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1993 YUKON RIVER BORDER SONAR PROGRESS REPORT

By

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and

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ABSTRACT

Side-looking scientific fisheries split beam hydroacoustic equipment was deployed in the Yukon River near Eagle, Alaska from 15 July through 23 September 1993 to collect target strength and three-axis position data on standard calibration spheres and on migrating chinook salmon and chum salmon. *In situ* target strength estimates of standard targets were close to theoretical values. Signal loss at range was documented during a high water event. Limited gillnet test fishing was conducted in support of acoustic data acquisition from 18 July through 27 July 1993. The temporal pattern of acoustic fish detections closely resembled the pattern of passage estimated from a nearby mark-recapture project conducted upstream in Canada.

Key Words: chinook salmon, chum salmon, split beam, fisheries hydroacoustics, Yukon River

INTRODUCTION

The Yukon River flows 3,700 km (2,300 mi.) from its headwaters in Canada's Yukon Territory to Norton Sound on the Bering Sea Coast of Alaska. Chinook salmon (*Oncorhynchus tshawytscha*) and chum salmon (*O. keta*) travel through various fisheries as they migrate up the Yukon River toward their spawning grounds, some of which are in Canada. Alaskan fisheries are managed by the Alaska Department of Fish and Game (ADF&G) while Canadian fisheries are managed by the Canada Department of Fisheries (CDFO). Fisheries managers in Alaska and Canada have long been interested in the number of salmon that cross the border, and past research activities to evaluate border passage have been based on relative fishwheel capture rates, tag/recovery data, and aerial surveys of spawning streams. However, because of the variability inherent in these assessment techniques, the U.S./Canada Joint Technical Committee (JTC) has identified the need for more accurate, timely data on the number of salmon passing the U.S./Canada border.

In response to the need for more accurate abundance estimates, the JTC appointed a Sonar Planning Subcommittee (SPS) to develop a plan for investigating the feasibility of using sonar to estimate the number of Yukon River salmon entering Canada. The SPS was comprised of representatives from ADF&G, U.S. Fish and Wildlife Service (USFWS) and CDFO. In 1991, SPS members agreed to a four year project plan and USFWS staff attended a formal week-long hydroacoustic workshop. Split-beam hydroacoustic equipment was purchased, potential sonar sites were surveyed, and the land status of the potential sites was determined. In 1992, split-beam sonar equipment was successfully deployed, calibration data were acquired, and baseline data were collected on free-swimming fish for two weeks each during the chinook salmon and chum salmon migrations in July and September, respectively, for use in evaluating the performance of the sonar hardware and software. In addition, gillnet samples of migrating and resident fish were collected in the vicinity of the sonar project location.

This report summarizes the results achieved during the 1993 field season. Objectives specified in the 1993 Yukon River Border Sonar Project Operational Plan are:

1) Collect acoustic data on fish abundance at the existing sonar site 24 hours per day during the entire field season.

2) Establish data management protocol for all project data.

3) Develop procedures to optimize sonar beam coverage of the river cross-section at the exact transducer deployment locations.

4) Formalize preliminary *in situ* split-beam calibration procedures.

5) Identify fish species present in the study area during periods of specific interest (to be determined inseason).

6) Acquire additional acoustic and non-acoustic data to describe the spatial distribution of fish present during the period of sonar operations.

7) Acquire additional acoustic target strength and non-acoustic fish length data for developing procedures to estimate the size class distribution of fish present in the study area.

8) Measure detected noise levels on both banks in order to determine the minimum detectable target strength possible while maintaining a minimum 10 dB signal-to-noise ratio (SNR).

METHODS

Site Description

The Yukon River at the U.S./Canada border is characterized by a single channel with islands and stable banks (Figure 1). The existing site, located 2 km downstream from Eagle, Alaska at river km 1,952 (river mi 1213) was chosen because of the single, narrow channel, proximity to the border at river km 1,970 (river mi 1,224), and nearly linear bottom slope outward some distance from both banks (Figure 2). Numerous transects were conducted in the immediate vicinity of the sonar site using a Lowrance[1] model X-15 portable depth sounder to determine the exact location to deploy the sonar equipment on each bank. The river at the sonar site varied from 275 m to 305 m in width and from 10 m to 15 m in maximum depth depending on the time of year and precipitation. The left bank bottom is mainly large cobble. It begins at the base of a cliff and slopes steeply to the thalweg at about 65 m. The right bank is sandy with sporadic rocky outcrops. The bottom shape there is complex with a gradually-inclined shelf, a steeply-sloped shelf-break, and a bottom that slopes gradually to the thalweg at roughly 240 m.

Sonar Data Acquisition

Split-beam sonar equipment deployed on both banks consisted of an HTI[1] model 240 Digital Echo Sounder (DES) to send and receive electronic signals, an HTI[1] model 340 Digital Echo Processor (DEP) with an internal HTI[1] model 404 Chart Recorder Interface (CRI) connected to a Panasonic[1] model KXP-1624 dot-matrix printer, and a Nicolet[1] model 310 digital storage oscilloscope (DSO) with on-board tandem 3.5-in floppy drives. Digitized raw echoes were recorded on a Panasonic[1] model SV-3700 digital audio tape (DAT) recorder. International Transducer Corporation[1] (ITC) elliptical split-beam transducers with nominal beam dimensions of $2.5^\circ \times 10^\circ$, $4^\circ \times 10^\circ$, and $6^\circ \times 10^\circ$ were used to transmit and receive sound pulses. Transducers were mounted on aluminum tripods placed 2 m to 7 m offshore, and remotely-aimed with a Remote Ocean Systems[1] (ROS) model PT-25 dual-axis pan and tilt rotator and ROS[1] model PTC-1 pan and tilt control unit with real-time angular relative position feedback accurate to 0.3°.

Sound pulses were generated by the transceiver at a frequency of 200 kHz. Pulse widths of 0.7 ms and 0.4 ms were used to acquire data on the left and right banks to prevent crosstalk between sounders. Pulse repetition frequencies varied between 5 Hz and 10 Hz. Effective listening ranges varied from 50 m to 64 m on the left bank and from 45 m to 90 m on the right bank. Returning echoes were filtered for correct frequency (within plus or minus 2.5 kHz), half-amplitude pulse width (within plus or minus 0.05 ms), minimum peak amplitude threshold voltage equivalent to -41 dB, and bank-specific range criteria. They were then routed through the CRI in the DEP to the printer. Chart recording thresholds were adjusted as conditions and aim warranted, although we normally tried to keep chart recording thresholds 3 dB lower than the acquisition threshold on each bank.

The DES and DEP were user-configured in software. The DES was configured for transmit power, pulse duration, trigger source, data routing, frequency bandwidth, receiver gain, pulse repetition frequency (PRF), calibration pulse spacing, time-varied gain (TVG) spreading loss factor and effective range, attenuation coefficient, receiver channel selection criteria, and internal/external calibration operation. The DEP allowed user-controlled filtering of returning echoes for pulse width, start and end processing range, range-dependent minimum peak voltage thresholds, maximum allowable angle off-axis in the horizontal and vertical planes, and maximum composite angle off-axis in dB. Tracking parameters which were user-configured in the DEP included the minimum number of pings required to constitute a fish, the maximum consecutive number of pings allowed to drop out within a single tracked fish, the maximum allowable rate of change in range (expressed in m/s), and the maximum and minimum allowable tracked fish velocities (m/s). Echogram (chart recording) parameters, also user-controlled in DEP software, consisted of start and end processing ranges, a single minimum voltage threshold, and paper speed (transmissions/line).

Information from all processed signals were automatically written to three separate ASCII files at specified time intervals; a file with a *.raw* extension comprised of information from all echoes which met filtering criteria, a file with an *.ech* extension containing information from each echo aggregated into groups likely to have come from a single tracked fish, and a file with an *.fsh* extension containing one line of summary information from each tracked fish. File nomenclature was controlled in proprietary software, and consisted of the bank (R or L), Julian date, and hour and minute that the file was opened. For example, R2600815 would be the name of a file from the right bank opened on Julian date 260 (17 September 1993) for a sampling interval that began at 0815 hours.

Whenever possible, the sonar equipment on each bank ran continuously 24 h per day, seven days per week except for half-hour periods around 0900 hours and

2100 hours. During those times, the generator was refueled and maintained. The equipment was monitored continually from 0800 hours through 2200 hours daily, and it typically operated unmonitored during the remainder of the day.

Data Management and Processing

Since this was the first application of this version of modified split-beam hardware and software to sample free swimming fish in a river, it was necessary to repeat experiments conducted during the previous year to verify the system's ability to detect and track fish. Inseason analysis was limited to visually scanning the echograms for fish traces in real time. Detections were tallied by 10 m range interval on the left bank and by total range on the right bank (which was not capable of printing range intervals until later in the field season) and recorded onto paper forms.

Each morning, the previous day's electronic data were downloaded from the DEP hard drives and all chart recordings, tally sheets, and electronic data were transported to the office in Eagle. There, all data were catalogued and hand tally data were entered onto standard electronic spreadsheet format. Computer- generated electronic (ASCII) data were also transferred to electronic spreadsheet format, and scanned to verify that equipment settings were proper and that the electronic data were not obviously corrupted. This process also generated backup copies of the raw data, which were archived using industry standard archival (.ZIP) format for long term storage. Chart recordings were annotated for date, time, and bank, and catalogued and stored.

Subsequent data processing involved reducing the electronic data to include only echoes certain to have come from fish. This was accomplished by locating tracked fish from electronic (*.ech*) data files on simultaneously collected echograms using information such as time, range, residence time in the beam, change in range, and proximity to nearby targets. All assemblages of valid echoes not likely to have originated from fish (bottom traces, for example) were deleted from the processed data files. In addition, echoes from a single fish which was electronically tracked as two or more fish, were manually combined in the data files.

Echograms were reviewed to identify targets not tracked in software which appeared to be fish. Echoes from these targets were located in the corresponding *.raw* files to determine the reasons that the software failed to classify the assemblages of echoes as fish. Where appropriate, the tracking parameters were adjusted, and the *.raw* files were re-run using the updated criteria.

After the data were reduced to include only valid echoes from tracked fish, we summarized spatial distribution, and direction of travel results.

Sonar Beam Pattern Geometry

We calculated maximum potential beam dimensions based on river bottom profiles from depth soundings at the site. The greatest possible beam dimension in the vertical plane was calculated as:

$$\theta = 2 \cdot \arctan\left(\frac{d}{2r}\right) \tag{1}$$

where: θ = angular beamwidth
d = depth
r = range

We chose elliptical beam transducers whose narrow axis most completely filled the water column on each bank while maintaining our minimum acceptable 10 dB SNR from the suite of transducers manufactured for this project. The transducers were positioned in the river perpendicular to the current with the wide axes of the beams oriented as close to a horizontal position and as close to the bottom of the river as possible in order to increase the number of echoes recorded for each tracked fish.

In Situ Calibration

Standard targets of known acoustic size were ensonified at many positions in the beam regularly throughout the period of data collection to verify the system's ability to detect the targets and estimate their acoustic size. All standard target data were collected with the beam roughly centered vertically in the water column to obtain the smallest noise levels, and acquisition threshold values were reduced to the lowest values possible. Targets were suspended in an equatorial net bag a known distance beneath the water surface on a strand of monofilament line. The targets we suspended in the beam were 38.1 mm stainless steel spheres. We measured the echo voltage of each target as close to the maximum response axis (MRA) as possible. We determined initial target position on the MRA by aligning the paired up-down and right-left phase angles on a DSO. Using calibration data in the signal processing software, the DEP calculated target strength estimates in real time. Finally, we compared our measured target strength values to theoretical values which we calculated following Urick (1983) as:

$$TS = 10 \log\left(\frac{\sigma}{4 \cdot \pi}\right) \tag{2}$$

where: TS = target strength in dB
σ = backscattering cross-section in m^2

Test Fishing

We conducted limited gillnet test fishing drifts immediately downstream of the transducers along both banks during the early portion of the season to identify species present in the study area, and to collect length frequency data on all fish caught. In addition, we made one gillnet set on the left bank to investigate low numbers of targets detected acoustically on that bank. Late season test fishing efforts were curtailed in order to avoid mortalities in a catastrophically weak fall chum salmon run. Three nets with the following dimensions were used in the course of test fishing:

1) 45.7 m long, 7.6 m deep, 89 mm (3.5 in) mesh multifilament
2) 45.7 m long, 7.6 m deep, 127 mm (5.0 in) mesh multifilament
3) 45.7 m long, 7.6 m deep, 140 mm (5.5 in) mesh multifilament

Drifts were conducted with one end of the net as close to shore as possible and the offshore end held perpendicular to the current with a boat. Typical drifts of about ten minutes duration were limited by our ability to keep the nets oriented perpendicular to shore due to the swift offshore current.

Captured fish were tallied by species. Salmon were sampled for mid-eye to fork of tail length and sex. Non-salmon species were measured for tip of snout to tail fork length. All ADF&G sampling mortalities were given to local residents.

Spatial Distribution

Since each echo fixed the target's three-axis position in the beam, we were able to acoustically describe the spatial distribution of all detected fish (larger than -41 dB target strength) which passed within the ensonified range on each bank. Direction of travel in terms of net upstream or downstream movement was calculated in software as the difference between the initial and final x-axis position for each tracked fish. Because of the limited test fishing conducted in 1993, only acoustic data were used to examine the spatial distribution of detected fish.

In Situ Background Noise Levels

Background noise corrupts both phase and amplitude information. Therefore we have specified a minimum 10 dB (SNR) in order to minimize the bias of the *in situ* estimate of target strength. Average and peak background noise levels were measured directly on a DSO on both banks of the river numerous times during the course of acoustic data collection and at every *in situ* system calibration. In addition, raw DAT data were collected for at least two hours every other day for later analysis to describe ambient background noise levels throughout the period of data collection.

RESULTS

Sonar Site Location

Based on bottom profiles obtained in 1993, the transducers were placed in nearly the same positions as during the 1992 project operations (Huttunen and Skvorc, 1994). The bottom slope on the left bank was essentially linear and stable while the right bank was characterized by a linear bottom to a shelf break at about 40 m (Figure 2). Outward from the inflection, the right bank bottom was slightly but evenly scalloped toward the channel. The left bank was steeply sloped and the substrate was rocky while the right bank was more gradual and sandy. River velocity was approximately 1.5 m/s. We deployed the transducers on both banks manually by carrying them out from shore. Immediately after aiming, we were able to detect bottom and fish echoes at ranges of 70 m from the right bank and 64 m from the left bank.

Similar to results observed during 1992 field activities, the river level at the sonar site initially rose 0.2 m (0.5 ft) between 19 and 30 July, and dropped continually thereafter, subsiding a total of 1.3 m (4.1 ft) during the remainder of the project (Table 1). The changing water level forced us to move the transducers several times during the field season.

Sonar Data Acquisition

In all, 3,036 h of simultaneous echogram and electronic split-beam acoustic data were collected in 1993 (Table 2). Of that, 1,411 h were collected on the left bank and 1,625 h were collected on the right bank. Acoustic sampling occurred continuously from 15 July through 23 September 1993. The temporal distribution of target detections from chart recordings agreed with the historic pattern of salmon catches in CDFO fishwheels operated approximately 15 km upstream from the border, which indicates that the salmon migration there occurs in two distinct pulses; chinook salmon migrate past the border mainly in July while chum salmon predominate in September (Milligan et al. 1985, 1986).

Data Management and Processing

Data management protocol was followed carefully throughout the period of data collection in 1993. All raw and processed hard-copy and electronic data were catalogued, archived, and stored during the field season as planned. Electronic data security was achieved through redundancy as all computer generated files were copied to hard drive on two separate data processing computers, and two copies of all electronically archived files were created on 3.5 in high density floppy disks.

We have analyzed the acoustic detections from the chart recordings for comparison with temporal passage estimates from CDFO tagging data (Table 3). Figures 3 and 4 depict the temporal pattern of detections on the right and left banks in 1993, adjusted by hours sampled. Figure 5 shows the combined right and left bank daily sonar tallies overlain by daily CDFO combined fishwheel catches without temporal correction for distance between the sonar site and fishwheel sites. Figure 6 illustrates the pattern of sonar detections with reference to salmon catches by species in the same fishwheels. Temporal patterns of abundance from both sources were similar with few targets detected from 8-30 August. Figure 6 also depicts similarities in pattern between the daily sonar tallies before and after 16 August plotted against independently scaled chinook salmon and chum salmon CDFO fishwheel catch data.

Beam Fitting

At the onset of the project, the river was approximately 305 m wide where the transducers were located, and the thalweg was 13 m deep, 65 m from the left bank (Figure 2) resulting in calculated bottom slopes of 11.3° and 3.5° on the left and right banks, respectively. To optimize river coverage and retain 10 dB SNR's at these bottom slopes, we deployed nominal 6°x10° and 2.5°x10° (effective 7.2°x10.8° and 2.5°x10.8°) beam angle elliptical transducers on the left and right banks, respectively, and were able to detect standard and fish targets. With these beam dimensions, we were able to rotate the left bank and right bank transducers through an additional 8.0° and 6.1° in the vertical axis, significantly more angular rotation than expected based on bottom angles calculated from depth measurements at range.

In Situ Calibrations

We conducted six *in situ* calibration experiments at the site during the 1993 field season using a standard target of known acoustic size suspended in the beam. Measured on-axis target strengths of a 38.1 mm stainless steel sphere varied from -41.7 dB to -48.5 dB (Table 4) depending on date and range ensonified. The largest average target strength value we observed was close to the theoretical value of -41.5 dB (Foote, 1982; MacLennan and Simmonds, 1992).

During the *in situ* calibrations on 1 and 3 August, we observed trends of decreasing target strength with range using 40 log R TVG. Figures 7 and 8 show the relationships between target strength and range on those days, resulting in estimated two way signal losses of 0.46 dB/m and 0.42 dB/m., respectively.

Test Fishing

Gillnet test fishing began on 18 July and terminated on 20 August (Table 5). Set and drift gillnets were used to catch fish during 1993, and all test fishing was stopped due to downstream indications of a catastrophically weak fall chum salmon run. A total of 10 fish were caught during 2.38 hours of sonar-related drift test fishing activities. Catches included five chinook salmon, two whitefish, one Bering cisco, one burbot, and one longnose sucker. These catches are not intended to reflect relative abundance. Rather, the main purpose of test fishing in 1993 was to document the presence or absence of typically small resident fish in light of smaller than expected target strengths observed for free-ranging targets ensonified at all ranges. No fish were caught in a 60-minute gill net set, located 100 m downstream from the left bank transducer during a time period characterized by extremely few acoustic target detections on that bank.

Spatial Distribution

The daily spatial distribution of fish passing through the right and left bank acoustic beams at range and depth are shown in Figures 9 and 10. These graphs clearly show the 'hard edge' effect of split-beam data in which effective beamwidth is not influenced by target size (for targets larger than the minimum detection threshold at the -6 dB_v beam edge).

In Situ Background Noise Levels

Average background noise levels varied from 30 mv to 65 mv on the left bank, and from 35 mv to 120 mv on the right bank during normal sampling activities. Typical electronic data acquisition thresholds of 160 mv on the left bank and 300 mv on the right bank (corresponding to -41 dB target strength) yielded minimum SNR's ranging from 8 dB to 14 dB on the left bank and 8 dB to 19 dB on the right bank.

DISCUSSION

We gained further experience in the capabilities and use of an upgraded version of the 200 kHz split beam sonar system during the 1993 field season. This knowledge will enhance our capacity to evaluate the feasibility of using this particular equipment to assess the number of salmon migrating up the Yukon River past the sonar site near Eagle. However, our progress toward accomplishing that task was hindered in a variety of ways. We encountered difficulties with various elements of sonar data acquisition and processing, and also with test fishing. In addition, equipment shortages prevented us from deploying all of the acoustic equipment simultaneously.

Split-beam technology is not new (Carlson and Jackson 1980) but as far as we know, the previous field season deployment at Eagle in 1992 was the first attempt to examine the ability of scientific split-beam hydroacoustic equipment to assess migratory fish abundance in a river (Huttunen and Skvorc, 1994). Riverine split-beam deployment was particularly innovative because of horizontal transducer orientation and resulting high noise levels reflected from river surface and bottom boundaries. In addition, it was the first field deployment of this prototype model sonar system. Split-beam was identified as the technology of choice primarily because of its: 1) theoretical advantage over dual-beam to reduce target strength estimation bias as a function of poor SNR's commonly encountered in riverine deployments (Ehrenberg, 1983); 2) demonstrated ability in laboratory and marine applications to fix the target's three-axis position in the beam; and 3) ability to complete these tasks in real time. If fully realized, these abilities may allow us to track the progress of targets as they move through the beam, and thus determine direction of travel. Past questions regarding direction of travel at other single and dual-beam riverine sonar sites have at times eroded confidence in abundance estimates generated by those projects. In concert with project participants from the USFWS, it remains our position that current version target tracking software will require further refinement before it can be considered fully capable of automatically tracking individual fish through the beam (D. Daum, USFWS, personal communication). In addition to target tracking, phase-determined three axis target position information may also provide an acoustic method to describe vertical fish distribution within the ensonified water column.

This was the second field season of a feasibility project designed to evaluate whether or not it is feasible to assess the number of chinook and chum salmon migrating past the border into Canada using split-beam sonar equipment. Delays in systematic data acquisition were realized in July as hardware and software deficiencies were again encountered. Data acquisition was inhibited as electronic component aging problems caused the DES's to systematically overload and disable for short (1.5 s) time periods at frequent (10 s) intervals. The problem was temporarily solved by installing component transmitter modules from unused equipment on hand. Malfunctioning equipment was permanently repaired after the field season by the manufacturer.

Acoustic data analysis was further hindered by processing software which was limited in its abilities to annotate charts, and which occasionally malfunctioned. The version of processing software used during 1993 was not able to annotate charts for both time and range simultaneously, which inhibited our abilities to identify electronically tracked targets on chart recordings. In addition, processing software periodically failed to close and open data files at prescribed times. When these malfunctions occurred during unmonitored periods of operation, extremely large data files were generated over several hours of uninterrupted data acquisition. During these and other times, electronically generated data, ordered by ping number, experienced resequencing of ping numbers within files. This malfunction caused uncertainty determining the exact chronology of data acquired electronically because ping number is used as the sole determinant of time in data files.

A final limitation to successful acoustic data acquisition and analysis on this project during its initial field season in 1992 was caused by a system design characteristic which increased the probability of ambiguous system operation. The DES and DEP were both user controlled in software. However, each piece of hardware was independently controlled by a separate set of manually entered control parameter values. Because many tracking and filtering decisions are based in part on DES acquisition settings, any discrepancy between manually entered DES and DEP settings can result in ambiguous data. This problem was ameliorated in 1993 by a software modification that wrote all DEP settings as header information to all automatically created data files. This enhancement made it possible for an operator to subsequently review acquisition and processing parameter values for discrepancies. We remain convinced, however, that in order for the gear to be considered fully operational, a software or hardware modification must be developed to allow either the DEP or the DES to interrogate the other component for all input settings required by controlling or processing software. This modification must also write processing, sounding, and filtering control values to the top of each data file as it is opened or changed.

In spite of these remaining shortcomings, we found that the system was capable of calculating target strength and three-axis position data from fixed standard targets and free-swimming fish in real time. Target strength estimates of standard targets measured in midwater close to the transducer (but well beyond the nearfield zone) were very close to theoretical values (Foote, 1982; Foote and MacLennan, 1984; Maclennan and Simmonds, 1992). We collected close proximity, midwater standard target data in order to minimize noise and thus achieve the greatest SNR. Noise perturbs both amplitude and phase information and it was our intent to evaluate the hydroacoustic equipment performance capabilities under optimal conditions at this stage of project development. Future research will be required to evaluate system performance with greater noise levels found at the longer ranges and bottom aiming orientations typical to riverine migratory salmon assessment projects.

Using split-beam technology in a riverine salmon assessment program requires optimizing conflicting acoustic requirements. Fish must pass through the effective beam to be detected, and a minimum 10 dB SNR must be maintained to accurately determine phase and amplitude information. Because phase information allows position in the beam to be calculated in real time, otherwise acceptable echoes are excluded based on their measured angular position relative to the MRA regardless of echo intensity. Therefore, the beam 'edge' must be positioned close to the bottom of the river so that fish migrating along the bottom pass through the effective beam. Forcing the beam so near a boundary can intensify acoustic noise (surface reverberation) to the point of degrading SNR below acceptable limits depending on the reflectivity of the boundary layer. Resulting noise-perturbed phase and amplitude information can combine to cause uncertainty in target strength estimates produced. In addition, perturbed phase data will cause erroneous target position determination. Erroneous positional information will effect automatic tracking results, and will cause some echoes to be discarded from the data set based solely on calculated position in the beam. Therefore, the relationship between effective beam position in the river and SNR must be determined on each bank of the Yukon River at the Eagle sonar site before an assessment of feasibility may be completed.

In addition to surface reverberation, volume reverberation has the potential to limit acoustic data acquisition at this project. Volume reverberation is sound reflected from unwanted, usually small, targets in the ensonified water column. These targets may be of any reflective source suspended in the water, including particulate debris and precipitation. Precipitation in the form of rain or snow both cause varying degrees of acoustic noise. However, snow appears to cause the greatest amount of noise as even lightly falling snow causes nearly complete reflection of acoustic energy at very short ranges. Therefore, no acoustic assessment is possible whenever any snow is falling. Yet while snowfall is not an unusual event at Eagle after 1 September, long term data collection was not severely hindered by weather during the chum salmon migration in the first two years of the feasibility studies there. Only experience will establish the amount of acoustic sampling time typically lost to weather events as we learn more about the relationship between SNR and data quality in terms of both phase and amplitude information, regardless of the noise source.

One of the uncertainties remaining after analysis of the 1993 acoustic data involves the relationship between target strength and mean length of migrating salmon at the sonar site. Because of mechanical problems with the dedicated test fishing boat, most test fishing activities were directed toward addressing temporally specific questions of species presence/absence in the nearshore areas which were acoustically sampled. Resulting catches were insufficient to permit calculating relative gillnet efficiencies, hence it was not feasible to correct for mesh-specific catchability. It was also impossible to document the spatial distribution of migrating fish, since the mid-section of the river was not acoustically or physically sampled.

Another uncertainty to be resolved in future investigations at this site lies in identifying the extent of the full cross-section of the river used by migrating chinook and chum salmon. Short duration side-looking acoustic samples of areas beyond the shelf break on the right bank, obtained by redeploying the existing transducer offshore, revealed no targets beyond the standard range of ensonification from the right bank transducer. More extensive sampling of offshore areas with other, perhaps down-looking, hydroacoustic equipment will be required to better understand the migratory behavior of salmon passing upstream at the sonar site if offshore deployment proves unfeasible.

A final area of uncertainty that remains to be resolved in future investigations is fully describing signal loss (greater than 40 log R) at range. Once described, acquisition software readily allows user input compensation for any range dependent signal loss.

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Table 1. Daily mean water level measured at the Yukon River border sonar site near Eagle, Alaska, from 19 July through 22 September 1993.[1]

Date	Gauge Ht. (m)	Date	Gauge Ht. (m)	Date	Gauge Ht. (m)
7/01/93		8/01/93	4.94	9/01/93	4.05
7/02/93		8/02/93	4.94	9/02/93	4.11
7/03/93		8/03/93	4.88	9/03/93	4.18
7/04/93		8/04/93	4.75	9/04/93	
7/05/93		8/05/93	4.75	9/05/93	4.30
7/06/93		8/06/93	4.75	9/06/93	4.27
7/07/93		8/07/93	4.69	9/07/93	
7/08/93		8/08/93	4.63	9/08/93	4.21
7/09/93		8/09/93	4.57	9/09/93	
7/10/93		8/10/93	4.54	9/10/93	4.15
7/11/93		8/11/93	4.48	9/11/93	4.08
7/12/93		8/12/93	4.45	9/12/93	3.99
7/13/93		8/13/93	4.45	9/13/93	3.99
7/14/93		8/14/93	4.51	9/14/93	3.99
7/15/93		8/15/93	4.57	9/15/93	3.99
7/16/93		8/16/93	4.54	9/16/93	3.96
7/17/93		8/17/93	4.51	9/17/93	3.96
7/18/93		8/18/93	4.45	9/18/93	3.96
7/19/93	4.94	8/19/93	4.36	9/19/93	3.93
7/20/93	4.94	8/20/93	4.24	9/20/93	3.93
7/21/93	4.82	8/21/93	4.11	9/21/93	3.87
7/22/93	4.79	8/22/93	4.15	9/22/93	3.84
7/23/93	4.79	8/23/93	4.11	9/23/93	
7/24/93	4.60	8/24/93	4.21	9/24/93	
7/25/93	4.60	8/25/93	4.30	9/25/93	
7/26/93	4.60	8/26/93	4.24	9/26/93	
7/27/93	4.66	8/27/93	4.15	9/27/93	
7/28/93	4.72	8/28/93	4.08	9/28/93	
7/29/93	4.82	8/29/93	4.08	9/29/93	
7/30/93	5.09	8/30/93		9/30/93	
7/31/93	5.00	8/31/93	4.02		

[1] Data referenced to an arbitrary baseline of 3.0 m (10.0 ft).

Table 2. Summary of split beam sonar data collected at the Yukon River border sonar site near Eagle, Alaska, from 15 July through 23 September 1993 by date and bank.

Date	Right Bank (Hrs)	Left Bank (Hrs)	Date	Right Bank (Hrs)	Left Bank (Hrs)
7/15	22.75	0.00	8/20	22.00	23.75
7/16	24.00	20.00	8/21	24.00	20.75
7/17	23.50	14.75	8/22	24.00	8.75
7/18	23.50	7.75	8/23	24.00	0.00
7/19	21.75	17.75	8/24	23.00	0.00
7/20	24.00	11.75	8/25	23.25	9.50
7/21	21.25	16.75	8/26	22.00	15.25
7/22	22.00	16.50	8/27	23.50	18.50
7/23	23.50	23.00	8/28	24.00	15.75
7/24	22.75	23.75	8/29	21.75	23.25
7/25	22.25	24.00	8/30	24.00	22.00
7/26	23.50	22.25	8/31	21.50	23.75
7/27	23.50	24.00	9/01	21.50	16.00
7/28	21.50	24.00	9/02	23.75	13.50
7/29	22.75	22.75	9/03	22.50	20.25
7/30	23.50	22.75	9/04	24.00	23.50
7/31	19.00	22.75	9/05	24.00	23.75
8/01	23.75	24.00	9/06	24.00	24.00
8/02	23.75	23.75	9/07	19.75	24.00
8/03	20.25	23.75	9/08	24.00	24.00
8/04	23.75	22.50	9/09	23.75	19.50
8/05	24.00	23.00	9/10	24.00	11.50
8/06	23.50	23.75	9/11	20.75	21.75
8/07	24.00	24.00	9/12	23.75	20.25
8/08	20.50	24.00	9/13	23.75	22.50
8/09	23.75	24.00	9/14	23.25	22.75
8/10	24.00	23.75	9/15	23.75	16.75
8/11	23.50	23.50	9/16	12.25	23.75
8/12	24.00	24.00	9/17	22.75	15.50
8/13	23.50	24.00	9/18	23.00	22.25
8/14	23.75	23.75	9/19	23.75	24.00
8/15	24.00	24.00	9/20	23.75	23.50
8/16	23.00	24.00	9/21	23.00	23.00
8/17	23.50	24.00	9/22	24.00	23.50
8/18	23.25	23.25	9/23	20.75	11.75
8/19	23.75	16.50			
Bank Totals				1,625.25	1,410.50
Total Hours Sampled				3,035.75	

Table 3. Daily raw and expanded sonar chart recording tallies by bank at the Yukon River border sonar site near Eagle, Alaska, and corresponding daily CDFO fishwheel salmon catches by species approximately 15 km upstream from the border, 1993.

	Right Bank			Left Bank			Total	Fishwheel Catch	
Date	Raw Tallies	15-min. Samples	Expanded Tallies	Raw Tallies	15-min. Samples	Expanded Tallies	Expanded Tallies	Chinook Salmon	Chum Salmon
07/15	1,033	91	1,090		0		1,090	38	
07/16	948	96	948	126	80	151	1,099	33	
07/17	752	94	768	109	59	177	945	26	
07/18	793	94	810	71	31	220	1,030	37	
07/19	1,031	87	1,138	126	71	170	1,308	32	
07/20	1,351	96	1,351	61	47	125	1,476	36	
07/21	1,185	85	1,338	78	67	112	1,450	34	
07/22	1,190	88	1,298	72	66	105	1,403	19	
07/23	1,143	94	1,167	98	92	102	1,270	50	
07/24	793	91	837	148	95	150	986	38	
07/25	850	89	917	323	96	323	1,240	24	
07/26	866	94	884	298	89	321	1,206	33	
07/27	752	94	768	338	96	338	1,106	36	
07/28	678	86	757	177	96	177	934	24	
07/29	771	91	813	168	91	177	991	30	
07/30	733	94	749	251	91	265	1,013	26	
07/31	417	76	527	55	91	58	585	49	
08/01	417	95	421	62	96	62	483	26	
08/02	405	95	409	68	95	69	478	27	
08/03	271	81	321	54	95	55	376	14	
08/04	303	95	306	48	90	51	357	8	
08/05	294	96	294	61	92	64	358	10	
08/06	198	94	202	95	95	96	298	18	
08/07	208	96	208	52	96	52	260	9	
08/08	128	82	150	91	96	91	241	11	
08/09	172	95	174	94	96	94	268	6	
08/10	150	96	150	104	95	105	255	6	
08/11	160	94	163	94	94	96	259	4	
08/12	184	96	184	90	96	90	274	5	
08/13	137	94	140	104	96	104	244	5	
08/14	179	95	181	83	95	84	265	1	
08/15	182	96	182	84	96	84	266	6	4
08/16	177	92	185	130	96	130	315	4	1
08/17	158	94	161	118	96	118	279	2	4
08/18	174	93	180	93	93	96	276	0	6
08/19	256	95	259	74	66	108	366	2	3
08/20	108	88	118	137	95	138	256	1	4
08/21	123	96	123	181	83	209	332	1	7
08/22	158	96	158	76	35	208	366	1	10
08/23	270	96	270		0		270	1	9
08/24	251	92	262		0		262	1	30
08/25	218	93	225	31	38	78	303	1	20
08/26	136	88	148	87	61	137	285	2	18
08/27	176	94	180	56	74	73	252	2	17
08/28	239	96	239	53	63	81	320	1	12

Continued

Table 3. (page 2 of 2)

Date	Right Bank Raw Tallies	Right Bank 15-min. Samples	Right Bank Expanded Tallies	Left Bank Raw Tallies	Left Bank 15-min. Samples	Left Bank Expanded Tallies	Total Expanded Tallies	Fishwheel Catch Chinook Salmon	Fishwheel Catch Chum Salmon
08/29	152	87	168	74	93	76	244	0	15
08/30	188	96	188	555	88	605	793	0	11
08/31	297	86	332	564	95	570	901	0	48
09/01	393	86	439	643	64	965	1,403		23
09/02	369	95	373	458	54	814	1,187		33
09/03	484	90	516	695	81	824	1,340		53
09/04	337	96	337	259	94	265	602		55
09/05	332	96	332	273	95	276	608		81
09/06	333	96	333	263	96	263	596		90
09/07	502	79	610	241	96	241	851		78
09/08	668	96	668	265	96	265	933		111
09/09	930	95	940	379	78	466	1,406		88
09/10	1,058	96	1,058	279	46	582	1,640		92
09/11	1,320	83	1,527	349	87	385	1,912		116
09/12	968	95	978	621	81	736	1,714		85
09/13	1,029	95	1,040	446	90	476	1,516		79
09/14	1,240	93	1,280	549	91	579	1,859		75
09/15	970	95	980	575	67	824	1,804		49
09/16	1,138	49	2,230	1,044	95	1,055	3,285		43
09/17	2,011	91	2,121	389	62	602	2,724		36
09/18	804	92	839	444	89	479	1,318		23
09/19	628	95	635	364	96	364	999		24
09/20	390	95	394	573	94	585	979		34
09/21	854	92	891	956	92	998	1,889		75
09/22	746	96	746	700	94	715	1,461		57
09/23	782	83	904	233	47	476	1,380		58
Total	40,041		43,011	16,910		20,030	63,041		

Table 4. Summary of *in situ* target strength estimates from standard targets measured with split beam hydroacoustic equipment at range at the Yukon River border sonar site near Eagle, Alaska, 1993.

Date	Range (m)	Mean Target Strength(dB)
9/01	5.0	-43.4
9/01	9.3	-44.3
9/01	13.0	-47.1
9/01	16.3	-48.5
9/03	6.1	-41.7
9/03	8.4	-42.7
9/03	10.5	-42.5
9/03	11.8	-44.7

Table 5. Summary of gillnet test fish data collected at the Yukon River border sonar project near Eagle, Alaska, 1993.

Date	Gear Type	Time (hrs)	Mesh (cm)	Chinook Salmon	Chum Salmon	White-fish[1]	Other fish[2]	Total
07/18	Drift	0.20	14.0[3]	0	0	0	0	0
07/18	Set	0.92	14.0[3]	0	0	0	0	0
07/22	Drift	0.18	12.7[4]	3	0	0	0	3
07/23	Drift	0.22	8.9[3]	1	0	2	1	4
07/23	Drift	0.25	8.9[3]	0	0	1	0	1
07/24	Drift	0.28	8.9[3]	0	0	0	1	1
07/26	Drift	0.23	8.9[3]	1	0	0	0	1
07/26	Drift	0.23	8.9[3]	0	0	0	0	0
07/27	Drift	0.22	8.9[3]	0	0	0	0	0
07/27	Drift	0.25	8.9[3]	0	0	0	0	0
08/20	Drift	0.20	14.0[3]	0	0	0	0	0
08/20	Drift	0.20	8.9[3]	0	0	0	0	0
Total		3.38		5	0	3	2	10

[1] Includes least cisco, Bering cisco, broad whitefish, and humpback whitefish.
[2] Includes burbot, longnose sucker, northern pike, sheefish, and arctic grayling.
[3] Net measurements are 45.7 m long and 8.6 m deep.
[4] Net measurements are 45.7 m long and 3.6 m deep.

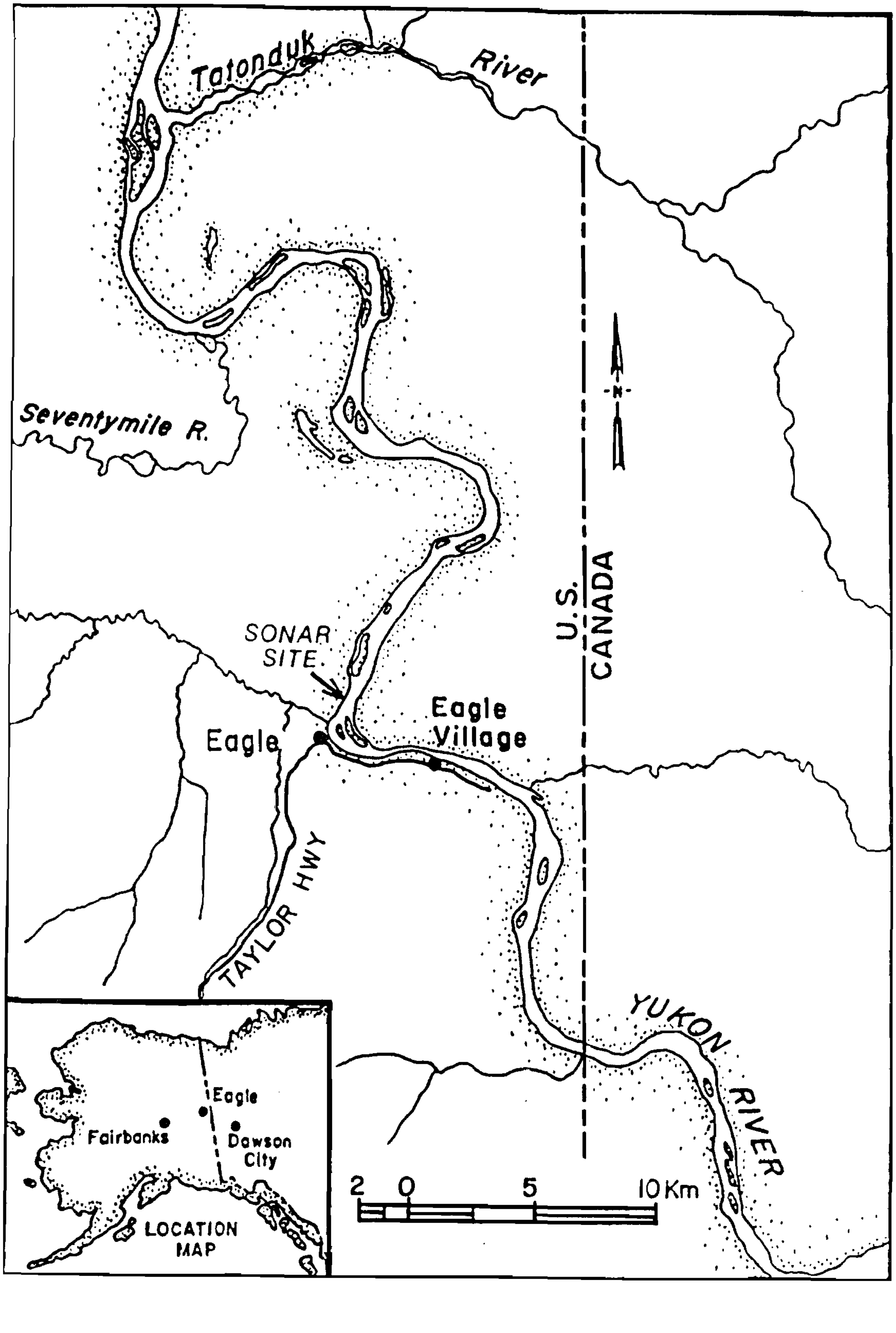

Figure 1. Map of the Yukon River near the U.S.-Canada border showing the location of the 1993 sonar site and Eagle, Alaska.

Right Bank Left Bank

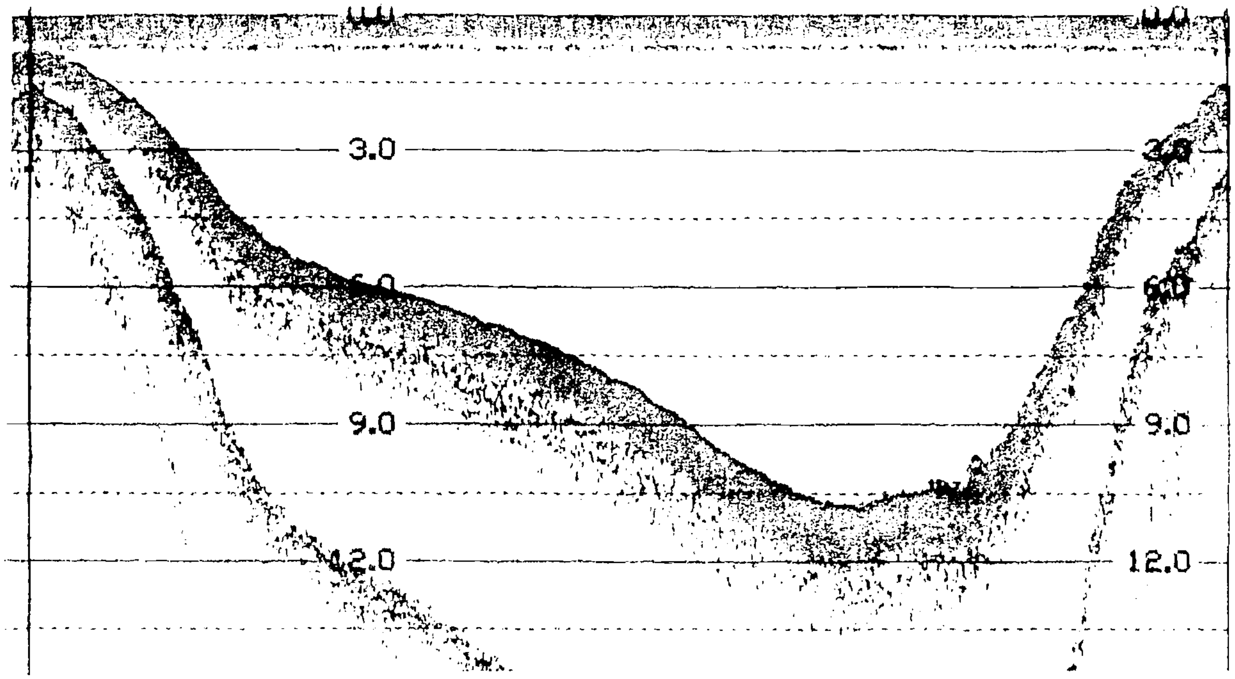

Figure 2. Typical bottom profile at the Yukon River border sonar site near Eagle, Alaska, in 1993.

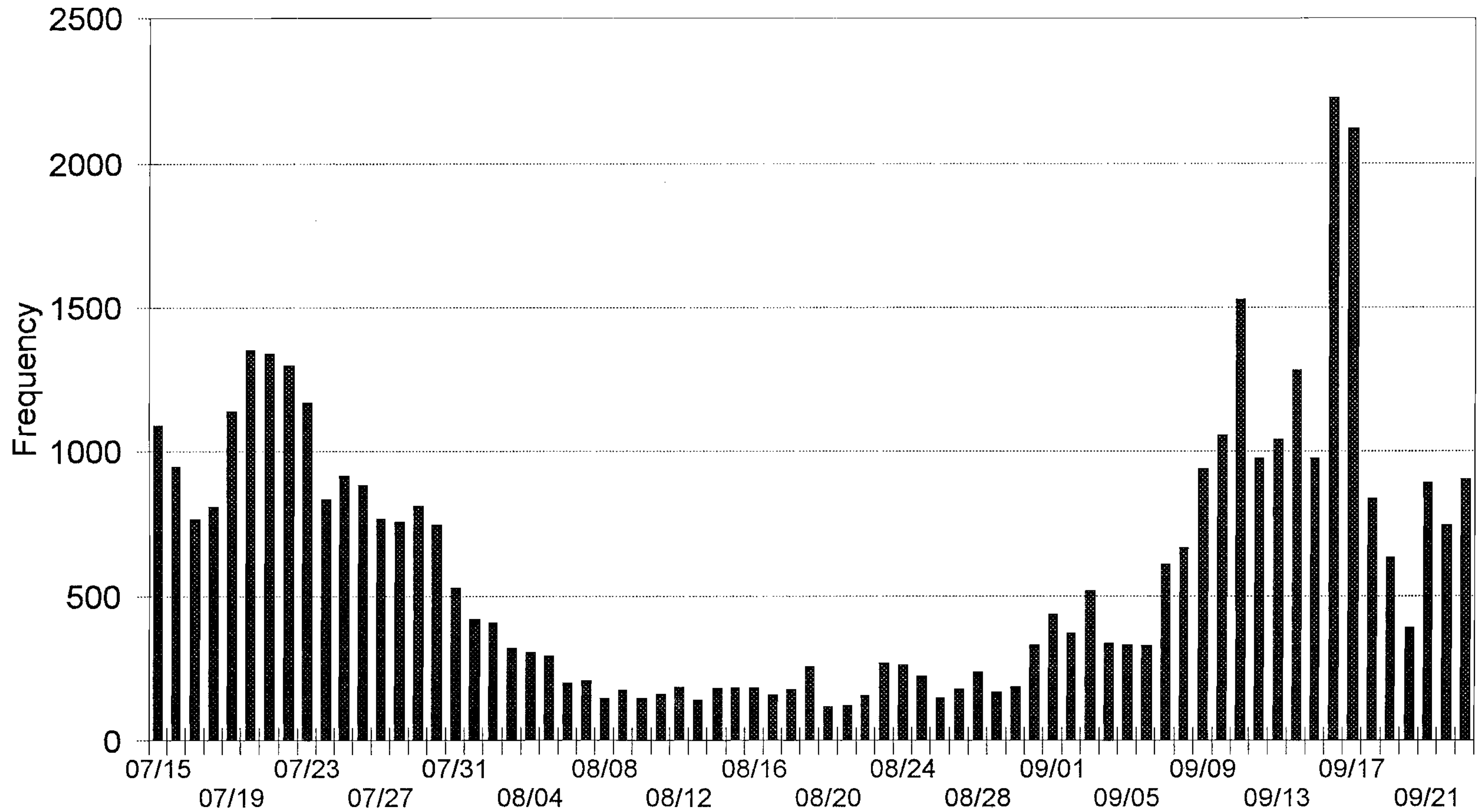

Figure 3. Temporal distribution of targets detected on chart recordings, adjusted for hours sampled, on the right bank at the Yukon River border sonar site near Eagle, Alaska from 15 July through 23 September 1993.

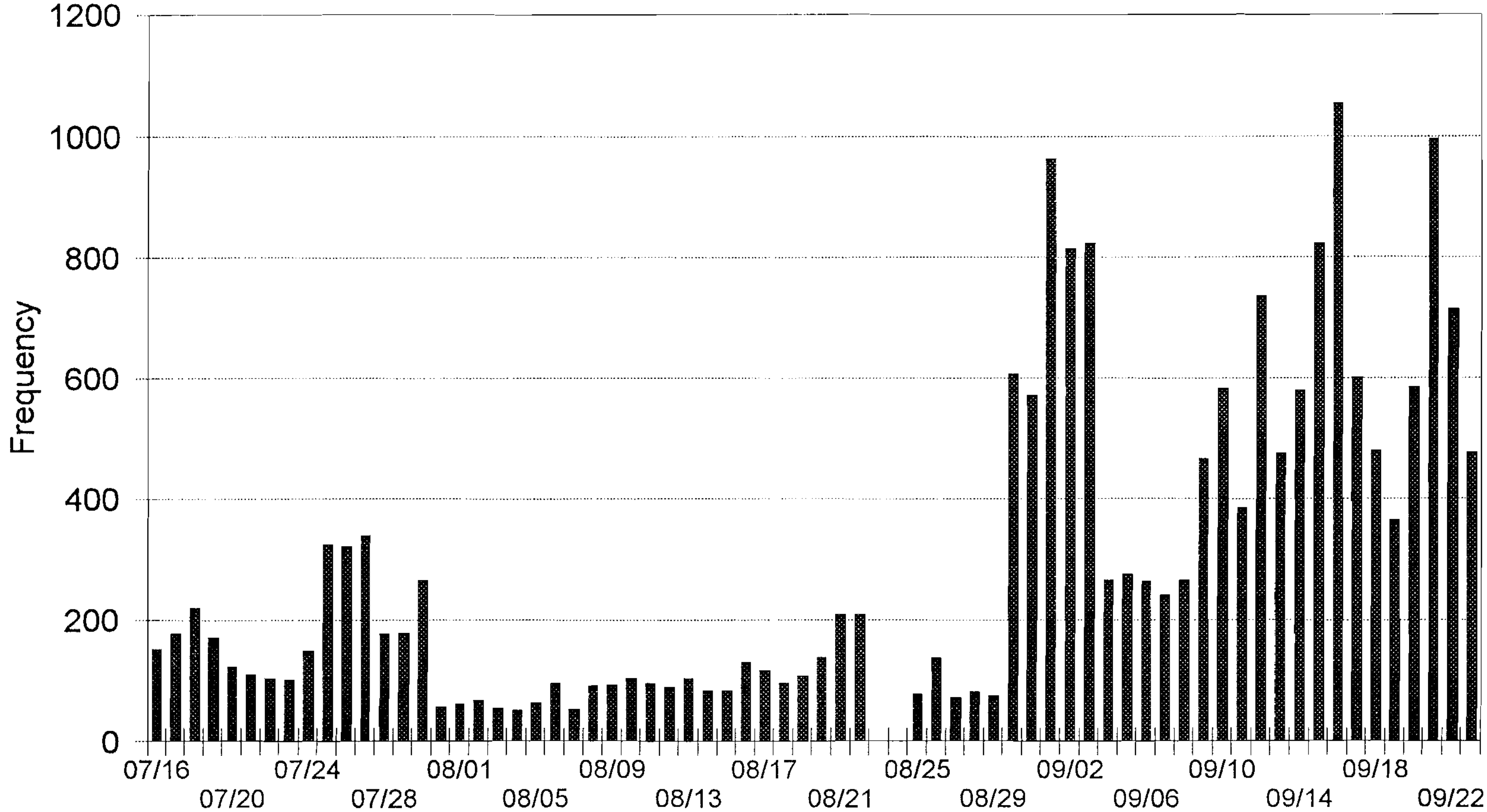

Figure 4. Temporal distribution of targets detected on chart recordings, adjusted for hours sampled, on the left bank at the Yukon River border sonar site near Eagle, Alaska from 16 July through 23 September 1993.

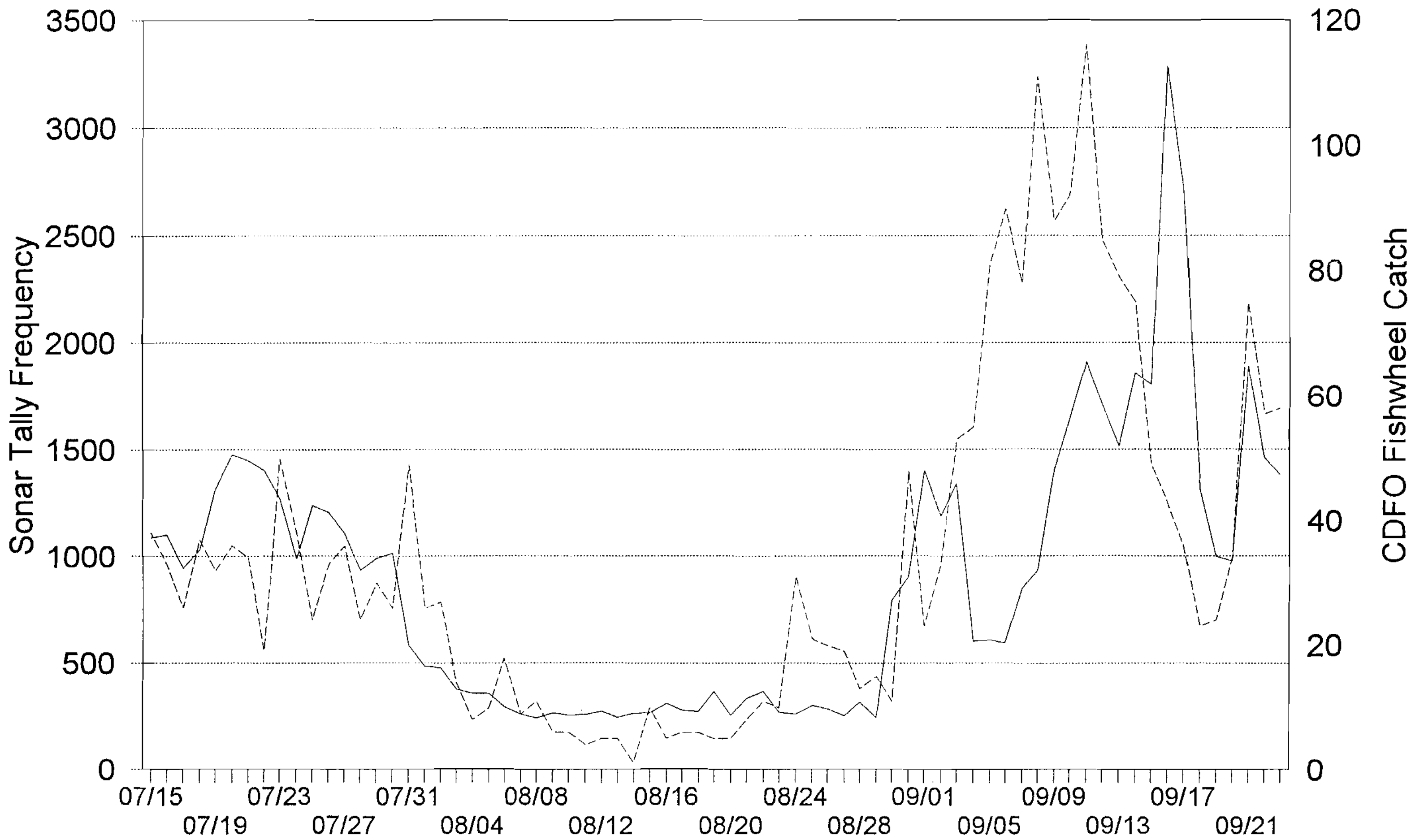

Figure 5. Temporal distribution of targets detected on chart recordings at the Yukon River border sonar site near Eagle, Alaska, (solid line) and combined CDFO fishwheel salmon catches approximately 15 km upstream from the border, by day (unlagged), 1993.

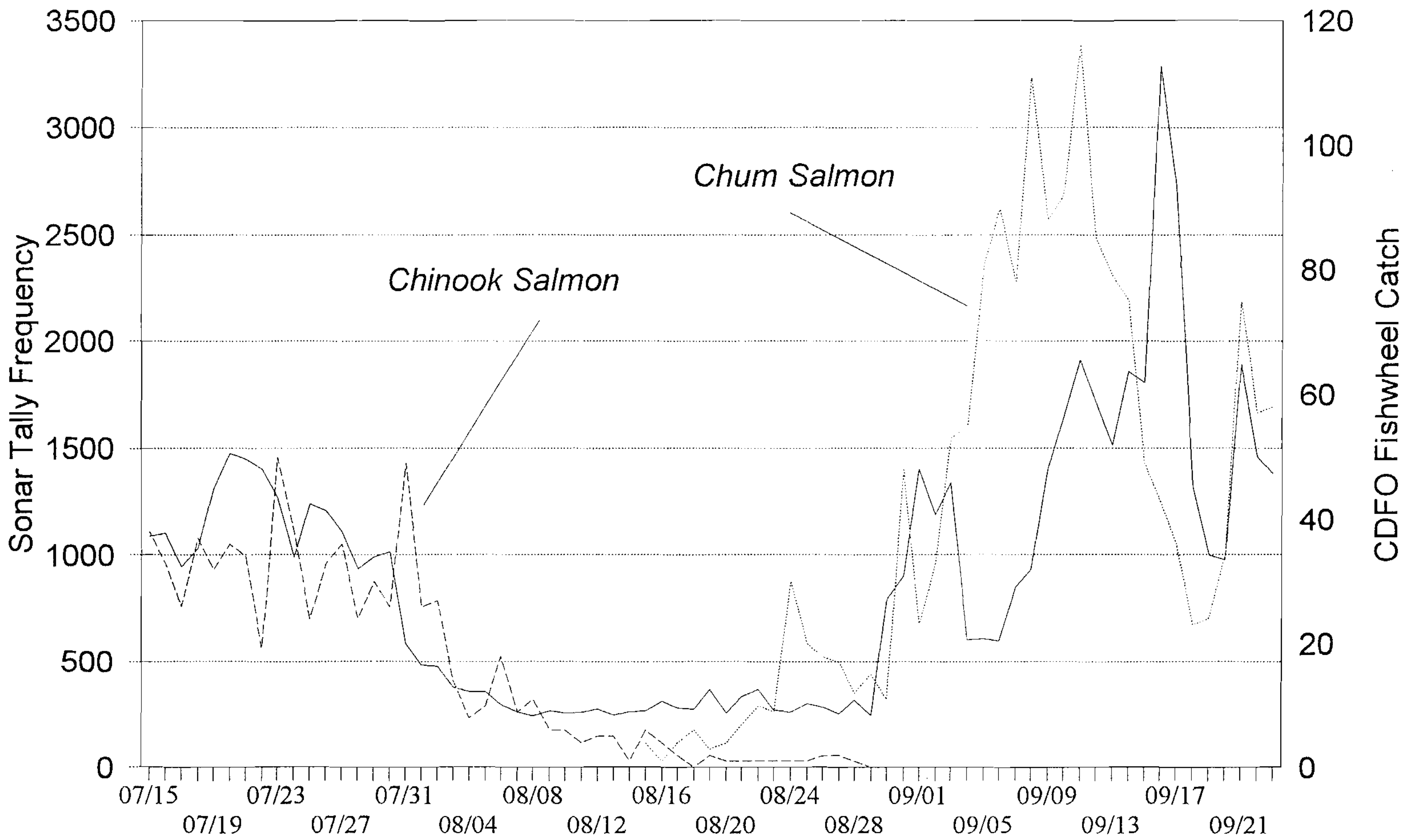

Figure 6. Temporal distribution of targets detected on chart recordings at the Yukon River border sonar site near Eagle, Alaska, (solid line) and CDFO fishwheel catches of chinook salmon and chum salmon approximately 15 km upstream from the border, by day (unlagged), 1993.

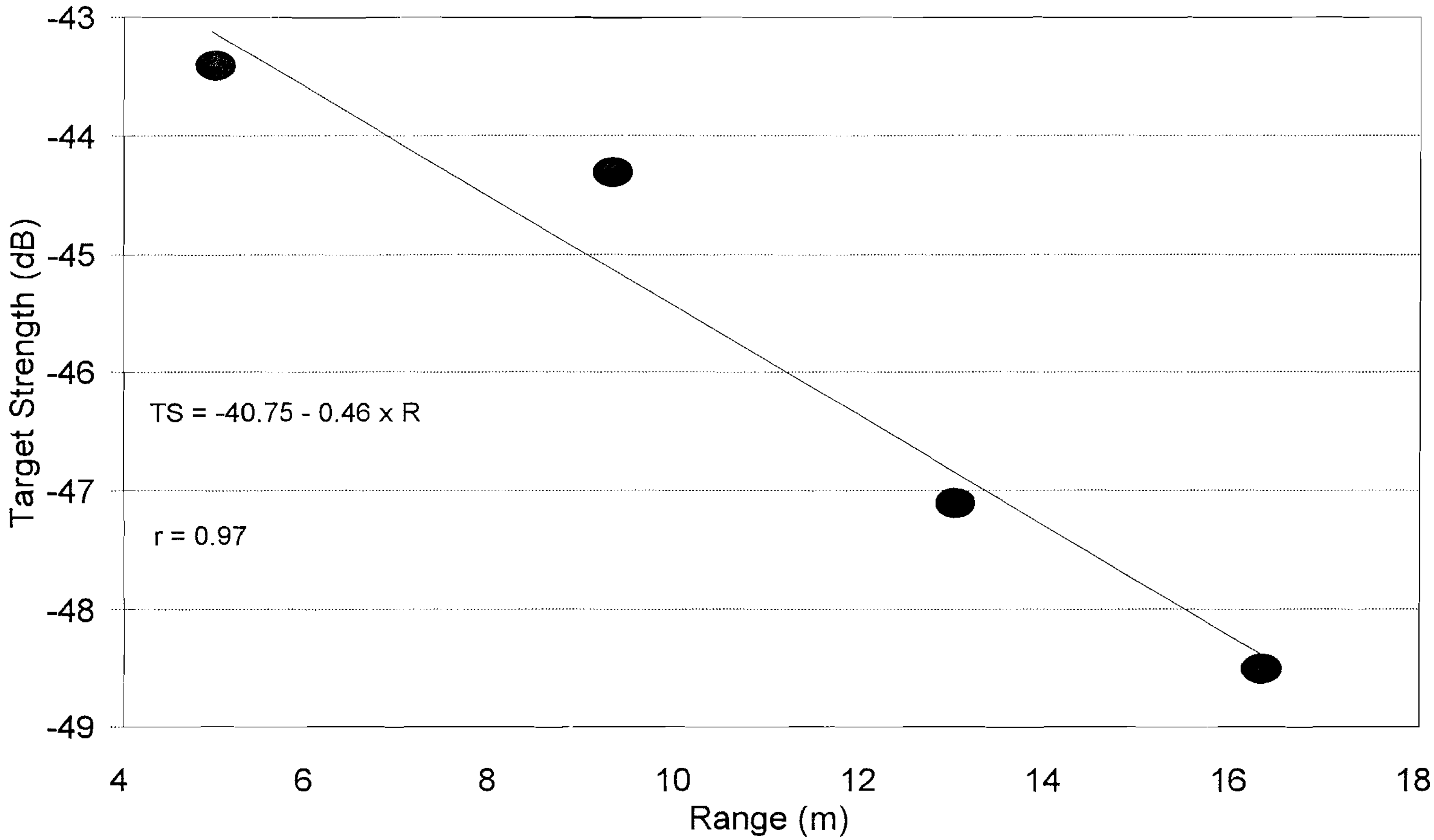

Figure 7. Target strength vs range of a 38.1 mm stainless steel standard target ensonified at the Yukon River border sonar site near Eagle, Alaska on 1 August, 1993.

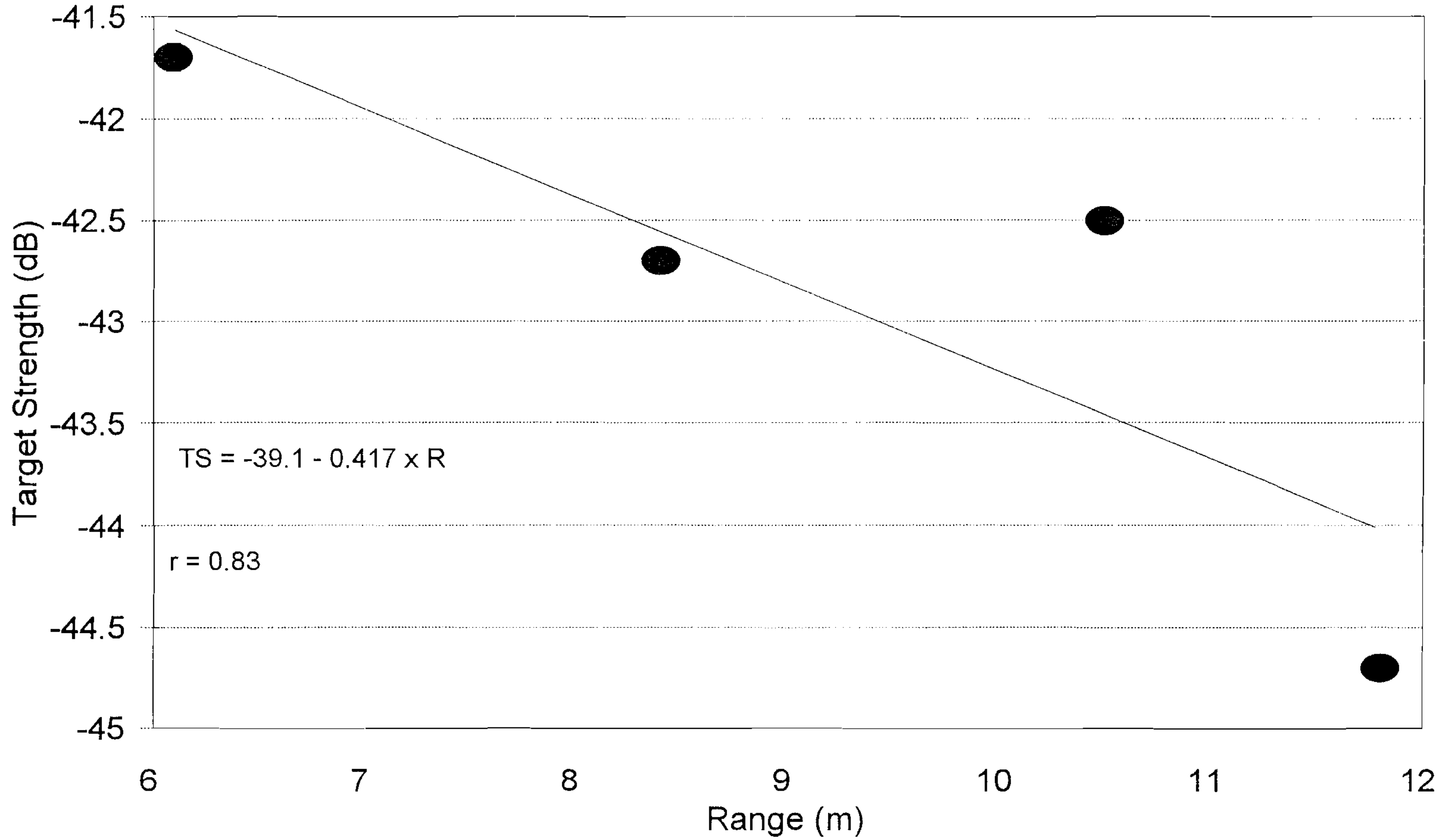

Figure 8. Target strength vs range of a 38.1 mm stainless steel standard target ensonified at the Yukon River border sonar near Eagle, Alaska on 3 August, 1993.

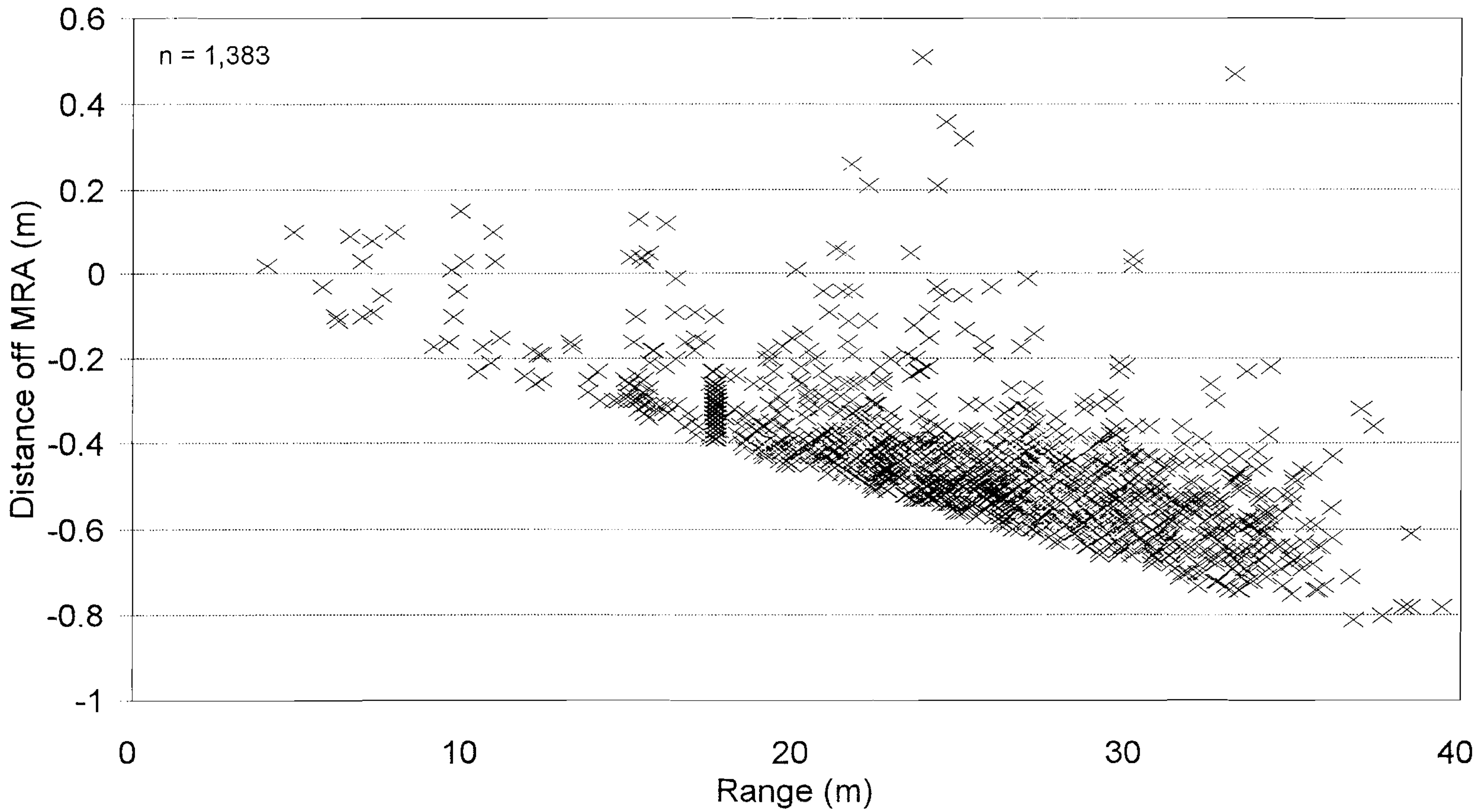

Figure 9. Spatial distribution of upstream fish ensonified on the right bank at the Yukon River border sonar site near Eagle, Alaska on 22 July, 1993.

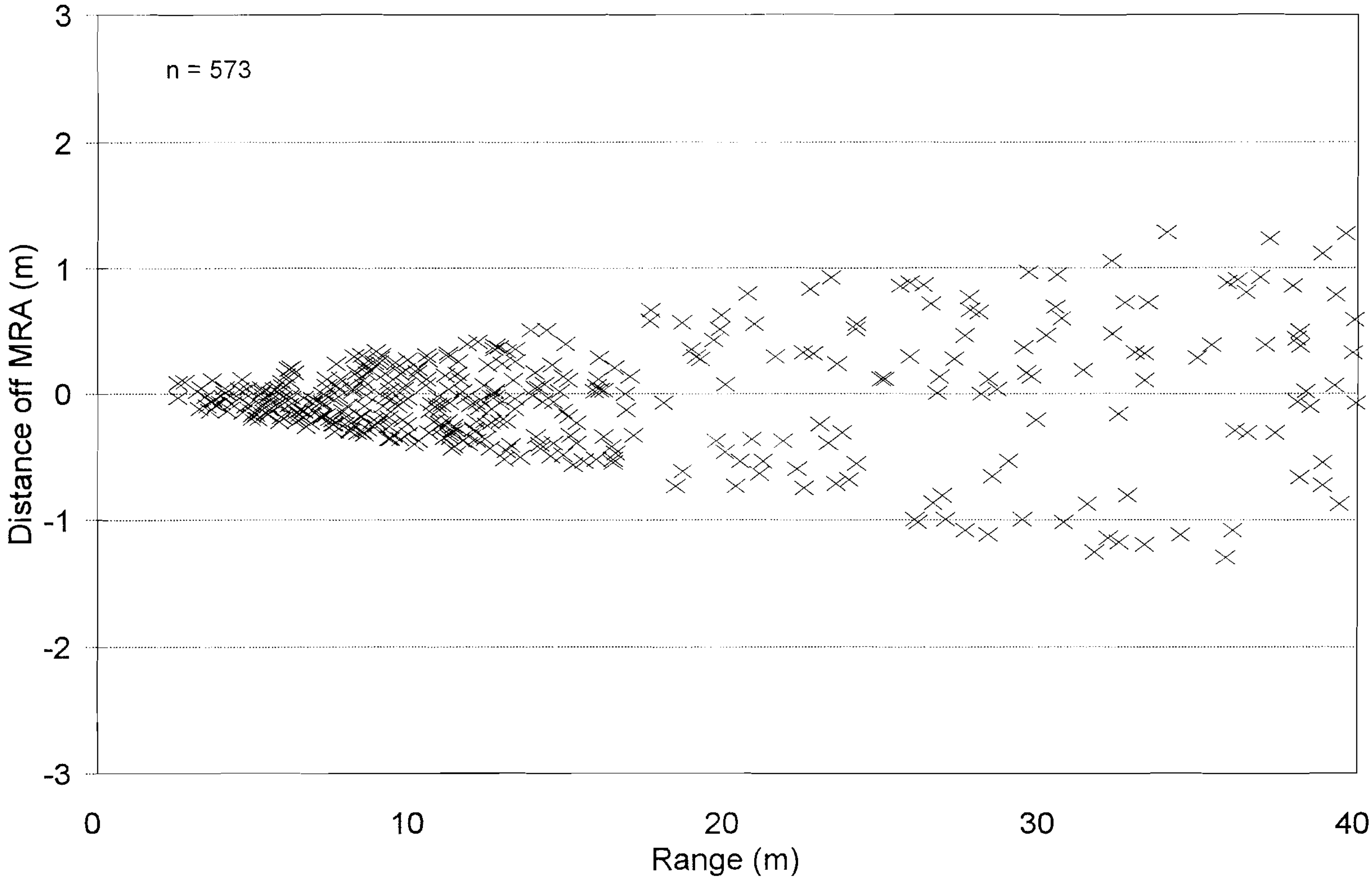

Figure 10. Spatial distribution of upstream fish ensonified on the left bank at the Yukon River border sonar site near Eagle, Alaska on 15-21 September, 1993.