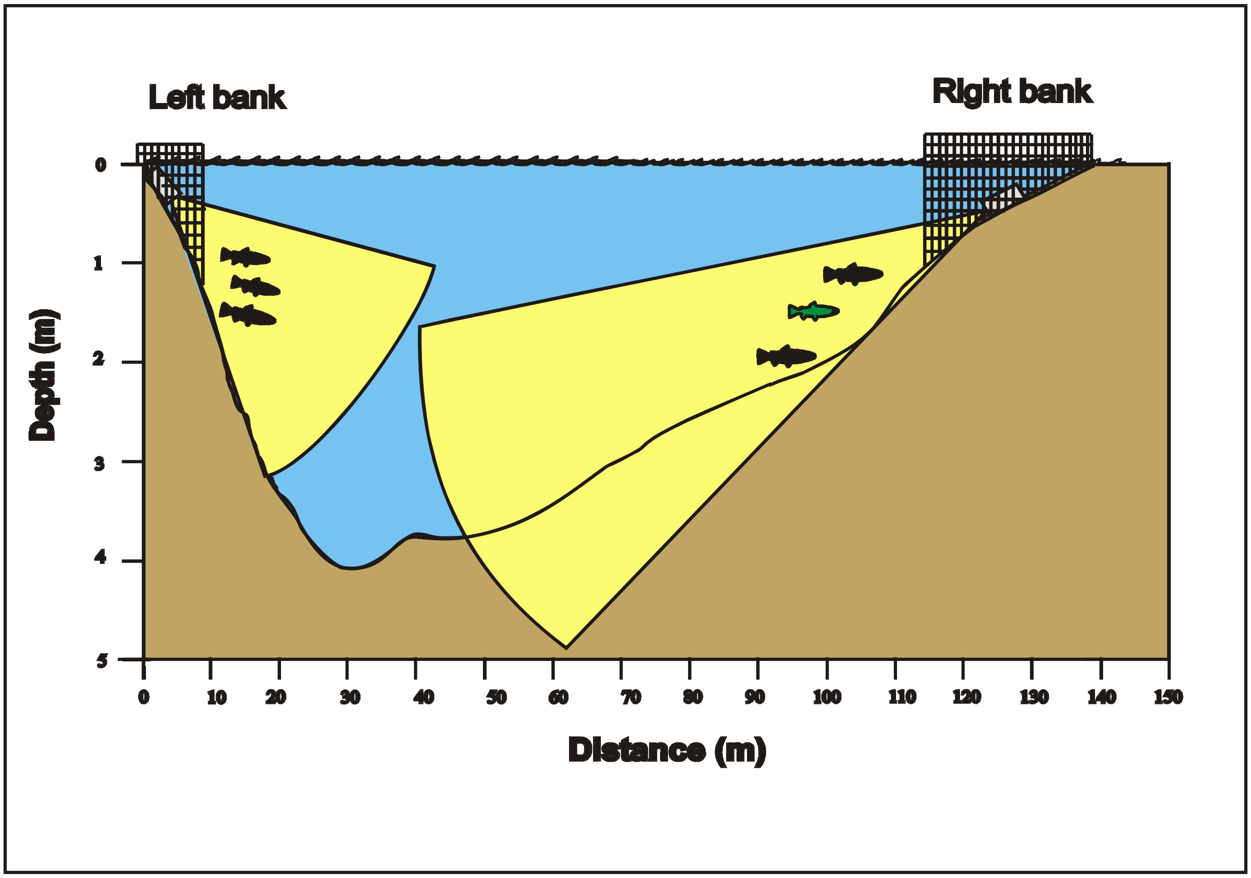
U.S. Fish & Wildlife Service

Use of Split-beam Sonar to Enumerate Fall Chum Salmon in the Chandalar River, Yukon Flats National Wildlife Refuge, Alaska, 2001

Alaska Fisheries Data Series Number 2006–6



Fairbanks Fish and Wildlife Field Office
Fairbanks, Alaska
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Bruce M. Osborne and Jeffery L. Melegari

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 have been provided since 1996. This report presents the results for the 2001 season and describes the annual variability in run size and timing. Sonar operation began on August 8 and continued through September 26. High water during August 18-20 resulted in 3 days of missed sampling on the right bank. A total of 2,208 hours of digital echo processor data were collected, resulting in 99,901 fish manually tracked. Upstream-traveling fish accounted for 98.1% of the total tracked targets. An estimated 110,971 ± 5,707 (95% confidence interval) fall chum salmon migrated upriver past the sonar. The count represents a conservative estimate of total escapement because it only included fish that passed during sonar operation. The passage rate (adjusted count) was 454 upstream fish on the first day of counting (0.4% of the total estimated count) and 440 fish on the final day (0.4% of the total). The median passage date (September 3) occurred 3 days earlier than the average (1995-2000) median passage date. Migrating chum salmon were shore-oriented and traveled close to the river bottom. Positional data suggested that most fish were detected by the sonar because few targets were observed near the vertical or outer range limits of acoustic detection. Target strength distributions, spatial positioning, and chart/tracked fish comparisons corroborated the assumption that few fish were missed due to the voltage threshold settings used for processing acoustic data. Underwater video monitoring and beach seining revealed the presence of schools of least cisco *Coregonus sardinella* in significant numbers during the second week of September. These data along with sonar trace patterns identified during 2000 were used to omit least cisco from the data during in-season tracking. No counts were generated for species other than chum salmon.

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, and monitoring long-term population trends. Weirs, counting towers, mark-recapture programs, ground surveys, and hydroacoustics are methods used to obtain escapement estimates of specific Yukon River salmon stocks (Bergstrom et al. 1999).

The Yukon River drainage encompasses 854,700 km^2 and is among the largest producers of wild Chinook salmon *Oncorhynchus tschawytscha* and chum salmon *O. keta* in North America (Daum and Osborne 1995). The salmon resources of this unique river support important

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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 within national wildlife refuge lands are conserved in their natural diversity, international treaty obligations are met, and subsistence opportunities are maintained. An important component of these mandates is to provide 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 of fall chum salmon during this period averaged 58,628, ranging from 33,619 to 78,631 fish.

Because Chandalar River fall chum salmon are important as a wildlife and subsistence resource, 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. Since 1994 these same main objectives have been retained.

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). During 1995, daily and seasonal estimates of spawning escapement were calculated 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 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). The estimate for 1999 was 88,662, only 46% of the 1995-1998 average (Appendix 5; Daum and Osborne 2000). The 2000 estimate of 65,894 is the lowest estimate with split-beam to date (Appendix 6; Osborne and Melegari 2002). This report presents the escapement information from the 2001 season and describes annual variability in run size and timing.

During the later part of the 2000 season, an underwater video camera was used to investigate the appearance of atypical sonar traces. This investigation revealed the presence of least cisco *Coregonus sardinella*. Post season comparison of video images and sonar data led to re-tracking of files to exclude these atypical traces. Since 2000 we have used trace pattern identification, and information from video monitoring, and beach seining to omit least cisco from our tracking in-season.

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, located at river km 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 an 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 2.4˚ on the right bank. River substrate consisted of small rounded cobble/gravel on the left bank and sand/silt on the right bank. During the 2001 season, river width at the site averaged 136 m (ranging from 132 to 149 m) and maximum depth averaged 4.3 m (ranging from 4.1 to 5.0 m). Water temperature ranged from 13° to 4° C, and generally decreased 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).

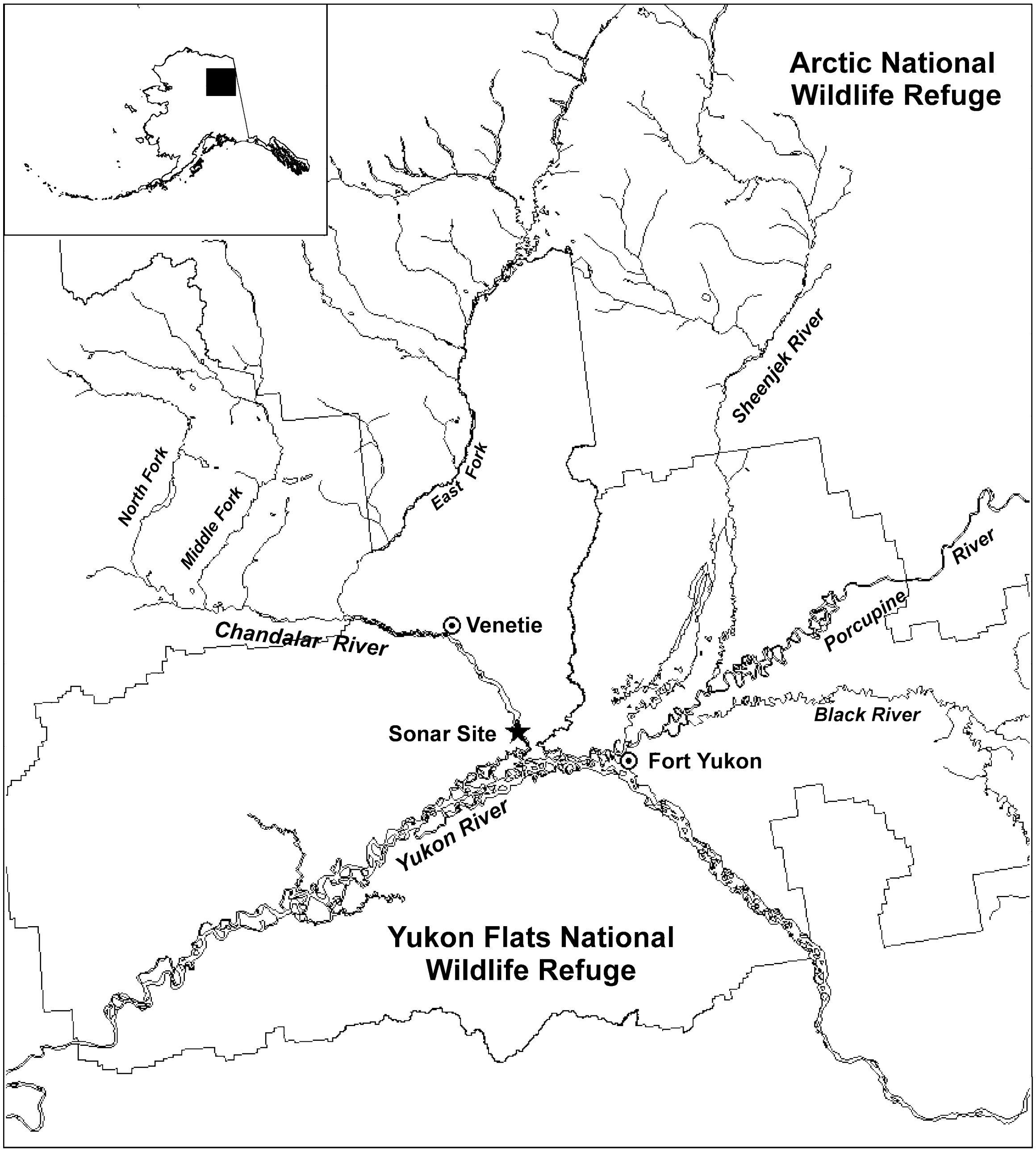

Figure 1.─ Sonar site and major tributaries of the Yukon River near U.S. Canada border.

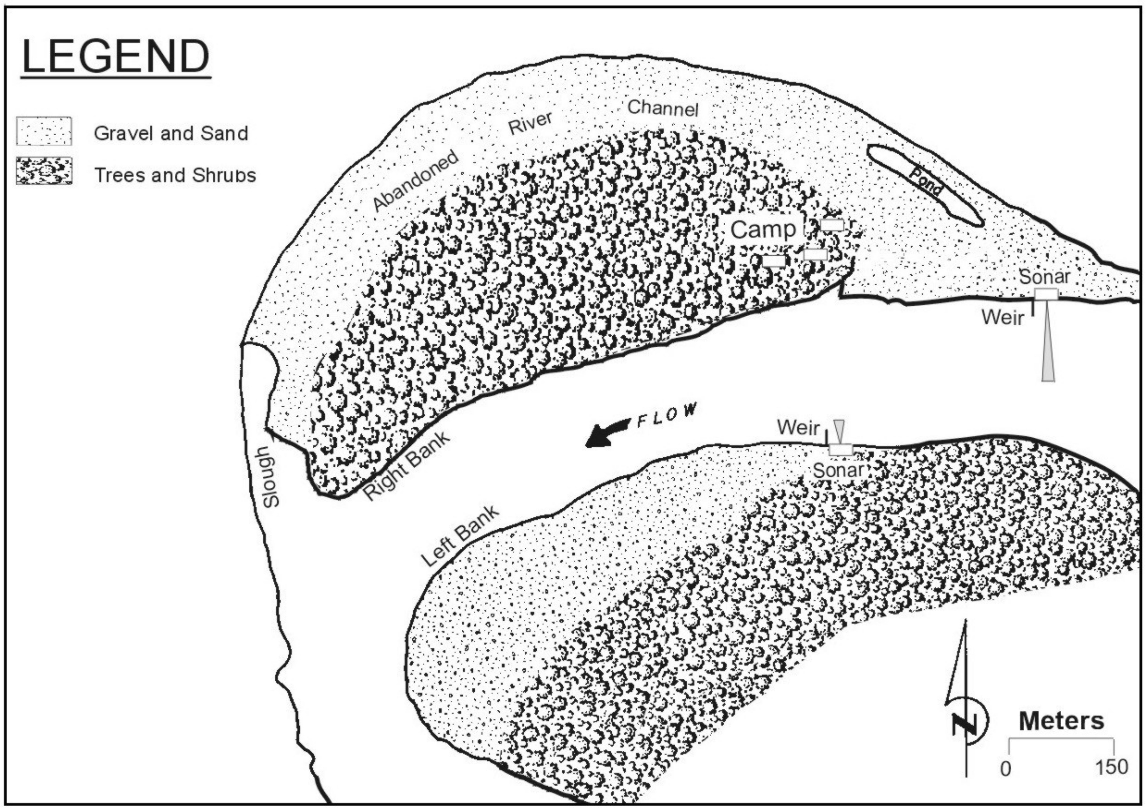

Figure 2.─ Site map of Chandalar River sonar facilities.

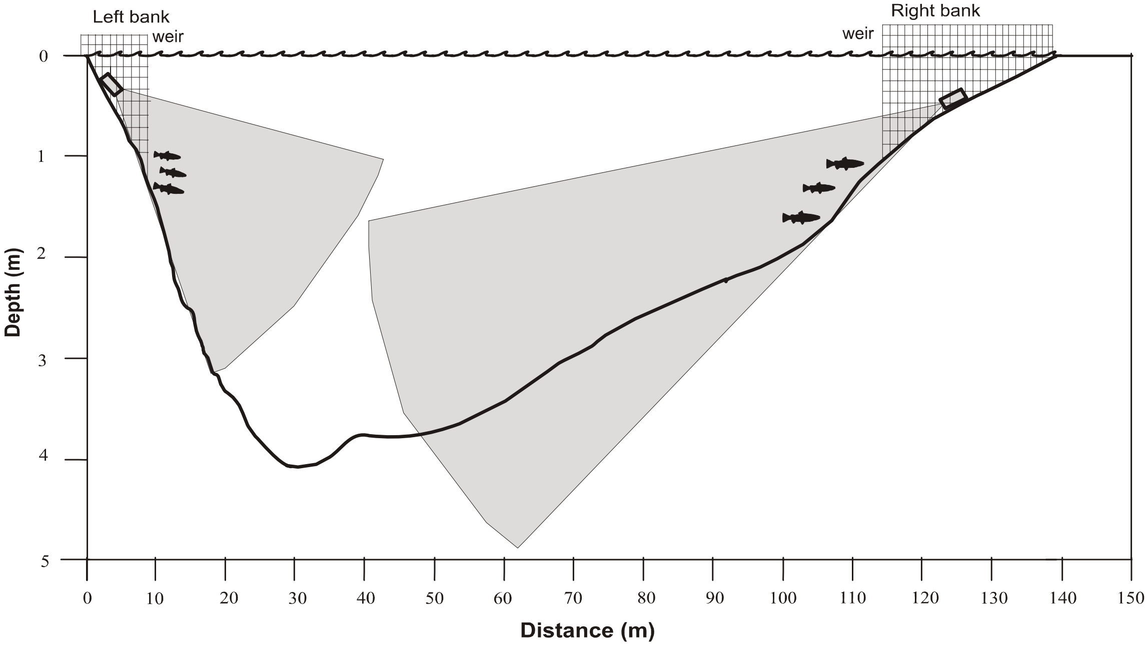

Figure 3.─ River channel profile and estimated ensonified zones of the left and right banks, Chandalar River, 2001. Different axis scales are used to enhance readability.

Methods

Data Collection

From August 8 through September 26 fixed-location, split-beam hydroacoustics was used to monitor the upstream migration of adult fall chum salmon in the Chandalar River. Systems were installed on opposite river banks to optimize sonar beam coverage of the river's cross-sectional area.

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 and 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, 2000) 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 4.0 dB of factory calibrated values.

Echo sounder settings differed between banks. Left bank settings were: 10 dBW transmit power; 3 dBV total receiver gain; 40log10(R) time-varied gain function, where R = target range (m); 0.2 ms pulse width; and 10 pings/s. Right bank settings, using FM slide, were: 25 dBW transmit power; 18 dBV total receiver gain; 40log10(R) time-varied gain function; 0.18 ms pulse width (compressed); and 6.25 pings/s. 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 -66 to -48 dB for the left bank and -57 to -39 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 12 to 19 m; the final 12 m distance to the thalweg was not ensonified due to a change in slope of the river bottom. Right bank beam coverage was 50 to 75 m throughout the season, with approximately 15 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.

Table 1.— Echo acceptance criteria used for digital echo processing, Chandalar River, 2001. 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	12 to 19
Right	0.00 to 0.38	-1.50 to 1.50	-4.87 to 4.87	-40[a]	50 to 75

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

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 -34 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 2001 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 2.1° by 9.7°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 23.6 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 frame 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. During aiming, a target was used to align the lower edge of the beam with the river bottom. Chart recordings, oscilloscope readings, and real-time positional displays of passing fish from the digital echo processor were used to monitor transducer aiming. The low acoustic reflectivity of right bank substrate (silt and sand) allowed the right bank transducer to be aimed slightly into the bottom, enhancing detection of bottom-oriented fish. 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.

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.

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 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 (>15min and < 60 min) were standardized to 1 h, using

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

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

Fish counts from missing hours were extrapolated from seasonal mean hourly passage rates. Seasonal mean hourly passage rates were calculated from days with 24 h of continuous data (40 days on the right bank, and 42 days on the left 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. Estimated fish counts for missing hours were calculated, using

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

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, the 3 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). For the season, total escapement was calculated by summing all estimated daily counts. 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 allow assessment of the likelihood of failing to detect fish that pass above, below, or beyond the detection range of the sonar beam. Spatial information also furnishes insight into behavioral differences between upstream and downstream-swimming fish. During 2001 on the right bank an equipment malfunction produced an error in the vertical position data. The source of this error was unable to be determined. Through target acquisition tests, and consultation with the equipment manufacturer (HTI) it was determined that this error would not significantly affect our ability to count salmon. However this error caused the vertical position data, as well as target strength data for right bank to be inaccurate, and analysis of these data could not be completed for right bank.

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

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

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 distributions of upstream and downstream fish were plotted for the season. Vertical distributions were plotted for left bank 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. For upstream and downstream fish on left bank, target strength distributions were plotted for the season, and mean target strengths were compared using a two-sample t test for means with unequal variances (Zar 1984).

Species Identification

During previous years, all upstream-swimming fish were assumed to be chum salmon based on five previous seasons of gill net (30.5 m long, 3.7 m deep, with stretch mesh sizes of 11.4 and 14.9 cm) catches that consisted of more than 99% chum salmon (Daum and Osborne 1996). However, during 2000 while investigating the appearance of atypical sonar traces, schools of least cisco were detected with an underwater video camera. Approximately 60 hours of video were recorded. During post-season analysis, the fish in these video images were compared to the corresponding sonar traces. This allowed identification of sonar trace patterns that were indicative of schools of least cisco. These sonar trace patterns were used to remove least cisco from the 2000 data set post season.

During 2001 a video monitoring system was deployed on the left bank to monitor a portion of the ensonified area. This system consisted of four 1/3" CCD submergible video cameras (Lorex Pro model CVC6990), a four channel multiplexor, a 24h realtime/48h time lapse video recorder (Lorex SG7924R), and 2 video monitors. All four cameras were attached, 0.75m apart, to a single steel rod to create an array. Maximum range (visibility) of the cameras varied slightly with changes in water clarity and light levels, ranging from approximately 0.5-2 m, however data was not used when visibility was <1m. The area of coverage was approximately 4 m wide x .9 m high at 2 m visibility and 3.25 m wide x .45 m high at 1 m visibility. The camera array was positioned along the upstream edge of the sonar beam looking downstream into the beam. Both real time monitoring of the video, and in-season review of video tapes were used to evaluate the presence of non-salmon species. Additionally a 90 m x 3.7 m 2.5 cm mesh beach seine was used to evaluate presence of non-salmon species. These data along with the sonar trace patterns identified during 2000 were used to omit least cisco from the data during in-season tracking.

Results

Acoustic Data Verification and Fish Tracking

During the 2001 season, 2,208 hours of acoustic data were collected and 99,901 fish were manually tracked (Tables 2 and 3). Upstream-traveling fish accounted for 98.1% of the total fish tracked. On the left bank, 94% of the season was monitored, with no complete days missed, and on the right bank 90% of the season was monitored, with 3 days missed due to high water.

Due to the error in vertical position data, and off axis filtering criteria, the number of acquired echoes for the right bank would be erroneous. Therefore echoes per fish data were not analyzed for the right bank. For the left bank, the median number of acquired echoes per fish was 21 (range = 4-423) for upstream fish, and 16 (range = 4-194) for downstream fish.

Acoustic Data Analyses

Escapement estimate and run timing — The 2001 fall chum salmon escapement estimate for the Chandalar River was 110,971 upstream fish (Table 4) with a 95% confidence interval of ± 5,707. The right bank accounted for 82% of the total escapement estimate. The estimate is a conservative estimate of total escapement because counts did not include fish that passed before or after the sonar was operated. The adjusted count was 454 upstream fish on the first day of sonar operation (0.4% of the total seasonal count), and 440 fish on the final day of counting (0.4% of the total). Daily adjusted counts were more than 2,000 fish/d for 30 of the 50 counting days. Daily upstream passage rates indicated a bimodal run, and peak daily counts within each mode were 7,024 and 4,437 fish during August 18 and September 7 respectively.

Table 2.─ Hydroacoustic data collected from the left bank, Chandalar River, 2001.

Date	Sample time (h)[a]	Upstream count	Downstream count	Total count
Aug-08	23.99	178	0	178
Aug-09	24.00	159	0	159
Aug-10	24.00	125	0	125
Aug-11	23.25	96	0	96
Aug-12	24.00	124	0	124
Aug-13	24.00	123	1	124
Aug-14	24.00	191	3	194
Aug-15	24.00	322	8	330
Aug-16	21.11	399	1	400
Aug-17	24.00	660	12	672
Aug-18	23.08	2,206	9	2,215
Aug-19	22.92	1,613	12	1,625
Aug-20	24.00	1,011	13	1,024
Aug-21	24.00	760	10	770
Aug-22	23.56	481	8	489
Aug-23	24.00	488	0	488
Aug-24	22.99	383	7	390
Aug-25	23.05	367	4	371
Aug-26	23.72	260	12	272
Aug-27	24.00	291	1	292
Aug-28	24.00	241	0	241
Aug-29	24.00	553	4	557
Aug-30	23.89	205	2	207
Aug-31	24.00	284	3	287
Sep-01	23.99	420	1	421
Sep-02	24.00	316	3	319
Sep-03	15.68	207	1	208
Sep-04	24.00	580	2	582
Sep-05	24.00	757	4	761
Sep-06	23.98	240	4	244
Sep-07	24.00	510	17	527
Sep-08	23.08	387	21	408
Sep-09	24.00	625	19	644
Sep-10	23.12	350	24	374
Sep-11	22.00	238	14	252
Sep-12	13.00	159	9	168
Sep-13	23.14	327	10	337
Sep-14	23.87	230	7	237
Sep-15	23.88	218	15	233
Sep-16	23.85	266	10	276
Sep-17	22.50	313	12	325
Sep-18	24.00	187	23	210
Sep-19	23.85	202	6	208
Sep-20	23.85	190	13	203
Sep-21	23.94	200	7	207
Sep-22	23.92	247	5	252
Sep-23	23.92	285	10	295
Sep-24	22.52	185	27	212
Sep-25	23.89	230	18	248
Sep-26	11.95	149	11	160
Total	1,127.49	19,050	403	19,453

[a] Times are recorded to the nearest second by the computer, then converted to decimal hours.

Table 3.─ Hydroacoustic data collected from the right bank, Chandalar River, 2000. Asterisks represent days when data collection did not occur due to high water.

Date	Sample time (h)[a]	Upstream count	Downstream count	Total count
Aug-08	23.47	272	0	272
Aug-09	23.57	204	3	207
Aug-10	23.84	228	10	238
Aug-11	23.93	218	3	221
Aug-12	23.42	258	4	262
Aug-13	23.63	194	2	196
Aug-14	21.88	408	3	411
Aug-15	22.36	611	6	617
Aug-16	20.78	728	7	735
Aug-17	19.83	803	13	816
Aug-18*	0	-	-	-
Aug-19*	0	-	-	-
Aug-20*	0	-	-	-
Aug-21	23.81	1,805	16	1,821
Aug-22	23.82	1,791	13	1,804
Aug-23	23.84	2,401	36	2,437
Aug-24	23.99	2,348	26	2,374
Aug-25	19.75	1,972	22	1,994
Aug-26	23.91	2,005	17	2,022
Aug-27	23.99	1,990	20	2,010
Aug-28	23.93	1,693	18	1,711
Aug-29	22.49	2,056	26	2,082
Aug-30	22.96	1,766	17	1,783
Aug-31	23.99	2,073	16	2,089
Sep-01	23.80	1,874	33	1,907
Sep-02	23.95	2,253	60	2,313
Sep-03	23.97	2,075	20	2,095
Sep-04	23.98	2,838	37	2,875
Sep-05	23.99	2,782	28	2,810
Sep-06	23.58	2,815	38	2,853
Sep-07	23.47	3,876	88	3,964
Sep-08	23.82	3,417	63	3,480
Sep-09	23.99	3,119	82	3,201
Sep-10	23.97	3,821	39	3,860
Sep-11	23.97	2,828	53	2,881
Sep-12	23.85	2,848	59	2,907
Sep-13	23.99	2,776	68	2,844
Sep-14	23.98	2,088	41	2,129
Sep-15	23.72	1,966	44	2,010
Sep-16	23.96	1,894	54	1,948
Sep-17	23.25	1,827	128	1,955
Sep-18	23.96	1,507	36	1,543
Sep-19	23.96	1,322	38	1,360
Sep-20	23.97	1,339	37	1,376
Sep-21	23.96	1,091	33	1,124
Sep-22	23.98	954	31	985
Sep-23	23.97	913	42	955
Sep-24	23.98	596	16	612
Sep-25	23.98	347	12	359
Sep-26	0	-	-	-
Total	1,080.19	78,990	1,458	80,448

[a] Times are recorded to the nearest second by the computer, then converted to decimal hours during analysis.

Table 4.─ Daily adjusted fall chum salmon counts, Chandalar River, 2001. Asterisks denote daily count estimated by ratio estimator method. (*)

Date	Left bank	Right bank	Combined	Cumulative	Cumulative (%)
Aug-08	178	276	454	454	0.41
Aug-09	159	209	368	822	0.74
Aug-10	125	230	355	1,177	1.06
Aug-11	99	218	317	1,494	1.35
Aug-12	124	261	385	1,879	1.69
Aug-13	123	199	322	2,201	1.98
Aug-14	191	435	626	2,827	2.55
Aug-15	322	647	969	3,796	3.42
Aug-16	443	827	1,270	5,066	4.57
Aug-17	660	901	1,561	6,627	5.97
Aug-18	2,244	4,780*	7,024	13,651	12.30
Aug-19	1,632	3,476*	5,108	18,759	16.90
Aug-20	1,011	2,153*	3,164	21,923	19.76
Aug-21	760	1,816	2,576	24,499	22.08
Aug-22	481	1,798	2,279	26,778	24.13
Aug-23	488	2,414	2,902	29,680	26.75
Aug-24	394	2,350	2,744	32,424	29.22
Aug-25	370	2,260	2,630	35,054	31.59
Aug-26	260	2,012	2,272	37,326	33.64
Aug-27	291	1,991	2,282	39,608	35.69
Aug-28	241	1,699	1,940	41,548	37.44
Aug-29	553	2,175	2,728	44,276	39.90
Aug-30	205	1,861	2,066	46,342	41.76
Aug-31	284	2,075	2,359	48,701	43.89
Sep-01	420	1,887	2,307	51,008	45.97
Sep-02	316	2,259	2,575	53,583	48.29
Sep-03	399	2,079	2,478	56,061	50.52
Sep-04	580	2,841	3,421	59,482	53.60
Sep-05	757	2,783	3,540	63,022	56.79
Sep-06	240	2,846	3,086	66,108	59.57
Sep-07	510	3,927	4,437	70,545	63.57
Sep-08	414	3,446	3,860	74,405	67.05
Sep-09	625	3,121	3,746	78,151	70.42
Sep-10	350	3,826	4,176	82,327	74.19
Sep-11	277	2,831	3,108	85,435	76.99
Sep-12	445	2,866	3,311	88,746	79.97
Sep-13	330	2,777	3,107	91,853	82.77
Sep-14	230	2,090	2,320	94,173	84.86
Sep-15	220	1,988	2,208	96,381	86.85
Sep-16	269	1,896	2,165	98,546	88.80
Sep-17	319	1,854	2,173	100,719	90.76
Sep-18	187	1,509	1,696	102,415	92.29
Sep-19	202	1,323	1,525	103,940	93.66
Sep-20	190	1,340	1,530	105,470	95.04
Sep-21	201	1,092	1,293	106,763	96.21
Sep-22	248	955	1,203	107,966	97.29
Sep-23	286	915	1,201	109,167	98.37
Sep-24	189	597	786	109,953	99.08
Sep-25	231	347	578	110,531	99.60
Sep-26	226	214	440	110,971	100.00
Total	20,299	90,672	110,971		

Of the final adjusted upstream count of 110,971 fall chum salmon, 88% were actually tracked (98,040 fish). Missing days made up the largest block of estimated counts. The right bank missed 3 days due to high-water events during August 18-20 (Figure 4). This represented 6% of the entire 50-day sampling period on the right bank. The left bank did not miss any complete days during the entire season. Counts were also estimated for 50 missing hours during the season, 11 on the right bank, and 39 on the left bank. Estimates for partial hours (sample times $\geq$ 0.25h but < 1h) made up only 6.5% of all hourly counts, with the majority of incomplete hours having sample times $\geq$ 0.75h.

During 2001, hourly passage rates of upstream fish showed a strong diel pattern on the left bank, and a slight diel pattern on the right bank. These patterns exhibited higher passage rates during late night/early morning hours (Figure 5).

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 6 and 7). More than 90% of upstream fish were within 11 m of the left bank transducer and 39 m of the right bank transducer. Downstream fish were distributed more equally across the full detection range. For the season, median range values for upstream fish were 2.5 m closer to shore than downstream fish on the left bank and 6.7 m closer to shore on the right bank.

Due to the vertical position error on the right bank, analysis of vertical data could only be completed on the left bank. Left bank vertical fish position data showed that most upstream-swimming chum salmon were bottom-oriented. More than 96% of upstream fish passed below the acoustic axis (Figure 8). Downstream fish were more widely distributed throughout the ensonified zone. For the season the median vertical position of upstream fish was lower in the water column than downstream fish.

Target strength distribution of tracked fish—The vertical position error on the right bank effected target strength data, therefore analysis of target strength data could only be completed on the left bank. The average target strength of upstream-swimming fall chum salmon was -28.4 dB on the left bank (Figure 9). Downstream fish had significantly smaller target strengths than upstream fish ($P < 0.001$), averaging -30.8 dB.

Species Identification

Approximately 406 hours of underwater video were compared to corresponding sonar data post season. Of the 7,361 fish seen on the video 7,286 (99%) were detected with the sonar. Of these 7,286 fish detected with both sonar and video, 4,767 (65%) were identified as least cisco on the video images. The sonar trace patterns corresponding to 4,606 (97%) of these least cisco were correctly identified as being indicative of least cisco. Conversely, there were 61 chum salmon (only 4% of the chum salmon seen in the video) whose trace patterns were misidentified as being indicative of least cisco.

During 2001 293 beach seine sets were completed between July 30 and September 24, with 801 fish captured. Chum salmon and least cisco accounted for 758 (95%) of the fish captured. The majority of least cisco (89%) were caught beginning the second week of September, corresponding with the video data. Other species captured with the seine included, northern pike *Esox lucius*, Arctic grayling *Thymallus arcticus*, longnose sucker, *Catostomus catostomus*, round whitefish *Prosopium cylindraceum*, and humpback whitefish *Coregonus pidschian*.

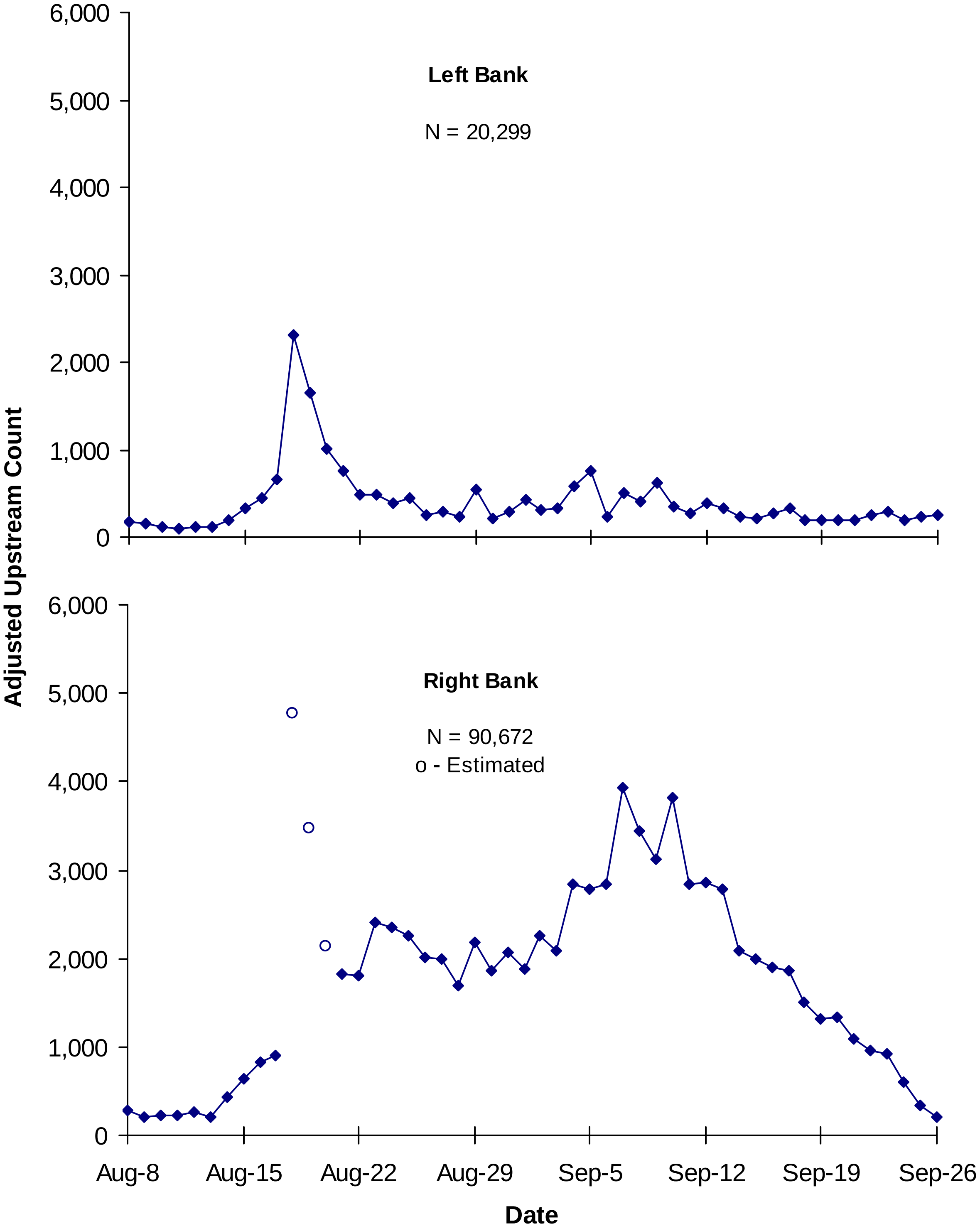

Figure 4.— Adjusted daily counts of upstream fall chum salmon by bank, Chandalar River, 2001. Daily counts were estimated using the ratio estimator method for 3 days on the right bank.

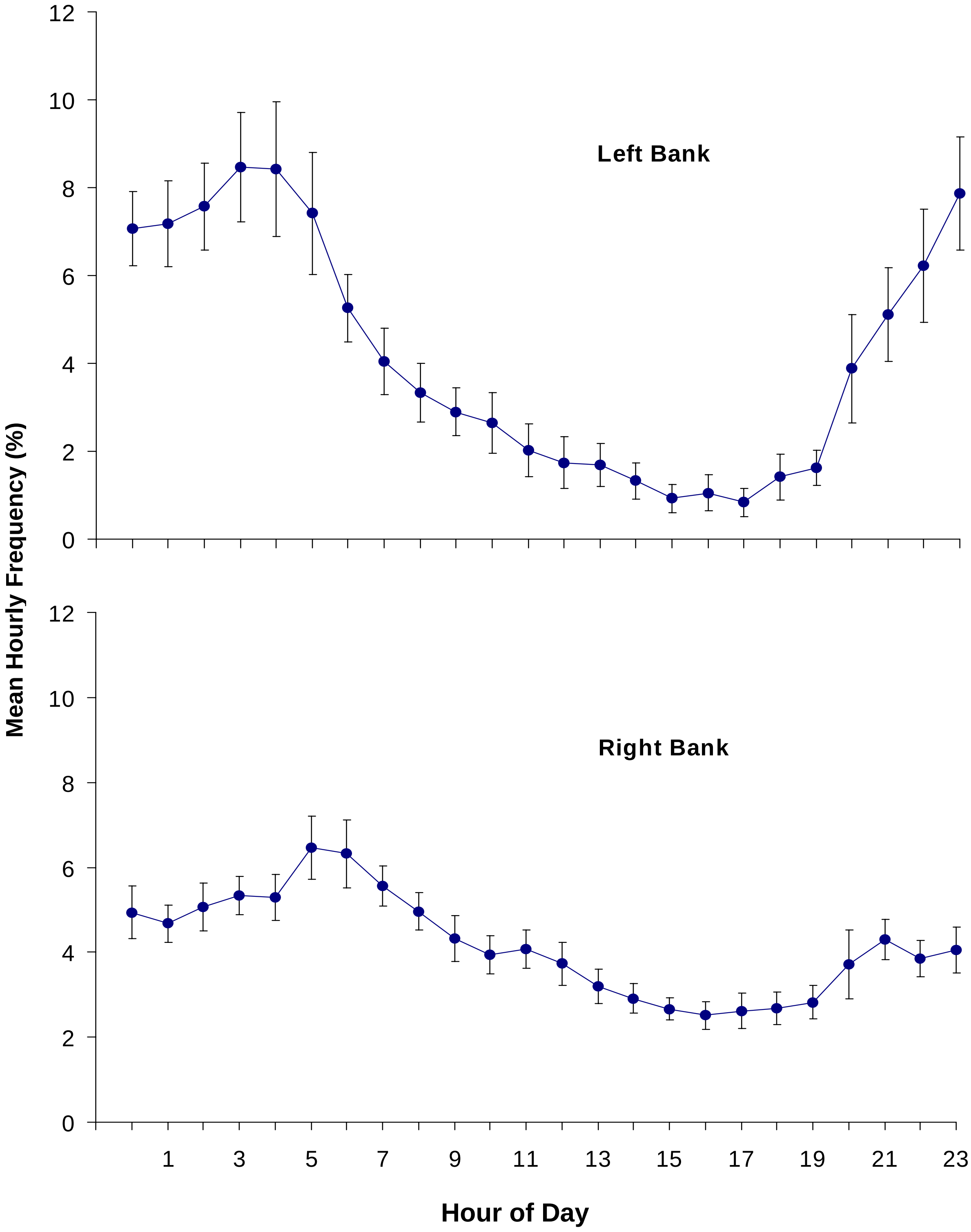

Figure 5.— Mean (±2 SE) hourly frequency of upstream fish, Chandalar River, 2001. Data from 42 days of continuous 24 hour data on the left bank, and 40 days on the right bank.

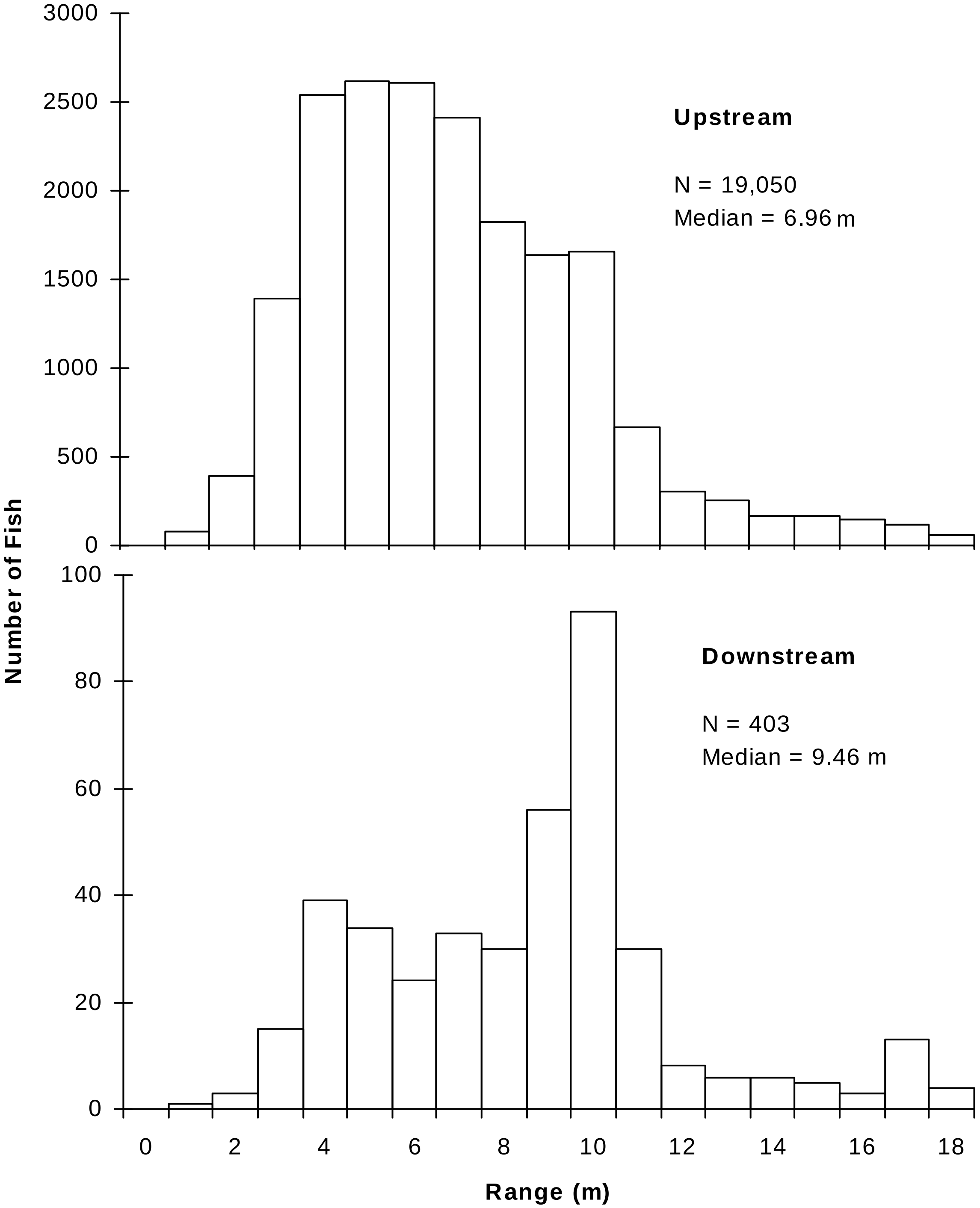

Figure 6.— Range (horizontal distance from transducer) distribution of upstream and downstream fish, from hydroacoustic data collected on the left bank Chandalar River, August 8 to September 26, 2001.

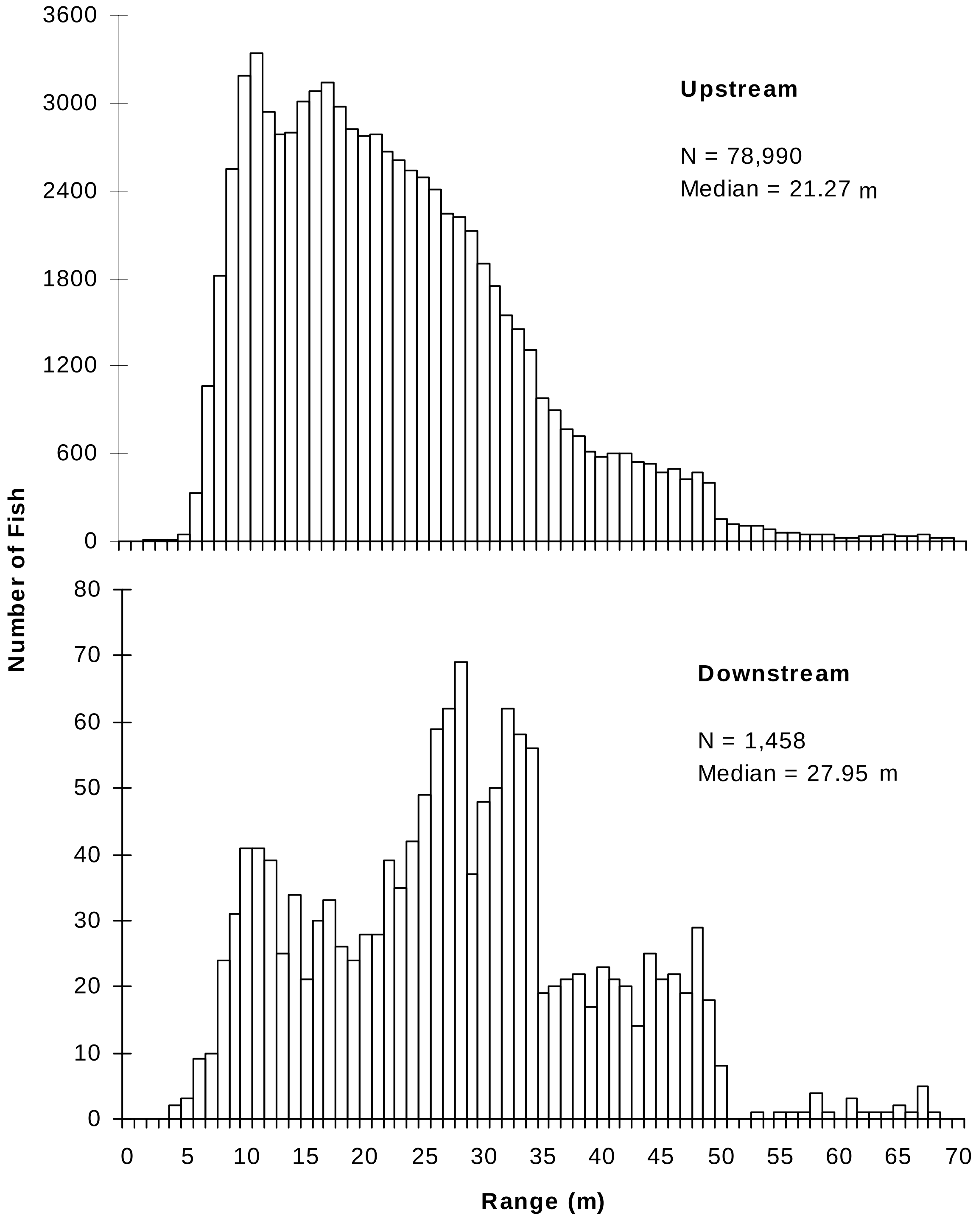

Figure 7.— Range (horizontal distance from transducer) distribution of upstream and downstream fish, from hydroacoustic data collected on the right bank Chandalar River, August 8 to September 26, 2001.

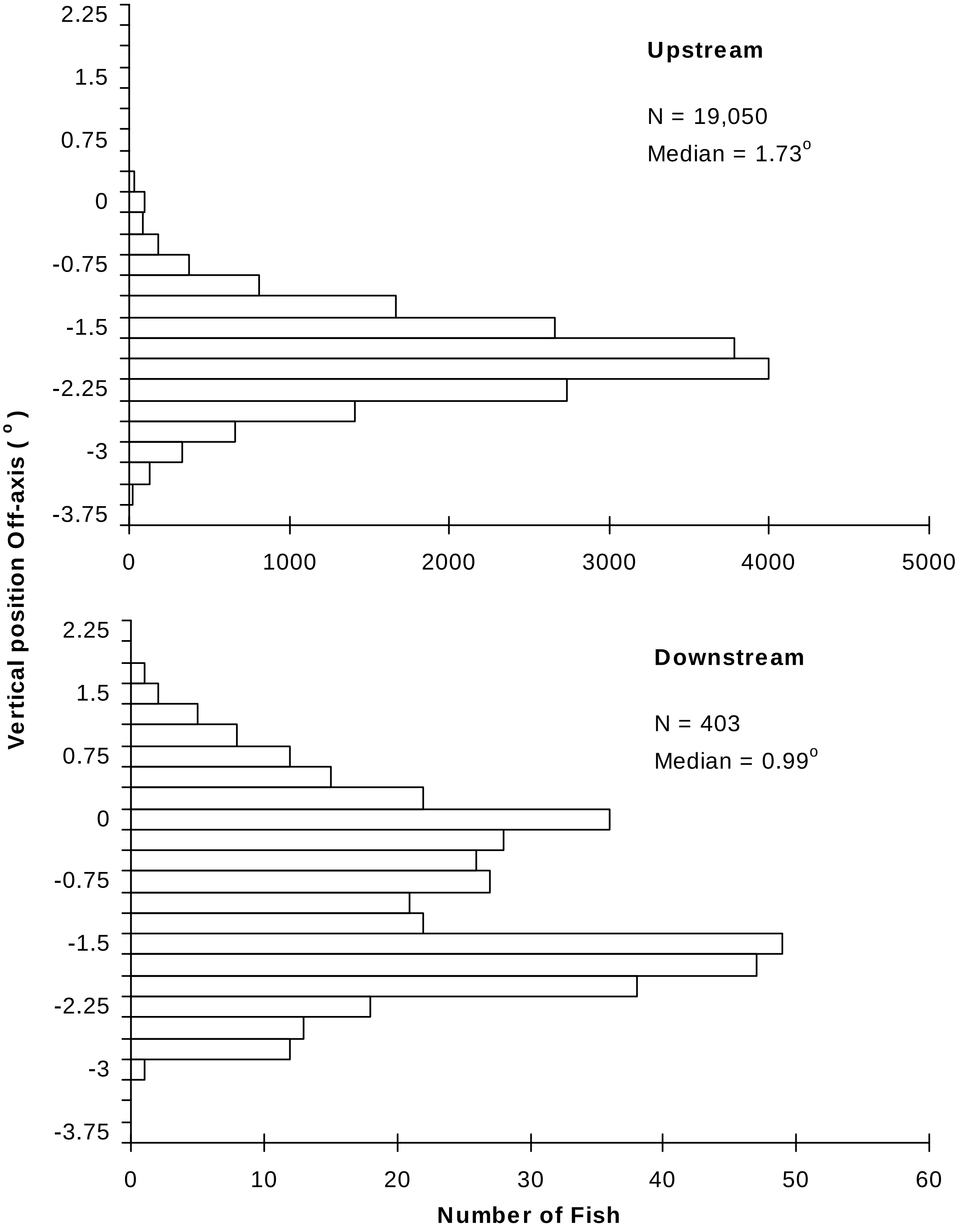

Figure 8.— Vertical distribution of upstream and downstream fish, from hydroacoustic data collected on the left bank Chandalar River, August 8 to September 26, 2001.

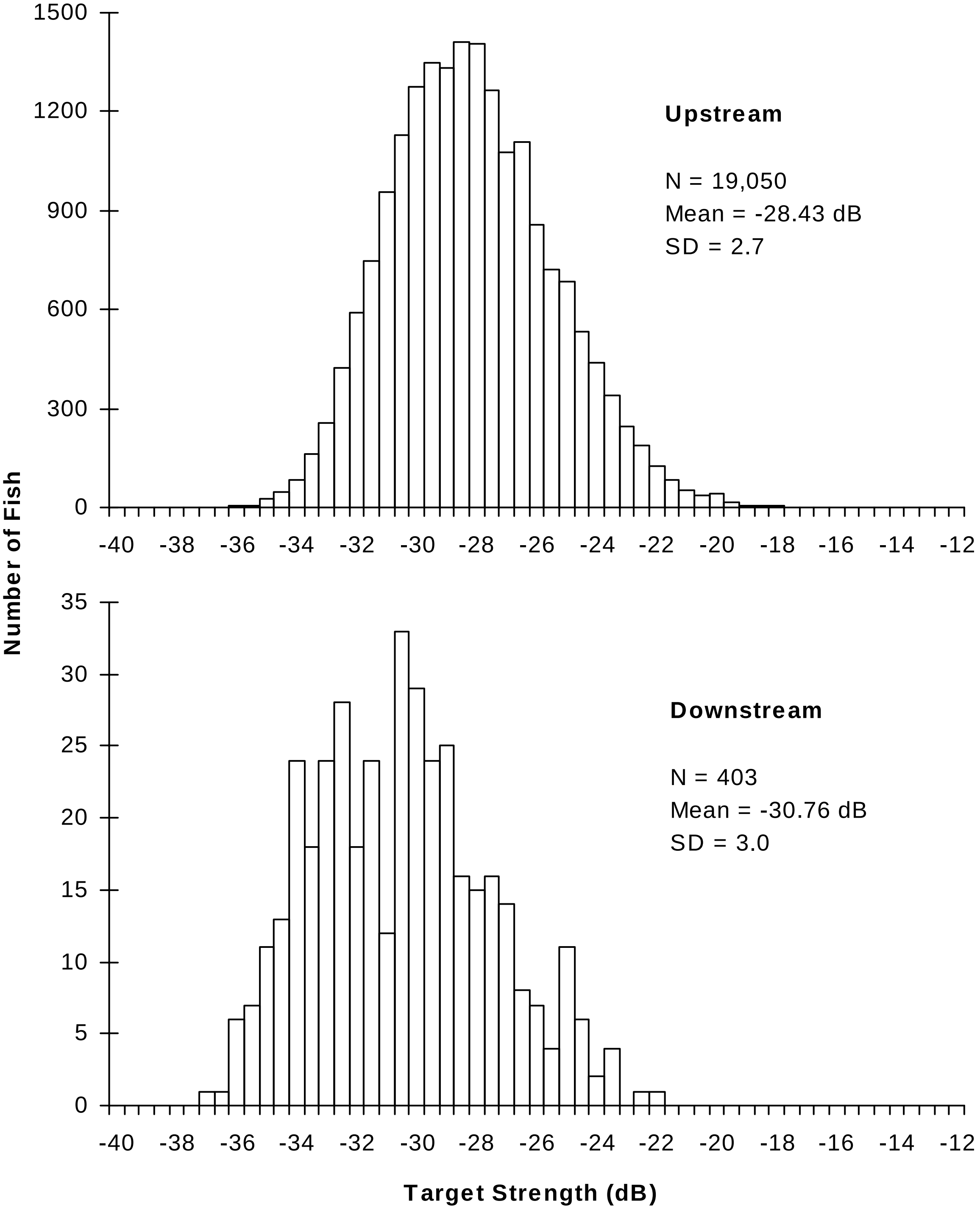

Figure 9 — Target strength distribution of upstream and downstream fish, from hydroacoustic data collected on the left bank Chandalar River, August 8 to September 26, 2001.

Discussion

Acoustic Data and Estimate

Although the number of fall chum salmon returning to the Chandalar River during 2001 was slightly higher than the past three years, the recent trend of low returns continued (Figure 10). The 2001 count of 110,971 fish was only 48% of the average annual returns during the three high-escapement years of 1995-1997. Escapements to other major spawning grounds in the upper Yukon River drainage have also dropped substantially from the 1995-1997 levels (Bergstrom et al. 2001). During five of the last six years, the Chandalar River has had the highest escapement estimate of all monitored fall chum spawning streams in the upper Yukon River drainage. The 2001 Chandalar River estimate was 45% of the combined total of the upper Yukon River enumeration projects (i.e., Chandalar River sonar, Sheenjek River sonar, Fishing Branch River weir, and Canadian boarder mark-recovery on the mainstem of the Yukon River).

The median passage date was September 3, three days earlier than the average for 1995-2000. The first quartile passage date, August 23, occurred five days earlier than the average for the years 1995-2000. However, The 1998 run was substantially later than in other years, i.e., 11 days later in both median and first quartile passage dates (Figure 11).

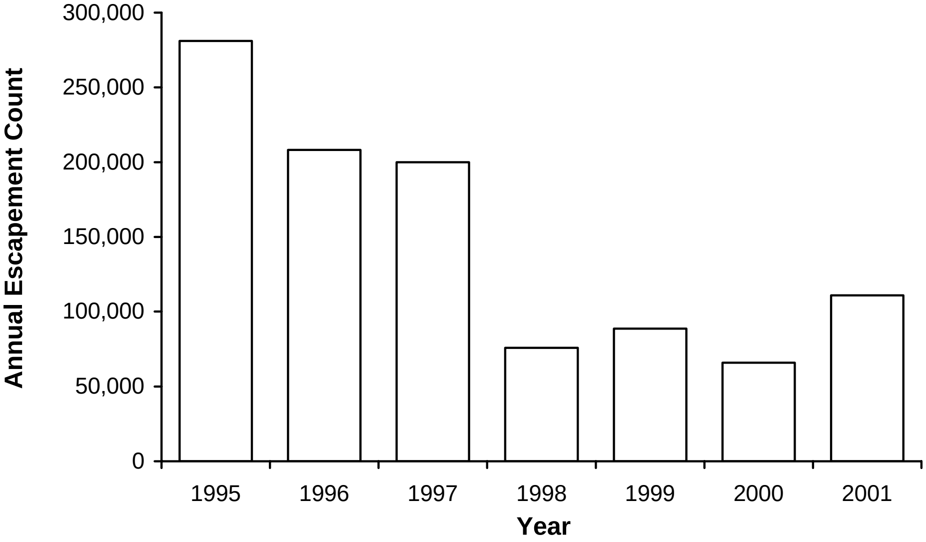

Figure 10 — Annual sonar escapement estimates of fall chum salmon in the Chandalar River, 1995-2001.

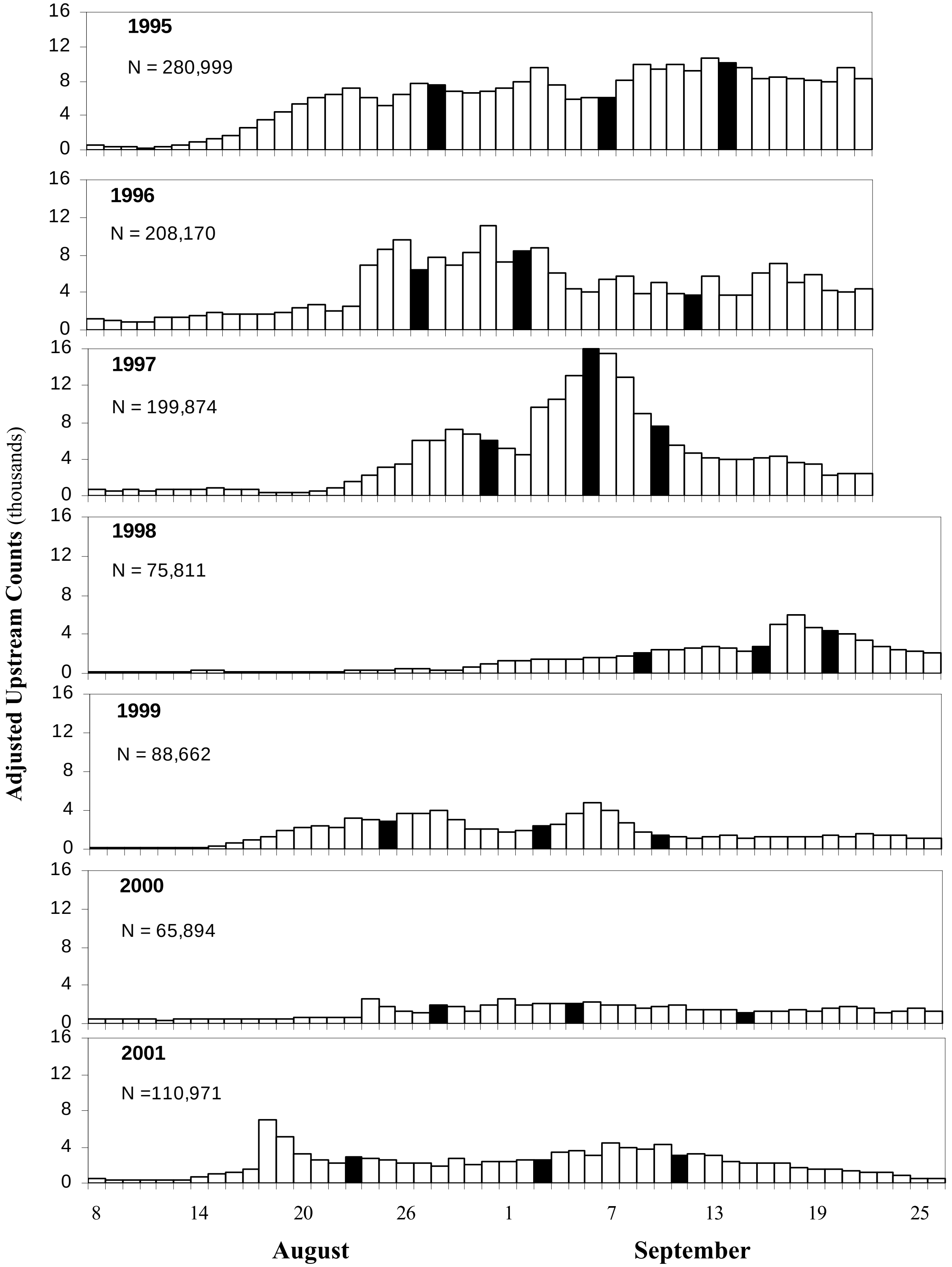

Figure 11.— Adjusted daily counts (thousands) of upstream fall chum salmon, Chandalar River, 1995 -2001. Shaded bars represent quartiles of the total count**.**

The precision of the 2001 Chandalar River escapement estimate varied between banks. On the left bank, acoustic data were collected for 94% of the season and few adjustments were made to the actual tracked fish count (94% of the left bank's final estimate was actually tracked). For the right bank acoustic data were collected for 90% of the season, and tracked fish represented 87% of the right bank's total estimate. The largest potential source of error was in estimating daily right bank counts for the 3 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 12). The left and right bank daily counts were correlated (r = 0.88, P < 0.001), (12 non-missing days) during the early portion of the season. The ratio estimator was used for the missing days, which occurred during this time period. The 95% confidence interval around the missing-days estimate was within 5.1 % of the total seasonal count. Fish position data suggested that most upstream fish passing the sonar site were within the ensonified zone during 2001. As in previous 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. As in 1999 & 2000, the non-linear, near-shore bottom contour on the right bank 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).

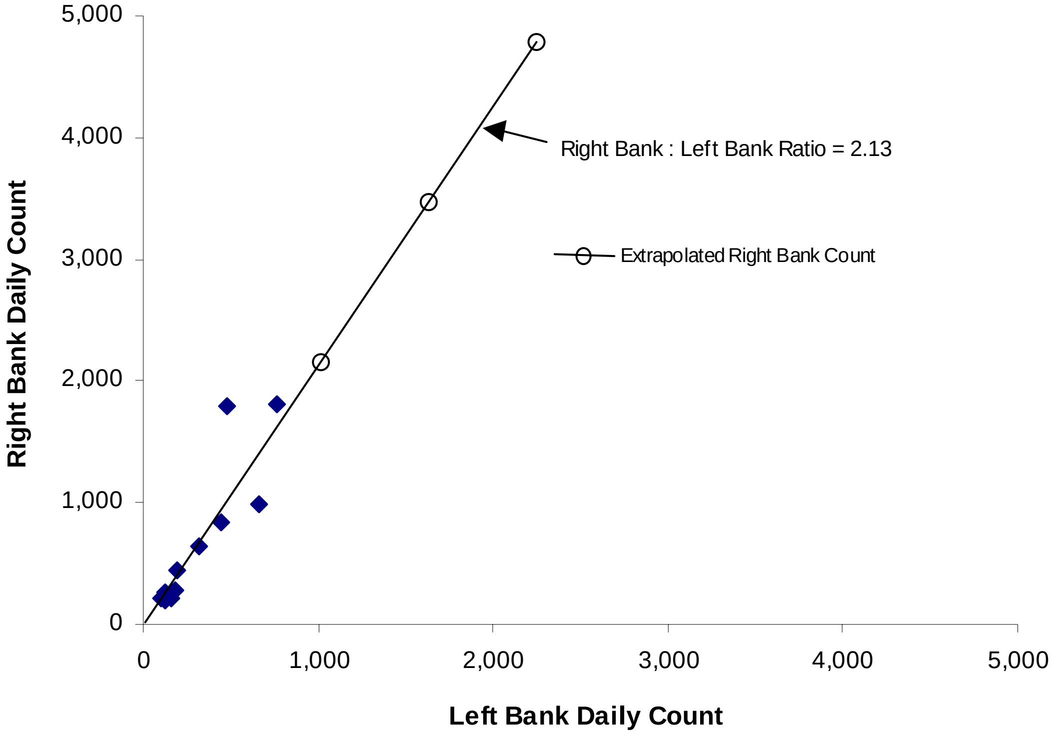

Figure 12.— Relationship of right bank to left bank adjusted daily counts of fall chum salmon, Chandalar River, August 8 through Aug 22, 2001. Missing right bank counts (Aug. 18 - 20) were extrapolated from left bank counts using the ratio estimator method (Cochran 1977).

During 2001, hourly passage rates of upstream fish showed diel patterns for both banks, with higher passage rates during late night/early morning hours. Fish on the left bank have shown similar diel trends during most years, however prior to 2000 fish on the right bank have shown very little diel pattern.

To insure that acoustic data were not biased, the voltage threshold was set at -40 dB for most of the 2001 season which was substantially lower (10 dB) than predicted target strength values for fish of chum salmon length (Love 1977). Due to high-noise events (primarily caused by increased debris load during higher flows), the voltage threshold on the right bank was increased to -34 dB beyond a range of approximately 10 m for 11 days, and beyond 24 m for 13 days. This could cause biased target strength values and undercounting of fish past these ranges. However, historically, most upstream fish have had target strengths substantially above the elevated threshold setting and the majority of fish were close to shore (Figure 8). Daily comparisons of chart counts to the electronic data set confirmed that few fish were missed at the elevated 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 threshold settings. Trends in target strength between upstream and downstream fish were similar to 1995-2000 results.

Species Identification

Species identification is important to obtaining accurate counts of chum salmon. Our data indicate that we can exclude least cisco from our counts by trace pattern identification with an acceptable amount of error (97% of least cisco trace patterns were correctly identified during our video comparison). Further evaluation and refinement of these methodologies under a wider range of conditions should continue in order to maintain and improve our ability to obtain accurate counts of chum salmon. Recommendations for future investigations include: (1) continue and expand video monitoring, (2) continue sampling with beach seine, and (3) radio telemetry. Video monitoring with an array of cameras synchronized with the sonar should continue and be expanded to include the right bank. This would allow monitoring more of the sonar beam and lead to a better understanding of the relationship between passing fish and their corresponding traces. Sampling with a beach seine provides a less selective sampling method to better understand timing and relative abundance of least cisco or other species, and will not cause mortality inherent in gillnet sampling (Hayes et al. 1996). Radio telemetry could be employed to help determine the destination and intent (spawning, feeding, or overwintering) of least cisco. This information could help predict or identify future changes or patterns in least cisco migration that could affect sonar counts of chum salmon.

Right Bank Relocation

The traditional site on the right bank for transducer deployment is located on the upriver side of a large gravel/sand/silt bar just down-river from a steep cut bank that is eroding. The river bottom here has a slope of approximately 2.4° and consists of sand and silt. This bottom type absorbs sound, resulting in little or no returning acoustic signal, which makes aiming the sonar more difficult.

The consistent linear appearance of the bottom on the right bank during 1994-1997 had changed in 1998, becoming bumpy and uneven past 57 m offshore. This was due to sediment deposited from severe bank erosion upstream during an early summer flood in 1998. Since then the area of unevenness has appeared to increase in size and extend somewhat closer to shore.

Additionally, the sonar at this site has to be shut down during high water events. As the river level rises, water floods back onto the shallow sloped shoreline leaving no room to deploy the transducer. Right bank sample time has been considerably less than the left bank due to down-time from high water events. From 1997 to 2000, the right bank missed an average of 21 sampling days due to high water. Thirty-three days were missed in 1998, representing 66% of the entire 50 days counting period.

Given these problems, a potential new site on the right bank approximately 300 meters down river from the original site was mapped during the 2000 field season. This site has a similar bathymetry (6˚ slope) and substrate type (round cobble) as the left bank. Attempts to evaluate the site were hampered by equipment problems. Future operations should again include testing the suitability of this location.

Annual sonar enumeration of fall chum salmon in the Chandalar River should continue, based on its contribution to the total run of Yukon River fall chum salmon and the importance of the stock to subsistence users throughout the drainage. Daily in-season counts and post-season escapement estimates will continue to be provided to managers. Large numbers of salmon and computer software limitations cause data verification and manual fish tracking to continue to be labor intensive.

Acknowledgements

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References

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

Bergstrom, D. J., 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.

Bergstrom, D. J., and ten coauthors. 2001. Annual management report, Yukon Area, 999. Alaska Department of Fish and Game, Division of Commercial Fisheries, AYK Region, Regional Information Report 3A01-01, 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, Fairbanks 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, Fairbanks 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, Fairbanks 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, Fairbanks Fishery Resource Office, Alaska Fisheries Technical Report 50, Fairbanks, Alaska.

Daum, D. W., and B. M. Osborne. 2000. Enumeration of Chandalar River fall chum salmon using split-beam sonar, 1999. U.S. Fish and Wildlife Service, Fairbanks Fishery Resource Office, Alaska Fisheries Technical Report 58, 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, Fairbanks 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.

Gunderson, D. R. 1993. Surveys of fisheries resources. John Wiley & Sons, Inc., New York.

Hayes, D. B., C. P. Ferreri, and W. W. Taylor. 1996. Active fish capture methods. Pages 193-220 in B. R. Murphy and D. W. Willis, editors. Fisheries techniques, 2nd edition. American Fisheries Society, Bethesda, Maryland.

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.

HTI (Hydroacoustic Technology, Inc). 2000. 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, Fairbanks Fishery Resource Office, Alaska Fisheries Technical Report 42, Fairbanks, Alaska.

Osborne, B. M., and J. L. Melegari. 2002. Use of split-beam sonar to enumerate Chandalar River fall chum salmon, 2000. U.S. Fish and Wildlife Service, Fairbanks Fishery resource Office, Alaska Fisheries Technical Report 61, 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.]

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 *	10,46	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		

Appendix 5 — 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		

Appendix 6 — Daily adjusted fall chum salmon count, Chandalar River, 2000. Asterisks denote daily count estimated by ratio estimator method (*).

Date	Left bank	Right bank	Combined	Cumulative	Cumulative (%)
Aug 8	131	395 *	526	526	0.80
9	116	350 *	466	992	1.51
10	111	334 *	445	1,437	2.18
11	130	392 *	522	1,959	2.97
12	100	301 *	401	2,360	3.58
13	119	359 *	478	2,838	4.31
14	132	398 *	530	3,368	5.11
15	108	325 *	433	3,801	5.77
16	120	362 *	482	4,283	6.50
17	126	374	500	4,783	7.26
18	118	333	451	5,234	7.94
19	109	351	460	5,694	8.64
20	205	460	665	6,359	9.65
21	176	445	621	6,980	10.59
22	203	503	706	7,686	11.66
23	216	375	591	8,277	12.56
24	635	1,913 *	2,548	10,825	16.43
25	449	1,353 *	1,802	12,627	19.16
26	342	1,030 *	1,372	13,999	21.24
27	292	880 *	1,172	15,171	23.02
28	484	1,458 *	1,942	17,113	25.97
29	444	1,338 *	1,782	18,895	28.67
30	452	851	1,303	20,198	30.65
31	417	1,526	1,943	22,141	33.60
Sep 1	658	1,943	2,601	24,742	37.55
2	450	1,531	1,981	26,723	40.55
3	463	1,558	2,021	28,744	43.62
4	343	1,816	2,159	30,903	46.90
5	359	1,791	2,150	33,053	50.16
6	370	1,892	2,262	35,315	53.59
7	243	1,659	1,902	37,217	56.48
8	282	1,701	1,983	39,200	59.49
9	276	1,374	1,650	40,850	61.99
10	266	1,525	1,791	42,641	64.71
11	424	1,497	1,921	44,562	67.63
12	275	1,209	1,484	46,046	69.88
13	254	1,242	1,496	47,542	72.15
14	353	1,164	1,517	49,059	74.45
15	231	929	1,160	50,219	76.21
16	299	993	1,292	51,511	78.17
17	423	802	1,225	52,736	80.03
18	431	978	1,409	54,145	82.17
19	466	823	1,289	55,434	84.13
20	514	1,176	1,690	57,124	86.69
21	644	1,121	1,765	58,889	89.37
22	457	1,150	1,607	60,496	91.81
23	488	625	1,113	61,609	93.50
24	582	698	1,280	62,889	95.44
25	685	980	1,665	64,554	97.97
26	449	891	1,340	65,894	100.00
Total	16,420	49,474	65,894		