. In addition, fish traces at far ranges were closely scrutinized while upstream targets were visually tracked to verify that off-axis echoes were being collected. This evidence supports the assumption that few fish were missed during periods of elevated voltage settings.

Annual sonar enumeration of fall chum salmon in the Chandalar River should continue into the future, based on the Chandalar River's significant contribution to the total run of Yukon River fall chum salmon and the importance of the stock to subsistence users throughout the drainage. During upcoming seasons, daily in-season counts and post-season escapement estimates will be provided. Future sampling schedules will attempt 24-h continuous acoustic monitoring. However, sub-sampling may become necessary if in-season manual fish tracking falls behind schedule due to high fish passage rates. Data verification and manual fish tracking continue to be labor intensive due to large numbers of salmon, and to software limitations. Considerable time would be saved if an automatic tracking system was developed that provided accurate counts of upstream-traveling fish in the Chandalar River. Until that time, manual tracking of fish targets will be necessary to ensure data integrity and count accuracy

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Special appreciation is extended to the people who participated in the fifth year of this project and who are largely responsible for its success: C. Gewin and L. Hanson for field assistance, and S. Johnston for technical assistance. We appreciate the assistance from R. Carroll for providing transportation to the site. Success of this project was also dependent on support from J. Gordon and M. Millard for assistance in computer programming and data analysis; S. Klosiewski for statistical advice; R. Simmons for editorial and project review; and J. Millard for editorial review.

REFERENCES

Alaska Department of Fish and Game. In press. Annual management report, Yukon Area, 1999. Division of Commercial Fisheries, AYK Region, Anchorage, Alaska.

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

Bergstrom, D. J., and six coauthors. 1995. Annual management report, Yukon Area, 1993. Alaska Department of Fish and Game, Commercial Fisheries Management and Development Division, AYK Region, Regional Information Report 3A95-10, Anchorage, Alaska.

Bergstrom, D. J., and ten coauthors. 1999. Annual management report, Yukon Area, 1998. Alaska Department of Fish and Game, Division of Commercial Fisheries, AYK Region, Regional Information Report 3A99-26, Anchorage, Alaska.

Cochran, W. G. 1977. Sampling techniques, 3rd edition. John Wiley and Sons, New York.

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

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

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

Daum, D. W., and B. M. Osborne. 1998a. Enumeration of Chandalar River fall chum salmon using split-beam sonar, 1997. U.S. Fish and Wildlife Service, Fishery Resource Office, Alaska Fisheries Technical Report 47, Fairbanks, Alaska.

Daum, D. W., and B. M. Osborne. 1998b. Use of fixed-location, split-beam sonar to describe temporal and spatial patterns of adult fall chum salmon migration in the Chandalar River, Alaska. North American Journal of Fisheries Management 18:477-486.

Daum, D. W., and B. M. Osborne. 1999. Enumeration of Chandalar River fall chum salmon using split-beam sonar, 1998. U.S. Fish and Wildlife Service, Fishery Resource Office, Alaska Fisheries Technical Report 50, Fairbanks, Alaska.

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

Eggers, D. M., P. A. Skvorc, and D. L. Burwen. 1995. Abundance estimates of chinook salmon in the Kenai River using dual-beam sonar. Alaska Fishery Research Bulletin 2(1):1-22.

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

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

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.

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

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

HTI (Hydroacoustic Technology, Inc). 1999. 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 72:1397-1402.

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

Osborne, B. M., and D. W. Daum. 1997. Enumeration of Chandalar River fall chum salmon using split-beam sonar, 1996. U.S. Fish and Wildlife Service, Fishery Resource Office, Alaska Fisheries Technical Report 42, Fairbanks, Alaska.

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, 2nd edition. Prentice and Hall, Englewood Cliffs, New Jersey.

Table 1. Echo acceptance criteria used for digital echo processing, Chandalar River, 1999. 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	-3.61 to 2.41	-5.42 to 5.42	-40[a]	10 to 20
Right	0.10 to 0.38	-1.50 to 1.50	-4.89 to 4.89	-40[a]	57

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

Table 2. Hydroacoustic data collected from the left bank, Chandalar River, 1999. Asterisks represent days when sampling was discontinued due to high water.

Date	Sample time (h)	Upstream count	Downstream count	Total count
Aug 8	23.67	54	3	57
9	16.29	60	4	64
10*	0	-	-	-
11*	0	-	-	-
12	6.3	14	0	14
13	23.55	85	1	86
14	23.14	88	1	89
15	23.73	156	2	158
16	23.67	237	0	237
17	23.48	432	0	432
18	23.43	519	0	519
19	23.49	838	4	842
20	23.75	965	2	967
21	23.30	996	2	998
22	23.80	949	3	952
23	20.80	1,200	4	1,204
24	13.71	695	5	700
25	23.74	1,213	3	1,216
26	23.80	1,568	5	1,573
27	23.69	1,542	5	1,547
28	23.69	1,665	2	1,667
29	23.78	1,260	2	1,262
30	23.75	860	3	863
31	23.44	859	4	863
Sep 1	23.62	865	12	877
2	23.50	919	2	921
3	23.47	922	9	931
4	23.75	1,161	5	1,166
5	23.42	1,556	9	1,565
6	23.65	2,014	12	2,026
7	23.56	1,676	12	1,688
8	23.65	1,177	5	1,182
9	22.65	721	7	728
10	23.76	601	7	608
11	23.55	556	4	560
12	23.76	498	7	505
13	23.59	572	7	579
14	23.72	558	24	582
15	23.68	468	11	479
16	23.79	526	10	536
17	23.80	586	19	605
18	23.82	532	16	548
19	23.77	450	10	460
20	23.79	480	13	493
21	23.81	466	17	483
22	23.79	603	24	627
23	23.80	658	21	679
24	23.71	664	28	692
25	23.77	490	19	509
26	11.89	332	11	343
Total	1,085.07	36,306	376	36,682

Table 3. Hydroacoustic data collected from the right bank, Chandalar River, 1999. Asterisks represent days when sampling was discontinued due to high water.

Date	Sample time (h)	Upstream count	Downstream count	Total count
Aug 8	23.71	93	0	93
9	17.73	30	1	31
10*	0	-	-	-
11*	0	-	-	-
12*	0	-	-	-
13*	0	-	-	-
14*	0	-	-	-
15*	0	-	-	-
16*	0	-	-	-
17*	0	-	-	-
18*	0	-	-	-
19*	0	-	-	-
20*	0	-	-	-
21*	0	-	-	-
22*	0	-	-	-
23*	0	-	-	-
24*	0	-	-	-
25*	0	-	-	-
26*	0	-	-	-
27*	0	-	-	-
28*	0	-	-	-
29*	0	-	-	-
30*	0	-	-	-
31*	0	-	-	-
Sep 1	6.75	194	1	195
2	23.77	1,028	13	1,041
3	23.76	1,488	29	1,517
4	23.74	1,383	5	1,388
5*	0	-	-	-
6*	0	-	-	-
7*	0	-	-	-
8*	0	-	-	-
9*	0	-	-	-
10*	0	-	-	-
11	10.91	244	9	253
12	21.83	629	12	641
13	23.51	637	16	653
14	23.61	784	11	795
15	23.63	647	5	652
16	23.63	817	11	828
17	23.73	739	16	755
18	23.35	799	15	814
19	23.43	865	13	878
20	23.58	1,005	15	1,020
21	23.72	847	11	858
22	23.54	996	18	1,014
23	23.62	814	5	819
24	23.55	677	4	681
25	23.62	604	2	606
26	11.85	244	13	257
Total	470.57	15,564	225	15,789

Table 4. Daily adjusted fall chum salmon count, Chandalar River, 1999. Asterisks denote daily count estimated by ratio estimator method (*) or linear interpolation (**).

Date	Left bank	Right bank	Combined	Cumulative	Cumulative (%)
Aug 8	55	94	149	149	0.17
9	89	39	128	277	0.31
10	76**	47**	123	400	0.45
11	63**	56**	119	519	0.59
12	49	65*	114	633	0.71
13	87	116*	203	836	0.94
14	92	122*	214	1,050	1.18
15	158	210*	368	1,418	1.60
16	241	320*	561	1,979	2.23
17	443	589*	1,032	3,011	3.40
18	529	703*	1,232	4,243	4.79
19	852	1,133*	1,985	6,228	7.02
20	974	1,295*	2,269	8,497	9.58
21	1,018	1,354*	2,372	10,869	12.26
22	956	1,271*	2,227	13,096	14.77
23	1,402	1,864*	3,266	16,362	18.45
24	1,310	1,742*	3,052	19,414	21.90
25	1,225	1,629*	2,854	22,268	25.12
26	1,579	2,100*	3,679	25,947	29.27
27	1,560	2,075*	3,635	29,582	33.36
28	1,686	2,242*	3,928	33,510	37.80
29	1,271	1,690*	2,961	36,471	41.13
30	868	1,154*	2,022	38,493	43.42
31	873	1,161*	2,034	40,527	45.71
Sep 1	876	878	1,754	42,281	47.69
2	932	1,042	1,974	44,255	49.91
3	940	1,504	2,444	46,699	52.67
4	1,175	1,396	2,571	49,270	55.57
5	1,595	2,121*	3,716	52,986	59.76
6	2,046	2,721*	4,767	57,753	65.14
7	1,702	2,263*	3,965	61,718	69.61
8	1,191	1,584*	2,775	64,493	72.74
9	748	995*	1,743	66,236	74.71
10	608	809*	1,417	67,653	76.30
11	568	659	1,227	68,880	77.69
12	503	692	1,195	70,075	79.04
13	583	655	1,238	71,313	80.43
14	567	796	1,363	72,676	81.97
15	474	659	1,133	73,809	83.25
16	531	826	1,357	75,166	84.78
17	590	750	1,340	76,506	86.29
18	536	816	1,352	77,858	87.81
19	455	877	1,332	79,190	89.32
20	486	1,024	1,510	80,700	91.02
21	470	854	1,324	82,024	92.51
22	607	1,021	1,628	83,652	94.35
23	663	827	1,490	85,142	96.03
24	672	690	1,362	86,504	97.57
25	495	617	1,112	87,616	98.82
26	622	424	1,046	88,662	100.00
Total	38,091	50,571	88,662		

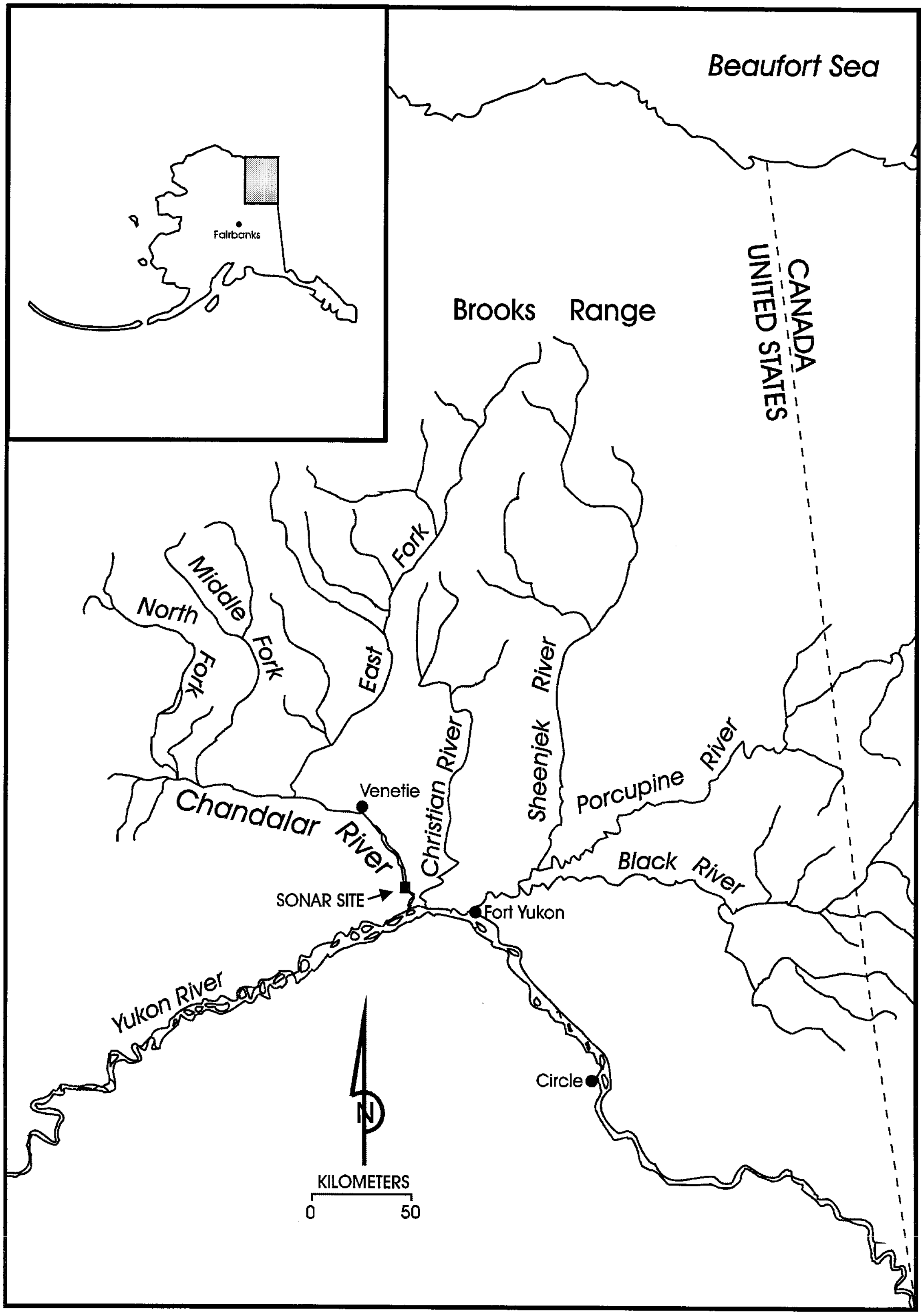

Figure 1. Major tributaries of the Yukon River near the U.S./Canada border.

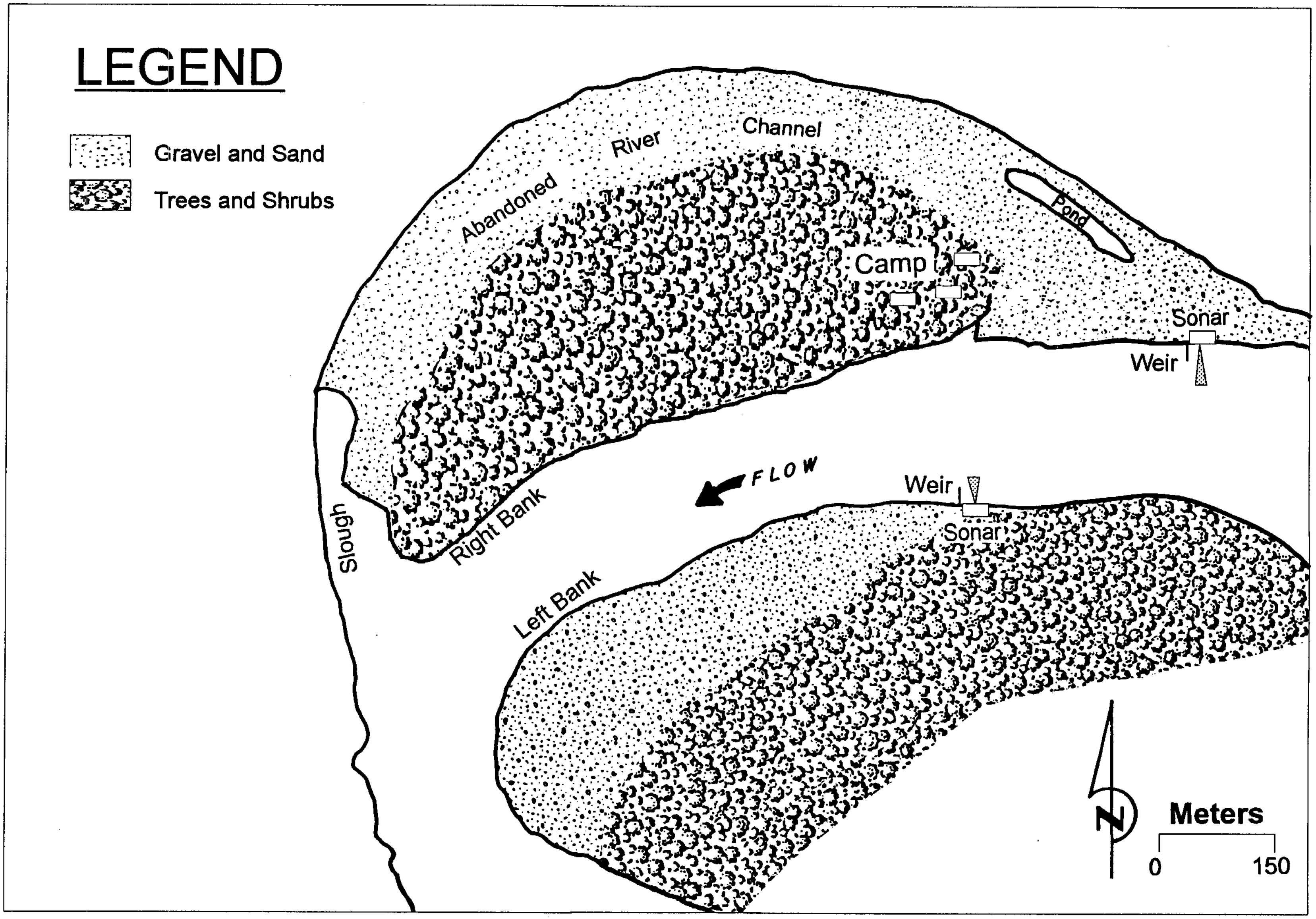

Figure 2. Site map of the Chandalar River sonar facilities, 1999.

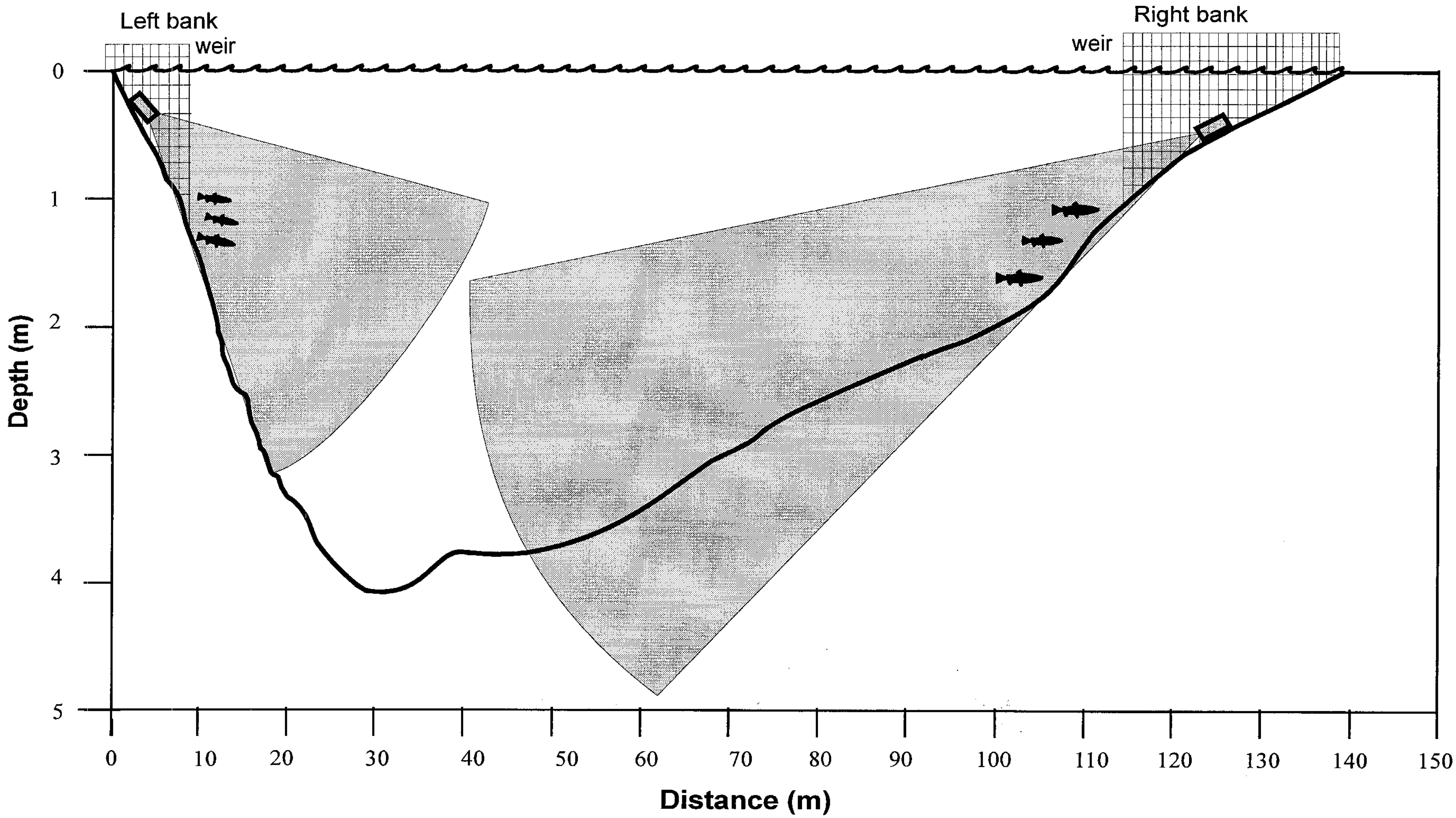

Figure 3. River channel profile and estimated ensonified zones of the left and right banks, Chandalar River, 1999. Different axis scales were used to enhance visibility.

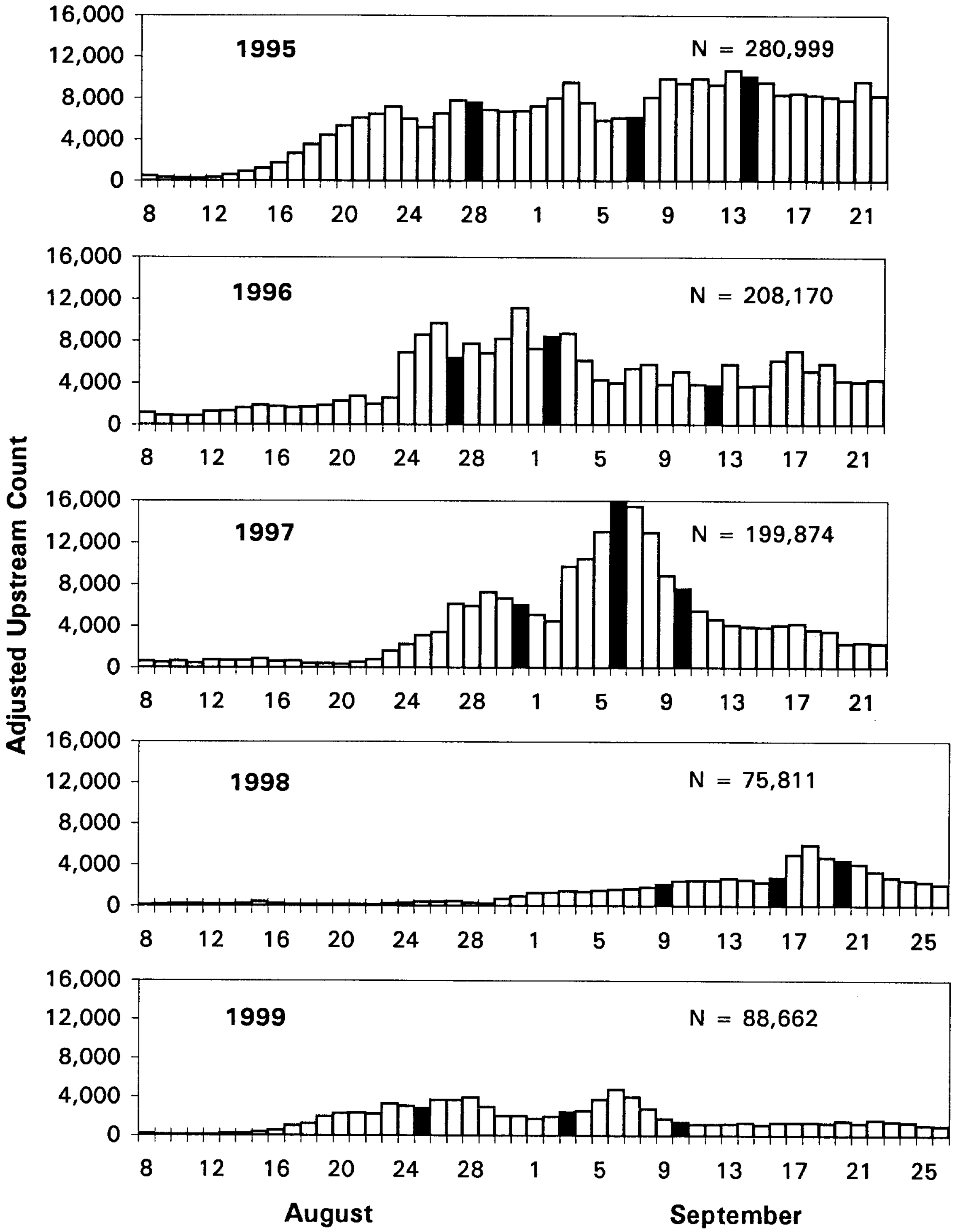

Figure 4. Adjusted daily counts of fall chum salmon, Chandalar River, 1995-1999. Shaded bars represent quartiles of the total count.

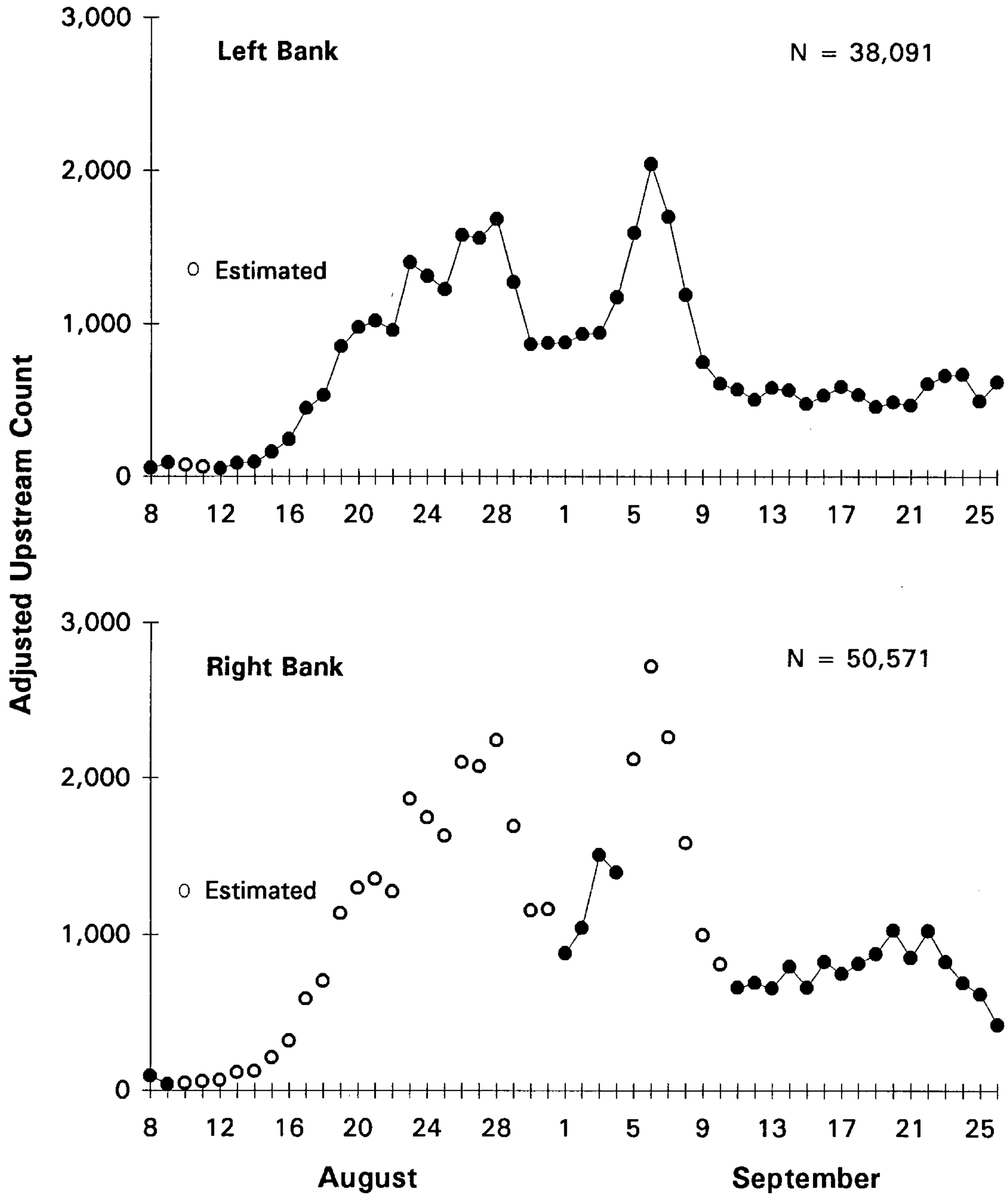

Figure 5. Adjusted daily counts of fall chum salmon by bank, Chandalar River, 1999. Daily counts were estimated for 28 days on the right bank and 2 days on the left bank due to high water.

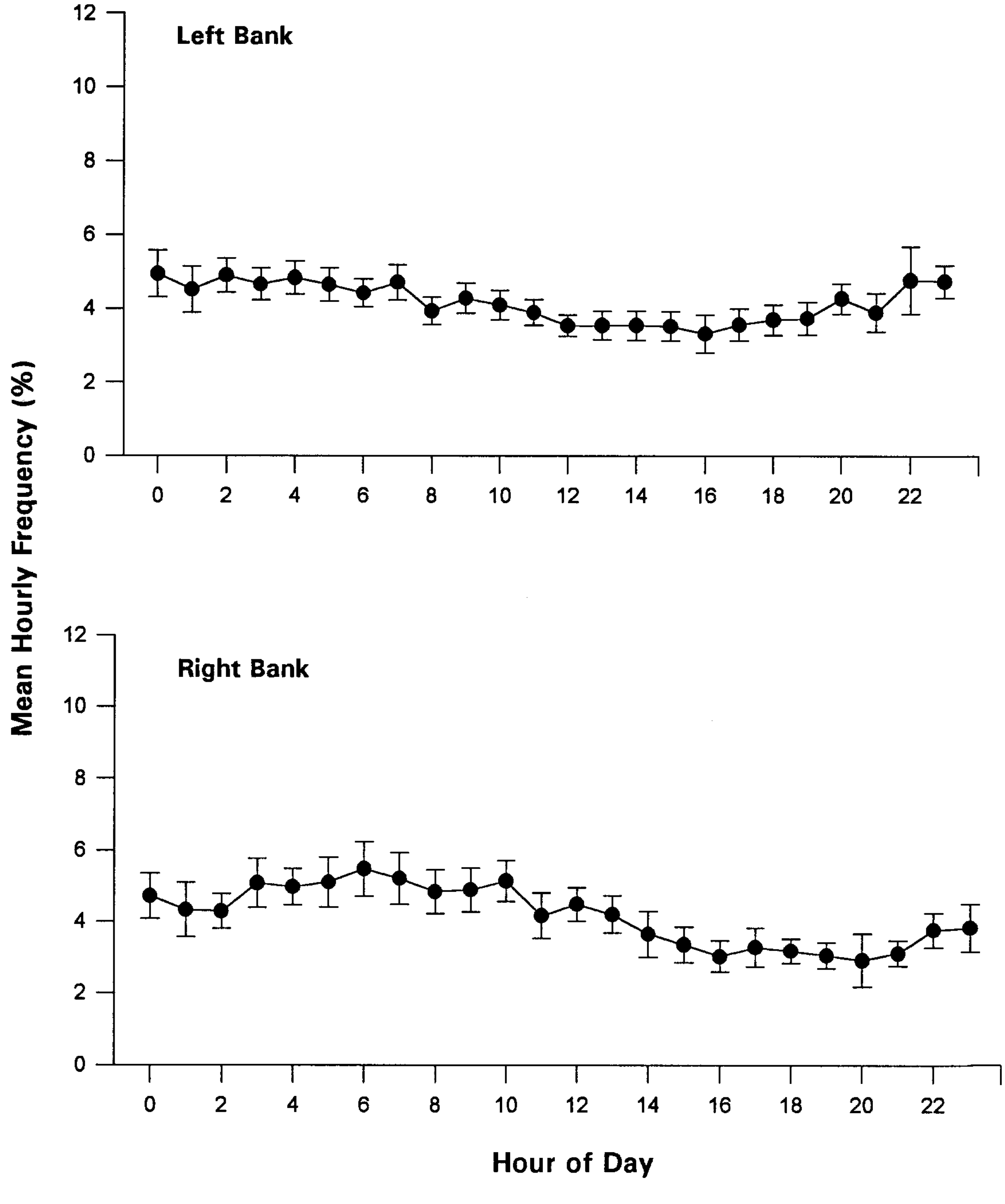

Figure 6. Mean (± 2 SE) hourly frequency of upstream fish, Chandalar River, 1999. Data from 43 days of continuous 24 h data on the left bank and 17 days on the right bank.

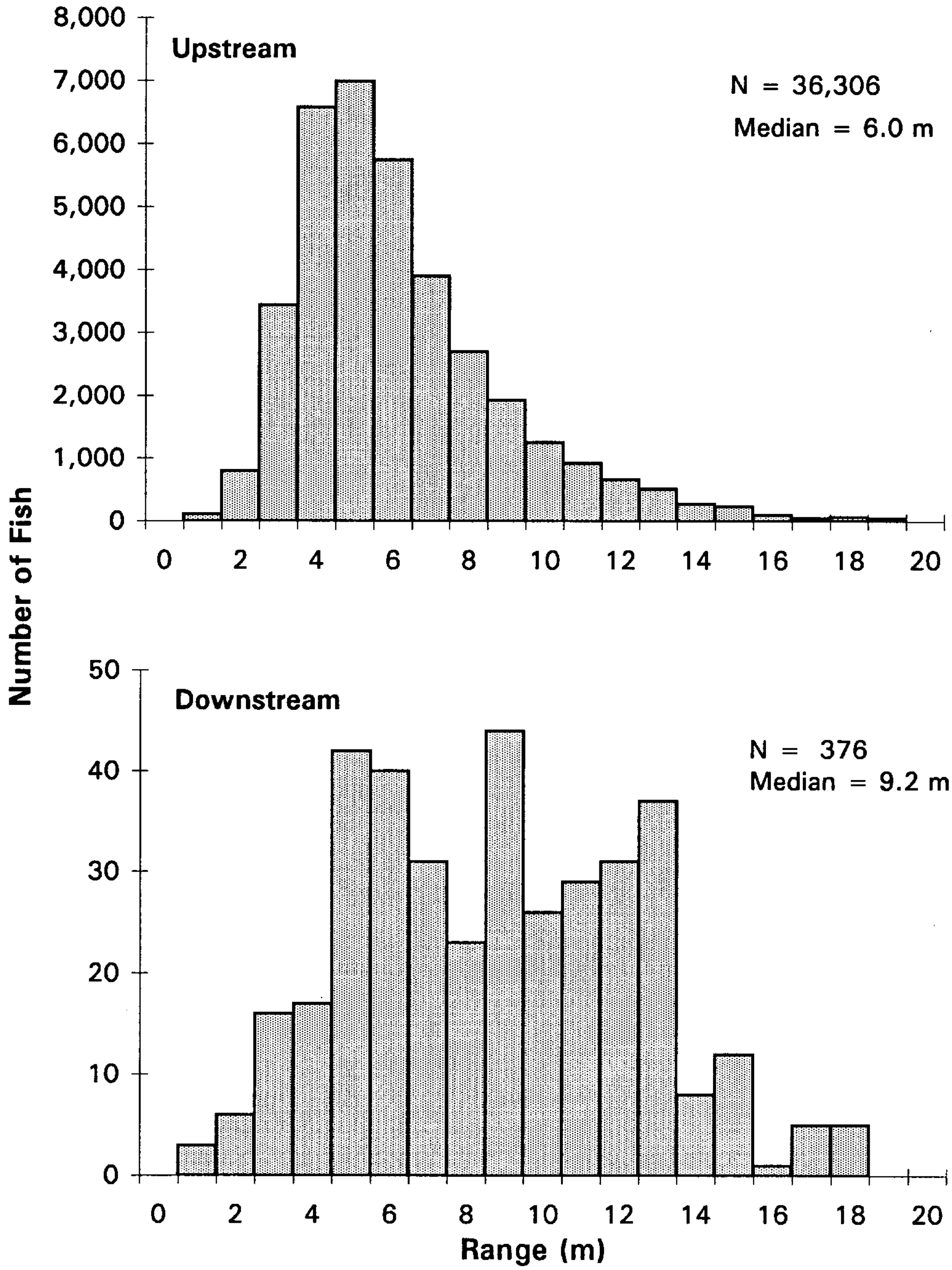

Figure 7. Range (horizontal distance from transducer) distribution of upstream and downstream fish, left bank, Chandalar River, August 8-September 26, 1999.

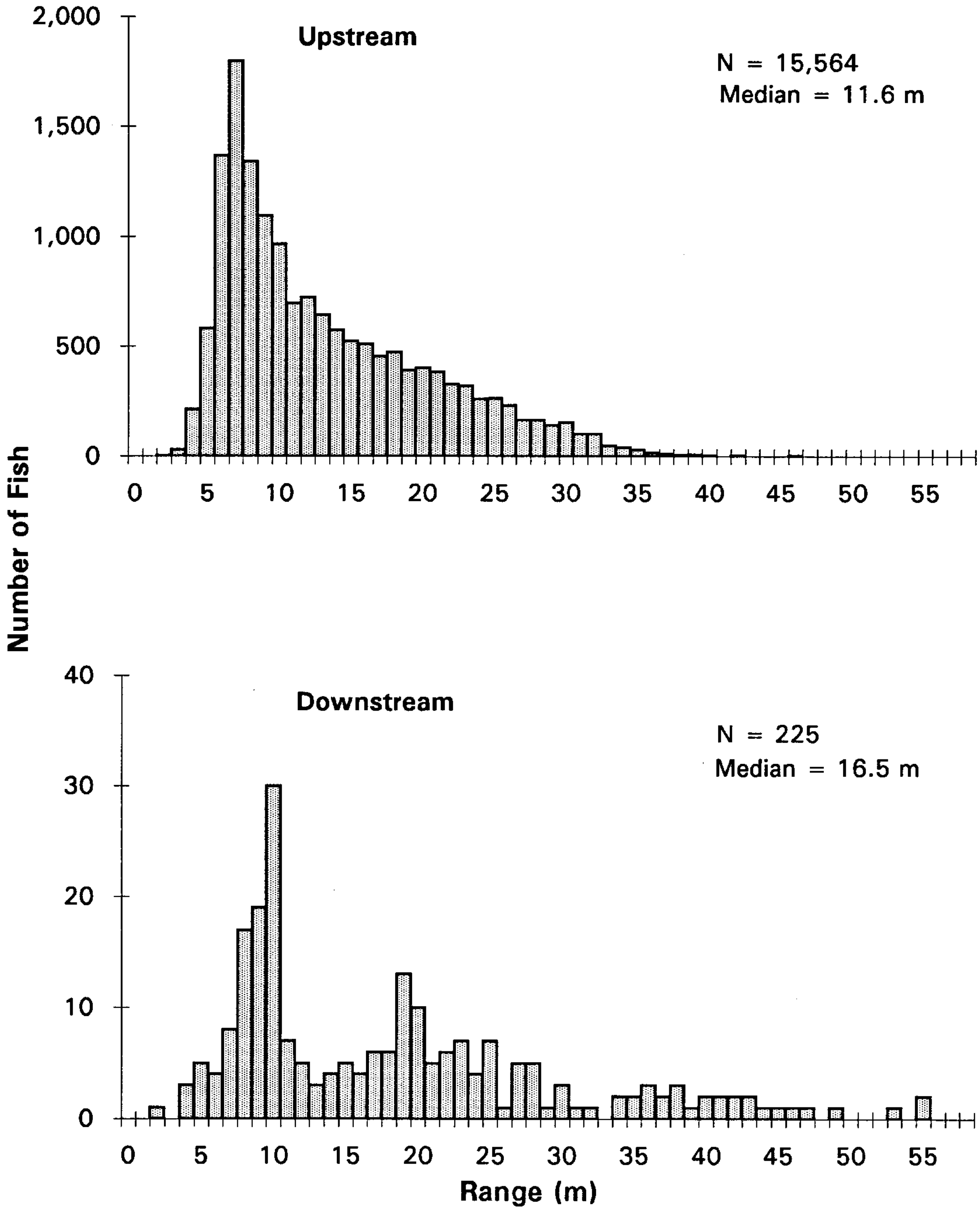

Figure 8. Range (horizontal distance from transducer) distribution of upstream and downstream fish, right bank, Chandalar River, August 8-September 26, 1999.

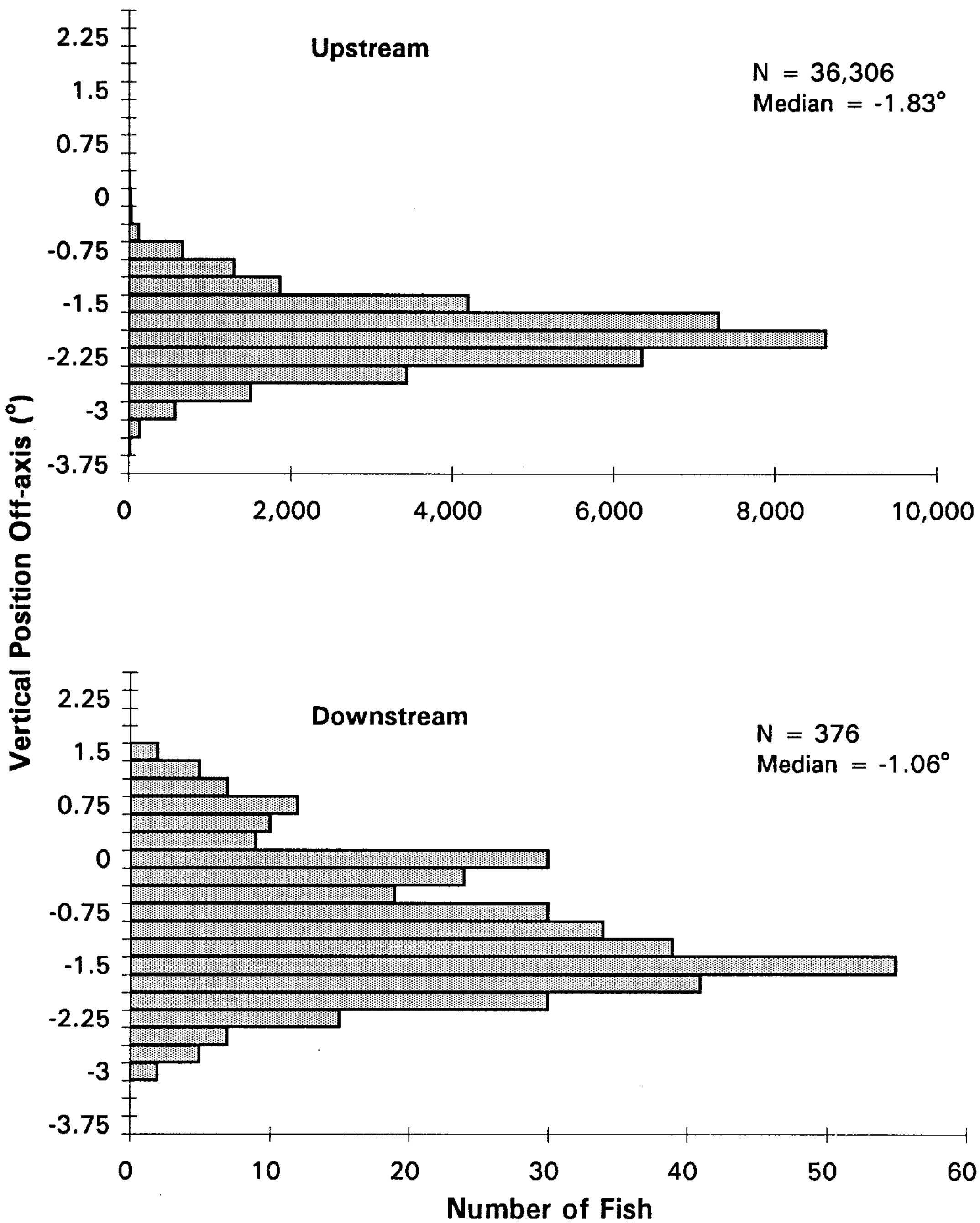

Figure 9. Vertical distribution of upstream and downstream fish, left bank, Chandalar River, August 8-September 26, 1999.

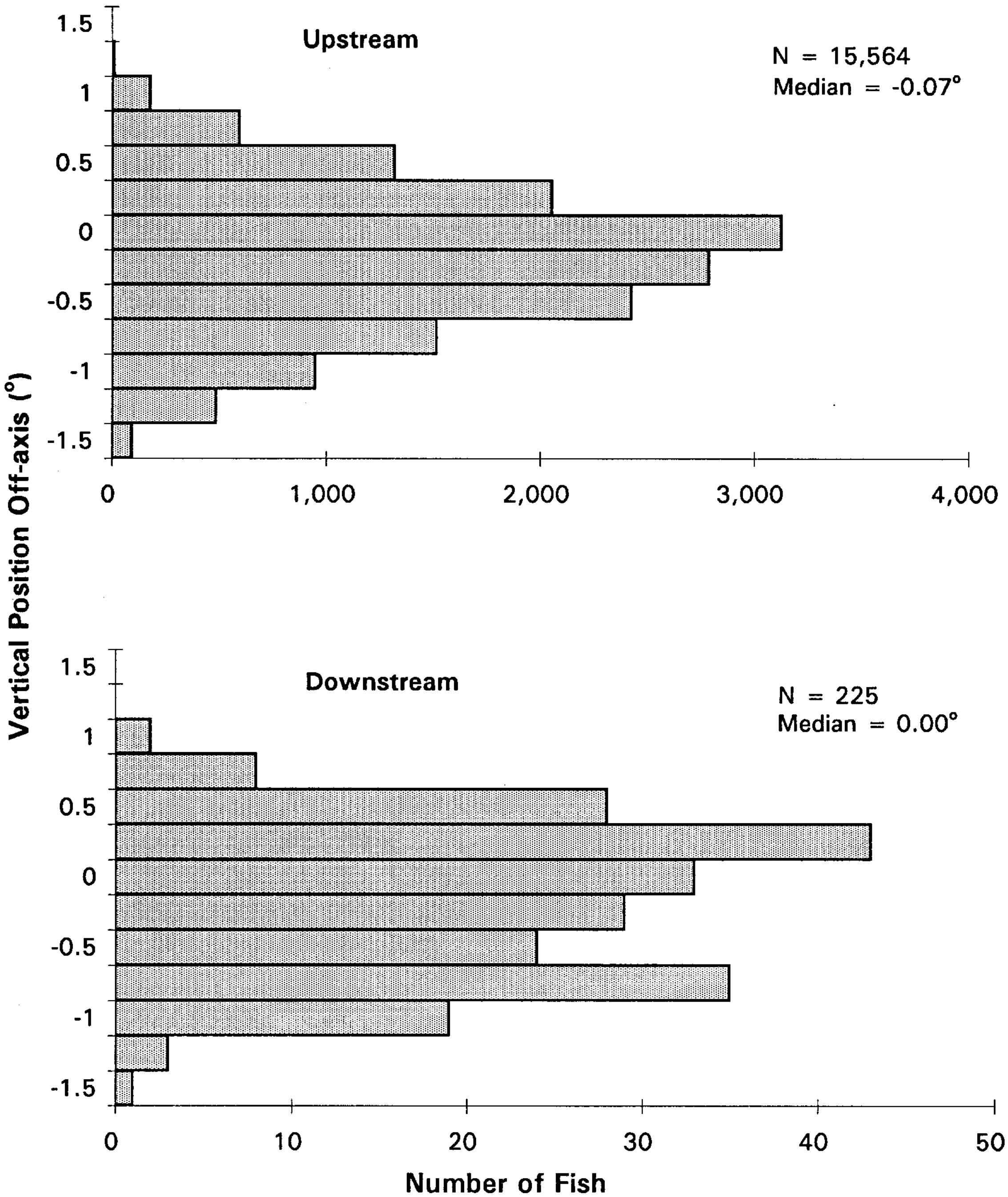

Figure 10. Vertical distribution of upstream and downstream fish, right bank, Chandalar River, August 8-September 26, 1999.

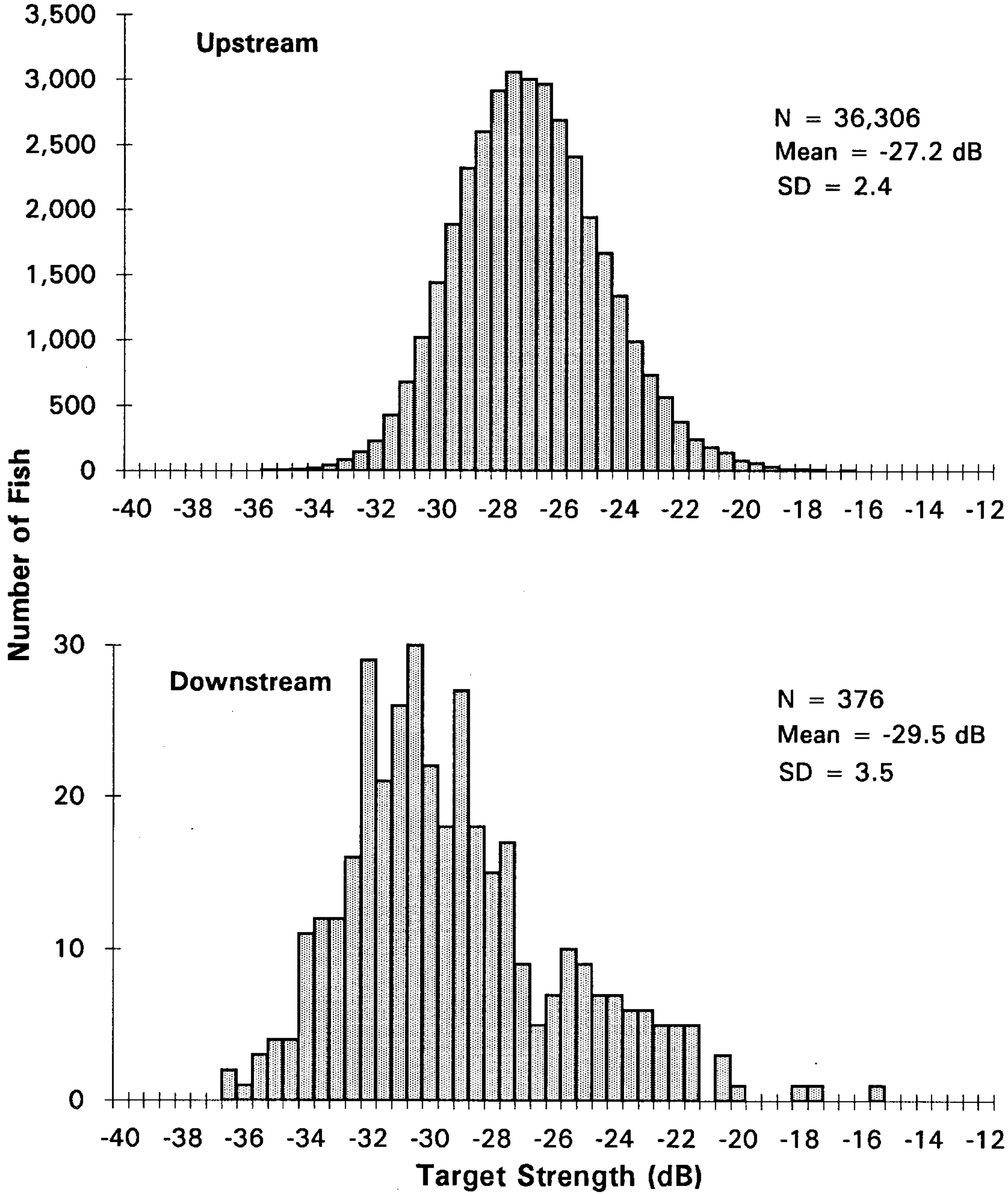

Figure 11. Target strength distribution of upstream and downstream fish, left bank, Chandalar River, August 8-September 26, 1999.

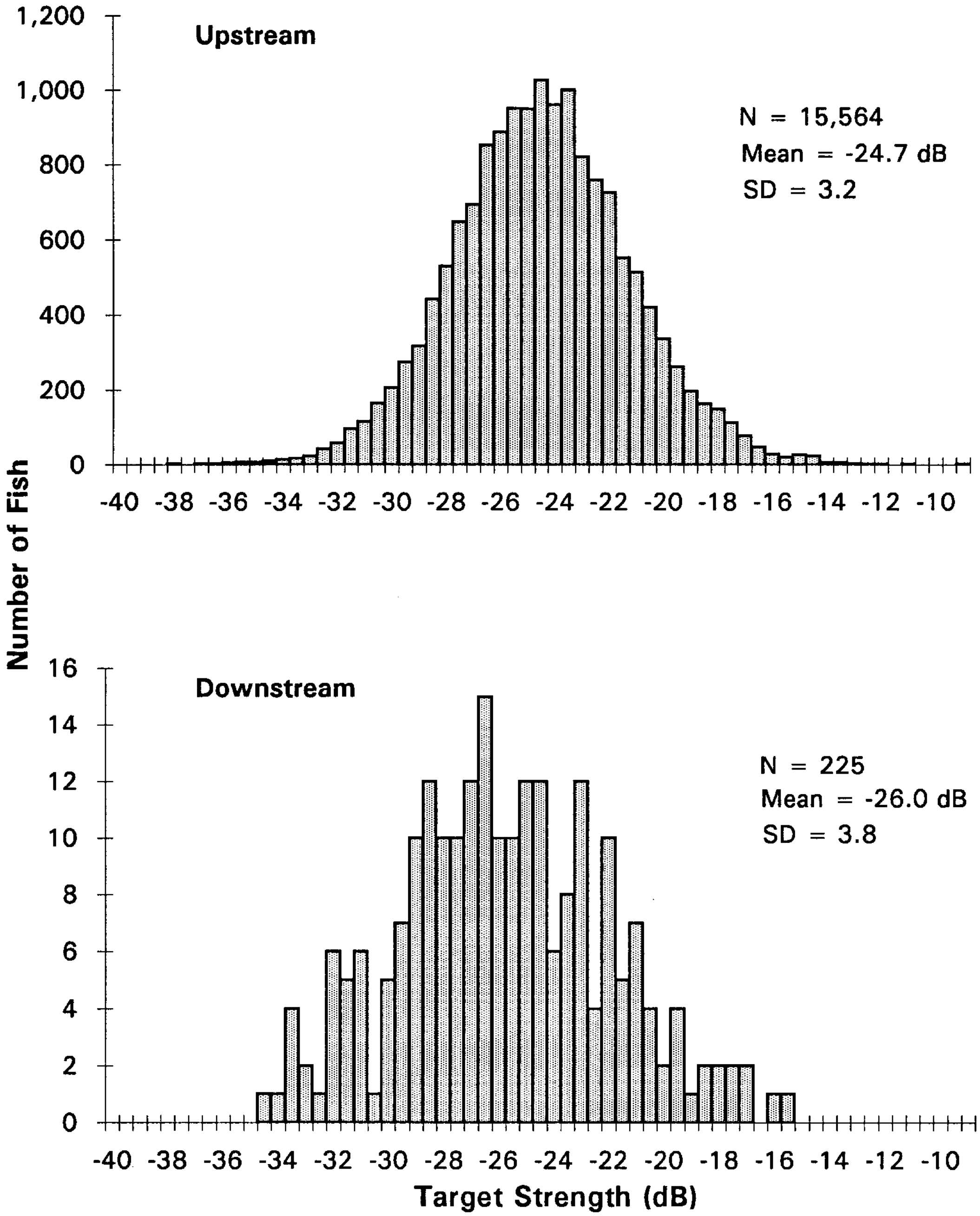

Figure 12. Target strength distribution of upstream and downstream fish, right bank, Chandalar River, August 8-September 26, 1999.

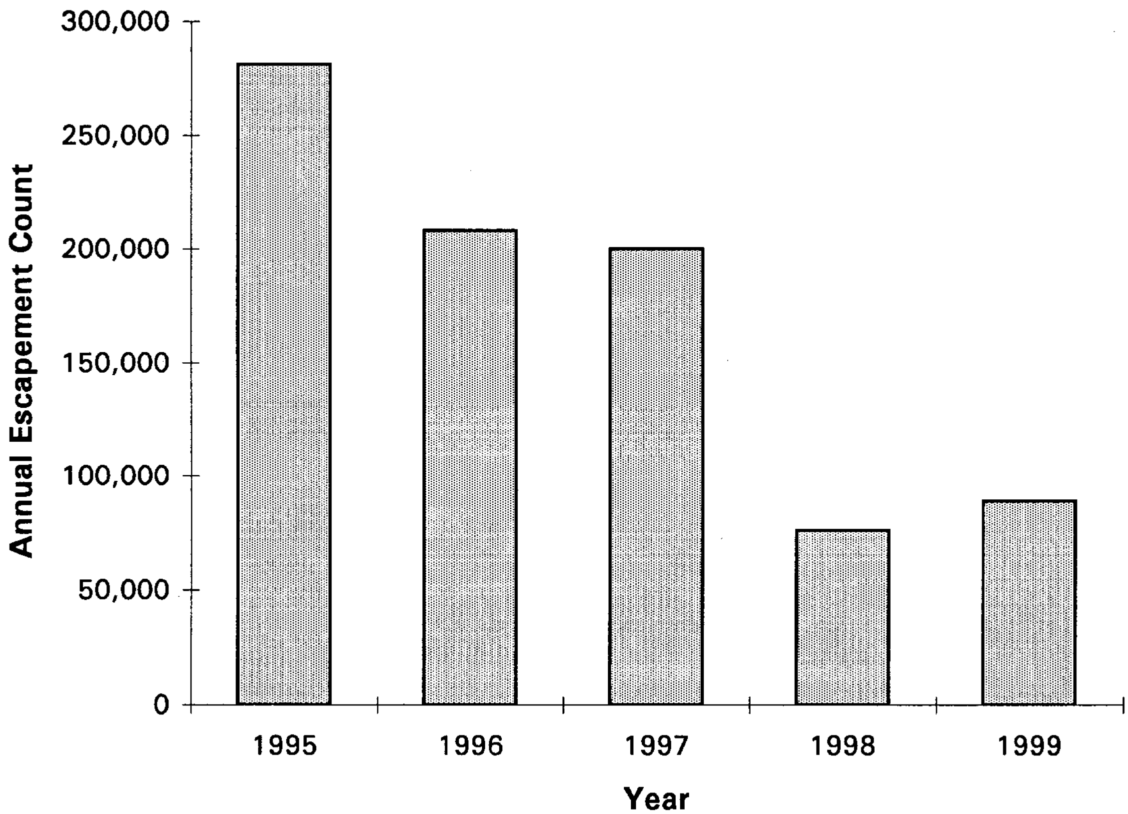

Figure 13. Annual sonar escapement counts of fall chum salmon, Chandalar River, 1995-1999.

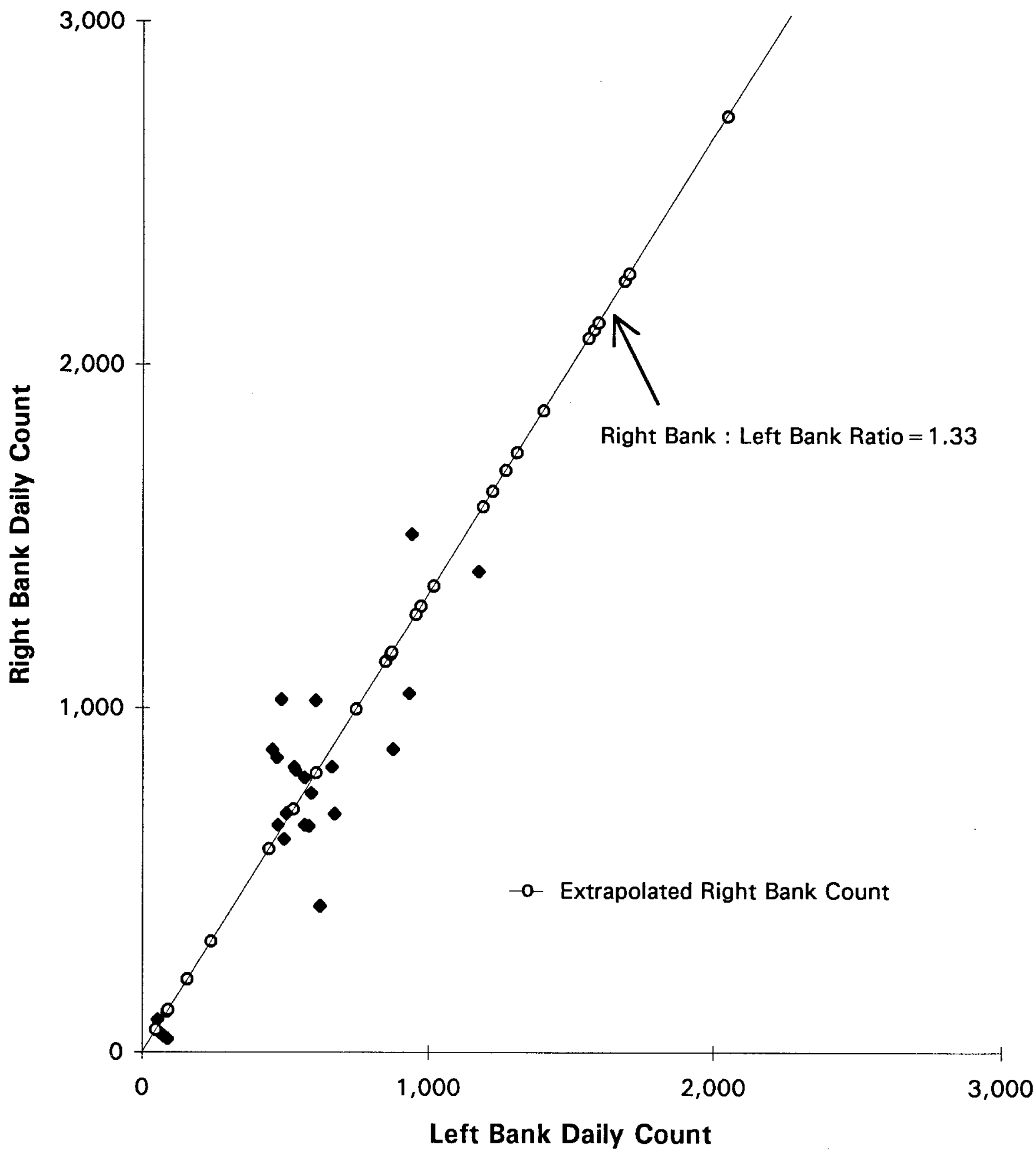

Figure 14. Relationship of right bank to left bank adjusted daily counts of fall chum salmon, Chandalar River, August 8-September 26, 1999. Missing right bank counts were extrapolated from left bank counts using the ratio estimator method (Cochran 1977).

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		

Appendix 3. 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		

Appendix 4. Daily adjusted fall chum salmon count, Chandalar River, 1998. Asterisks denote daily estimate by ratio estimator method* and linear interpolation**.

Date	Left bank	Right bank	Combined	Cumulative	Cumulative (%)
Aug 8	56	34	90	90	0.12
9	105	47	152	242	0.32
10	90	125*	215	457	0.60
11	79**	110**	189	646	0.85
12	68**	94**	162	808	1.07
13	57	79*	136	944	1.25
14	113	157*	270	1,214	1.60
15	165	230*	395	1,609	2.12
16	98	137*	235	1,844	2.43
17	67	93*	160	2,004	2.64
18	66	92*	158	2,162	2.85
19	63	88*	151	2,313	3.05
20	58	81*	139	2,452	3.23
21	59	82*	141	2,593	3.42
22	70	98*	168	2,761	3.64
23	114	159*	273	3,034	4.00
24	133	185*	318	3,352	4.42
25	167	233*	400	3,752	4.95
26	176	245*	421	4,173	5.50
27	203	283*	486	4,659	6.15
28	138	192*	330	4,989	6.58
29	114	159*	273	5,262	6.94
30	272	379*	651	5,913	7.80
31	383	534*	917	6,830	9.01
Sep 1	514	716*	1,230	8,060	10.63
2	552	769*	1,321	9,381	12.37
3	608	847*	1,455	10,836	14.29
4	576	803*	1,379	12,215	16.11
5	629	876*	1,505	13,720	18.10
6	681	949*	1,630	15,350	20.25
7	700	975*	1,675	17,025	22.46
8	762	1,062*	1,824	18,849	24.86
9	889	1,239*	2,128	20,977	27.67
10	1,015	1,414*	2,429	23,406	30.87
11	1,046	1,457*	2,503	25,909	34.18
12	1,282	1,230	2,512	28,421	37.49
13	1,203	1,520	2,723	31,144	41.08
14	1,145	1,379	2,524	33,668	44.41
15	1,066	1,207	2,273	35,941	47.41
16	1,091	1,656	2,747	38,688	51.03
17	1,848	3,151	4,999	43,687	57.63
18	2,173	3,762	5,935	49,622	65.45
19	2,004	2,727	4,731	54,353	71.70
20	1,744	2,657	4,401	58,754	77.50
21	1,661	2,392	4,053	62,807	82.85
22	1,492	1,837	3,329	66,136	87.24
23	1,282	1,456	2,738	68,874	90.85
24	993	1,505	2,498	71,372	94.14
25	962	1,374	2,336	73,708	97.23
26	844	1,259	2,103	75,811	100.00
Total	31,676	44,135	75,811		