FEASIBILITY OF SPLIT-BEAM HYDROACOUSTIC GEAR TO PROVIDE ESTIMATES OF COHO SALMON ABUNDANCE IN THE KENAI RIVER: SECOND-YEAR INTERIM REPORT

By

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ABSTRACT

In 1992, we focused on split-beam sonar as we continued to investigate the feasibility of using hydroacoustic gear to estimate coho salmon *Oncorhynchus kisutch* abundance in the Kenai River. Through the second year of the study, we have found split-beam sonar to have approximately twice the precision of dual-beam sonar for both tracked fish and standard target spheres. Hydroacoustic data were collected from 21 August to 25 September. A fish wheel was operated from 21 August to 17 September, when the water level became too low to operate. It appears that intrinsic noise levels at the mile 19 site did not allow the voltage threshold to be set low enough to include modal target strength values for sockeye *O. nerka* and pink salmon *O. gorbuscha*. No diel pattern was found that might help distinguish coho salmon from other species passing concurrently. Data from 1991 and 1992 indicate that sockeye salmon passing the mile 19 site after 20 August are significantly smaller than those passing during 25-30 July (t test, $P < 0.001$, both years). This means that historical coho and sockeye distributions compiled in 1991 show modes that are unrealistically close. A site that appears superior to the mile 19 site was located at Big Eddy Jetty (approximately mile 14). It is hoped that the narrower and deeper channel at this site would result in a substantially lower signal to noise ratio (SNR).

KEYWORDS: Salmon abundance, hydroacoustic sampling, fish wheel, split-beam sonar, migratory behavior, Kenai River

INTRODUCTION

Investigations in 1992 represent the second year in a study to examine the feasibility of using sonar to provide seasonal estimates of coho salmon passage in the Kenai River. In 1991, hydroacoustic sampling carried out using dual-beam sonar was deemed unreliable because of attenuation at 420 kHz and wide-beam roll off phenomena (Vaught et al. 1991). Additionally, the sonar site used at river-mile 19 was judged marginally acceptable, because of its relatively broad, shallow channel morphometry and because historical hydrographic data (USGS, Water Resources Division, unpublished data) showed substantial water level drop after late August.

Split-beam sonar (200 kHz) was used in 1992 to solve the problems of attenuation and wide-beam roll off. This project was part of a comprehensive coho research and management effort in Upper Cook Inlet initiated by the Division of Sport Fisheries (Meyer et al. 1991).

Specific objectives for the 1992 season were as follows:

1. collect acoustic size data for fish species present;

2. separate coho salmon from other species present by modal analysis of target strength data;

3. locate a site more suitable for deploying sonar gear than the present site, if possible.

Field investigations in 1992 again took place approximately at river-mile 19 (Figure 1). While it was apparent from 1991 investigations that this site was only marginally acceptable, it was felt that a more thorough search for a better site was in order before trying to relocate. This site is also used by the Commercial Fisheries Division to estimate sockeye salmon passage with Bendix side-looking sonar. Documented spawning of coho salmon (Booth 1990) placed this site at the extreme downstream limit of fish spawning in the Kenai River mainstem.

METHODS

Hydroacoustic Sampling

Sonar data were collected from 21 August through 25 September on the right bank (facing downstream). A Hydroacoustic Technology, Inc.[1] (HTI) split-beam 200 kHz transducer was deployed by means of an aluminum tripod on the right bank of the river. The transducer's nominal beam width, 2.5° X 10.0° (elliptical), was positioned in the river channel such that the long axis was horizontal. Remote aiming equipment (Remote Ocean Systems, Inc.) allowed the transducer to be aimed through pan and tilt planes for optimizing beam aim. The sonar system's instrumentation consisted of an HTI model 240 Split-Beam Digital Echosounder (DES), used in conjunction with an HTI model 340 Digital Echo Processor (DEP). The DEP consisted of a custom processor card mounted in an 80486 microcomputer. Support electronics included an HTI model 402 digital chart recorder interface (DCR) connected to a Panasonic model KX-1624 dot-matrix printer, a Victor XD-2700 Digital Audio Tape Deck, and a Nicolet 310 digital storage oscilloscope. An existing building used by the Sockeye Salmon Bendix Sonar Project (Commercial Fisheries Div.) was employed to house electronic equipment. The sonar system and support electronics were powered by a Yamaha EF3800 electric-start generator housed in a small shed to provide shelter from weather and minimize noise. A Grumman 5.5-m (18-ft) flat-bottomed river boat with a 25 h.p. Yamaha outboard engine was used to ferry crew members and equipment from the river access on the left bank to the sonar site on the right bank.

Hydroacoustic data were processed in real-time by the DEP and recorded to computer file. For each period sampled, data were written to *.raw, *.ech, and *.fsh extension files. Raw (*.raw) files contained all echoes meeting basic processing criteria such as voltage threshold and pulse width set in DEP software. Echo (*.ech) files contained all echoes found in the *.raw files that met tracking software criteria such that individual echoes could be combined into tracked fish. Fish (*.fsh) files contained summarized data (e.g. mean target strength) for groups of echoes combined into tracked fish in *.ech files. Echoes were simultaneously recorded in unprocessed hard copy form by the DCR for future corroboration with digital data on computer file. Acoustic sampling took place on a continuous 24-h basis. Samples were collected in 1-h increments for ease of data processing and to minimize data loss in the event of file corruption. Voltage threshold was set just above the maximum noise level to avoid filling up computer storage space with erroneous echoes. During the period 0000-0800 hours, the sonar system ran unattended. Data from this period were collected as a single 8-h sample. Digital audio tapes 2 h long were recorded twice daily, except when supplies were too low, as a means of backup in the event of real-time processing errors with the DEP.

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[1] use of company names does not constitute endorsement.

Several methods of deploying standard target spheres (tungsten carbide) as a means of in-season calibration were tested. These included: (1) manually suspending the sphere from a 2.5-m (8.2-ft) pole out of a boat anchored in the current; (2) suspending the sphere from a small float, which was in turn anchored to a weight upstream; and (3) suspending the sphere from a pole extended from the crosspiece of a tripod set up in the current. The tungsten carbide target used had a previously observed acoustic size of -42.3 to -42.4 dB, depending on water temperature and other physical parameters (Foote and MacLennan 1983) and was hung by means of an equatorial net bag made from 9.1 kg (20 lb) test monofilament line.

Test-Fishing Program

Fish Wheel

A fish wheel located about 75 m (246 ft) downstream from the transducer was in operation on the right bank from 21 August through 17 September. The fish wheel operated continually, except when fish were being sampled from the live-box or routine maintenance was being performed. Because of a diel movement pattern suggested from the 1991 fish wheel catch data, the catch in 1992 was recorded at approximately 6-h intervals (2300, 0600, 1200, 1800). This sampling scheme provided greater resolution in identifying a diel pattern that might aid in separating fish passage by species. At the end of each 6-h period, length and species of all fish in the fish wheel's live box were recorded. Scales were also removed from coho salmon for age analysis as a supplement to coho age-length data obtained from creel survey (Schwager-King *In Press*). Fish length was measured from mid-eye to tail fork. Scales were collected from the preferred area (Scarnecchia 1979).

To accommodate falling water levels late in the season, angle-iron extensions were fitted to the fish wheel's axle supports. The extension allowed the fish wheel to operate in approximately 45 cm (1.5 ft) less water, thereby extending its operating season.

Drift Gillnets

Species composition with range was qualitatively estimated with drift gillnets fished in the reach of the river sampled by hydroacoustic gear. Nets used were approximately 18.3 m (60 ft) in length, and 13.5 cm (5.4 in) mesh size. In an effort to determine the extent of bank-orientation in pink salmon migration, nets were fished in a corridor of the river ranging from immediately adjacent to the bank to two net lengths offshore. A 6.1-m (20-ft) open aluminum boat with a 70 h.p. Johnson outboard engine was used to attend the drift gillnets. At the end of each drift, the net was pulled completely in. Fish caught were disentangled and immediately returned to the river. Length of fish captured was not recorded because of the sporadic nature of this sampling program, the single mesh-size fished, and to minimize fish mortality.

Data Analysis

Because accurate calibration data for the combination of transducer and DES used were not available in-season, hydroacoustic data in *.raw files were reprocessed postseasonally using an HTI signal-processing package (DSBP). This step corrected target strength estimates in the resulting *.ech and *.fsh files output by DSBP. Once reprocessing was complete, *.ech files were compared to corresponding hard copy fish traces output by the DCR. Targets tracked by DSBP that appeared from chart traces to be debris, boat wake, or bottom were marked on *.ech files to be deleted. Fish appearing as single targets on chart recordings, but were broken into several smaller electronic "fish" by the tracking software, were also noted in *.ech files. Software developed by Sonar & Technical Services (FISHED 0.0) was used to modify *.fsh files. Fish identified in *.ech files as invalid or needing to be joined together with other fish were entered into input files to be used by FISHED. Invalid fish numbers were deleted from *.fsh files by FISHED. Target strength of fish numbers to be combined together were output as weighted means (weighted by number of echoes per fish). Other parameters, such as swimming speed and distance traveled in X, Y & Z axes, were also modified by FISHED to reflect data from all fish combined into single fish.

Alternate Site Selection

To identify alternative sites suitable for hydroacoustic sampling, a Lowrance X-16 graphing fathometer was used to obtain bottom profile data in an effort to identify alternate sites suitable for hydroacoustic sampling. Transects performed in 1991 covered the area between river-mile 12 and 19. Transects in 1992 were carried out in a more intensive search between river mile 11.5 and 25. Site investigations took place on 19 June, 29 June and 13 September.

RESULTS

Hydroacoustic Sampling

Falling water level neccesitated moving the transducer successively farther from the bank. It is not believed that moving the transducer offshore to accommodate falling water levels allowed significant salmon passage in the shallow water behind the transducer. However, in an operational project dedicated to estimating coho passage, a weir would have to be extended after each move to ensure that significant passage did not occur behind the transducer.

Approximate mean acoustic noise levels through the season ranged from approximately -42.5 to -45.5 dB. Maximum noise level was fairly constant at about -37 dB. Voltage threshold in the early part of the season was set at 100 mV to clear the maximum noise level. After 10 September, transmit power was increased by 15.9 dBv. Voltage threshold after this date was set at 500 mV.

The mean (and s.d.) 'fish' target strength (mean of all echo group means, each echo group denoting a fish) for the period 21-25 August was -29.9 (1.74) dB (Figure 2). Note that the distribution shown in Figure 2 appears unimodal. Of a total of 3,216 apparent fish targets from this period, 26.9% were determined to be downstream oriented. Mean (and s.d.) of target strengths for the period 23-25 September was -30.6 (2.5) dB. Of a total of 2,390 targets reviewed for the September period, 80.9% were downstream oriented.

Hanging the tungsten carbide sphere from a pole attached to a tripod crosspiece was the most successful method of standard target deployment. This method suspended the sphere in the water column with the best stability in the current. Suspending the target from a float caused instability as the float bobbed and swung in the current. Because the sphere was deployed in shallow water (approximately 0.6 m, 2 ft) the method of suspending the sphere from a float was also found to introduce noise from the turbulence of the current around the float. Stability was difficult to attain when manually suspending the sphere from a boat anchored in the current. Noise introduced from the boat's wake was also a problem.

The mean target strength of 392 echoes from the sphere (as deployed by the tripod method) was -41.76 (s.d.= 1.67) dB (Figure 4). This represented a deviation from observations of Foote and MacClennan (1983) of approximately 0.6 dB.

Test-Fishing program

Fish Wheel

No diel or diurnal pattern of coho migration was apparent from the daily fish wheel catch (Figure 5). In both night (1800-0600) and day (0600-1800) periods, coho always made up less than 20% of the catch until 5 September, when the proportion of coho in the catch began to increase only gradually. Extending the fish wheel's axle adjustment brackets to allow operation in shallower water met with only limited success. Ice glazing was a problem after 9 September. The extra weight of the ice on the fish wheel's baskets counteracted the river's force against the paddles, keeping the wheel from turning fast enough to effectively capture fish.

Drift Gillnets

Sampling with gillnets showed pink salmon to be migrating in the offshore zone also utilized by coho salmon. During the peak of the pink salmon run, gillnets were used in an effort to remove spawning salmon from the transducer beam area. This technique was not effective. Pink salmon on redds proved difficult to catch consistently in nets. Also, the magnitude of the pink run ensured that newly vacant redds were reoccupied quickly.

Length Distribution

Early-run coho salmon (1 August - 1 September) pooled from the fishwheel and creel census had a mean length of 599 mm (23.6 in) (s.d.= 62 mm, 2.4 in) . This was approximately 75 mm (3.0 in) greater than sockeye salmon mean length measured from the fishwheel catch ($\bar{x}$ = 526 mm, 20.7 in, s.d. = 56 mm, 2.2 in). Pink salmon mean length was about 105 mm (4.1 in)less than early run coho mean length (Figure 6). Pink salmon showed the least variability in length (s.d. = 29 mm, 1.1 in), while coho were most variable. Coho mean length from the fish wheel was significantly smaller than coho mean length from creel census, for both early and late runs (Student's t = 5.72 [early], $P < 0.001$, df = 307; t = 8.25 [late], $P < 0.001$, df = 106).

Alternate Site Location

Fathometer transects between mile 12 and mile 25 of the Kenai River revealed two sites with bottom contours suitable for sonar sampling (Figure 1). The site that appears best is located at mile 14 (Big Eddy Jetty). The bottom profile appears to have a very smooth, uniform gradient. The river here is relatively narrow (about 85-100 m), and deep (max depth 2.4-3.0 m, 8-10 ft). In comparison, the river is approximately 130 m (427 ft) wide at the mile 19 site. Transects performed at both sites on 13 September show the Big Eddy site to be approximately 0.3-0.6 m (1-2 ft) deeper than the mile 19 site at the river's thalweg. Negotiations with a private owner of land on the left side of the river (facing downstream) have been encouraging. A lot owned by the Alaska Department of Transportation on the right side of the river may also be available for ADF&G use.

Spawning pink salmon at the mile-19 site caused a significant problem with the tracking software used. Pink salmon constantly in the sonar beam caused other fish targets to be broken into multiple targets. In processing, this required sorting and correctly reconnecting multiple targets by corroborating echo groupings written to file with chart traces. This was necessary to prevent echoes from more than one actual fish being combined in mean target strength calculations for each fish written to *.fsh files. This increased data processing complexity and time expenditure considerably.

DISCUSSION

Hydroacoustic Samples

The close agreement of target strength data from the standard target sphere with observations of Foote and MacClennan (1983) indicate that the sonar system was correctly calibrated. The precision of the split-beam estimate is approximately twice that obtained with dual-beam sonar (s.d. = 3.21, N = 543) using the same target sphere on 3 June, 1992. Similarly, within-fish variability from this study ($\bar{x}$ s.d.= 2.53, N= 321) is approximately half that for chinook salmon tracked with dual-beam sonar on the Kenai Chinook Sonar Project in 1992 ($\bar{x}$ s.d.= 5.31, N= 332). Traynor and Ehrenberg (1990) also found an approximate two-fold increase in precision for target strength estimates of standard target spheres and fish using split-beam over dual-beam at a SNR of about 25. Ehrenberg (1983) estimated in monte carlo simulations that split-beam sonar should deliver approximately twice the precision of dual-beam sonar at a signal-to-noise-ratio (SNR) of 15.

It appears that the early season target strength distribution is unimodal because the voltage threshold was not set low enough to include modes from pink and sockeye salmon. This was due to the intrinsic noise level at the site, which precluded setting the voltage threshold lower. A preliminary target strength-length relationship developed by Sonar and Technical Services (unpublished data) for chinook salmon in the Kenai River predicts modal values for pink and sockeye salmon of -39.0 and -37.6 dB, respectively. The smallest target that could be detected with the voltage threshold and system settings used in 1992 was -37.1 dB. Tracking parameters allowed echoes detected up to 6 dB from the acoustic axis to be accepted. A -37.1 dB fish would generate a signal as large as the voltage threshold only on the acoustic axis. At 6dB from the acoustic axis, a fish of -31.1 dB in acoustic size would be required to generate a signal higher than the voltage threshold. Thus, this is the smallest acoustic fish size that was sampled in an unbiased fashion throughout the 6 dB acceptabilty range of the sonar beam.

Transmit power on the echosounder was increased by 15.9 dBv on September 10. The voltage threshold at this setting was 500 mV (-38.3 dB). At these settings, the smallest fish that could be sampled through the entire acceptance zone of 6 dB would have an acoustic size of -32.3 dB.

In order to acoustically detect separate modes of pink, sockeye and coho salmon, we would need to be able to sample fish with target strengths down to at least -40 dB in an unbiased fashion. There is currently no SNR widely agreed upon in the literature as necessary to estimate target strength relaiably. Weimer and Ehrenberg (1975) report a target strength bias of about 25% at SNR of -30 dB. However, this study estimated target strength bias of a single target by simulation techniques. Carlson and Jackson (1980) mention a SNR of 20 as "large." Minimum SNR (low tide) on the Kenai Chinook Sonar Project is 10. It is felt that the large sample size of detected fish on this project compensates for relatively low SNR. We feel a SNR of at least 10 and very large sample sizes are required for reliable target strength data. This would require a site with a mean background noise level no greater than -56 dB, in order to sample -40 dB fish in an unbiased fashion.

The upstream-downstream orientation of targets discussed here has been verified as correct. On 22 September the transducer was pointed significantly downstream. This causes targets that are downstream oriented to show a characteristic angled trajectory going toward the transducer as the target goes through the beam. Targets showing this orientation were also identified as downstream oriented by the tracking software. However, it is felt that a significant proportion of these targets may be debris. This is particularly true of the 23-25 September period. During this period in 1991, it appeared that a substantial amount of small debris was entrained in the current (Vaught et al. 1991). Some diagnostic indices need to be developed that would help separate noise from downstream oriented fish targets. This is mostly necessary when target traces are small. Longer target traces can be identified as being fish or debris by trajectory and range-change criteria.

Test-Fishing Program

It appears that the fish wheel is selective toward smaller coho salmon. Figures 7 and 8 show that the fish wheel did not capture coho from the right-most length categories. While it is possible that the catch from anglers is also selective toward larger fish, a definite bias toward smaller fish in the fish wheel is demonstrated by the fact that both figures show several length categories at the high end of the distribution in which only the sport fishery captured fish.

The mean length of sockeye salmon (526 mm; Figure 9) for the period 20 August - 17 September was significantly smaller than for the period 25-30 July (544 mm; Student's $t = 9.57$, $p < 0.001$, $df = 494$). Fish lengths for July were reported by the Sockeye Salmon Bendix Sonar Project, from the same fish wheel and location. Likewise, the mean for sockeye for the period 22 August - 1 September in 1991 was significantly smaller than that reported by the Sockeye Salmon Bendix Sonar Project for 25 July - 5 August, 1991 (Student's $t = 6.9$, $P < 0.001$, $df = 369$). The differences between July and August-September sockeye salmon means are very similar for 1991 and 1992 (17.9 and 20.6 mm, respectively). If this time-dependent size difference for sockeye salmon length in the Kenai River holds true in general, then length distributions of sockeye and coho salmon for 1988-1990 would have less overlap than reported previously (Vaught et al. 1991). This would increase the probability for successfully separating coho and sockeye target strength distributions by modal analysis.

Alternate Site Selection

The mile-19 site is too broad and shallow to be considered an ideal site. As water levels begin to drop in late August, the sonar beam is increasingly squeezed between the surface and bottom. USGS discharge data (unpublished) for 1980-1992 shows that the river water level drops about 0.3 m (1 ft) between 20 August and 30 September in an average year (Figure 10). In 1992, the water level dropped about 1 m (3.25 ft) in this period.

The characteristics of the Big Eddy site should result in decreased hydroacoustic noise. Calculations of beam widths necessary for the Big Eddy and mile-19 sites were approximately 2.8° and 1.4°, respectively. Beam widths were calculated based on transects performed at both sites on 13 September. In general, the more room between the surface and bottom for the sonar beam to fit in, the less noise will be experienced. The main concern regarding the quality of the Big Eddy site for hydroacoustics is boat traffic in the area. This could be alleviated somewhat by funneling boat traffic into the middle of the river. Signs and radio announcements requesting boats to stay between a pair of buoys in the middle of the channel could accomplish this. Another possible concern is that entrained air bubbles from Olsen's Rock approximately 100 m upstream could introduce noise to the hydroacoustic environment. It is believed that the relatively fast current at the Big Eddy site would preclude any spawning behavior, another advantage over the mile 19 site.

It is probable that pink and red salmon would be more bank oriented at the Big Eddy site than at the mile-19 site, because of higher current velocity in the constricted bend of the river at Big Eddy. King and Tarbox (1989a) noticed that sockeye salmon shifted onshore as water level and current velocity rose at the mile-19 site. Except for the period at the beginning of the sockeye run, over 90% of fish at mile 19 pass within 7.5 m of of the transducer between 1 July and 7 August (King and Tarbox 1991, 1989a, 1989b). The higher current velocity at Big Eddy should keep sockeye and pink salmon close to the banks. Whether coho salmon predominantly travel farther offshore than sockeye and pink salmon at the site remains to be seen.

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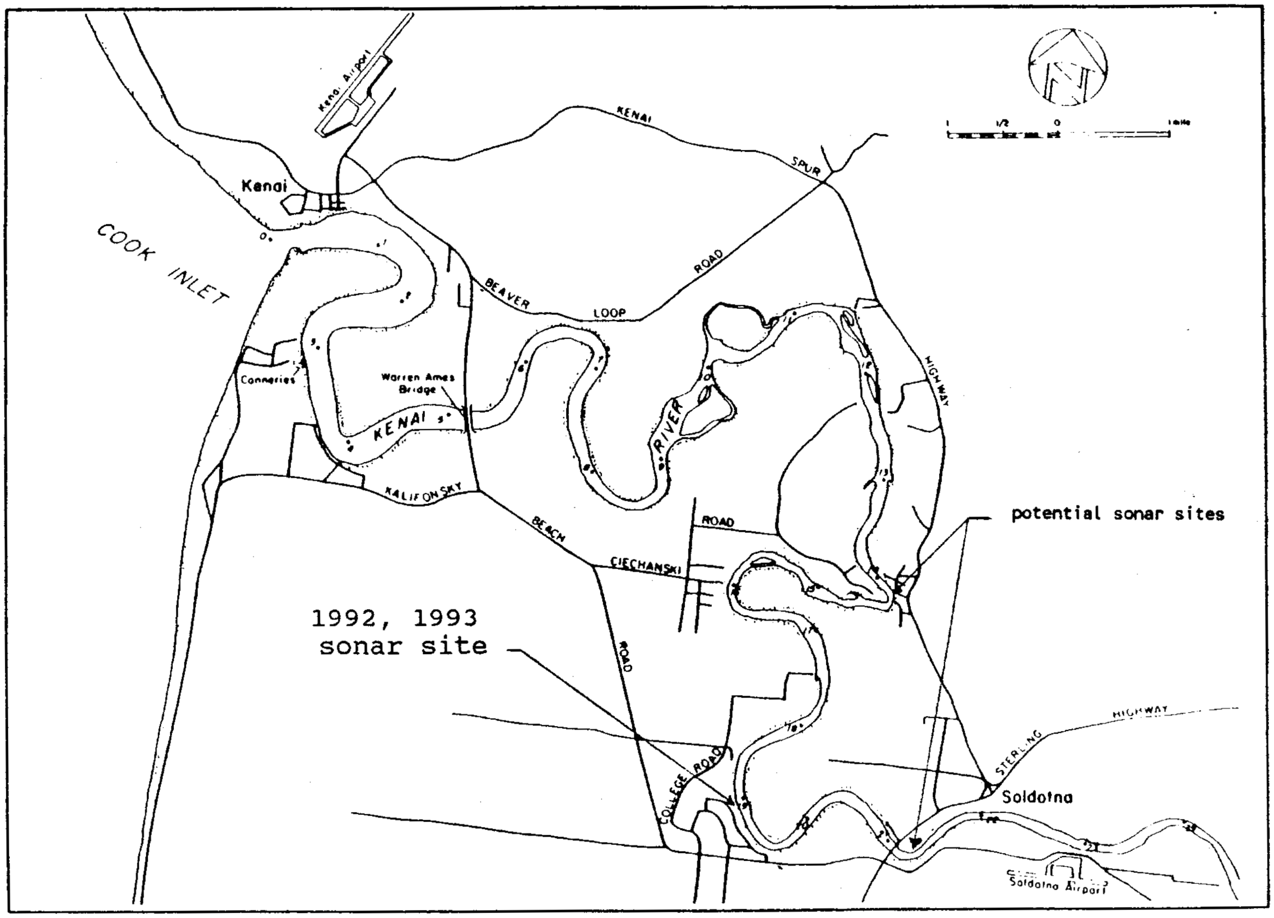

Figure 1. Kenai River study area, showing mile 19 site and possible sites identified in FY93.

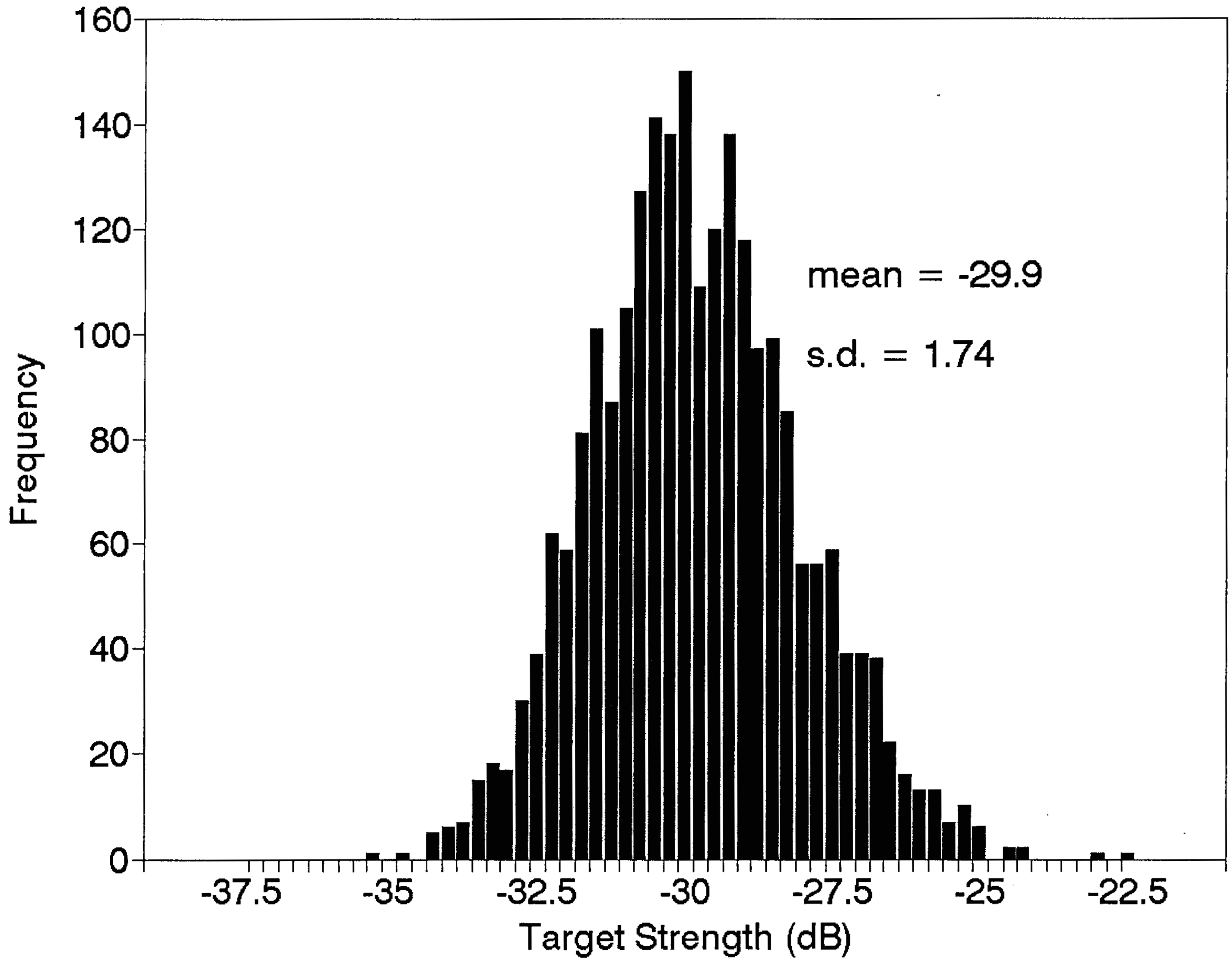

Figure 2. Target strength distribution of upstream oriented fish, 21-25 August.

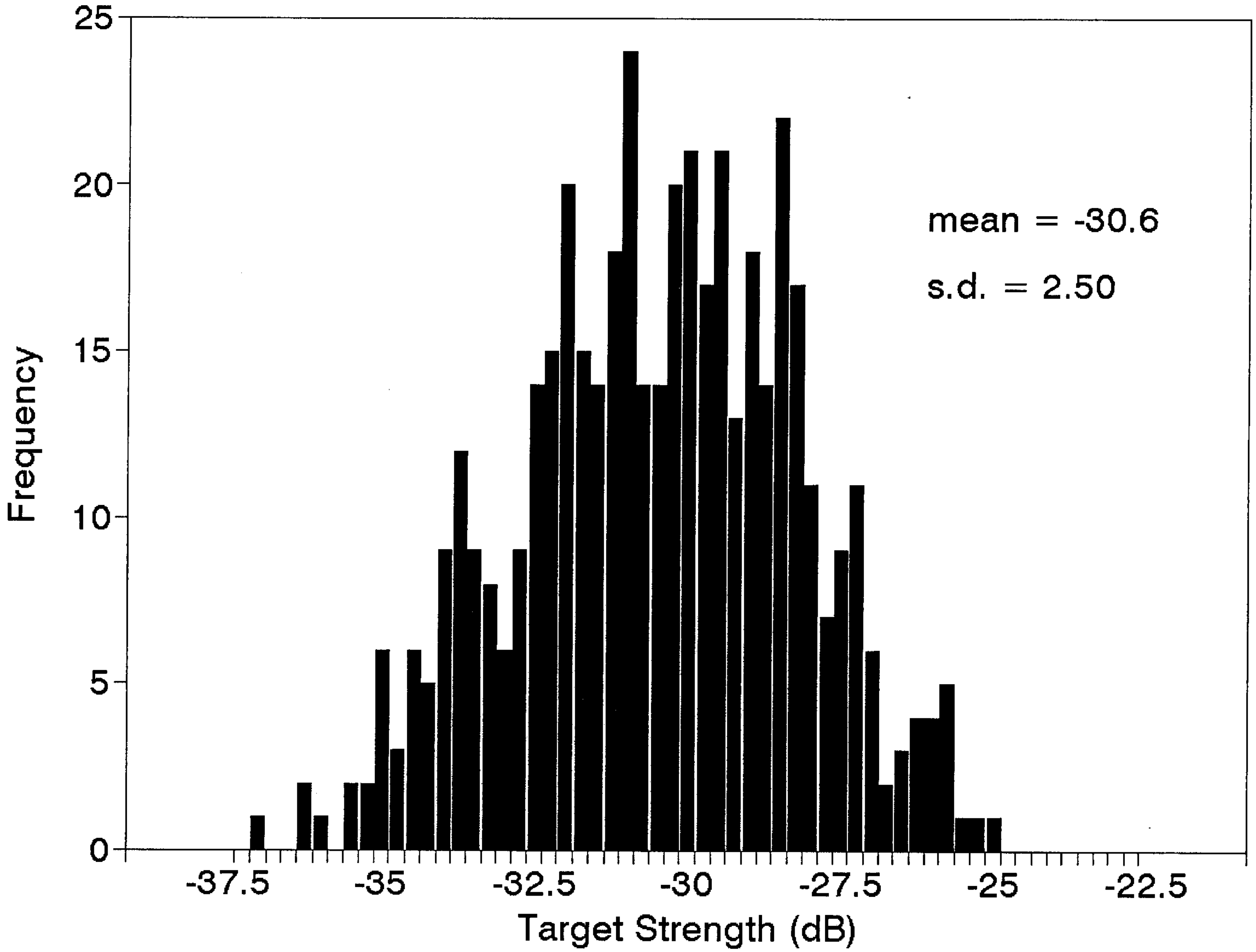

Figure 3. Target strength of upstream oriented fish, 23-25 September.

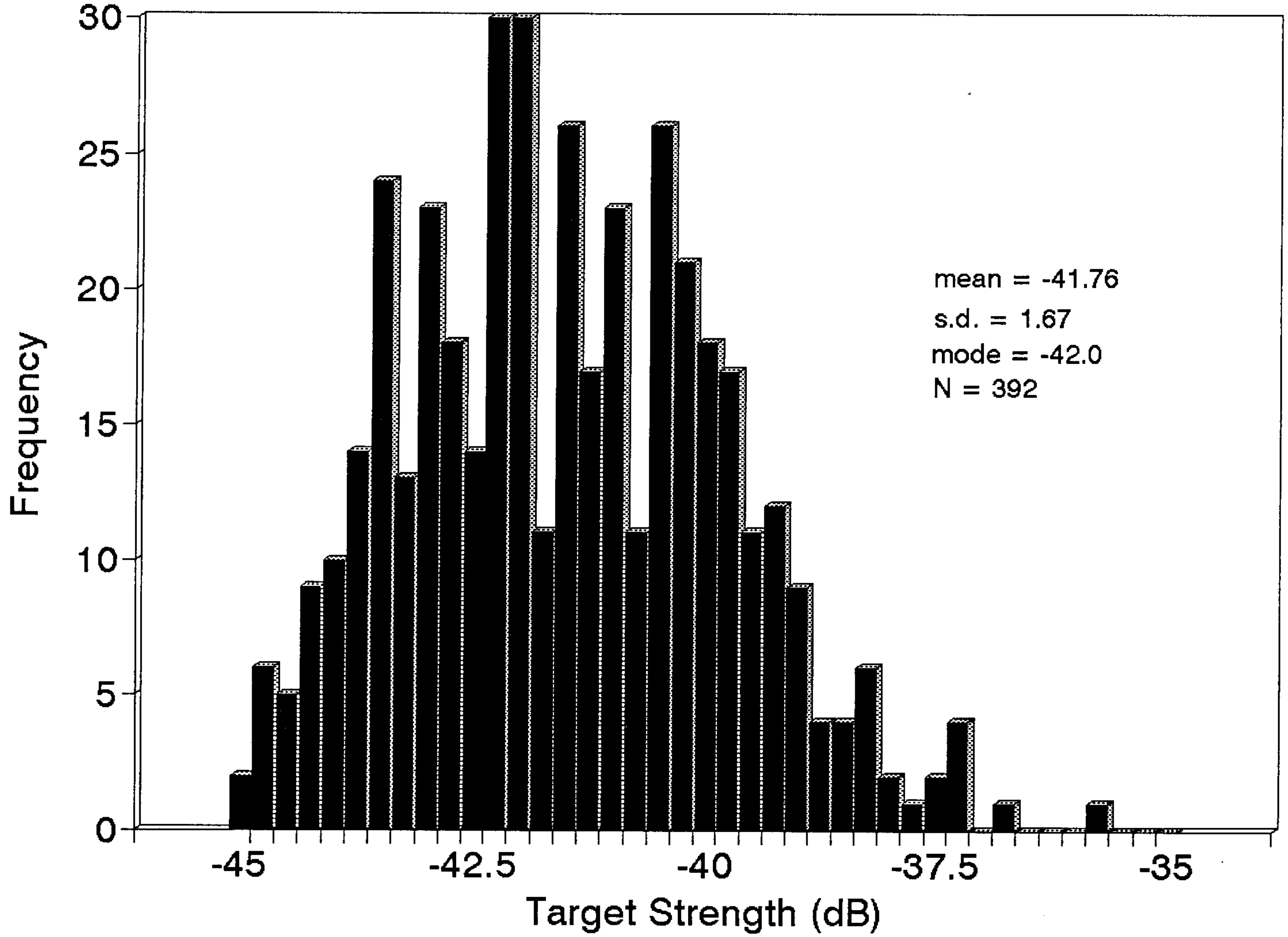

Figure 4. Histogram of echoes from -41.54 dB tungsten carbide standard target sphere.

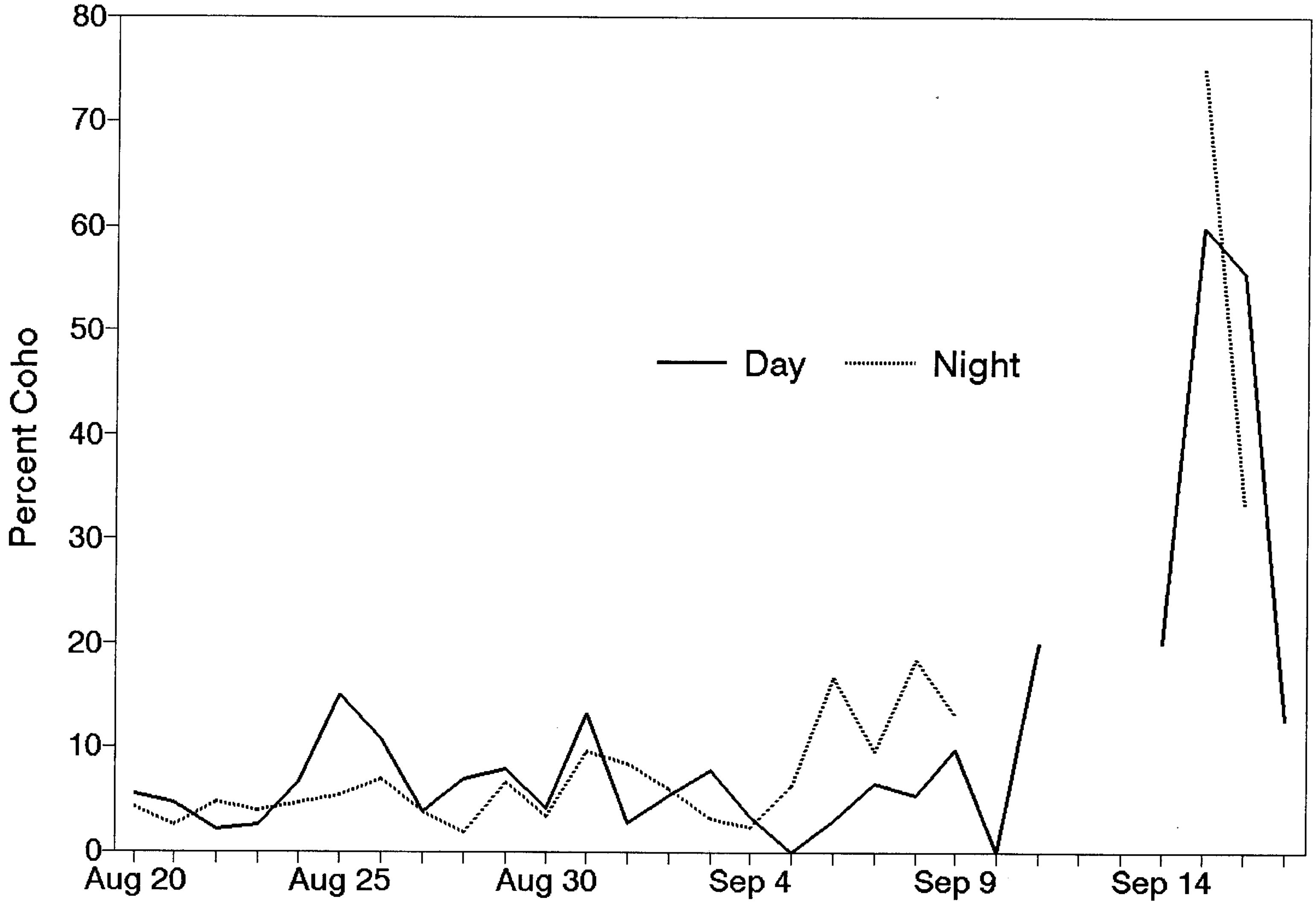

Figure 5. Relative proportion of coho salmon in fishwheel catch. Day: 0600-1800; Night: 1800-0600. Blank portions of lines represent periods when the fish wheel was not operational.

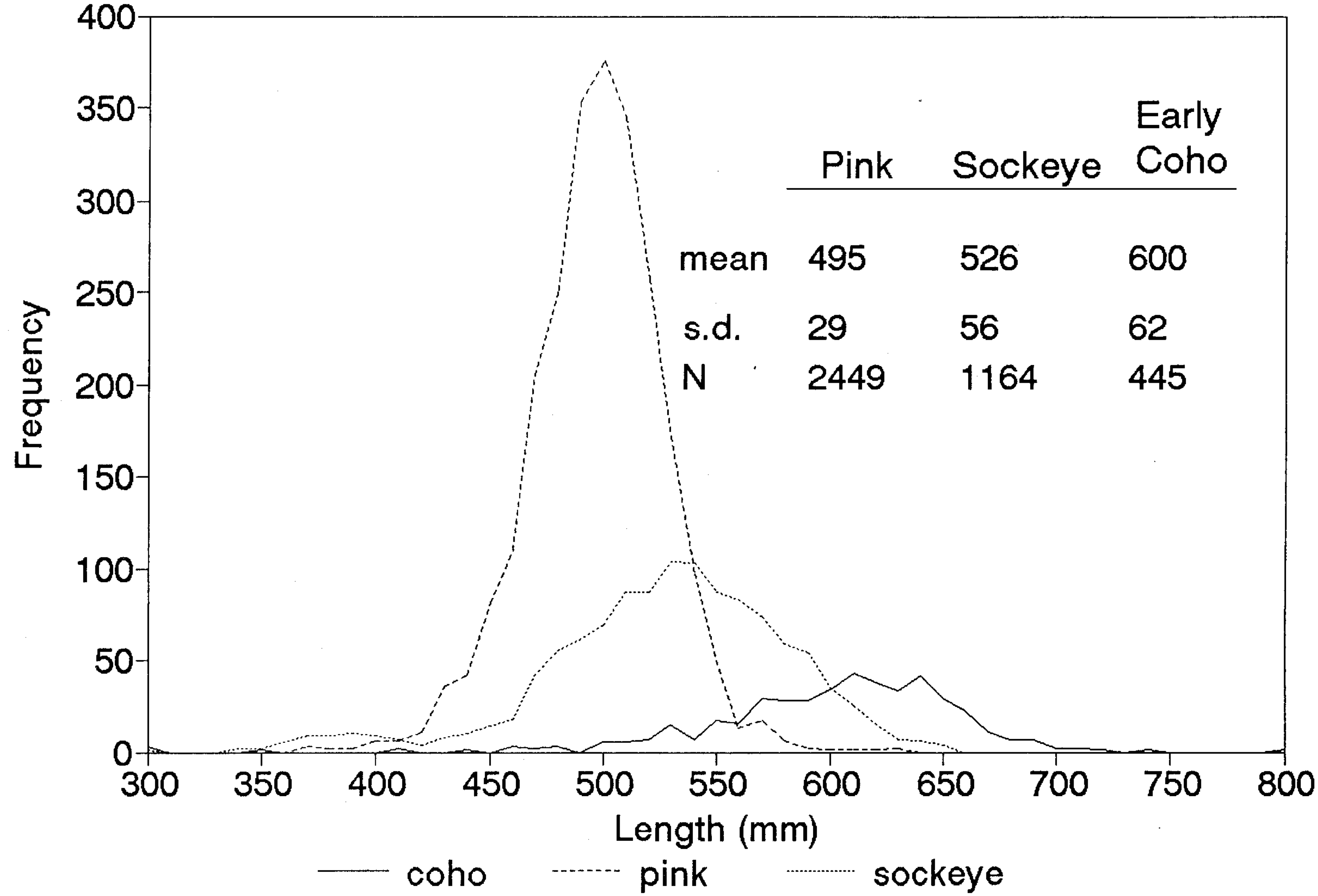

Figure 6. Distributions and statistics for salmon species in the Kenai River. Pink and sockeye sampled in fishwheel, coho pooled from fishwheel and creel survey.

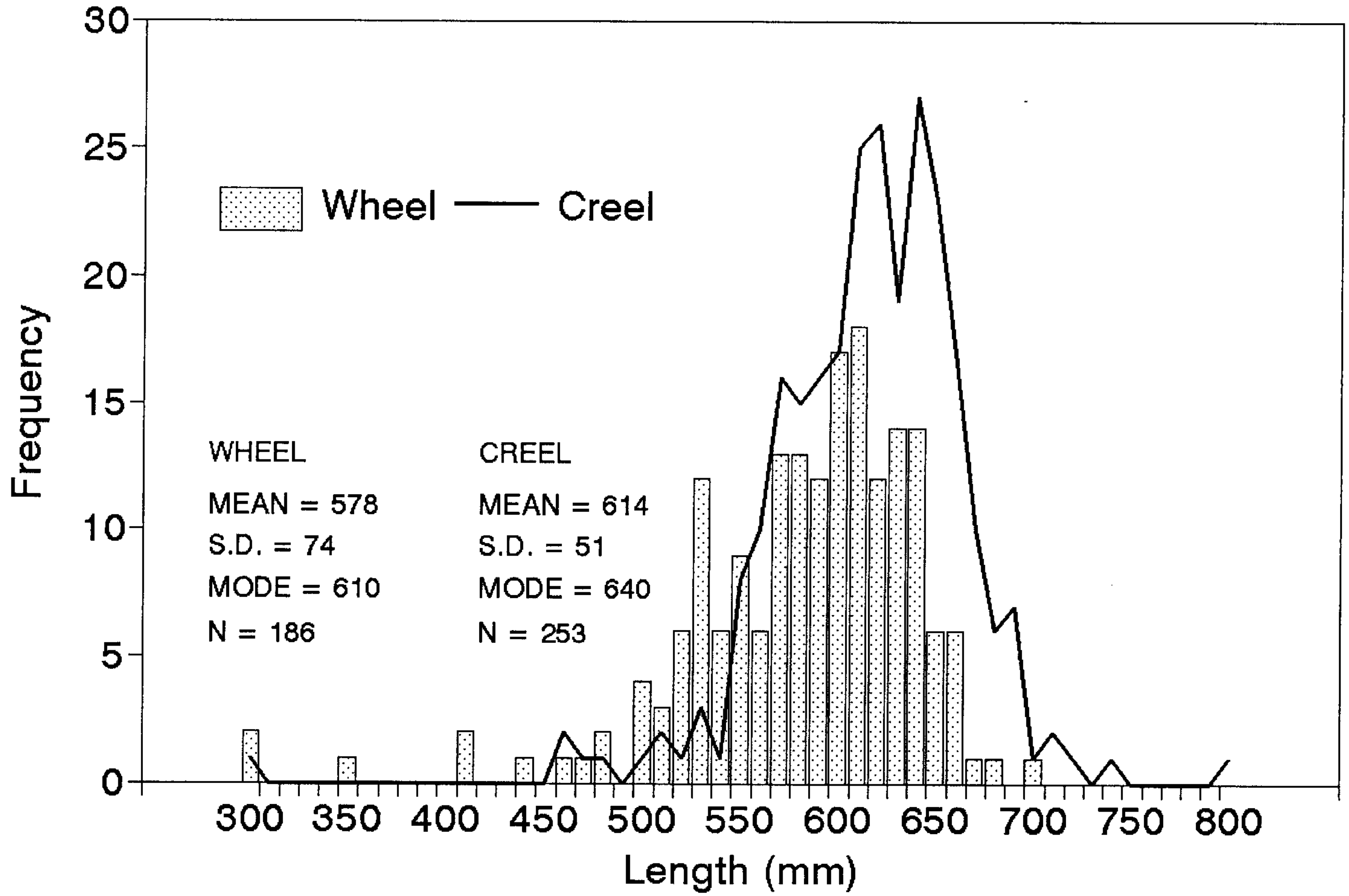

Figure 7. Length frequency of early-run coho salmon sampled in fish wheel and creel survey.

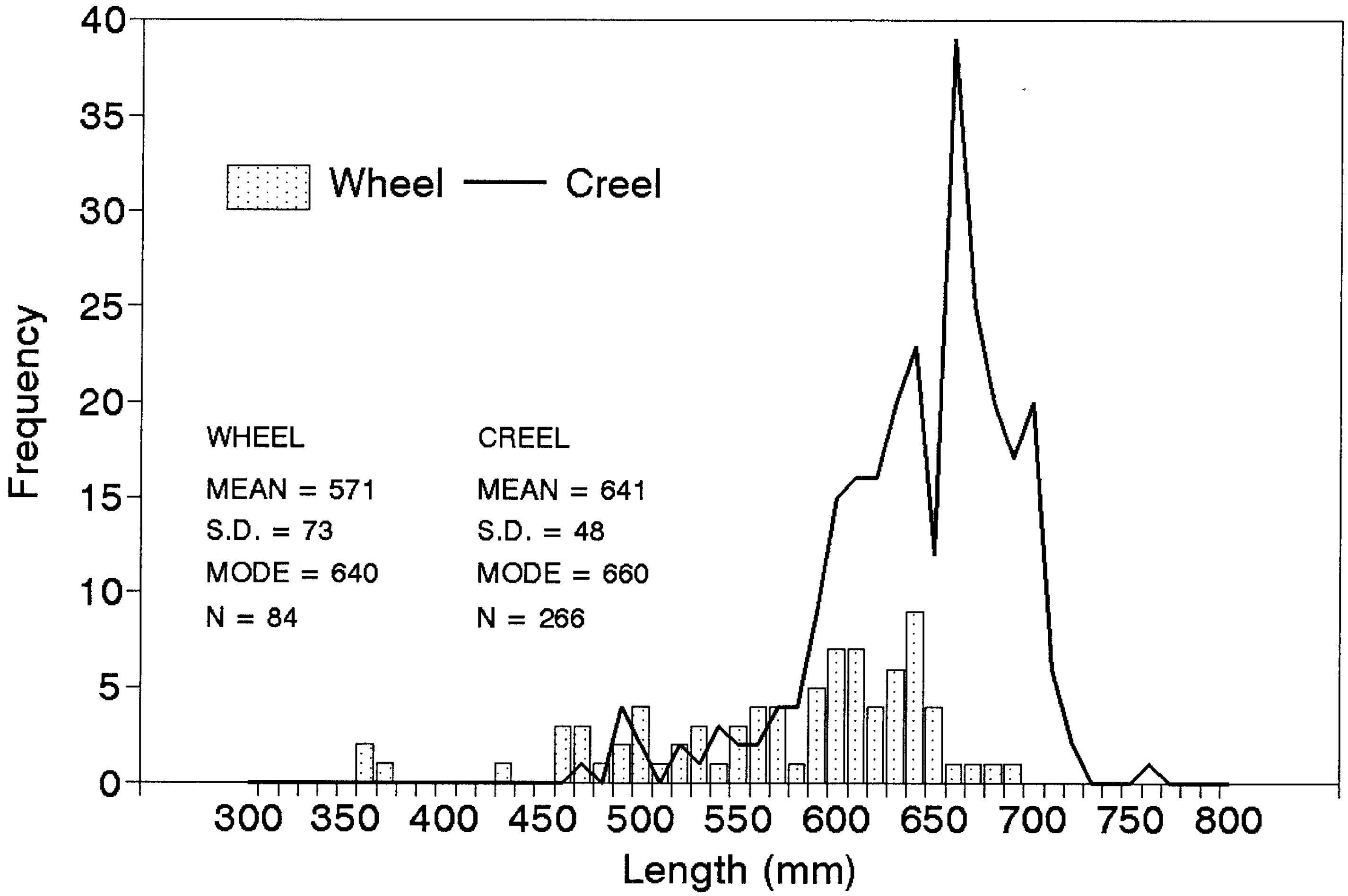

Figure 8. Length frequency of late-run coho salmon sampled in fish wheel and creel census.

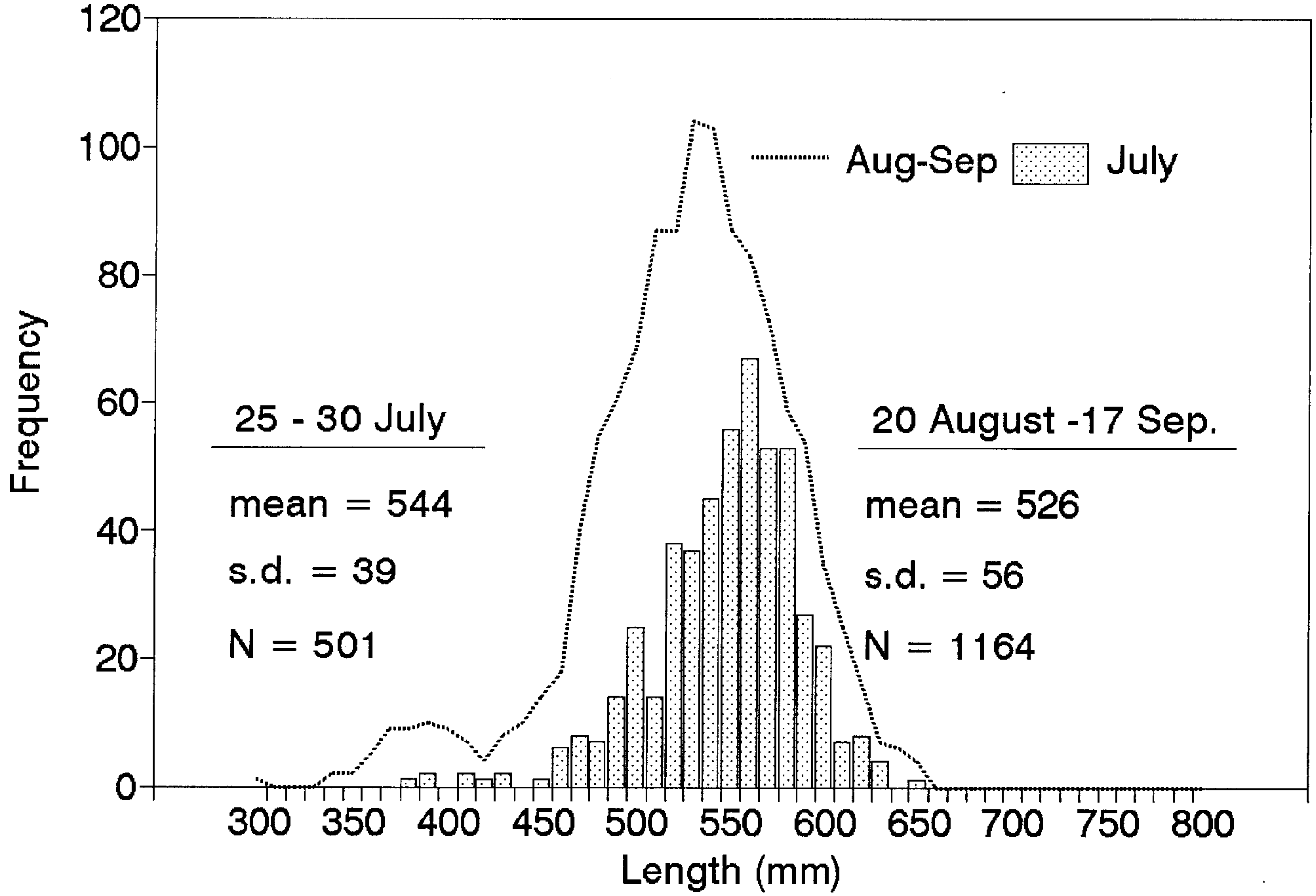

Figure 9. Length distribution of sockeye salmon collected in the mile 19 fishwheel during July and August-September.

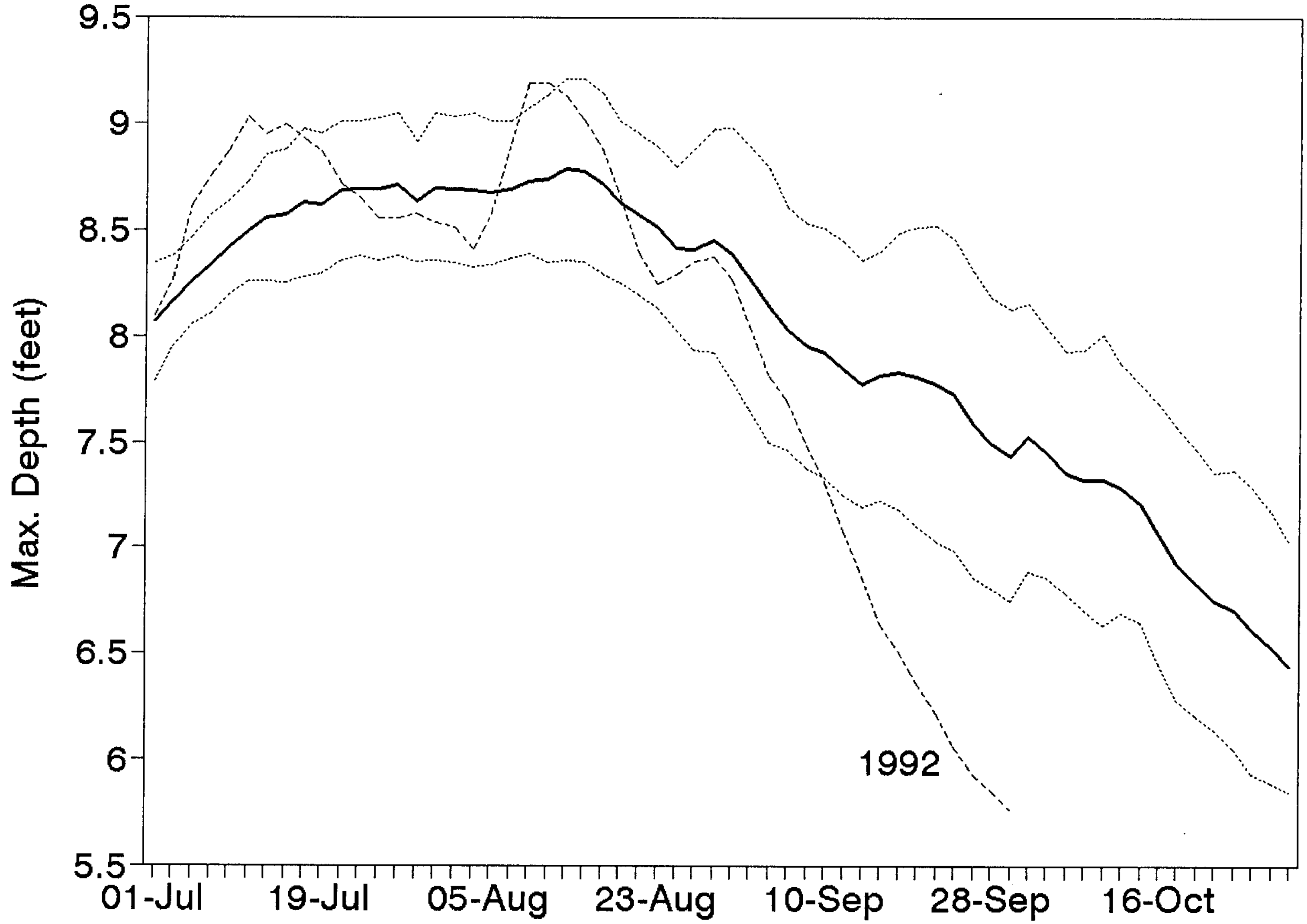

Figure 10. Daily mean water depth at mile 19 site and 95 % CI. Calculated from USGS gage height data (unpublished,1980-1992) measured at Soldotna bridge, and bottom profiles performed at mile 19 site.