THE FEASIBILITY OF ESTIMATING MIGRATING SALMON PASSAGE RATES IN TURBID RIVERS USING A DUAL FREQUENCY IDENTIFICATION SONAR (DIDSON)
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By

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ABSTRACT

We tested the feasibility of using a dual frequency identification sonar (DIDSON) to count migrating adult salmon in turbid Alaskan rivers as a potential replacement for Bendix echo counting sonars. Our evaluation was divided into five main components: 1) a comparison of sockeye salmon (*Oncorhynchus nerka)* counts from DIDSON, Bendix sonar, and split beam sonar against visual tower and video counts; 2) a range test in a turbid river to test the DIDSON's detection limits; 3) a comparison of two sonars (DIDSON and split beam) at the Miles Lake sonar site; 4) a comparison of two sonars (DIDSON and Bendix) at the Kenai River; and 5) a test of the performance of the DIDSON on rocky river bottoms and artificial substrates. The sonar, video, and tower methods produced similar sockeye salmon counts in the clear Wood River, although the split beam sonar was only tested at relatively low fish passage rates. We detected an artificial target 17-18 m from the transducer in the turbid Copper River. More total fish were counted from DIDSON images compared to counts obtained from split beam sonar echograms with the largest difference occurring in the first 5 m at the Miles Lake sonar site on the Copper River. The discrepancy was greater if downstream-moving fish were subtracted from upstream-moving fish. In the turbid Kenai River, a DIDSON (high frequency) and Bendix sonar comparison of fish counts produced mixed results with one dataset producing regression slopes close to one while a second dataset was more dissimilar. From DIDSON images, we observed a variety of fish behaviors that could impact counts made by more traditional sonars. We successfully deployed DIDSON and observed fish over rocky river bottoms and artificial substrates. Advantages of the DIDSON include easy-to-detect images of fish; a wider viewing angle, better coverage of the water column, simpler aiming and operation, accurate upstream-downstream target resolution, background subtraction feature, less multi-pathing, and reasonable measures of fish length out to 12 m. Disadvantages include limited range capabilities, high electronic data loads, and manual target counting. In addition, the majority of the DIDSON's electronics are deployed in the river making the unit vulnerable to damage from debris. Better data storage methods and automated fish counting software are being investigated. The DIDSON exceeded our expectations for counting salmon in turbid rivers and is our choice for a Bendix sonar replacement.

KEY WORDS: Bendix, Bendix replacement, DIDSON, dual frequency identification sonar, echo counter, hydroacoustic, multi-beam sonar, sockeye salmon, *Oncorhynchus nerka*, salmon, sonar, sonar transition, split beam, underwater acoustics

INTRODUCTION

We tested the feasibility of estimating migrating adult salmon (*Oncorhynchus spp.)* in Alaskan rivers using a dual frequency identification sonar (DIDSON) to determine whether the DIDSON is a viable replacement for the existing and older Bendix[1] sonars. Our evaluation of the DIDSON included comparisons of sockeye salmon (*O. nerka)* counts from the DIDSON, Bendix sonar, and split beam sonar against visual observations in a clear river; range tests using an artificial target acoustically similar in size to sockeye salmon in a highly turbid river; a comparison between the DIDSON and a split beam sonar at the Miles Lake sonar site; a comparison between the Bendix sonar and DIDSON at the Kenai River sonar site; and deployment of the DIDSON on rocky river bottoms and artificial substrates to observe fish behavior at these sites.

The DIDSON is a high frequency, multi-beam sonar with a unique acoustic lens system designed to focus the beam to create high resolution images. Originally developed by the University of Washington Applied Physics Lab (APL) to allow divers to identify mines in turbid waters, the DIDSON creates video-like images (Belcher et al. 2001; Belcher et al. 2002). The DIDSON's two frequencies, 1.8 and 1.1 MHz are used singly. The high frequency beam is divided into 96 - $0.3^{\circ} \times 12^{\circ}$ beams with range settings up to 12 m. The 1.1 MHz beam is divided into 48 - $0.6^{\circ} \times 12^{\circ}$ beams with range settings up to 40 m. Other specifications include: a 29° field-of-view for both frequencies; acoustic lens focusing from 1 m to the maximum range setting; range-dependent pulse widths varying from 4 to 128 μS; frame rates up to 20 frames/s, however, 8 frames/s is closer to what we were able to obtain; control and playback software with controls resembling a digital video program; and a menu option that converts data files to .jpg or .avi formats.

Prior to this study, APL staff demonstrated the DIDSON in a hatchery pond outside the lab showing us high resolution images of adult salmon. A bottom subtraction option removed static images leaving bright fish traces on a dark background. The DIDSON was initially set up facing the center of the pond then turned to face directly toward the slope rising toward shore with little or no detriment to the fish images. A preliminary automated fish counter accurately counted the salmon images (Figure 1). The DIDSON lacked both a time-varied gain to compensate for beam spreading loss and a linear range-dependent gain to compensate for attenuation. APL staff has added both features as options during playback per our request, but these were not available during this study and have not yet been tested.

Bendix sonars have been used by the Alaska Department of Fish and Game (ADF&G) since the early 1970's to provide an index of salmon passage for several river systems across the state (Barton 2000, Chapell 2001, Davis 2002, Dunbar 2001, and McKinley 2002). Salmon passage indices from these sonars are an important tool for inseason management of predominantly sockeye salmon for the Copper River, Upper Cook Inlet, and Bristol Bay commercial fisheries; and chum salmon (*O. keta*) for the Yukon River commercial fisheries. The Bendix systems are outdated and maintenance of these systems has become impractical and costly. A replacement for the Bendix sonar must be able to produce a daily index of salmon escapement inseason under a wide range of environmental conditions, store data electronically, and be operated by minimally-trained staff.

[1] Mention of a company's name does not constitute endorsement by ADF&G.

The Bendix adult salmon counter is an echo-counting, shore-based, side-looking, single beam sonar developed for counting sockeye salmon. A single 500 or 515 kHz transducer alternately transmits 4° and 2° beams sampling the nearshore and offshore range, respectively. The controller can be set to transmit a single beam if needed, i.e., during low water conditions the 2° beam may be used for the entire range. Echoes that exceed the voltage threshold are counted and divided by range-dependent, hard-wired, echo/fish criteria (Gaudet 1990). To adjust for changes in fish swimming speed and behavior, an operator periodically 'calibrates' the system by counting echo returns displayed on an oscilloscope for a set period of time and adjusting the ping rate until the machine count matches the manual count using an oscilloscope. These systems typically run 24 hours/day during the field season producing estimates, which are available to fishery managers hourly. Bendix transducers are positioned close to the river bottom or artificial substrate and aimed just high enough to avoid receiving echoes from bottom structure. Start and end ranges are set to maximize the counting range while avoiding false counts from bottom structure. Ping rates and range settings are adjusted during the field season to account for changes in fish behavior and water level.

Over the last few years, ADF&G has been testing split beam sonar as a possible replacement for the Bendix sonar for estimating migrating adult sockeye salmon in the Nushagak and Kenai Rivers. Split beam sonar is used in Alaska for estimating migrating chinook salmon (*O. tshawytscha*) in the Kenai River (Miller and Burwen 2002) and chum salmon in the Chandalar River (Daum and Osborne 1998). Both sites manually track fish from electronic echograms, a method too time-consuming for the substantially higher numbers of sockeye salmon, which require an automated method. A cooperative effort between the Department of Fisheries and Oceans (British Columbia, Canada), ADF&G, and Hydroacoustic Technologies, Inc. has led to the development of an autotracking software program using Blackman's algorithm (Blackman 1986). Autotracking and editing fish tracks on split beam sonar echograms is proving difficult and time consuming for the following reasons: 1) unwanted reverberation from bottom structure, bubbles, upstream disturbances, floating debris, and other objects is frequently interspersed with fish targets; 2) transmitted sound travels through fish and reflects off either rocks or the river surface to create a myriad of echoes, making it difficult to track fish as passage rates increase; and 3) the close range of the fish to the transducer, their proximity to the river bottom and each other, and other environmental variables corrupt the split beam sonar's phase information and compromise our ability to assess the direction of fish travel.

The DIDSON may solve many of these problems, because it's wide horizontal beam is divided into narrow multiple beams allowing a much longer look at migrating fish. Multiple fish at one range are much easier to distinguish in DIDSON images. Direction of fish travel is accurately determined, even at ranges less than 1 m from the transducer. The small size of the individual beams makes it unlikely multiple fish will simultaneously enter one beam so there is less distortion of echoes compared to the larger beams used in single and split beam systems. The higher frequency sound returns fewer multiple images and reflects off more of the fish than the swim bladder, creating an almost complete fish image at close range.

For us to consider the DIDSON as a Bendix sonar replacement, we needed to know if sonar operators could accurately count migrating fish in Alaskan rivers from the images produced. To accomplish this, we tested the DIDSON in a clear river to judge its accuracy, and at our most turbid river sonar site, the Copper River, to determine its range limitation under the poorest conditions. This report is meant to be comprehensive, summarizing all the data collected with the DIDSON during the summer of 2002 with the exception of the work done at the Kenai River chinook salmon sonar site (Burwen *in press*) where the primary focus was to test the accuracy of fish length measures from DIDSON images. To improve the report's readability the objectives, methods, and results are divided into the following chapters: 1) Comparisons of Sonar and Visual Methods of Counting Migrating Salmon in a Clear River, 2) Turbid River Range Tests with an Artificial Target, 3) Miles Lake Sonar Evaluation, 4) Comparisons of DIDSON and Bendix Sonar Counts of Migrating Salmon in the Kenai River, and 5) Fish Behavior on Artificial Substrates and rocky river bottoms.

CHAPTER 1: A CLEAR RIVER COMPARISON OF DIDSON, BENDIX AND SPLIT BEAM SONAR COUNTS OF MIGRATING SOCKEYE SALMON AGAINST VISUAL COUNTS

A necessary first step in testing a new sonar is to ground truth its reliability under ideal conditions, i.e. in a clear river. The Bendix (Al Menin, personal communications) and split beam sonars (Biosonics, Inc. 1999ab, Enzenhofer and Mulligan 1998) have been tested in clear rivers comparing the sonar count to either a count from a video image or from a real-time visual tower count. Ideally, sonar counts at each new site should be checked against another independent counting method.

The clear river tests were performed in the Wood River, which flows into Nushagak Bay northeast of Dillingham (Figure 2). The Wood River tower site is an ideal test site due to its clear water and large, time-condensed, sockeye salmon run (Figure 3). The tower project provides daily salmon passage estimates from visual observations dating back to 1956. The river bottom profile at the tower site is smoothly sloping with an ~8.5° slope and a substrate ranging from silt to small cobble. Although the area is tidally influenced with water level fluctuations of approximately 60 cm, no salt water reaches this site and current flow (1-2 m/s; Bucher 1981) is strong enough that little milling of salmon occurs. Migrating salmon generally concentrate within a band ranging from approximately 2½ to 7½ m from shore (Biosonics, Inc. 1999ab).

The specific objectives of the study include:

1. Testing the hypothesis that the DIDSON, Bendix sonar, and split beam sonar counts of migrating sockeye salmon are similar to visual counts up to 6,000 fish/hr/bank; and
2. Testing the hypothesis that the different sonar methods have the same relationship with the tower counts using a linear mixed effect (LME) model.

Methods

For the clear river comparisons, we installed a video camera on the Wood River counting tower and deployed the DIDSON in front of the tower so the DIDSON, video, and tower all sampled the same region of water. The Bendix and split beam sonars were positioned just upstream. Initially, we deployed green flash panels for the fish to cross for easier video and tower viewing, but the fish avoided the panels. Instead, we pushed one panel offshore and used it like a weir to force fish toward shore. The nearshore edge of the panel, 8.5 m from the DIDSON transducer, served as the end range for each counting method. We did not install a weir to keep fish from traveling inshore of our transducers; however, fish appeared to stay offshore possibly due to the influence of the tower.

The control for this study was a visual, real-time count from an observer perched on a tower located along the shoreline. The water level was high enough that the front legs of the tower were submerged. A single observer counted and rated each sample as very good, good, moderate, or uncertain. We intended to use the video to re-examine samples with moderate or uncertain observer ratings; however, the passage rates obtained were lower than expected, and all the samples were rated very good or good. Instead of combining tower and video counts for our control, we compared the video counts against the tower counts. The camera, a high-resolution, color video camera (Supercircuits Model PC-33C), was mounted on the counting tower approximately 4 m from the river's surface. The camera was equipped with a Computar 3.5-8.0-mm varifocal, auto-iris lens fitted with a polarizing filter. The varifocal lens was set at a focal length of 6.0 mm for a 7-m horizontal field of view at a range of 8.5 m. Video images captured by the remote camera were stored on an analog SVHS recorder (GYYR TLC2100-SHD) recording 9.1 m/s (30 ft/s), and also a desktop PC (DELL Smartstep 150D) recording 4.6 m/s (15 ft/s) via an Osprey (Model 101) video capture card. Salmon were counted from both the SVHS analog and digitized video images.

A DIDSON transducer and attitude sensor were deployed in water 63 cm deep, mounted higher than either the Bendix or split beam sonars (36 cm from river bottom to the lower edge of the transducer), and pitched -8.0° from level. This position facilitated coverage of the nearshore range and reduced shadowing from fish traveling close to the transducer. DIDSON settings, which controlled data collection, included: high frequency mode, range 0.75-8.5 m, and 8 frames/s. Settings controllable on playback, which did not effect data collection, were adjusted to maximize target detection and included a 2 dB threshold, 42 dB intensity, and background subtraction.

The Bendix transducer, set to a range of 0.75-8.5 m, was mounted 10 cm from the river bottom (to the lower edge of the transducer) in water 39 cm deep, and aimed high enough to avoid receiving echoes from bottom structure. The automated Bendix counter was 'calibrated' hourly to match manual counts from an oscilloscope.

A Biosonics' 201 kHz, 6.4° circular, split beam transducer and attitude sensor were deployed in water 36 cm deep, 12 cm above the river bottom (to the lower edge of the transducer), and pitched -4.4° from level. Other settings included: 17.2 pings/s; 0.2 mS transmit pulse width; -50 dB data collection and editing threshold; 1.0-8.5 m range; and single target criteria including a –50 dB target threshold, 0.02-0.6 pulse width acceptance measured 6 dB below the pulse peak, 10 dB maximum beam compensation, and 3 dB maximum standard deviation of the alongship and athwartship angles. A sound speed of 1443 m/s and absorption coefficient of 0.013068 dB/m were calculated using a measured water temperature of 9° C, (Del Grosso & Mader 1972) and (Francois and Garrison, 1982) respectively. Split beam sonar data was displayed, autotracked, edited, and exported using SonarData's Echoview software with the integrated Blackman autotracking algorithm. The split beam sonar counts were obtained by visually counting the echogram traces (manual count) and by autotracking using the Blackman algorithm then carefully editing out all non-fish echoes (autotrack method).

Calibrations

All sonar systems were field-calibrated using a 38.1 mm tungsten carbide sphere (calibration sphere) dangled outside the nearfield of each sonar. The calibration sphere was clearly visible in DIDSON images. Peak voltages from the same sphere crossed the counting threshold in the Bendix sonar. The theoretical target strength of the calibration sphere is –40.3, -43.3, -41.7, and –39.2 for the DIDSON's 1.8 MHz and 1.1 MHz frequencies, the Bendix sonar's 515 kHz, and the Biosonics' sonar's 201 kHz, respectively (Faran 1951). Prior to the field study, reciprocity calibrations with a standard transducer were performed for the 6.4° split beam transducer by Biosonics' in Seattle (Appendix A). A field calibration of the split beam transducer using the calibration sphere resulted in an average target strength of –40.4 ± 2.8 dB (± 1 standard deviation). The target strength of the calibration sphere was obtained by averaging the logarithmic target strength values from 2,059 echoes. Echoes were received predominantly from the lower two transducer quadrants (Figure 4).

Although the tower counts were not made available until after the counting was completed, the sonar and video operators were located in the same structure and may have been influenced by each other. The DIDSON, split beam sonar, and video counting occurred post-season so any transfer of information would only affect the setup. The Bendix sonar counts, which are operator-dependent, were obtained on-site. Because of an error discovered in the Echoview software, the split beam sonar data had to be re-tracked and edited after the tower counts had been given out and the sonar operator was made aware that the split beam sonar counts were low compared to the other sonars. Therefore, this was not a true blind test.

Sampling Design

A sample length of 15 minutes was selected. Although a smaller sample duration would have been adequate, the larger time period was chosen to lessen the effects from the different arrival times of fish at the split beam and Bendix sonars, positioned 194 and 245 cm upstream of the DIDSON, respectively. To determine the number of samples needed for the analysis, the power of the slope estimate from a regression model was predicted for a given range of sample sizes, and detectable effects. The variance (s^2) of the slope (β) depends on the mean square error (MSE) and the range of the independent variable (X) using the following formula:

$$s_\beta^2 = \frac{MSE}{\sum_{i=1}^{n}\left(X_i - \overline{X}\right)^2}.$$

The approximation for MSE was obtained from a regression of the 1998 Wood River sonar and tower data for fish passage rates up to 6,000 fish per hour, scaled to 15 minute estimates with an approximated MSE of 8,442. We used X_i's ranging from 0 to 1500 in regularly spaced intervals and sample sizes (n) ranging from 25 to 60 with minimum detectable differences (δ) of 0.1 and 0.15 and a significance level (α) of 0.05. The following formulas were used to calculate the power ($1 - \beta$):

$$t_{1-\beta} = t_\alpha + \frac{\delta}{s_\beta},$$

and

$$\text{POWER} = 1-\beta = P(t \geq t_{1-\beta})$$

The sample size power analysis showed that for δ = 0.15, the power is high for all of the sample sizes listed in Table 1. For δ = 0.1, increasing the sample size improves the power, but even a sample of 30 has a power of 73%.

Table 1. Estimated power of the slope of a linear regression with an MSE of 8,422, α = 0.05, and the dependent variable evenly distributed between 0 and 1500.

Sample Size	Power (δ = 0.1)	Power (δ = 0.15)
25	0.65	0.94
30	0.73	0.97
35	0.79	0.985
40	0.85	0.993
45	0.88	0.996
50	0.91	0.998
55	0.94	0.999
60	0.95	1.000

Statistical Methods

We used least squares regression analysis to test the hypothesis that the slopes between paired comparisons of the sonar, video, and tower counts were equal to one (Johnson and Bhattacharyya 1987), assuming the tower counts were without error. We plotted regression lines using each counting method as the independent variable to determine the extent of the error from each variable. In addition, a linear mixed effects (LME) model (Pinheiro and Bates 2000) was used to determine whether the different sonar and video methods had the same relationship with the visual counts, again assuming no error in the tower counts. The LME model is:

$$C_{ij} = \alpha + \beta C_T + \tau_i + \gamma_i C_T + b_{0j} + \varepsilon_{ij}$$

with

$$b_{0j} \sim N(0, \sigma^2_{Sample}), \quad \varepsilon_{ij} \sim N(0, \sigma^2_{Error})$$

where

C_{ij} = Counts from method *i* in sample *j*,

C_T = Tower counts,
α = intercept (Expected sonar count when the tower count = 0),
β = slope of tower counts,
τ_i = effect of method *i* on the intercept,
γ_i = effect of method *i* on the slope,
b_{0j} = random effect of sample *j*,
σ^2_{Sample} = the variance of the random effect of sample, and
σ^2_{Error} = random error.

The random effect of the sample was tested using a likelihood ratio test (Hogg & Craig 1978) compared to a mixture of χ^2_0 and χ^2_1 (Stram and Lee 1994). Details on the mixed chi-square distribution are presented in Appendix B. The interaction term (γ_j) was tested with an F-test to determine if the video and sonar methods have different relationships with the visual counts.

Results

At the Wood River, we collected paired data from July 2-5, 2002. We obtained 40 samples of paired DIDSON and tower count data for a power of 85% for $\delta = 0.1$. For six of the samples, the DIDSON and tower counter were brought to the opposite side of the river to obtain higher passage rate samples. This resulted in fewer paired samples from the Bendix sonar and video methods (n=34) and even fewer paired samples (n=31) from the split beam sonar, which missed the first three samples due to a problem with the initial aiming angle.

Each counting method produced similar salmon counts (Figure 5) with counts ranging from 8-1,330 fish per 15 min sample, as visually counted from the tower. The majority of fish counted were sockeye salmon. Fish images from the DIDSON were clearly visible even during higher passage (Figure 6). In situations where the surface of the water was rippled or shadowed by clouds, the DIDSON fish images were easier to detect than actual fish viewed from the tower. Counts from each method compared to tower counts were significantly different from 0 ($p<0.001$), but also significantly different from 1 using a 95% confidence interval (Table 2). The regression lines plotted with the tower as the independent variable were very similar to regression lines plotted using each of the other counting methods as the independent variable (Figures 7-8). The standard error of the slope was small for each counting method. Counts from the video methods were the most variable. Staff counting fish from video images reported better quality, easier-to-count images from the SHVS video and observed poorer resolution from the digital video. Regression results verified this observation. Compared to the digital video, results from the SHVS video included a coefficient of determination (r^2) closer to one, smaller variability in the counts, a smaller confidence interval, and a slope closer to one. Autocorrelation in the residuals of each comparison appeared to be minimal. Even if the residuals had been autocorrelated and the variance had doubled, the results would still be significant.

Table 2. Regression results from each of the sonar and video methods compared with visual tower counts. The split beam sonar data contains no higher passage samples and must be considered carefully.

Assessment Method	*Fitted Equation*	*95% Confidence Interval (Slope)*	*S.E. (Slope)*	r^2
DIDSON	$y = 1.71 + 1.06\,x$	1.03-1.09	0.0131	0.99
Bendix Sonar	$y = -5.73 + 1.08\,x$	1.04-1.12	0.0197	0.99
Split Beam Sonar Autotracked	$y = 2.95 + 0.88\,x$	0.83-0.93	0.0221	0.98
Split Beam Sonar Manual Count	$y = 19.00 + 0.82\,x$	0.77-0.87	0.0239	0.98
SHVS Video	$y = 7.23 + 0.93\,x$	0.88-0.98	0.0257	0.98
Digital Video	$y = -12.09 + 1.10\,x$	1.01-1.18	0.0399	0.96

We attempted to obtain a variety of passage rates up to 6,000 fish/hr/bank, a maximum chosen because higher rates are not common in the rivers we ensonify. A delay in our setup caused us to miss the run peak and only 3 of the 40 samples approached this value. Unfortunately, these 3 samples were missed by the split beam sonar resulting in a maximum split beam sonar count of 328 fish per fifteen minutes (1,312 fish/hr). These results must be carefully considered since data from prior studies (Biosonics, Inc. 1999a; Enzenhofer 1998) conducted in clear rivers showed that split beam sonar counts leveled off between 2,000 and 3,000 fish/hr while visual counts continued to increase.

Fish targets, tracked with the split beam sonar, were predominately bottom-oriented (Figure 9) with over 90% of the fish passing within 4-7 m from the transducer. The average target strength of tracked targets increased significantly (p<0.001) as distance from the transducer (range) increased (Figure 10), with an overall average of –32.2 ± 2.9 dB. The average horizontal position of individual fish targets clustered around the central portion of the beam indicating the fish were traveling relatively straight through the beam (Figure 11).

Results of LME analysis indicated the random effect of the sample was not significant (p=0.82) and was removed from the model. The multiple regression was used to estimate the remaining parameters. The interaction term (γ) between tower and counting method was significant ($F_{5,\,191}$ = 10.78, p<0.0001), suggesting the slopes shown in Table 2 were unequal. In particular, the regressions using autotracked split beam sonar, the manual count split beam sonar, and the SVHS video counts as the dependent variables produced slopes less than one, while the regressions using DIDSON, Bendix sonar, and digital video counts as the dependent variables produced slopes greater than one. Although these differences were statistically significant, we interpreted them to be small, and of little biological consequence.

CHAPTER 2: TURBID RIVER RANGE TESTS WITH AN ARTIFICAL TARGET

Because of the high frequency, we expected the DIDSON to be extremely range-limited in turbid rivers. Although the primary cause of attenuation in freshwater is usually attributed to water viscosity (MacLennan and Simmonds 1992), scatter off macroscopic particles can substantially reduce the returning signal strength (Richards et al. 1996). For example, significant signal loss has been observed under conditions of high turbidity on the Yukon River using a 120 kHz sonar ensonifying a range of 300 m (Pfisterer and Maxwell 2000). Although the sampling ranges needed to assess sockeye salmon are much less compared to the Yukon River project, signal scattering caused by silt particles may limit our ability to detect fish. The Copper River was chosen for the turbid river tests because of its high concentration of suspended sediment and because ADF&G operates a Bendix sonar on this river at Mile 49, below Miles Lake. The high river velocities at this site make target work from a boat difficult so a lower river site at the Mile 27 Bridge was selected for the study (Figure 12). During 1991 and 1993, USGS measured suspended sediment levels at the Mile 27 bridge of 0.5-2.3 kg/m^3 with corresponding discharges of 29,400-73,600 ft^3/s making this the most turbid ensonified river in Alaska (Brabets 1997). We hoped the water level was high enough to allow the sonar beams to reach 30 m or more without encountering bottom obstructions or slope changes. Unfortunately, we had no bottom profile of this site. However, the slope, which appeared to be linear and gradual, was dry at the time bathymetry data were being collected, and no land-based surveying was conducted.

We also had the opportunity to briefly test an older, lower frequency (0.75 MHz) version of the DIDSON, the LUIS (Lensing Underwater Imaging System) in a clear, calm, lake and in a glacial river, the Kenai River, to determine if the lower frequency beam could detect targets at greater ranges than the DIDSON.

The specific objectives for the range tests were:

1. Identify the maximum detection range of an artificial salmon-sized acoustic target using the DIDSON, Bendix, and split beam sonars in the Copper River;
2. Verify the target strength of the salmon-size target using the split beam sonar data;
3. Determine the extent of signal loss in the Copper River;
4. Identify the maximum detection range of the salmon-size target using the LUIS sonar in a glacial river; and
5. Measure the turbidity at each site.

Methods

A 10.16 cm, bb-filled plastic sphere (plastic sphere) was chosen for the range tests because the acoustic target strength of the plastic sphere approximates a sockeye salmon (split beam sonar measures of Wood River sockeye salmon reported in the previous section averaged –32.2 ± 2.9 dB). We have used this plastic sphere extensively for aiming and determining detection limitations of split beam sonars. However, the wide range of frequencies between the sonars makes it difficult to select a single target that approximates a salmon for each sonar. Because the higher frequency sound of the DIDSON reflects off more of the fish and the plastic sphere is physically smaller than fish, we are confident the actual detection range of a sockeye salmon by the DIDSON is similar to or beyond the detection range of the plastic sphere. We deployed DIDSON, Bendix, and split beam sonars side-by-side near the edge of the river, paralleling the three sonar beams to align their range as closely as possible. The sonars were aimed far enough above the river bottom to facilitate target detection, which is simpler when conducted away from the river's boundaries. A range test was attempted with the Bendix sonar, but due to the difficulty of finding an offshore target in the narrow beam during the short time scheduled for this study, the test was abandoned.

The DIDSON transducer was deployed near the edge of the Copper River, mounted higher than either the Bendix or split beam sonars, and pitched -9.8° from level. DIDSON settings, which controlled data collection, included low frequency mode (1.1 MHz), 9-18 m range, and 8 frames/s. Settings, which did not influence data collection but were controllable on playback, were adjusted to maximize target detection and included a 13 dB threshold, 33 dB intensity, and background subtraction. The calibration sphere dangled outside the nearfield of the DIDSON transducer was clearly visible indicating the threshold was below –43.3 dB, at close range.

A Biosonics 201 kHz, 3.8 x 7.8°, elliptical split beam transducer was positioned 0.5 m from the river surface and pitched -2.9° from level. Sonar settings included: 10 and 15.2 pings/s; 0.2 mS pulse width; -50 dB data collection and editing threshold; 1-40 m range; and single target criteria including a –50 dB target threshold, 0.04-2.0 pulse width acceptance measured 6 dB below the pulse peak, 10 dB maximum beam compensation, and 3 dB maximum standard deviation of the alongship and athwartship angles. A sound speed of 1455 m/s and absorption coefficient of 0.011642 dB/m was calculated using a measured water temperature of 12° C, (Del Grosso & Mader 1972) and (Francois and Garrison 1982) respectively. SonarData's Echoview software was used for displaying, editing, and exporting target echoes. Calibration results from the split beam sonar, calibrated later at the Miles Lake site, are presented in the next section.

To identify the maximum detection range of each sonar in the lower Copper River, the plastic sphere was lowered in front of each transducer just beyond the nearfield, then transferred to a boat and lowered midway between the surface and bottom. After we detected the target with the sonar, the boat moved slowly offshore in line with the beam until the dangling target was no longer detectable. The process was repeated for each sonar. To verify the target strength of the salmon-size target, we collected echoes from the plastic sphere using the split beam sonar and plotted the average target strength by range.

A rough measure of signal loss was determined by measuring the intensity of the plastic sphere in DIDSON images at several ranges in the Copper River. Although this does not provide us with how much signal loss to expect from fish images, it does give us an idea of the degree of signal loss in the Copper River. With no absolute calibration information on the DIDSON, we measured signal loss in relative terms only by relating the loss to the signal level at the closest range measured, and then subtracting the theoretical spreading loss. Signal loss was determined within 1 m range bins. The following equation summarizes the process of obtaining the total signal loss (*A*) observed:

$$A = \sum_{r=a}^{b} ((T_{r+1} - T_r) - (40Log(r+1) - 40Log(r))$$

where

T = target threshold (in dB),
r = range in 1 m increments,
a = start range, and
b = end range.

The target threshold (T) was determined by stopping the DIDSON playback program every fifth frame and leaving the intensity constant, increasing the threshold until the target was no longer visible, and then recording the threshold level at that point. All threshold measures within 1 m were averaged for that range bin. In the above equation, theoretical spreading loss (which is not corrected for in the DIDSON) is subtracted out. The resultant signal loss is a combination of scattering, absorption, and the target's position in the beam (also not corrected for in the DIDSON). The average signal loss per range bin (A_{avg}) was calculated by

$$A_{avg} = \frac{A}{n-1}$$

where
n = the number of range bins.

We tested the LUIS in late September in a lake and in the glacial Kenai River at Centennial Park, to determine the range limits of this lower frequency sonar. The LUIS display is analog with few setting adjustments. The threshold was set to maximize visibility of the target and minimize noise. We taped the images onto VHS tape and later digitized the images.

A factory calibrated, Global Water Model WQ770 turbidity meter ranging from 1-1000 nephelometric turbidity units (NTU) was used to measure turbidity of the Copper River at the Mile 27 Bridge and Miles Lake sonar sites, the Wood River, and the Kenai River. We planned to derive a relationship between turbidity and range limitation of the sonar. However, since we were unable to conduct range tests at all the sites no correlations were attempted, only turbidity measurements are reported.

Results

Range tests were conducted 24 June 2002 in the lower Copper River at the Mile 27 Bridge site using the plastic sphere. From DIDSON images, the plastic sphere was detectable at a range of 17-18 m, although the image quality degraded substantially after 16.5 m (Figure 13). We were unable to determine the range limitation of the split beam sonar due to interference with bottom structure, which started at 21 m. The plastic sphere remained visible between bottom structure echoes to approximately 30 m (Figure 14).

The target strength of the plastic sphere from all ranges showed a high degree of variability and the average target strength was lower than expected, –34.3 ± 6.6 dB. There was no clear trend associated with the target strength as a function of range measured by the split beam sonar as evidenced by the degree of overlap among the interquartile range boxes (Figure 15). Target echoes were received throughout the vertical limits of the beam starting at a 10 m range and continuing until the target was no longer discernable from bottom structure. Figure 16 shows the vertical position of the echoes plotted against range with the nominal and effective beams overlaid and both the echoes and beam pitched to -2.9°, the attitude of the transducer during these tests.

The average signal loss per meter was calculated from DIDSON images of the plastic sphere. Unfortunately, the target file began at 10 m rather than 1 m. Since no data were available between 1 and 10 m, it was necessary to calculate all signal loss relative to 10 m. The average two-way signal loss per meter within the 10-16 m range was 3.07 dB/m or –18.4 dB total, not including the 40 Log theoretical spreading loss. Figure 17 illustrates the signal loss observed in DIDSON images by range (red line) and the signal corrected with a 40 Log plus 3 dB/m model (green line). The 3 dB/m signal loss includes an unknown amount of loss from the target potentially moving closer to the edge of the beam as it was drawn offshore.

The plastic sphere was visually detectable to a range of 60 m with the LUIS sonar in a clear lake and 45 m in the Kenai River. In the lake environment, the signal was sharper. The target in the Kenai River was more difficult to discern, and although it was visible beyond 45 m, the image quality was very poor.

Turbidity was highest at the Miles Lake sonar site and lowest at the Wood River (Table 3). Readings were taken by submerging the probe and waiting for the reading to stabilize. At the Mile 27 bridge site, the reading continued to oscillate but most measurements were beyond 800 NTU. Because the maximum range of the turbidity meter is 1,000 NTU, the reading at the Miles Lake sonar site is suspect. The actual turbidity at this site may be higher.

Table 3. Turbidity measures from three Alaskan rivers.

Site	*Turbidity (NTU)*	*Date*
Copper River, Mile 27 bridge site	>800	6/24/02
Copper River, Miles Lake sonar site	~1,027	6/26/02
Wood River	8	7/2/02
Kenai River Mile 19, north bank	21	7/30/02
Kenai River Mile 19, south bank	28	7/30/02

CHAPTER 3: MILES LAKE SONAR EVALUATION

We evaluated the potential of using the DIDSON or split beam sonar as a replacement for the Bendix sonar at the Miles Lake sonar site. The Miles Lake site is located below the Million Dollar Bridge at the outlet of Miles Lake on the Copper River (Figure 12). Our work focused on the south bank where the majority of fish pass and a new 28×5 m concrete structure with a 7.4° slope served as a substrate for the sonars. At this site, an artificial substrate is necessary because traditional sonars are unable to ensonify fish across the large, boulder-strewn regions of the river bottom. Raising the sonar beam off the river bottom to reduce the overwhelming number of echoes reflected from boulders also moves the beam away from the fish. We compared counts and range distributions of migrating salmon from DIDSON and split beam sonars; plotted the range distribution of Bendix counts; counted upstream and downstream moving fish using split beam positional information and from DIDSON images; and determined the target strength, position of echoes, and missed echoes of tracked fish from the split beam sonar. The Bendix sonar is deployed on an older concrete substrate, which is broken and damaged due to the impact of icebergs exiting Miles Lake. We decided to continue using the old substrate for the Bendix sonar until comparisons studies with a new sonar system can be completed. We deployed the DIDSON on the natural rocky river bottom to determine whether fish could be distinguished against the rocks and on the old concrete substrate adjacent to the Bendix sonar to observe fish behavior as they crossed the artificial structure.

The Bendix sonar at this site is used to count migrating salmon, predominately sockeye, to assist in the management of the Prince William Sound commercial fishery. The site was originally chosen because of the river's single channel, accessibility, and the strong current, which minimizes fish milling and forces salmon close to shore within the range of the Bendix sonar. Bendix sonar was first deployed side-looking along the south bank in 1978 on an aluminum substrate and on the north bank's natural substrate in 1979. The aluminum substrate was replaced October 1978, with a 25 m long permanent concrete substrate installed perpendicular to the river flow with a raised narrow gauge rail serving as the transducer mount. A chain link fence was positioned slightly downstream to prevent fish swimming inshore of the transducer. The new concrete substrate, used by the DIDSON and split beam sonar, was installed ~30 m downstream from the old substrate in October 2001. River bottom profiles at the old and new substrate prior to the installation of the new substrate are shown in Figure 18.

Although higher salmon passage rates typically occur in late June (Dunbar 2001), the limited availability of the DIDSON made it necessary to synchronize the timing of this study with the Wood River tests. Since the goal at this site was to study signal loss of the DIDSON due to turbidity, and not to assess fish passage for the season, the end of June timing was sufficient. The specific objectives of the study at Miles Lake were:

1. Test the hypothesis that sample fish counts from the DIDSON and split beam sonar counts are similar;
2. Compare range distributions from the DIDSON, split beam and Bendix sonars;
3. Test the hypothesis that the range distribution of fish is similar for both the DIDSON and split beam sonar;

4. Test the split beam sonar's calibration, aim, and coverage of fish by:
    a. Field calibrating the split beam transducer and comparing to published values;
    b. Measuring the signal to noise ratio across the effective sampling range;
    c. Plotting the horizontal and vertical fish distribution;
    d. Determining the target strength of fish echoes;
    e. Determining the number and percentage of dropped echoes by range;
5. Observe fish behavior on the concrete structures along the south bank of the Copper River;
6. Determine whether fish are detectable against the natural rocky river bottom of the Copper River;
7. Establish an aiming protocol for the split beam sonar (see Appendix C); and
8. Determine the best sonar to use as a Bendix sonar replacement at the Miles Lake sonar site and the optimal settings for this site (see Discussion).

Methods

The DIDSON and split beam sonar were deployed side-by-side at the Copper River Miles Lake Bendix sonar site on the new concrete substrate. We positioned both transducers 12 m from the onshore edge of the substrate in water 57.2 cm deep, leaving 16 m of remaining substrate to direct the sonar beams. A downstream weir extended from shore to 105 cm beyond the transducers. Biosonics' attitude sensors were attached to both transducers. The DIDSON transducer was mounted higher than either the Bendix or split beam sonars with 34.3 cm between the substrate and lower edge of the transducer, and pitched -10.2° from level. This position facilitated coverage of the region in front of the transducer and reduced shadowing effects. DIDSON settings that controlled data collection included low frequency mode (1.1 MHz), 0.75-18.75 m range, and 8 frames/s. Settings that did not effect data collection but were controllable on playback were adjusted to maximize target detection and included a 2 dB threshold, 42 dB intensity, and background subtraction.

The Biosonics 201 kHz, 3.8 x 7.8° elliptical split beam transducer was placed adjacent to the DIDSON with its lower edge 11.4 cm above the substrate, and pitched -6.6° from level on June 25 and –7.0 on June 26. Sonar settings included: 15.2 pps on June 25 and 18.2 pings/s on June 26; 0.2 mS pulse width; -50 dB data collection and –45 dB editing threshold; 0.5-1 and 17.7-24.2 m start and end ranges; and single target criteria including a –45 dB target threshold, 0.16-2.0 pulse width acceptance measured 6 dB below the pulse peak, 20 dB maximum beam compensation, and 3 dB maximum standard deviation of the alongship and athwartship angles. Split beam sonar data was displayed, autotracked, edited, and exported using SonarData's Echoview software with the integrated Blackman autotracking algorithm.

The Bendix sonar, deployed earlier in the season on the old concrete substrate, was in operation 24 hrs daily. The Bendix transducer was positioned close to bottom and aimed high enough to avoid counting echoes from bottom structure. A weir extended 1-3½ m (depending on the water's roughness) beyond the end of the transducer. Bendix sonar settings included 1.7-2.1 and 16.9-17.4 m start and end ranges, and fish velocity settings of 0.34-0.55 s/ft (the fish velocity setting alters the machine’s ping rate). Bendix calibrations were conducted every three hours for 30 minutes or until 100 salmon were counted (Dunbar 2001).

DIDSON and Split Beam Sonar Comparisons

We collected paired data of migrating fish with the DIDSON and split beam sonar counting upstream- and downstream-moving fish separately to compare the DIDSON and split beam counts. We used a least squares linear regression to test the hypothesis that the slope between DIDSON counts, used as the independent variable, and split beam sonar counts was equal to one. Counts from upstream minus downstream fish and counts from a total of all fish targets detected (upstream plus downstream) were regressed separately. For the regression analysis, the DIDSON was assumed to be without error, but in reality, there is variation associated with the DIDSON. Results from the regression model hold for the conditional distribution of the dependent variable given the independent variable, but the interpretation of the results changes in that a single sample includes both the dependent and independent variable (Neter et al. 1990). The least squares method will be sufficient for determining if a relationship is present. We plotted regression lines using each counting method as the independent variable to determine the extent of the error from each variable.

To compare the performance of the sonars at different ranges, we grouped the counts by range (i.e. distance from the transducer). Starting at the transducers, the range was divided into one-meter intervals, called range bins. Fish counts were then grouped into the one-meter range bins and range distributions were plotted for the three sonars. Because the Bendix transducer was not aligned with the other two, its’ range distribution provides a gross comparison. The current at the Bendix substrate is stronger, whereas at the new substrate a small back eddy weakens the current close to shore. We expected fish to swim closer to shore at the old substrate compared to the new substrate. A Pearson’s chi square test (Zar 1984) was used to test that the distribution of fish across the range bins was the same for both the DIDSON and split beam sonar.

Split Beam Sonar Tests

To determine the reliability of the information from the split beam sonar, we conducted a field calibration, determined the *in situ* signal to noise ratio (SNR), and plotted various parameters from the received target echoes. Laboratory reciprocity (Appendix A) and field calibrations for the 3.8 x 7.8° elliptical split beam transducer were conducted in the same manner described in the methods section for the Wood River tests. An aiming protocol for the DIDSON and split beam transducers was established using the 10.16 cm plastic sphere. Field methods for calibrating and aiming the split beam are described in Appendix C. A signal to noise ratio (SNR) was determined at the new substrate site using the split beam sonar set at a data collection threshold of –150 dB. Noise (or unwanted reverberation) was calculated from the average target strength of all non-fish echoes within one-meter range bins. The signal level was calculated from the average target strength of wild fish targets summarized within the same one-meter range bins. The horizontal and vertical fish distribution, average target strength per fish, and number of dropped echoes were all plotted using fish echoes tracked from the split beam sonar. To obtain the average target strength per fish, target strength values from all tracked echoes were averaged.

The DIDSON on Rocky and Artificial Substrates

The DIDSON was also deployed on the old concrete substrate and the boulder-strewn river bottom between the two substrates. The DIDSON was placed approximately halfway between the two substrates on the boulder-strewn river bottom and pitched -13.6° from level. On the old concrete substrate, the DIDSON was set upstream and adjacent to the Bendix transducer, pitched -4.4°, and pointed downstream toward the weir so the behavior of the fish moving past the weir could be observed. Qualitative observations were made of both fish behavior and image quality.

Results

DIDSON and Split Beam Sonar Comparisons

Twelve paired 15-minute DIDSON and split beam sonar samples were collected 25-26 June 2002 at the Copper River Miles Lake sonar site from the new south bank concrete substrate. Samples 1-5 were collected on 25 June and samples 6-12 were collected the following day. All sonar gear was removed from the river and redeployed the next day resulting in potentially different aims between the two groups of samples. Passage rates were low throughout the comparison; DIDSON counts peaked at 284 fish/hr. Fewer total fish were counted by the split beam sonar compared to the DIDSON. When upstream minus downstream targets were compared, there was an even greater disparity between counts from the two methods (Figure 19). The percentage of split beam sonar downstream counts ranged from 3.6-17.8% and averaged 10%. In comparison, the percentage of DIDSON downstream counts ranged from 0-5.4% and averaged 2.4%. A regression of the upstream minus the downstream counts from the two sonars, with the DIDSON counts as the independent variable, resulted in a relatively flat slope (0.36) and poor r^2 value (0.19). The correlation between total counts from the two sonars was slightly better ($r^2 = 0.46$) with a steeper slope (0.58). Because the error in the DIDSON is unknown, regression slopes were plotted using each sonar method as the independent variable (Figure 20) to illustrate the error from both methods.

At ranges less than 5 m from the transducers, DIDSON counts were considerably higher compared to split beam sonar counts. Beyond 5 m, the split beam sonar counts were slightly higher. Range distributions from both sonars showed fish to be concentrated nearshore with 75% of the counts between 8 and 9 m, respectively (Figure 21). A Pearson’s chi square test showed a significant relationship between the range-distributed counts from the two sonars ($p<0.001$, df = 14), indicating the two distributions are different. At the old substrate where the current is stronger, 75% of the Bendix sonar counts were within the first 5 m (Figure 22).

Split Beam Sonar Tests

Results from the split beam tests were within expected parameters. The target strength of the calibration sphere measured by the split beam system averaged –40.2 ± 5.0 dB. The target strength was obtained by averaging the logarithmic target strength values from 2,448 echoes. This mean was close to the sphere's theoretical value of –39.5 dB (MacLennan and Simmonds 1992). Echoes from the calibration sphere were received across each of the transducer quadrants (Figure 23). The overall SNR calculated from the split beam sonar was 20 dB. From 0-14 m range, most of the non-fish reverberation was due to volume reverberation. The SNR remains fairly constant by range until the sonar beam interacts with the river bottom at approximately 14 m causing the SNR to drop to 0 (Figure 24). Using positional information from the split beam sonar, the location of individual echoes from tracked fish were averaged and plotted to produce vertical and horizontal fish distributions by range with the outline of the transducer beam overlaid (Figure 25). Vertically, fish targets were oriented throughout the beam within the first 5 m, then mostly along the bottom for the remaining sampling range. In the horizontal distribution, the averaged echoes were more concentrated in the downstream half of the beam indicating fish were not traveling a straight line through the beam. Target strength measures from migrating fish averaged –34.7 ± 2.3 dB. Target strength plotted against each spatial dimension (Figure 26) showed no apparent pattern except a slight increase with increasing range. The number of dropped echoes within a fish track ranged from 1 to 692 and averaged 71, with the overall number increasing by range as expected. The percentage of dropped echoes, although highly variable (mean 46.5% ± 12.9%), did not increase with range (Figure 27).

The DIDSON on Rocky and Artificial Substrates

At the Miles Lake sonar site, we deployed the DIDSON on both concrete substrates and the rocky river bottom. When the DIDSON was deployed directly on the river bottom, large rocks were clearly visible, but fish were easily detected moving over the rocks. In the still image, the fish are difficult to detect until the DIDSON's background subtraction algorithm removes the static rocks, leaving only images of fish (Figure 28). At the old substrate, the raised rail, weir, and fish darting around the weir were clearly visible in DIDSON images (Figure 29). In the moving images, several fish were seen holding once they reached the substrate, moving several meters offshore, then either continuing upstream or dropping back downstream ("sliders"). On the new substrate, only seven sliders were observed in DIDSON images during 10.5 hrs of sampling (<1% of the fish) while on the old substrate, within one hour of sampling, 22 sliders were observed (>10% of the fish). Samples collected with the DIDSON deployed on the rocky river bottom between the substrates were not counted, but some sliders were observed.

CHAPTER 4: COMPARISONS OF DIDSON AND BENDIX SONAR COUNTS OF MIGRATING SALMON IN THE KENAI RIVER

At the glacially turbid Kenai River, we compared counts of migrating salmon from side-by-side DIDSON and Bendix systems deployed along the south bank at the Bendix sonar site (Mile 19). The Kenai River is located on the Kenai Peninsula in southcentral Alaska (Figure 30). Bendix sonar counts of sockeye salmon at this site are used daily in-season to assist with the management of the Upper Cook Inlet commercial fisheries. The sonar has been in operation since 1968. The site was chosen for the fast current, which reduces fish milling, linear bottom profile along both sides of the river, location above tidal influences, and relative proximity to the commercial fishery. At this site, the river is approximately 120 m wide with water level gradually increasing through the month of July, usually peaking in late July or early August. Along the south bank the slope is 12° for the first 8-9 m, then abruptly flattens (Figure 31) limiting the range of the Bendix sonar to less than 9 m, but not the range of the DIDSON, aided by the bottom subtraction feature.

In 2000, we experienced problems comparing salmon counts from Bendix and split beam sonars along the south bank. The Bendix sonar was positioned directly adjacent to a weir with the split beam sonar slightly upstream, but closer to the riverbank. We believe the salmon were darting around the weir and forced back toward shore by the strong current, allowing detection by the Bendix sonar, but not the split beam sonar. Split beam sonar echograms showed several instances of what appeared to be multi-path echoes from fish at close range when no fish echoes were present. We deployed the DIDSON at this site to determine if its wide field-of-view and larger vertical beam would allow us to detect more close-range fish when positioned adjacent to the Bendix transducer. The specific objective of this study was to test the hypothesis that the DIDSON and Bendix sonar counts are similar.

Methods

On the south bank of the Kenai River, the Bendix sonar was in operation when we arrived to set up the DIDSON. We positioned the DIDSON transducer in water 82 cm deep as close to the Bendix transducer and weir as the mounts would allow (71 cm upstream) to prevent fish from swimming inshore of the DIDSON transducer. The weir, adjacent to the Bendix transducer, extended 2.2 m offshore of the Bendix transducer and 2.5 m offshore of the DIDSON. The Bendix transducer was positioned close to the river bottom and aimed just high enough to avoid receiving echoes from bottom structure. The start range varied from 0.3-0.6 m, the end range from 5.8-7.0 m, and fish velocity settings (comparable to ping rates) were between 0.645-0.900 s/ft. Full hour Bendix counts were available 24 hours daily. Bendix calibrations were conducted roughly hourly during the data collection period averaging approximately 21 calibrations per day. The south bank calibration schedule is included in Appendix D. The DIDSON transducer was positioned 55 cm above the river bottom (to the lower edge of the transducer) and pitched –15.6° from level to detect the plastic sphere positioned inshore of the weir 10-15 cm above the river bottom. The DIDSON threshold and intensity settings were set to maximize visibility of the targets with the background subtraction turned on to facilitate target detection. Samples were collected at 8 frames/s. The water temperature was 10.4° C with a resulting sound speed of 1448 m/s (Del Grosso & Mader 1972).

Paired data, divided into two datasets was collected with the DIDSON and Bendix sonar. In the first dataset, the DIDSON was set on high frequency sampling in 15-minutes periods. Due to target work and other interruptions, the sampling was not continuous. Fifteen-minute samples collected close to the top of the hour were expanded to a full hour count and compared against full hour Bendix counts. In the second dataset, the DIDSON was operated continuously on low frequency. Full hour DIDSON counts were compared to the full hour Bendix counts. Clocks were not synchronized between the two systems; however, the hour-long sample period was long enough that a slightly offset start and stop should have had little effect on the comparison. Both datasets from the DIDSON and Bendix sonars were compared using least squares linear regressions. Slopes were estimated using each method as the independent variable to determine the extent of the error from each variable. Because the variance in the data increased as passage rates increased, we performed a second regression analysis using logarithmic (ln) transformed values.

Results

From July 8-9, 2002, we obtained 12 paired samples of migrating salmon counts from the DIDSON and Bendix counters. The DIDSON was operated in high frequency mode (1.8 MHz) sampling from 0.75-9.0 m for the first 15 minutes of each hour. The DIDSON counts were then multiplied by four to obtain full hour counts. We collected full hour counts from the Bendix counter during this same time period. After observing images of fish entering the DIDSON beam near the outer range setting and swimming offshore and out of the beam, we changed to low frequency (1.1 MHz) and extended the DIDSON range to 18.75 m. We collected 50 full hour samples during July 12-14, 2002 from both sonars.

During the DIDSON and Bendix sonar comparisons, fish captured in the fish wheel near the sonar site were predominately sockeye salmon. The 12 high frequency DIDSON samples expanded to hourly estimates ranged from 88-1,424 fish/hr and totaled 6,520 (Figure 32). Full hour Bendix counts from that same time period ranged from 148-1,625 fish/hr for a total of 6,678. Regression analysis of the 12 paired DIDSON and Bendix samples resulted in a slope that was not significantly different from one (Table 4, Figure 33). Logarithmic (ln) transformed samples of the same dataset were less similar.

Salmon passage rates from the 50 full hour low frequency DIDSON and full hour Bendix sonar samples were fairly low ranging from 62-717 fish/hr and totaling 12,062 from DIDSON samples with fewer fish, 44-463 fish/hr totaling 9,110 from Bendix sonar samples (Figure 34). The DIDSON counted 24% more fish than the Bendix during this sampling period. The regression slope for both linear and logarithmic data are significantly greater than zero, butalso significantly different from one; both slope and r^2 values are considerably lower than the prior comparison (Table 4, Figure 35).

Table 4. Comparison of linear regression models to predict Bendix sonar counts from DIDSON counts.

Dependent Variable	*Independent Variable*	*Fitted Equation*	*95% Confidence Interval (Slope)*	*S.E. (Slope)*	r^2	*p-value*
Bendix	DIDSON_{exp}	$y = 46.92 + 0.94\,x$	0.71-1.17	152.28	0.89	<0.001
ln Bendix	ln DIDSON_{exp}	$y = 1.51 + 0.77\,x$	0.59-0.94	0.24	0.91	<0.001
Bendix	DIDSON_{full}	$y = 67.75 + 0.47\,x$	0.35-0.60	66.12	0.55	<0.001
ln Bendix	ln DIDSON_{full}	$y = 1.16 + 0.73\,x$	0.55-0.92	0.36	0.58	<0.001

CHAPTER 5: FISH BEHAVIOR ON ARTIFICAL SUBSTRATES AND ROCKY RIVER BOTTOMS

Although the main topic of this last section is fish behavior, it also serves as a place to discuss all of the remaining work accomplished with the DIDSON during the 2002 study. The primary objectives of the study were the sonar comparisons on the Wood River and range tests on the Copper River. However, in the time remaining on the borrowed DIDSON, we also deployed it briefly on the rocky bottom and aluminum tube substrate in the Kasilof River and on the natural sand and cobble substrate of the Kenai River's north bank. The wide horizontal beam of the DIDSON (29°) divided into narrow multiple beams provides a much longer and more accurate glimpse of fish as they swim past the transducer providing us a unique opportunity to observe fish traveling across artificial and rocky substrates. We were particularly interested in whether fish would be detectable swimming over large rocks and across regions with less than linear bottom profiles, i.e. in areas where more traditional sonar gear fails us.

The Kasilof River is the only site where long aluminum tubes (18.3 m) serve as artificial substrates for the Bendix sonar. These tubes were once standard equipment at each Bendix site. The bottom profile of the Kasilof River at the sonar site is fairly linear for about 15 m along each shore (Figure 36), but the riverbed is strewn with large rocks. The site was selected because it is upriver from tidal influences yet close enough to the fishery for the daily inseason counts to be useful to fishery managers.

The Kenai River's north bank at Mile 19 is smoothly sloping (Figure 31) and composed of fine sand and small gravel. We have been testing the feasibility of using split beam sonar at this site for the past two seasons and are currently analyzing these data. The primary difficulties at this site include: 1) a narrow water column, which creates a myriad of multi-path echoes as fish travel through the sonar beam; 2) a slower current, which allows fish to hold in the sonar beam; 3) fish passage that can exceed 6,000 fish/hr during the run peak; and 4) chinook salmon spawn at this site. With fish ranging offshore beyond 35 m, a split beam sonar or lower frequency DIDSON is necessary for estimating salmon passage. At this site, we were interested in determining how far offshore the high frequency DIDSON could detect the plastic sphere.

The specific objectives of this study were to:

1. Determine whether fish are detectable against the rocky river bottom of the Kasilof River;
2. Identify the maximum detection range of the plastic sphere in DIDSON images at the Kasilof River;
3. Observe fish behavior along the artificial tube substrate in the Kasilof River; and
4. Identify the maximum detection range of the plastic sphere in DIDSON images at the Kenai River.

Methods

On July 23, we deployed the DIDSON along the north bank of the Kasilof River 15 m upstream of the Bendix transducer on a stretch of rocky river bottom. Our purpose was to determine whether fish could be detected in DIDSON images against the rocky bottom. To test the range limit, we positioned the plastic sphere near the river bottom in front of the DIDSON then towed the target offshore using a small skiff. The DIDSON was mounted relatively high in the water column (no measurements were made) and pitched –12.5° from level. DIDSON settings that controlled data collection included low frequency mode, a 0.75-18.75 m range, and 8 frames/s. Settings, which did not effect data collection but were controllable on playback, were adjusted to maximize target detection and included an 18 dB threshold, 79 dB intensity, and background subtraction. On July 24, we moved the DIDSON adjacent to the Bendix transducer along the aluminum tube at the Kasilof River to take advantage of the weir and observe fish behavior along the artificial substrate. The DIDSON was operated at both high and low frequencies and initially pitched –9.0°, and later re-aimed to –13.0°. Qualitative observations were made of both fish behavior and image quality. On July 25, we moved the DIDSON to the north bank of the Kenai River. We deployed the DIDSON 35 m upstream of the fish wheel and 79 m downstream of the Bendix and split beam sonars. This site was chosen because the current was stronger and staff believed fish migrated closer to shore. We attempted to complete a range test at this site with the plastic sphere, but were unsuccessful, because of the lack of trained staff available and a shortage of time in which to do the tests. Nonetheless, we collected a few files to observe fish behavior.

Results

In the Kasilof River, the DIDSON images of the rocky river bottom were similar to those seen at the Miles Lake site. Fish were easily detectable swimming across the rocky river bottom and large rocks were clearly visible and easily removed with the background subtraction feature. Fish targets were few. Because there was no weir, we suspected most fish were swimming inshore of the DIDSON transducer. We detected the plastic sphere out to 11 m using the low frequency setting. It was not clear whether the limited range was caused by signal loss, shadowing by rocks, or the beam geometry.

With the DIDSON deployed alongside the Bendix transducer and the beam directed along the aluminum tube, the tube and weir were clearly visible in DIDSON images. Soon after this deployment, we observed a substantially greater number of fish appearing in DIDSON images compared to the number counted by the Bendix sonar. Rather than attempting a comparison, the DIDSON was used to troubleshoot the Bendix sonar, whose daily counts were needed by commercial fishery managers. Sonar operators re-aimed the Bendix transducer and repositioned the tube until counts from both systems merged. The DIDSON was run through the night of July 24 and part of the next day to continue troubleshooting. The counts again diverged, and the Bendix transducer was re-aimed and recalibrated until sonar operators were satisfied the counts were comparable.

The Kasilof River's tube substrate appeared to have little effect on fish behavior as they swam around the weir and across the tube. Some fish holding behavior was observed. In one case it was obvious from the length of the fish (1,070 mm measured by the DIDSON), the fish was a chinook salmon rather than a sockeye salmon. The fish held in the beam a short distance upstream of the tube, the tail initially visible at a range of 5 m. In time, the fish backed downstream moving to the center of the DIDSON beam then moved gradually offshore staying 7-8 m offshore for up to a minute. A second behavioral pattern observed at this site has been cause for concern among sonar operators for some time. Several fish were observed swimming around the weir, which extended 3½ m offshore of the DIDSON, and immediately dodging toward shore ending up 1 m or less from the DIDSON as they crossed the beam. This abrupt change in aspect coupled with the close range to the transducer can create detection issues for traditional sonars.

At the Kenai River north bank, we observed several fish, which based on their image length appeared to be sockeye salmon, holding in the sonar beam. Fish frequently crossed the beam and stayed on the upstream edge with only the tail visible until a new pod of fish arrived and pushed the holding fish onward. The image appeared fuzzier at this site. After dismantling the DIDSON, we observed silt buildup in the lens housing. On July 26, the DIDSON was removed from the water in the late afternoon and returned the following day to the Applied Physics Lab.

DISCUSSION

In the Wood River, the DIDSON counts and other sonar and video methods closely matched the tower counts. However, the correlations would be more compelling had we achieved a wider variety of passage rates within our samples. Several features of the DIDSON provided an advantage over tower observations including the variable replay rate, clear and easy-to-count fish images even when the surface of the water was rippled or shadowed by clouds, and the capability of counting at night without disturbing fish. We expected good agreement between the Bendix and tower counts because the Bendix sonar was developed and extensively tested at the Wood River site (Al Menin personal communications and Gaudet 1990). We expected a poorer performance of the split beam sonar based on past studies (Biosonics 1999ab and Enzenhofer et al. 1998). Due to the problem with the initial aim that invalidated the three highest passage samples, we were unable to adequately test the split beam sonar. From our experience, post-season software problems requiring re-analysis of the split beam data have become typical when working with split beam sonar. In contrast, the DIDSON was easy to use and virtually problem-free.

The range tests in the Copper River demonstrated that the DIDSON can be used to count fish in very turbid rivers if the fish swim within 17-18 m of the transducer. Because of the small size of the plastic sphere used in the range tests, we are confident that migrating fish will be detectable offshore to at least this range and possibly beyond. Signal loss in the Copper River tests was substantial. If the 3 dB/m loss holds for ranges closer to shore, the overall signal loss could approach 48 dB. In this study, the target was not lowered as it was drawn offshore, so it is likely the target's position within the beam played a factor in the signal loss. Without beam pattern plots of the DIDSON's individual beams, we can not determine how far from the nominal edge the target might be detectable. The large vertical beam, which could easily spread from the river's surface to the bottom, suggests the signal loss due to beam position was minimal. Optional 40 log and linear gain features have been added to the DIDSON playback software. In some data files, the gain seems to enhance target visibility while in others the added noise is overwhelming. More files need to be examined under a variety of settings to determine whether or not these added features will push fish detection limits further offshore.

We were unable to test the LUIS under the same conditions as the DIDSON, so results from this test were tentative. However, the 60 m detection range in the lake and 45 m detection range in the Kenai River were well beyond the 30 m maximum range setting of the standard DIDSON. A new lower frequency (0.7 MHz), longer range DIDSON (DIDSON LR) is now available. Preliminary side-by-side tests with the standard DIDSON suggest a potential tripling of the detection range (Maxwell et al. *in press*). The DIDSON LR will have a lower resolution because the lens is the same size as the Standard DIDSON. The effects of the reduced resolution on fish detection have yet to be determined. Tests in turbid streams will be necessary to determine the effectiveness of this new tool.

In the Copper River, correlation between the DIDSON and split beam sonar counts was poor. Direction of fish travel is obvious in DIDSON images, even at ranges less than 1 m. According to the upstream/downstream classification of fish from DIDSON images, 13% of the split beam sonar's tracked fish were incorrectly classified as downstream. This is cause for concern given the low passage rates sampled (284 or fewer fish/hr from DIDSON counts). At higher passage rates when multiple fish enter the beam at the same time, we would expect more degradation of the split beam positional information resulting in higher error rates in the upstream/downstream classification of fish tracks. The range distribution data showing the greater number of fish counted by the DIDSON in the nearshore region demonstrated an advantage of the wider vertical DIDSON beam. To 'fit' the water column, the vertical split or single beam has to be sufficiently narrow to avoid boundary interference, but the drawback is a much smaller beam nearshore where the bulk of fish passage occurs. Fish targets occupied the entire first 5 m of the split beam (Figure 25), so we expect to miss fish in this region. Beyond 5 m, fewer targets were found in the upper beam and the split beam sonar counts more closely matched DIDSON counts. Because the majority of fish were traveling close to the transducer, we expected the split beam sonar phase information from the targets to be poor at this range. In addition, the transducer aim may have been an issue. Counts from the samples collected on the second day (June 26) were closer to each other than counts from samples collected the first day. On the second day, the split beam transducer may have had a more effective aim. Range information from all three sonars indicates that fish abundance declines dramatically offshore. Although we were reasonably certain this represents the real migration distribution of salmon at this site, detection is still an issue in the offshore regions.

With the DIDSON deployed on the old substrate at Miles Lake, we observed fish as they traveled around the weir and across the substrate. It was unknown whether the observed 'sliding' fish behavior was caused by the faster current, or by a combination of faster current and the rail, which extends above the concrete substrate. The large concentration of sliders has an unknown effect on the Bendix sonar counts, but could potentially result in counting the same fish at multiple ranges. The range distribution of Bendix sonar counts (Figure 22), does not show a large number of fish counted offshore, instead, the range distribution drops off abruptly after 5-6 m. It is possible that many of the counts at 7 m and beyond (10% of the fish) represent the sliders.

The DIDSON was positioned higher on the mount than the single and split beam sonars and tilted downward ensonifying the backs of fish to prevent shadowing by fish close to the DIDSON. After completing these tests, we decided a better geometry might be a compromise between this raised position and the more traditional low-to-the-ground mount. With the DIDSON high on the mount (lower edge ~35-55 cm above river bottom), an extreme pitch angle was required to ensonify fish close to the DIDSON. Lowering the DIDSON and using a more level pitch angle has the potential of increasing the range as shown in the extreme example in Figure 37. In general, a higher mounting position and more oblique pitch are desirable in rivers where fish passage is densest close to the transducer. In rivers where fish passage is less dense nearshore and a longer range is desired, the axis of the beam needs to be more closely aligned with the river bottom.

One final objective specifically related to the Miles Lake sonar site was to determine the best sonar to replace the Bendix sonar and the optimal settings. Although the DIDSON LR may be the better choice, it hasn't been tested in rivers. The Standard DIDSON easily outperformed the split beam sonar and is our choice for the Bendix sonar replacement. For optimal sampling, the DIDSON should be positioned a little lower on the mount and pitched downward until a target dangled near bottom just inside the weir is visible. Longer range settings, beyond 18 m, should be attempted. At these range settings, the DIDSON will automatically operate in low frequency mode (1.1 MHz). The playback threshold setting should be adjusted low enough that fish observed at the furthest range are still detectable. For the best resolution of targets, the frame rate should be increased until the capacity of the computer has been reached and frames begin to drop out then reduced to a lower value.

In the Kenai River, DIDSON and Bendix sonar counts were less correlated than counts from the Wood River. The error in the Bendix sonar counts was considerably higher than the error in the DIDSON counts. Although the first paired Kenai River dataset contained similar counts, in the second dataset 24% fewer fish were counted with the Bendix sonar compared to the DIDSON. For the second dataset, the DIDSON was switched to low frequency and the range extended because we observed fish moving out of the beam at the end of the range. Although it is unlikely the increase in fish numbers came entirely from the outer ranges, the range increase could account for some of the difference. A range distribution from the DIDSON data would help us to understand the difference between the two datasets. However, producing a DIDSON range distribution is done manually and is very time intensive. We lacked the time and personnel to accomplish this task at the time of the study. Another possibility for the discrepancy between counts from the DIDSON and Bendix sonar is the possibility of the salmon swimming higher in the water column, which would reduce the Bendix sonar count but because of the large vertical beam, the fish would be detected by the DIDSON. More sampling across a wider range of salmon passage rates and water levels needs to be conducted before more meaningful conclusions can be drawn.

A potential operator bias was observed during these tests. Sonar operators appear to have a natural tendency to engage in short comparison counting from each sonar. This opens up the possibility for subconscious influences altering the highly observer-dependent Bendix sonar. For example, an observer counting rapid oscilloscope spikes generated by the Bendix sonar may be influenced to count more spikes if he/she feels the count should be higher. Also, a mismatch in counts during these short comparisons will likely cause the Bendix sonar operator to recheck the aim or the sensitivity, again altering the comparison. A completely blind test is necessary to ensure the counts from one sonar do not influence the counts from the other.

We may find a large degree of variability between DIDSON and Bendix sonar counts. Even with a completely blind test, it is possible that the two sonars may compare favorably one day and not the next depending on fish behavior, water level, and other environmental conditions. If the fish move off bottom, the Bendix sonar may undercount until other information (fish wheels, catch rates, etc.) alert the operators to the possibility the counts are low. If fish are distributed throughout a larger area of the water column, re-aiming will not eliminate undercounting. If fish hold in the beam, the Bendix sonar may overcount unless sonar operators are able to detect the holding behavior and either recalibrate or remove the sector count to compensate. Counts from holding fish, easily removed during low passage, are less distinguishable during higher passage rates.

The DIDSON appears to be a powerful tool for use in rivers with rocky substrates and less than linear profiles. Slopes that change from steeper to flatter nearshore to offshore, as is often the case, appear to be no problem for the DIDSON, although detection limitations need to be addressed. Slopes with the reverse situation (i.e. flatter nearshore steeper offshore) will likely have insurmountable detection issues because fish are shadowed by the nearshore slope. At the Kasilof River, our inability to detect the plastic sphere beyond 11 m may have been more a result of the beam geometry limitations and less a result of rock shadowing or signal loss. It is imperative the beam geometry at each site is worked out in advance to understand the beam limitations. Developing a better fish-sized target and better methods of moving the target from nearshore to the furthest detectable offshore range are also necessary. Although the bottom structure is outlined in the DIDSON image, knowing whether that structure can interfere with fish detection requires adequate mapping of the beam with a reasonable target. Despite these difficulties, our ability to sample on rocky and non-linear river bottoms with the DIDSON opens a whole realm of possibilities for new sonar sites previously deemed unsuitable.

Observations of fish behavior from DIDSON images were very revealing. Knowledge of how fish move through the beam can provide useful troubleshooting information for existing sonars. As a fish counting device, the DIDSON seems immune to many problems that plague other sonars including fish changing aspect, holding for long periods in the sonar beam, and traveling downstream. The wide horizontal beam of the DIDSON allows for longer viewing of fish behavior than was possible with past sonars.

The buildup of silt in the lens housing observed at the Kenai River's north bank site most likely occurred during the deployment at the lower river Chinook sonar site, where tidal fluctuations slosh muddy water back and forth across the DIDSON. This is a problem that we have addressed with the manufacturers, and they are designing a silt-proof lens housing.

During the course of these tests, we observed the following advantages of the DIDSON over the more traditional single and split beam sonars:

1. Clear fish images that are easier to detect because they are moving across a static background;
2. A wide viewing angle;
3. Better water coverage with the large vertical beam that we are able to push into the river bottom with few ill effects (this could be one of the largest advantages in bringing the sonar fish count closer to the true count for strongly bank-oriented fish);
4. Simpler to aim and simpler to operate the DIDSON whose aiming angle is far less critical compared to split beam and Bendix sonars;
5. Accurate upstream/downstream determination of fish travel even at ranges less than 1 m from the transducer;
6. Background subtraction;
7. Less multi-pathing issues; and
8. Fish length can be accurately measured out to 10-12 m.

Drawbacks of the DIDSON include the large size of data files, range limitations, and the lack of automated counting software. In addition, the majority of the DIDSON's electronics are deployed in the river making the unit vulnerable to damage from floating logs, icebergs or other debris. The new DIDSON LR remains to be tested in rivers, but has the potential of ensonifying longer ranges. If a longer ranging sonar is required, split beam sonars may be the best choice.

The signal loss issue has not been resolved. Whether or not additional gain will enhance the signal needs to be tested. It will be important to test detection issues at each site prior to sampling with the DIDSON. Although automated counting software is still in the future, manually counting fish from DIDSON images is a viable option now. The high labor costs of manual counting and the large quantity of data produced (12-28 MB/min) can be decreased by subsampling. The sampling design currently in use at tower sites in Alaska where migrating sockeye salmon are counted is a systematic ten minute count each hour. The length and frequency of the sample was determined by Becker (1962) and later tested by Seibel (1967). Testing the sampling design will be necessary at each sonar site.

Each site has unique challenges. Changes in water level and fish behavior may cause one sonar system to count differently than another. Because of these potential environmental changes, future testing should include comparison testing between the DIDSON and Bendix sonar across a range of fish density and water levels at each site prior to replacing the Bendix sonar. The comparison tests should be blind, i.e. housed and operated separately or initiate a three day lag in counting fish images from DIDSON files. In conclusion, the DIDSON exceeded our expectations as an instrument for counting shore-based salmon in turbid streams and is the department’s choice to replace the Bendix sonar.

LITERATURE CITED

Barton, L.H. 2000. Sonar Estimation of Fall Chum Salmon Abundance in the Sheenjek River. Alaska Department of Fish and Game, Commercial Fisheries Division, Regional Information Report 3A00-27, Anchorage.

Becker, C.D. 1962. Estimating Red Salmon Escapements by Sample Counts from Observation Towers. Fishery Bulletin 192. Fishery Bulletin of the Fish and Wildlife Service, Volume 61. United States Department of the Interior, Fish and Wildlife Service, Bureau of Commercial Fisheries.

Belcher, E.O., B. Matsuyama, and G. M. Trimble. 2001. Object Identification with Acoustic Lenses. Pages 6-11 *in* Conference proceedings MTS/IEEE Oceans, volume 1, session 1. Honolulu Hawaii, November 5-8.

Belcher, E.O., W. Hanot, and J. Burch. 2002. Dual-Frequency Identification Sonar. Pages 187-192 *in* Proceedings of the 2002 International Symposium on Underwater Technology. Tokyo, Japan, April 16-19.

Biosonics Inc. 1999a March. Alaska Statewide Sonar Project Results of 1998 Field Demonstrations, Final Report. Report to the Alaska Department of Fish and Game, Juneau.

Biosonics Inc. 1999b December. Alaska Statewide Sonar Project Results of 1999 Field Demonstrations, Final Report. Report to the Alaska Department of Fish and Game, Juneau.

Blackman, S.S. 1986. Multiple-Target Tracking with Radar Applications. Artech House, Inc., Norwood, Massachusetts.

Brabets, T.P. 1997. Geomorphology of the Lower Copper Rover, Alaska. U.S. Geological Survey Professional Paper 1581.

Bucher, W. 1981. 1980 Wood River Sockeye Salmon Smolt Studies. Pages 16-33 *in* 1980 Bristol Bay sockeye salmon smolt studies. Alaska Department of Fish and Game, Commercial Fisheries Division, Technical Data Report No. 63, Anchorage.

Burwen, D.L., Fleischman, S.J. and Miller, J.D. 2003. Evaluation of a Dual-Frequency Imaging Sonar for Estimating Fish Size in the Kenai River. Alaska Department of Fish and Game, Sport Fish Division, Fishery Data Series. No. 04-*In Press.*

Chapell, R.S. 2001. Anvik River Chum Salmon Escapement Studies, 1997-1999. Alaska Department of Fish and Game, Commercial Fisheries Division, Regional Information Report No. 3A01-12, Anchorage.

Daum, D.W. and B.M. Osborne. 1998. 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 J of Fisheries Management, 18: 477-486.

Davis, R. Z. 2002. Upper Cook Inlet Salmon Escapement Studies 2001. Alaska Department of Fish and Game, Commercial Fisheries Division, Regional Information Report No. 2A02-17, Anchorage.

Del Grosso, V.A. and C.W. Mader. 1972. Speed of Sound in Pure Water. J. acoust. Soc. Am.,. 52: 1442-6.

Dunbar, R. 2001. Copper River Hydroacoustic Salmon Enumeration Studies, 2000 and 2001. Alaska Department of Fish and Game, Commercial Fisheries Division, Regional Information Report No. 2A01-3, Anchorage.

Enzenhofer, H.J., N. Olsen, and T.J. Mulligan. 1998. Fixed-Location Hydroacoustics as a Method of Enumerating Migrating Adult Pacific Salmon: Comparison of Split-Beam Acoustics vs. Visual Counting. Aquatic Living Resource. 11(2): 61-74.

Faran, J.J., Jr. 1951. Sound Scattering by Solid Cylinders and Spheres. J. Acoust. Soc. Am., 23, pp. 405-418.

Francois, R.E. and G.R. Garrison. 1982. Sound Absorption Based on Measurements. Part II: Boric Acid Contribution and Equation for Total Absorption. J. Acoust. Soc. Am., 72, pp. 1879-90.

Gaudet, D.M. 1990. Enumeration of Migrating Salmon Populations using Fixed-Location Sonar Counters. Rapports et Proces-Verbaux des Reunions, Conseil International pour l'Exploration de la Mer 189:197-209.

Hogg, R.V. and A.T. Craig. 1978. Introduction to Mathematical Statistics. Wiley, New York.

Johnson, R, and G. Ghattacharyya. 1987. Statistics Principles and Methods. John Wiley and Sons, Inc. pp. 378-382.

MacLennan, D.N. and Simmonds, J.E. 1992. Fisheries Acoustics. Chapman and Hall. pp. 42-44, 73.

Maxwell, S.L., Burwen, D.L., and Pfisterer, C.T. 2004. Testing the Range Limitations of the Long Range and Standard versions of the Dual Frequency Identification Sonar (DIDSON). Alaska Department of Fish and Game, Commercial Fisheries Division , Regional Information Report No. *In Press*, Anchorage.

McKinley, W.L. 2002. Sonar enumeration of Pacific salmon into the Nushagak River, 2001. Alaska Department of Fish and Game, Commercial Fisheries Division, Regional Information Report No. 2A02-25, Anchorage.

Miller, J.D. and D. Burwen. 2002. Estimate of Chinook Salmon Abundance in the Kenai River using Split Beam Sonar, 2000. Alaska Department of Fish and Game, Sport Fish Division, Fishery Data Series No. 02-09, Anchorage.

Neter, J. W. Wasserman, and M.H. Kutner. 1990. Applied Linear Statistical Models. 3rd ed. Boston: Irwin. pp. 86-87.

Pfisterer, C.T. and S.L. Maxwell. 2000. Yukon River Sonar Project Report, 1999. Regional Information Report No. 3A00-11, Alaska Department of Fish and Game, Commercial Fisheries Division, Anchorage.

Pinheiro, J.C. and D.M. Bates. 2000. Mixed-Effects Models in S and S-Plus. Springer-Verlag, New York.

Richards, S. D., Heathershaw, A.D., and P.D. Thorne. 1996. The Effect of Suspended Particulate Matter on Sound Attenuation in Seawater. Journal of the Acoustical Society of America, 100(3):1447-1450.

Seibel, M.C. 1967. The use of Expanded Ten-Minute Counts as Estimates of Hourly Salmon Migration Past Counting Towers on Alaskan Rivers. Informational Leaflet 101, Alaska Department of Fish and Game, Commercial Fisheries Division, Juneau.

Stram, D.O. and J.W. Lee. 1994. Variance Components Testing in the Longitudinal Mixed-Effects Models. Biometrics 50:1171-1177.

Zar, J.H. 1984. Biostatistical Analysis 2nd ed. Prentice-Hall, Inc. pp. 40-42.

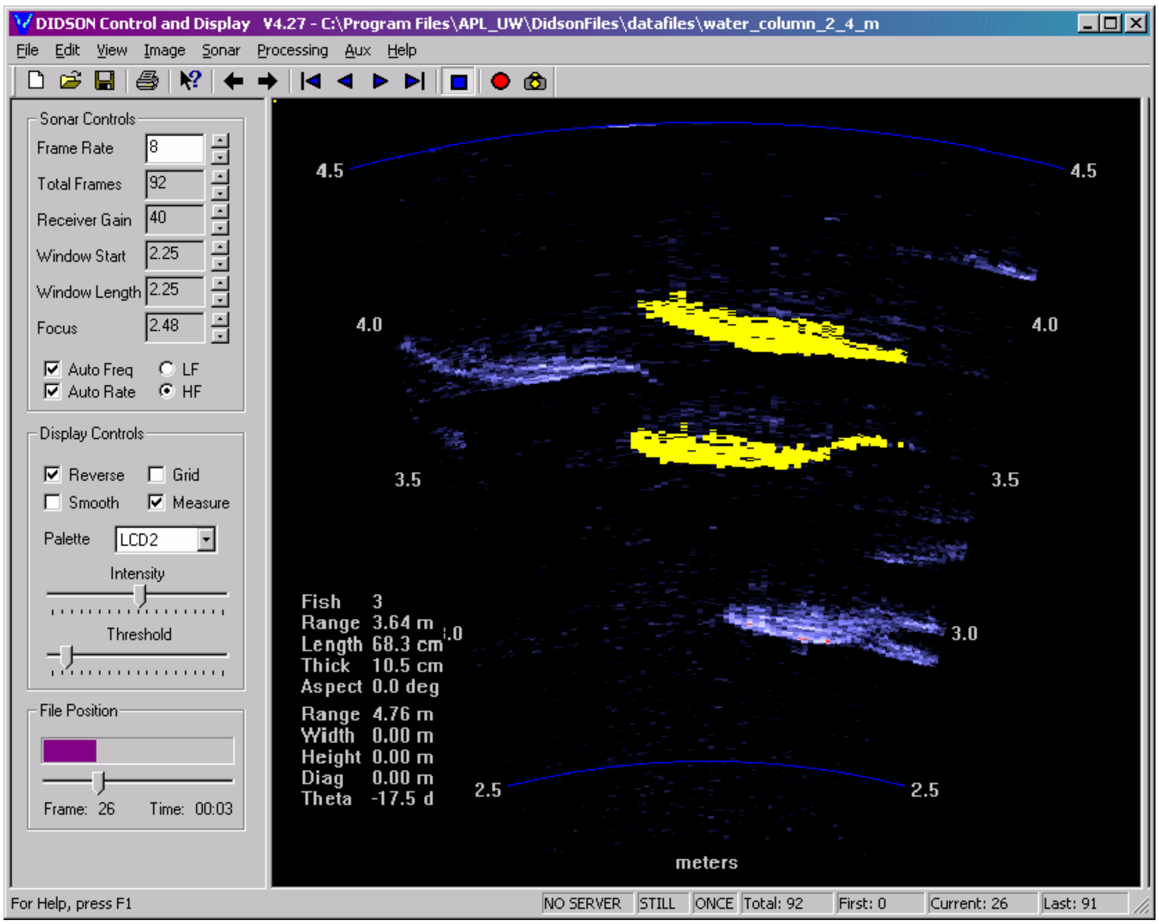


Figure 1. DIDSON image of fish in a hatchery pond at the University of Washington with two autocounted fish shown (highlighted).

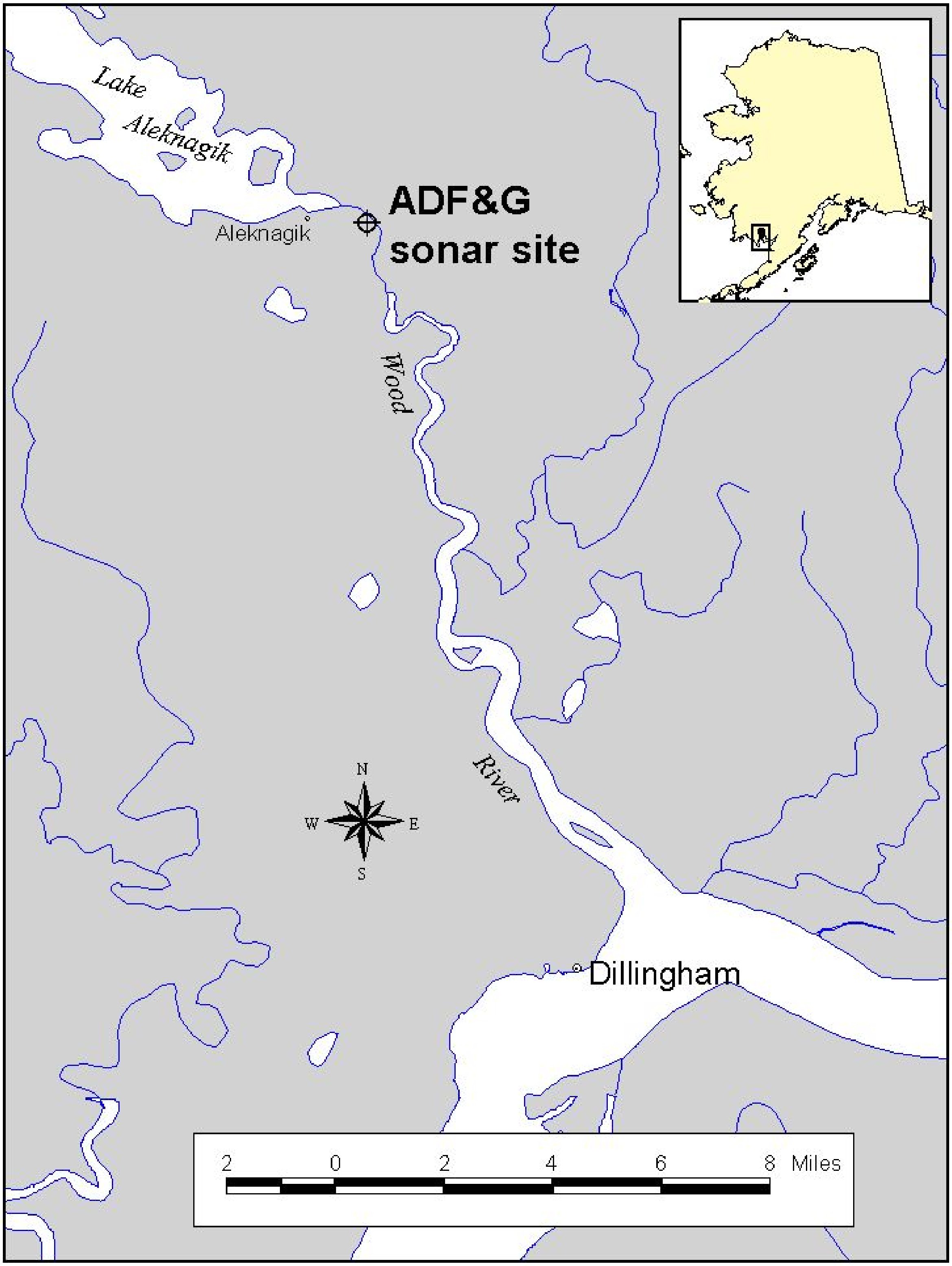


Figure 2. Location of the Wood River, Alaska.

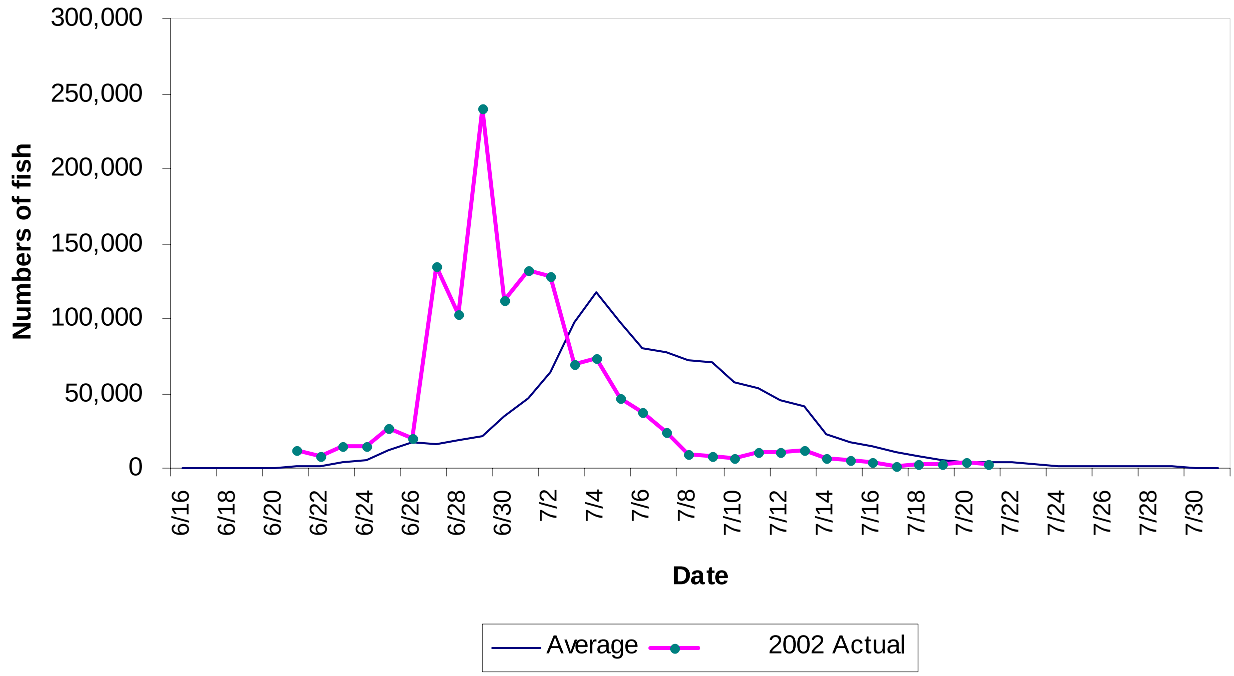


Figure 3. 2002 Wood River sockeye salmon escapement and the average escapement over the past ten years.

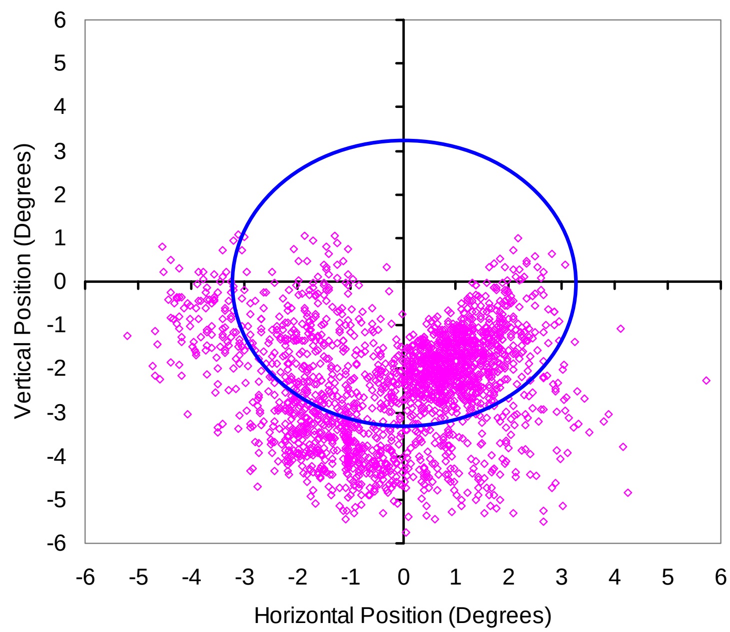


Figure 4. Horizontal and vertical position of split beam echoes from the 38.1 mm tungsten carbide calibration sphere with the 6.4° nominal beam overlaid, Wood River, July 2, 2002.

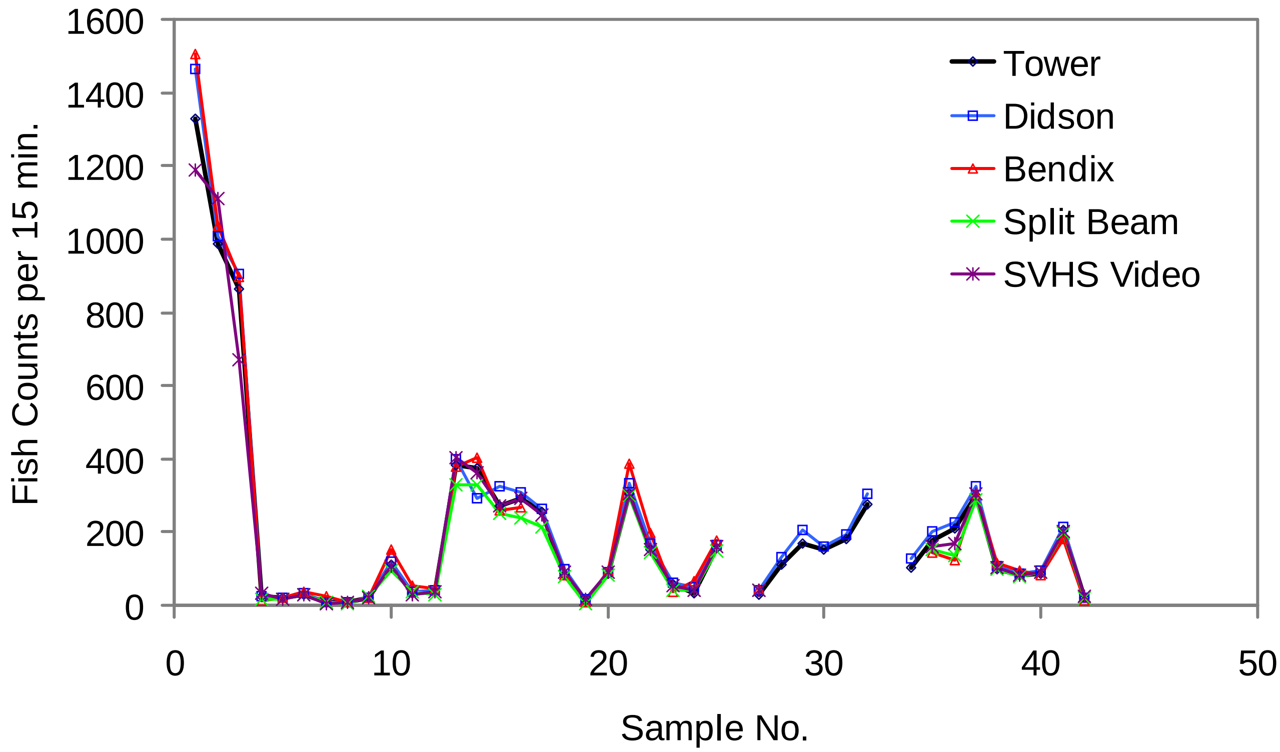


Figure 5. Time series of fifteen minute salmon counts from the tower, video, and three sonars, Wood River, July 2-5, 2002.

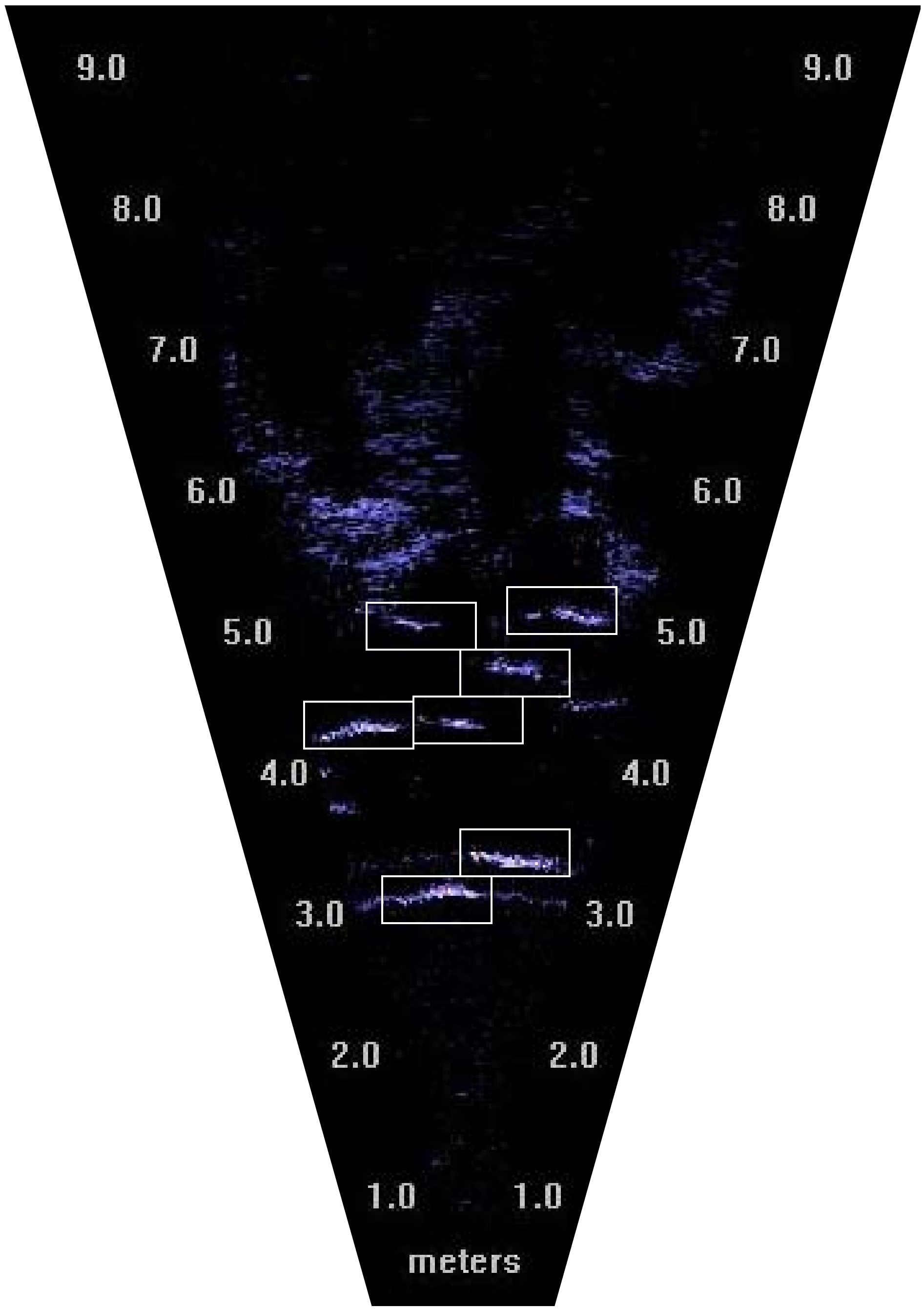


Figure 6. DIDSON image of migrating sockeye salmon with the salmon images outlined. The remaining signal comes from a combination of river bottom and volume reverberation, Wood River, July 2, 2002.

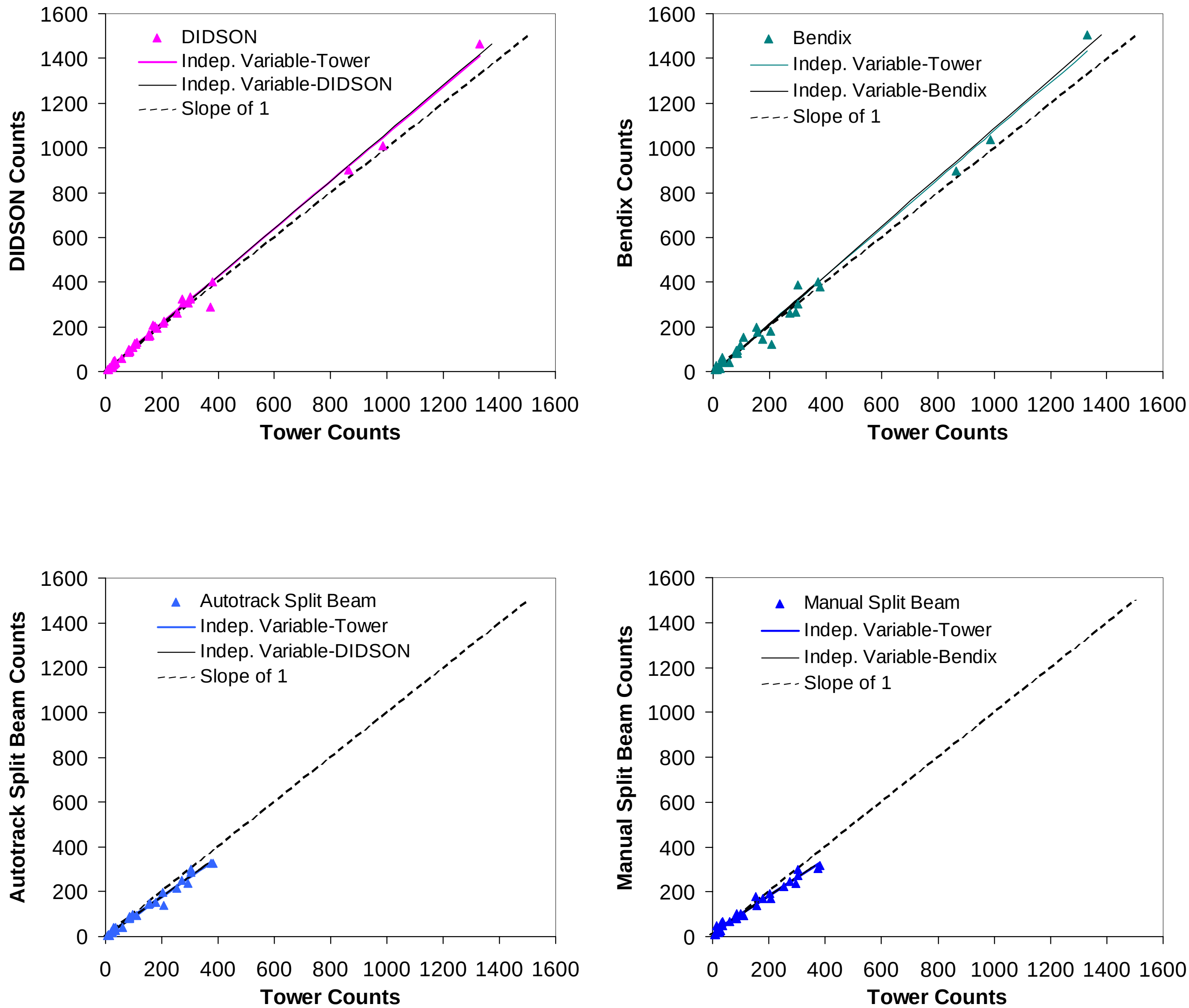


Figure 7. The DIDSON (upper left), Bendix sonar (upper right), autotracked (lower left) and manual tracked (lower right) split beam sonar counts compared to tower counts with regression lines using each counting method as the independent variable, Wood River, July 2-5, 2002.

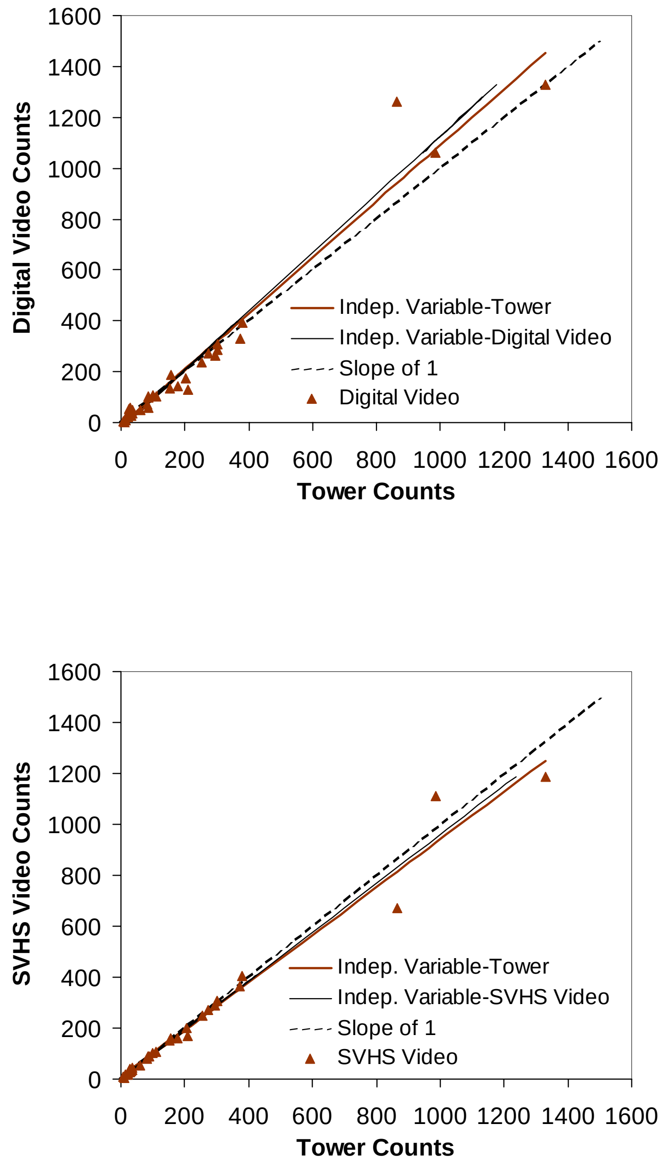


Figure 8. The digital (top) and SVHS (bottom) video counts compared to the tower counts with regression lines using each counting method as the independent variable, Wood River, July 2-5, 2002.

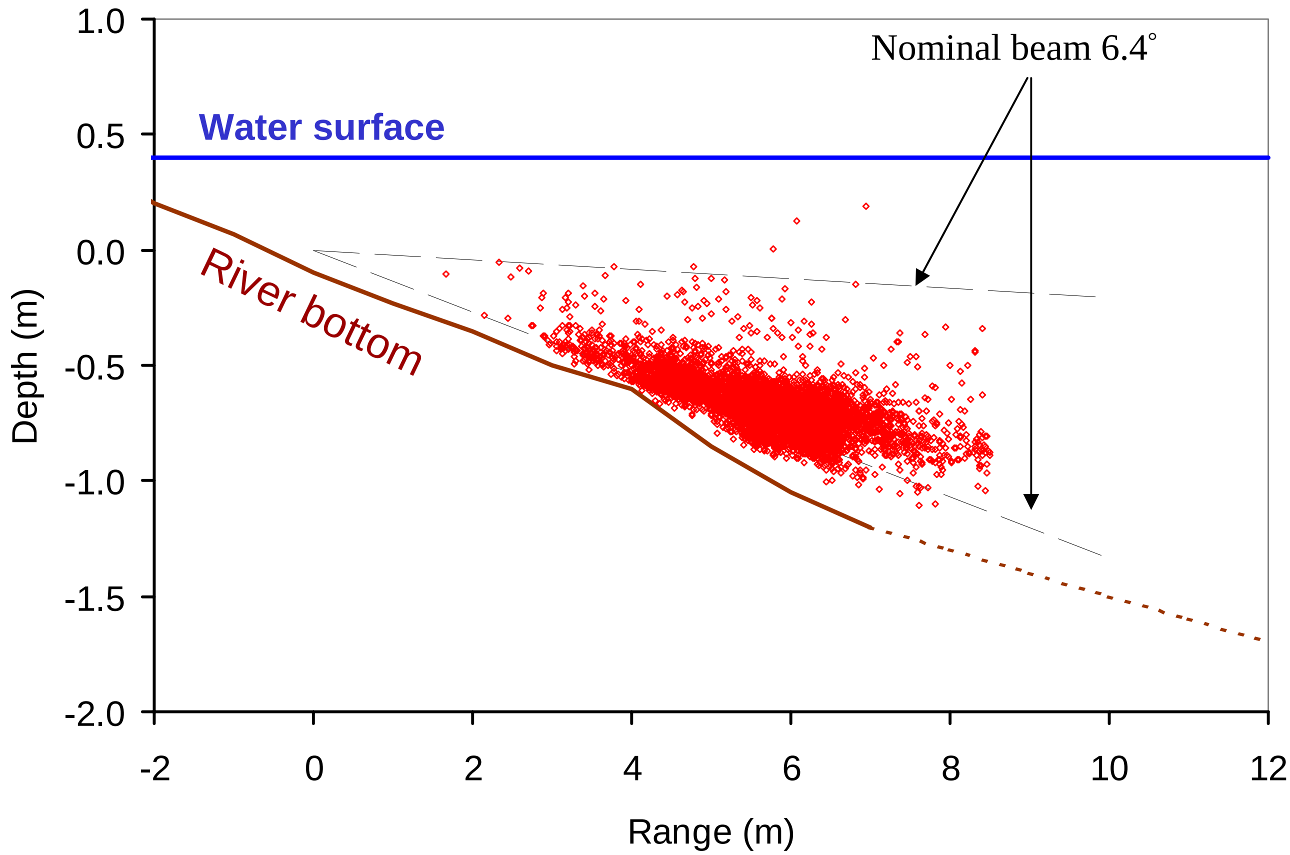


Figure 9. The Wood River bottom profile with the average vertical position and range of tracked fish targets (diamonds) and the nominal split beam edges shown. The sonar beam is pitched -4.4° from a depth of 0.4 m, July 2-5, 2002.

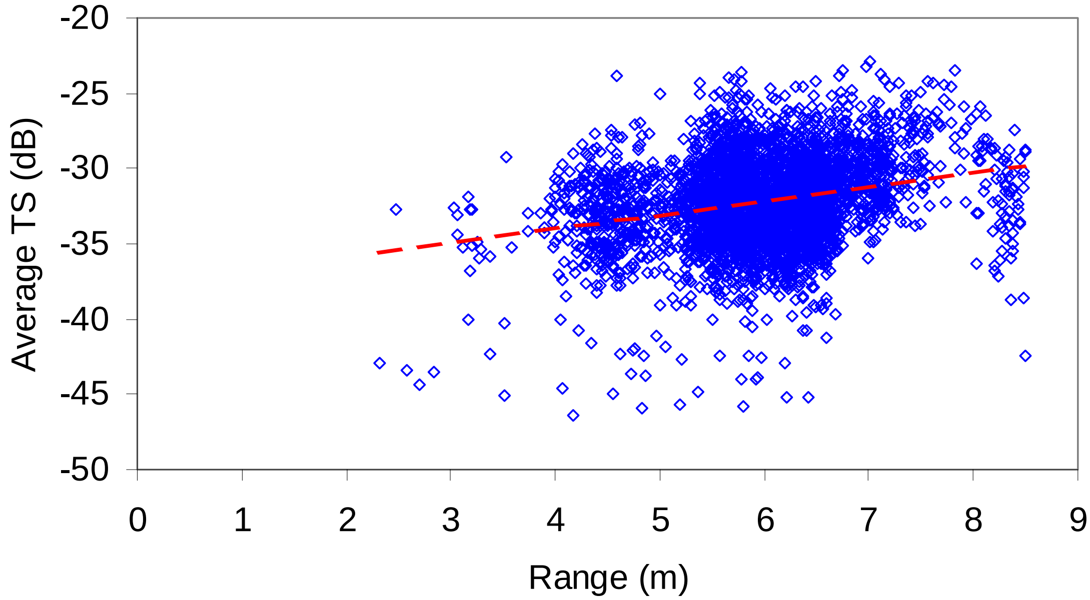


Figure 10. Average target strength (TS) of fish targets measured with the split beam sonar at the Wood River, July 2-5, 2002.

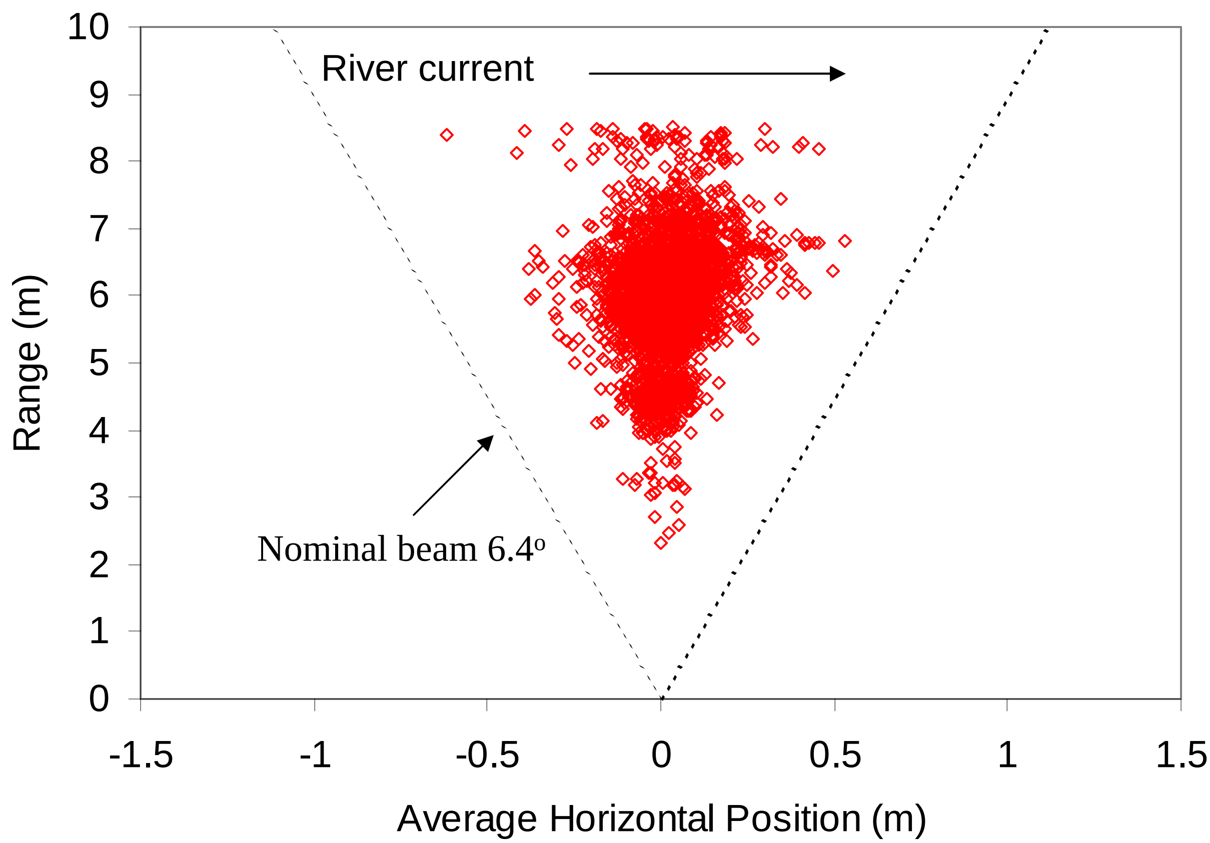


Figure 11. Average horizontal position of fish with the nominal beam overlaid, Wood River, July 2-5, 2002.

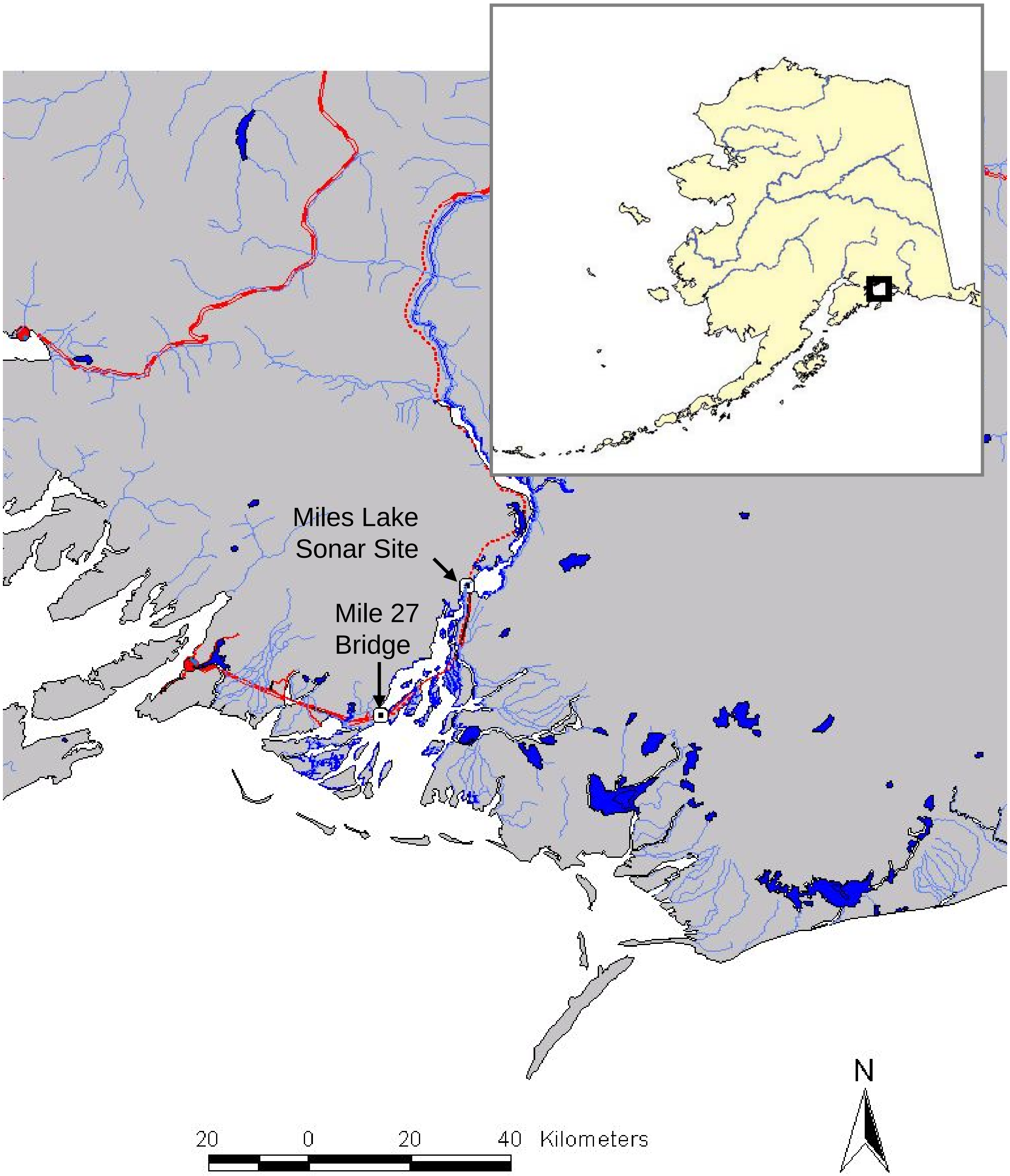


Figure 12. Location of the Copper River's Mile 27 bridge and Miles Lake sonar sites.

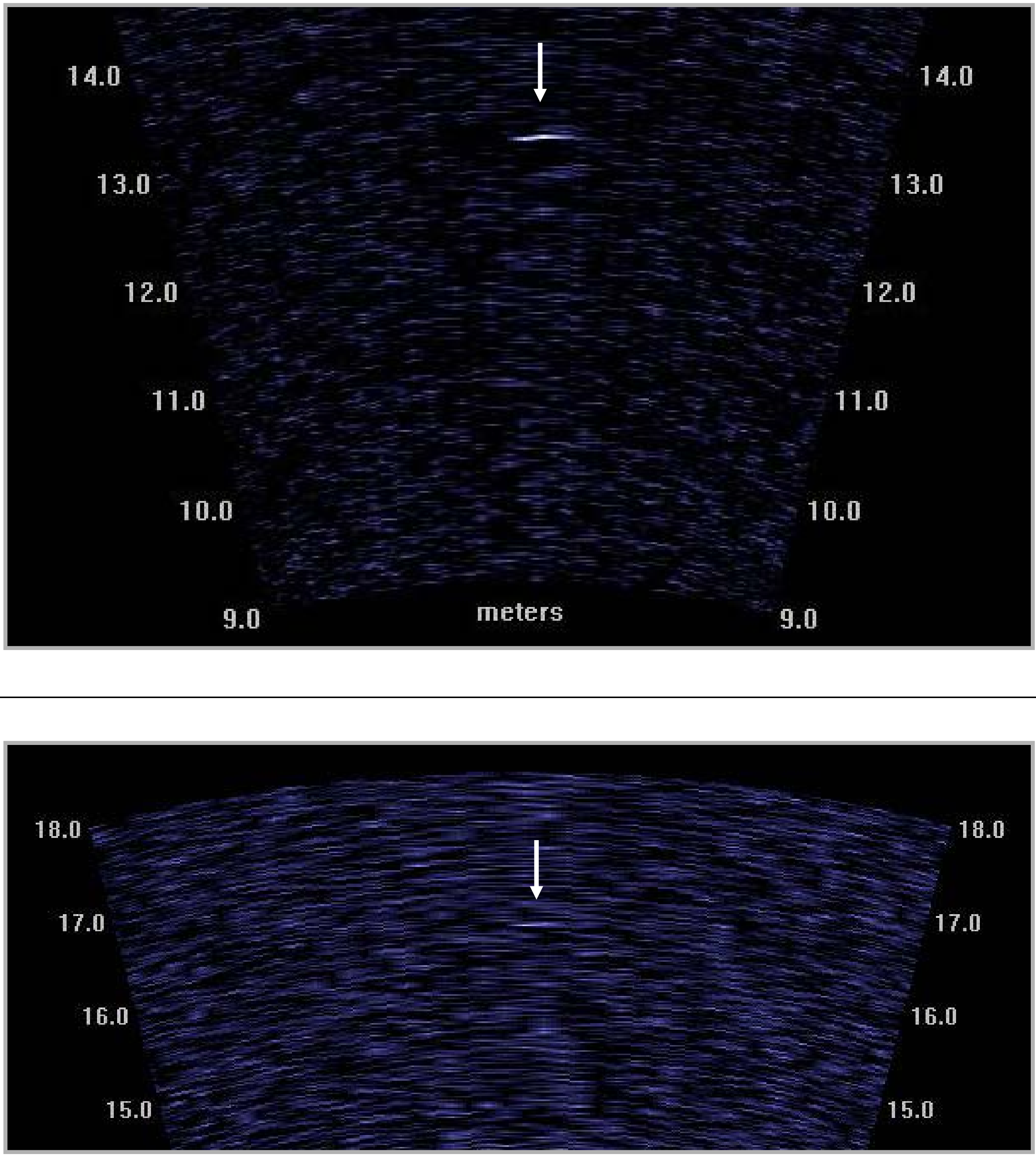


Figure 13. DIDSON image of the 10.16 cm plastic sphere shown at 13 m (top) and at 16.5 m (bottom), Copper River Mile 27 bridge site, June 24, 2002.

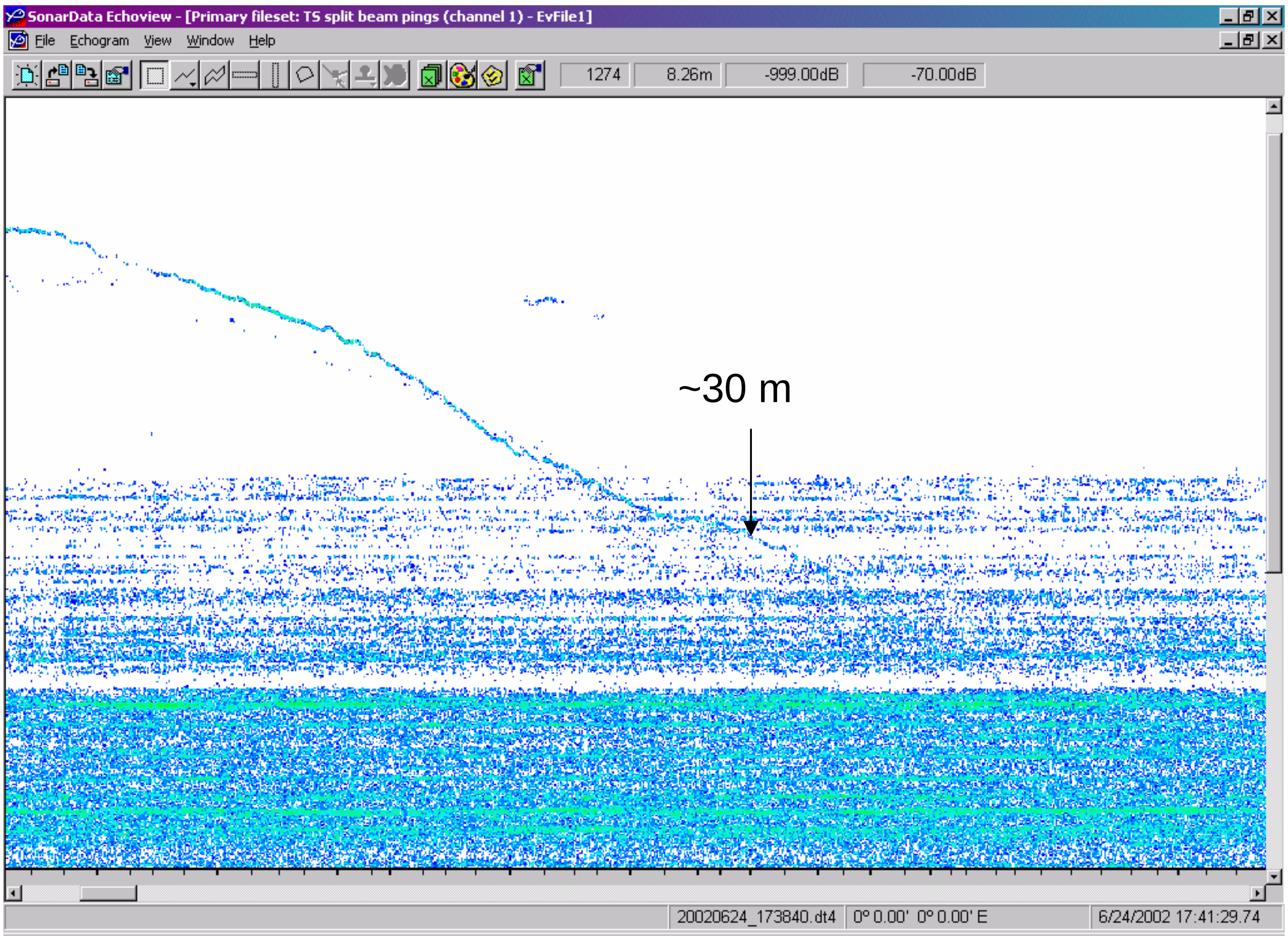


Figure 14. Split beam sonar echogram showing echoes from the 10.16 cm plastic sphere moving offshore. The target is visible beyond 30 m; however, river bottom interference begins at 21 m, Copper River Mile 27 bridge site, June 24, 2002.

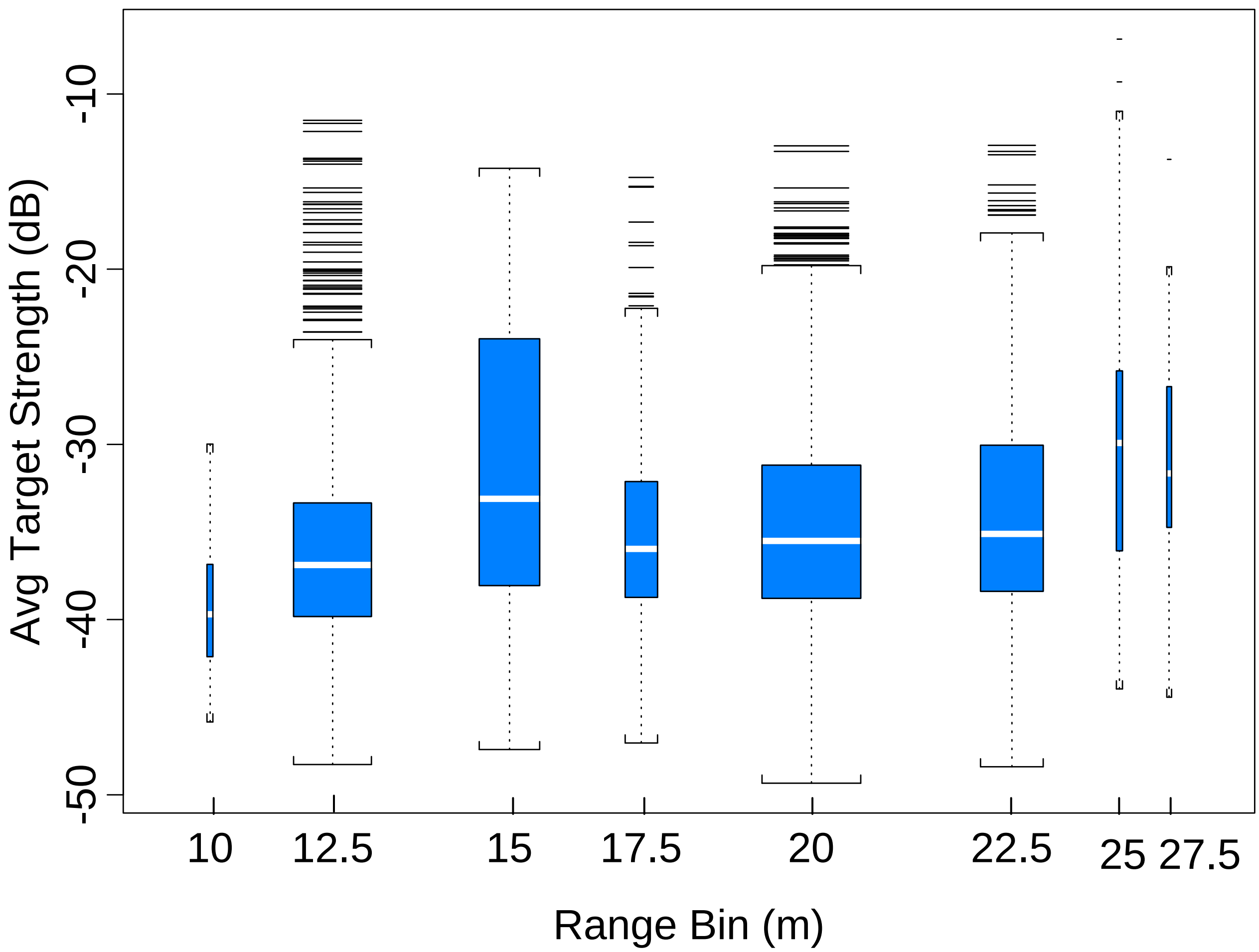


Figure 15. Split beam sonar average target strength boxplot of echoes reflected from the 10.16 cm plastic sphere with the width of the box reflecting the number of echoes received, Copper River Mile 27 bridge site, June 24, 2002.

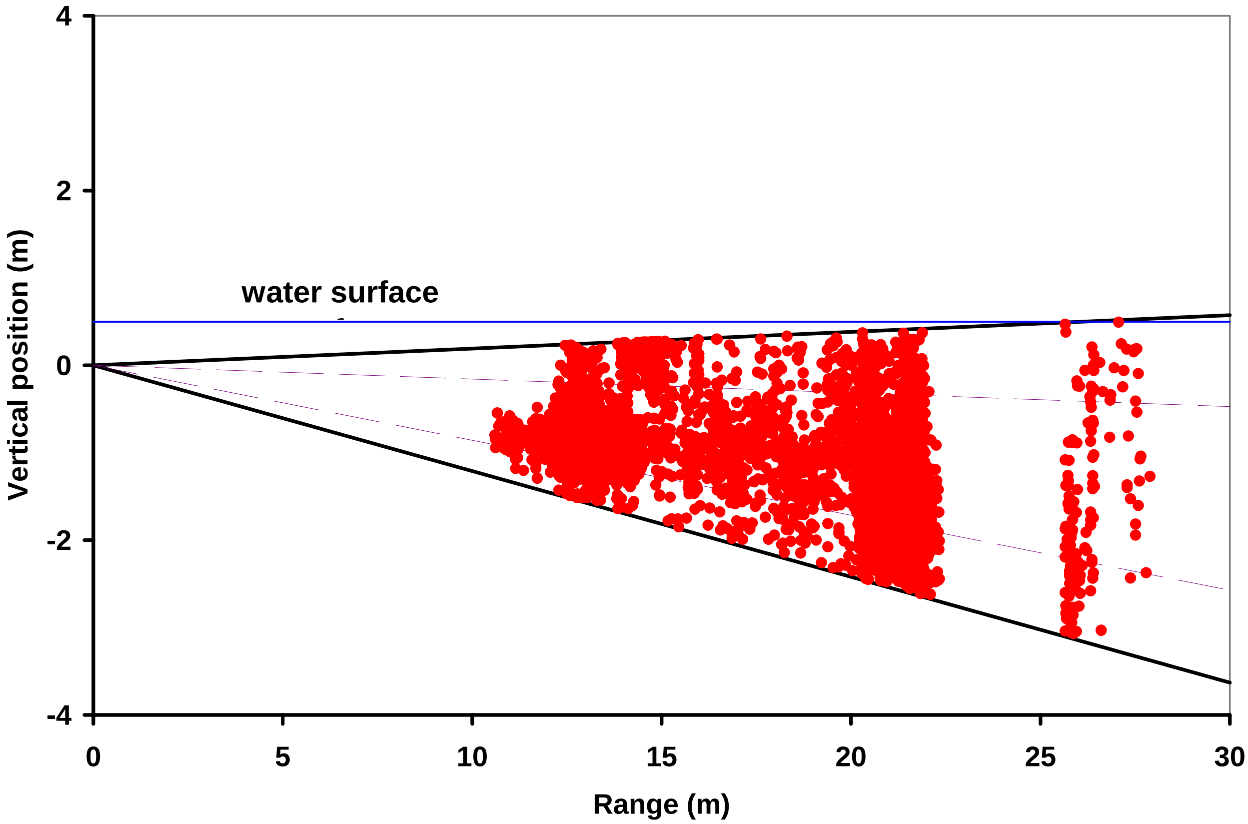


Figure 16. Vertical position and range of split beam sonar echoes reflected from the 10.16 cm plastic sphere, overlaid with the nominal beam (3.8º, dotted line) and the effective beam (8º, solid line) pitched -2.9º, from a depth of 0.5 m, Copper River Mile 27 bridge site, June 24, 2002.

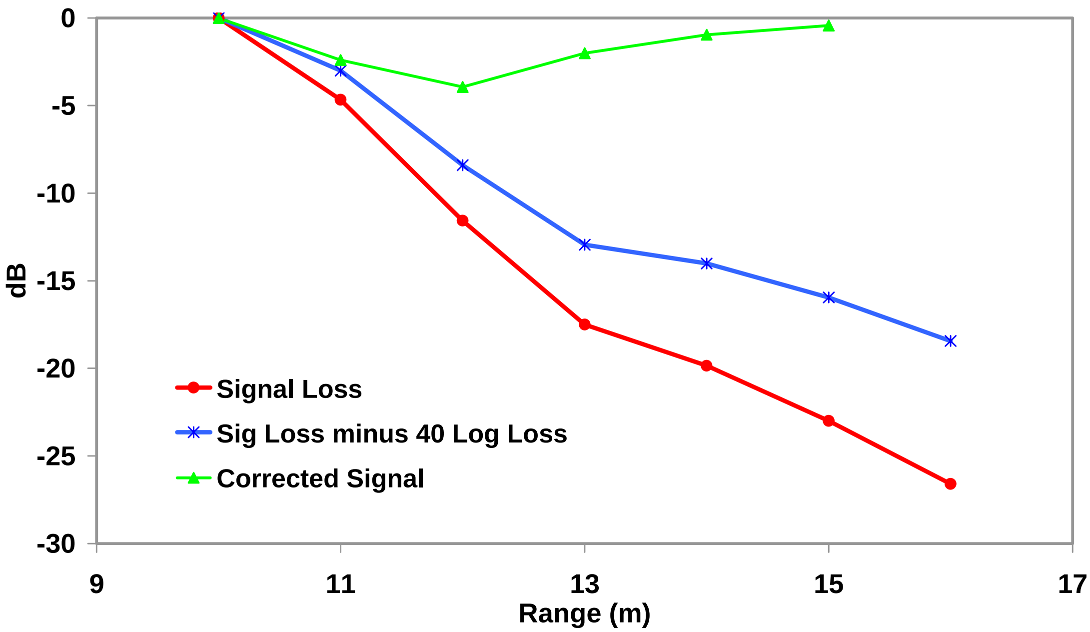


Figure 17. Signal loss from DIDSON images of the 10.16 cm plastic sphere, Copper River, Mile 27 bridge site, June 24, 2002.

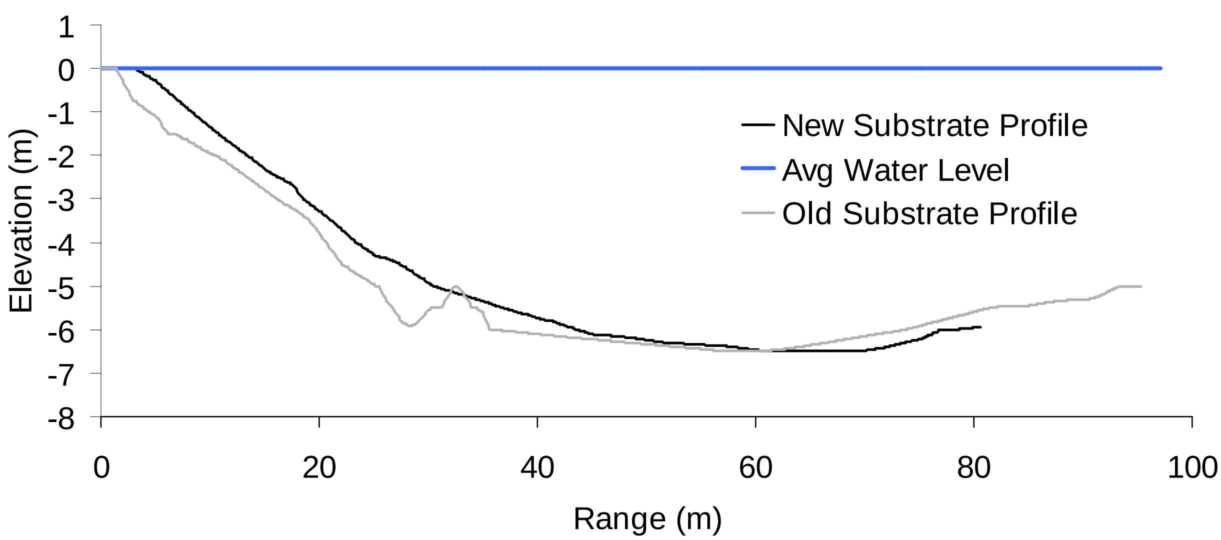


Figure 18. Copper River bottom profile at the Miles Lake sonar site (south bank) showing the old and new substrate profiles prior to the installation of the new substrate.

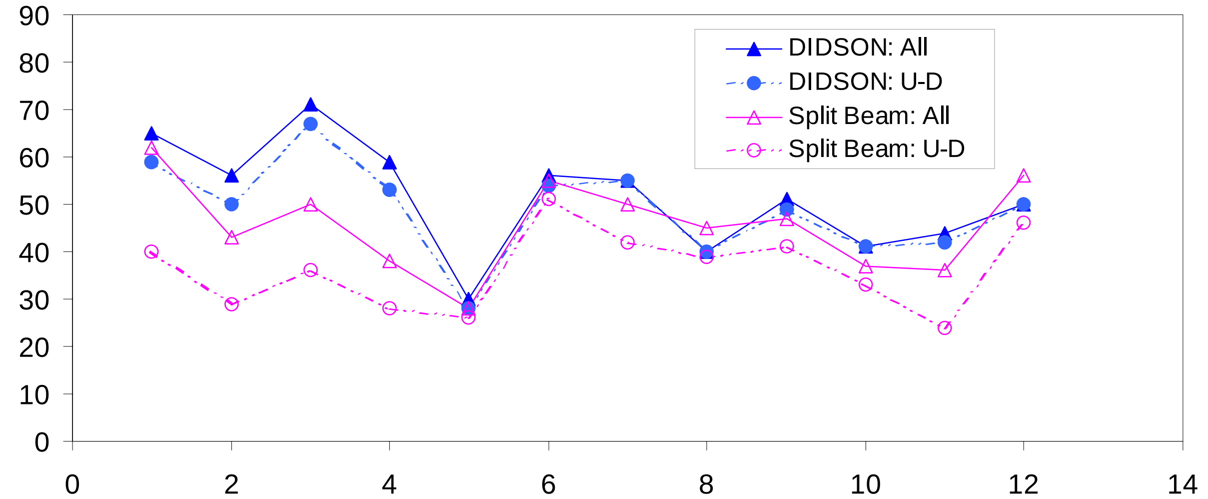


Figure 19. Didson and split beam sonar upstream minus downstream counts (U-D) and total counts (ALL) in 15 minute samples from the Miles Lake sonar site, Copper River, June 25-26, 2002.

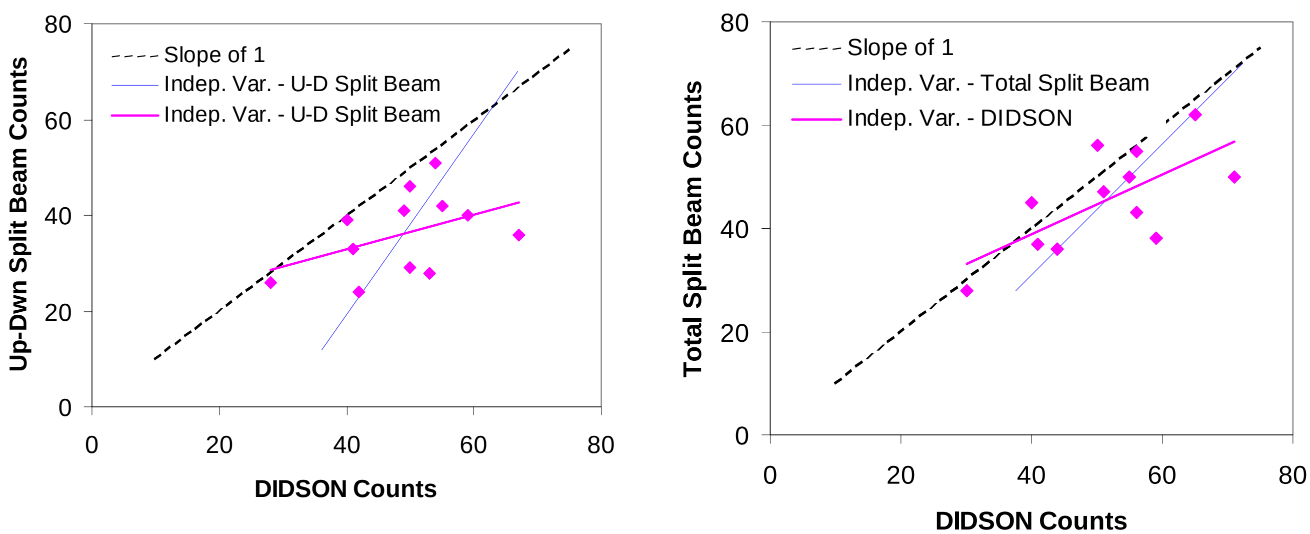


Figure 20. Comparison of DIDSON and split beam sonar upstream minus downstream counts (left) and total counts (right) with regression lines using each counting method as the independent variable, from the Copper River Miles Lake sonar site, June 25-26, 2002.

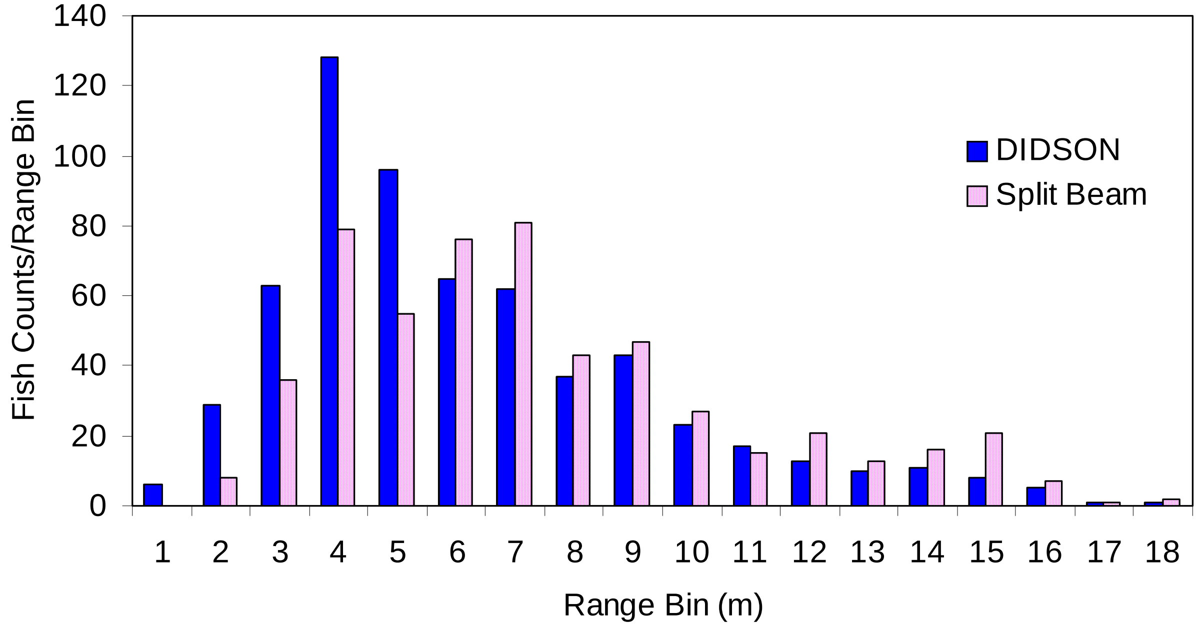


Figure 21. Range distribution of paired fish counts from DIDSON and split beam sonars, Copper River Miles Lake sonar site, June 25-26, 2002.

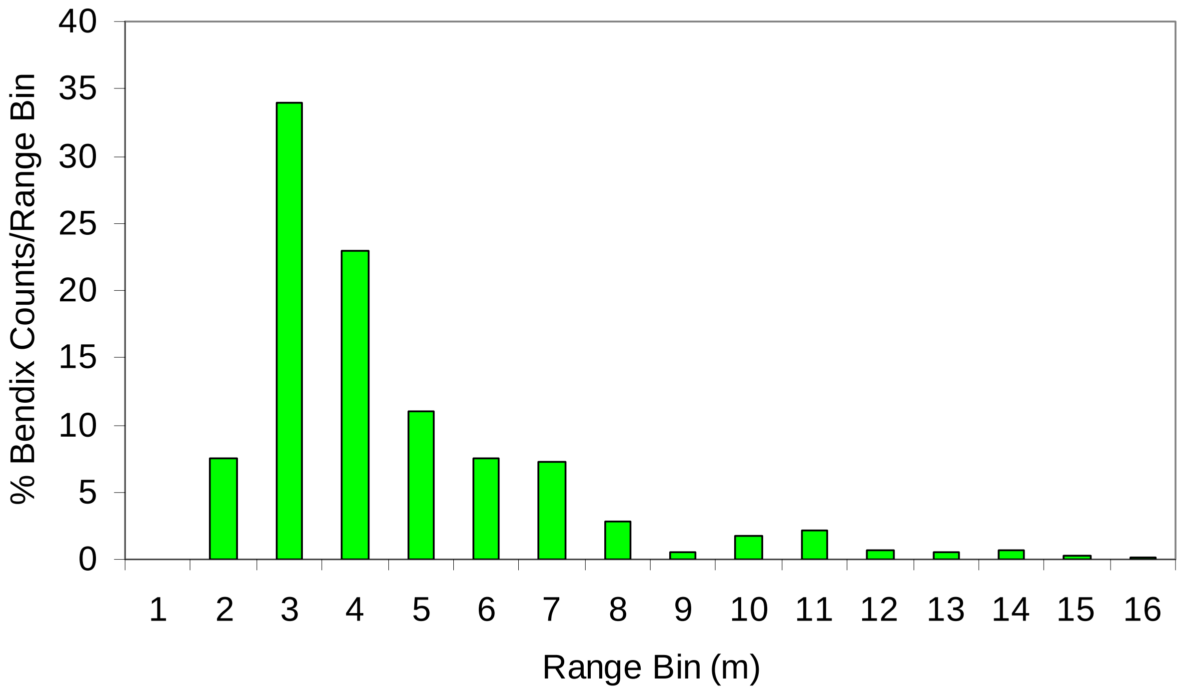


Figure 22. Range distribution of Bendix counts on the old substrate at the Miles Lake sonar site, Copper River, June 25-26, 2002.

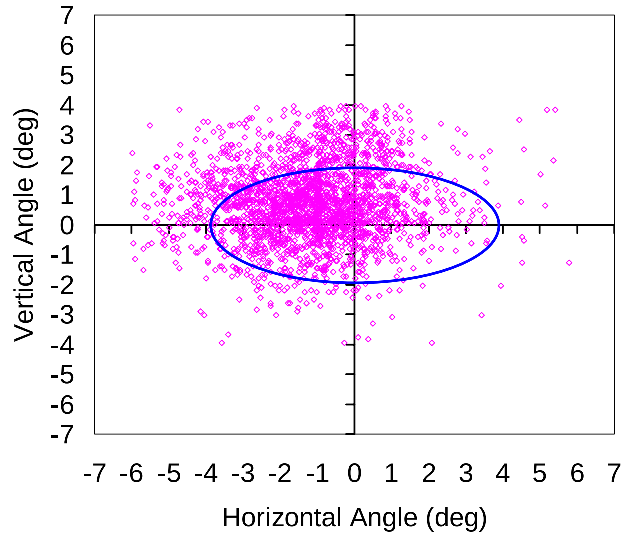


Figure 23. Horizontal and vertical position of split beam sonar echoes from the 38.1 mm tungsten carbide calibration sphere with the 3.8º x7.8º nominal beam overlaid, Copper River Miles Lake sonar site, June 27, 2002.

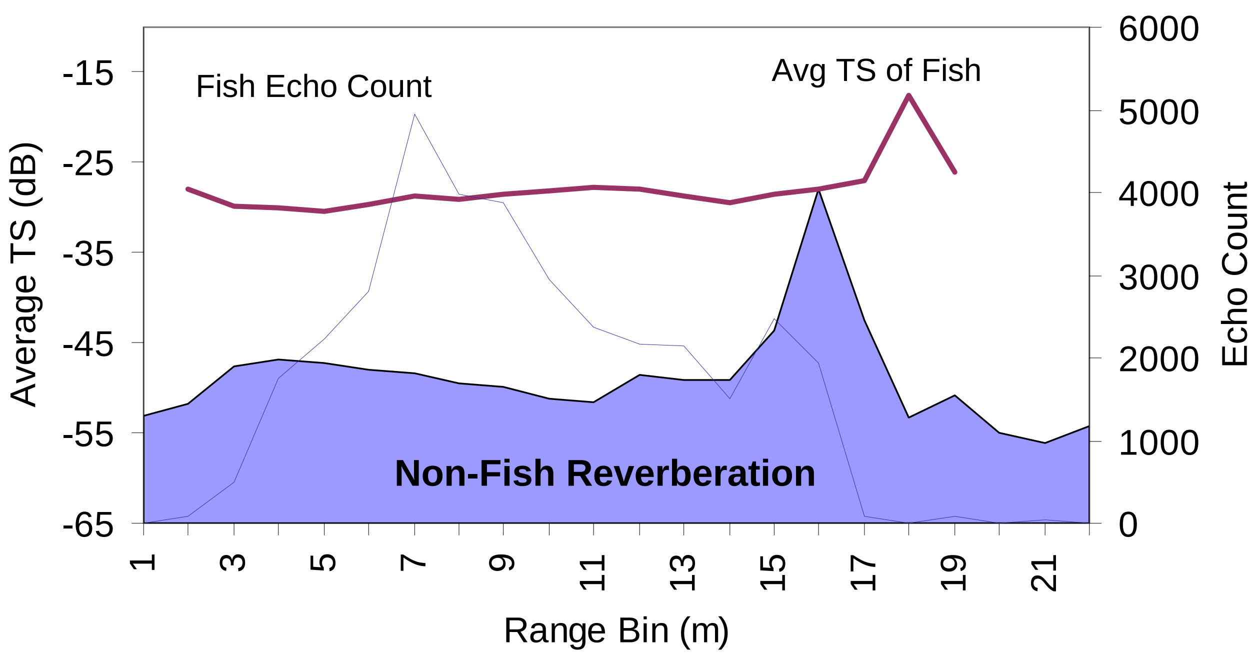
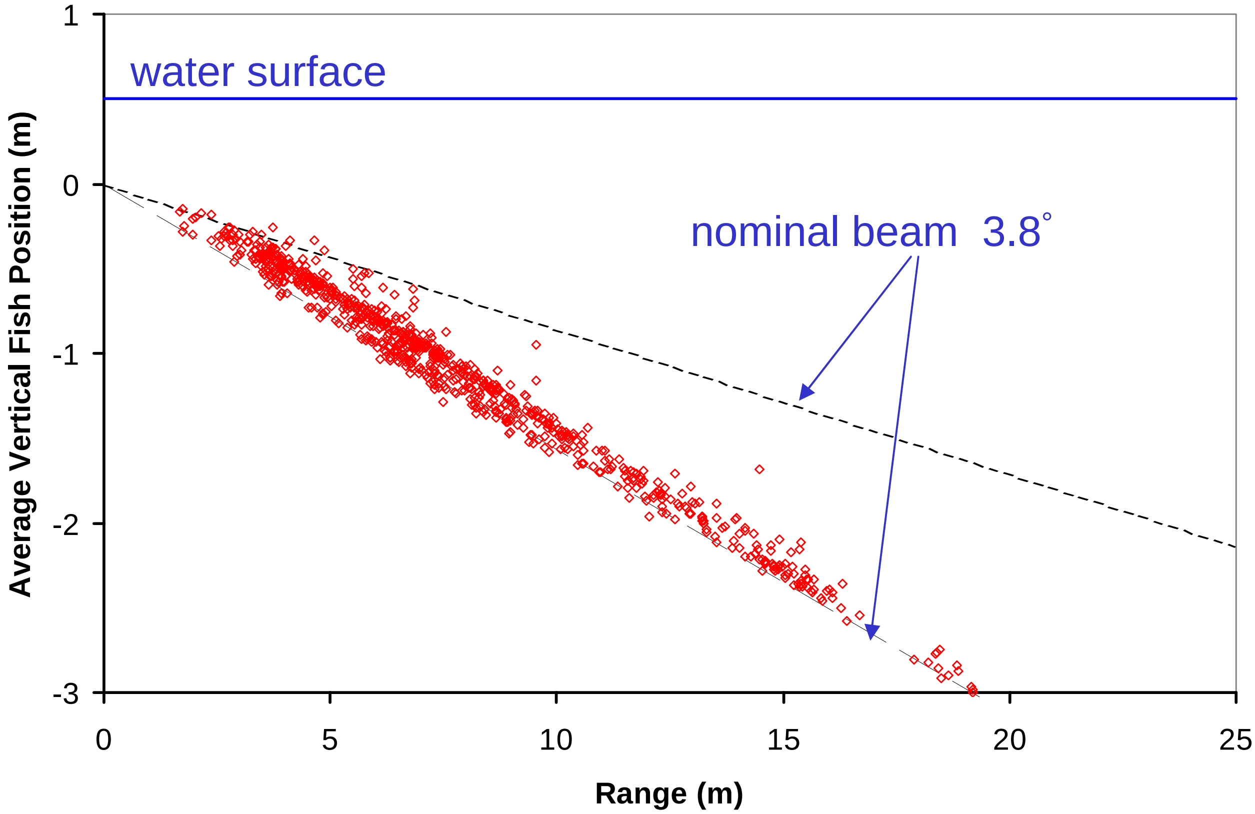


Figure 24. Average target strength of fish and non-fish reverberation levels by range at the Miles Lake sonar site's new concrete substrate measured with a 201 kHz split beam sonar, Copper River, 27 June 2002.



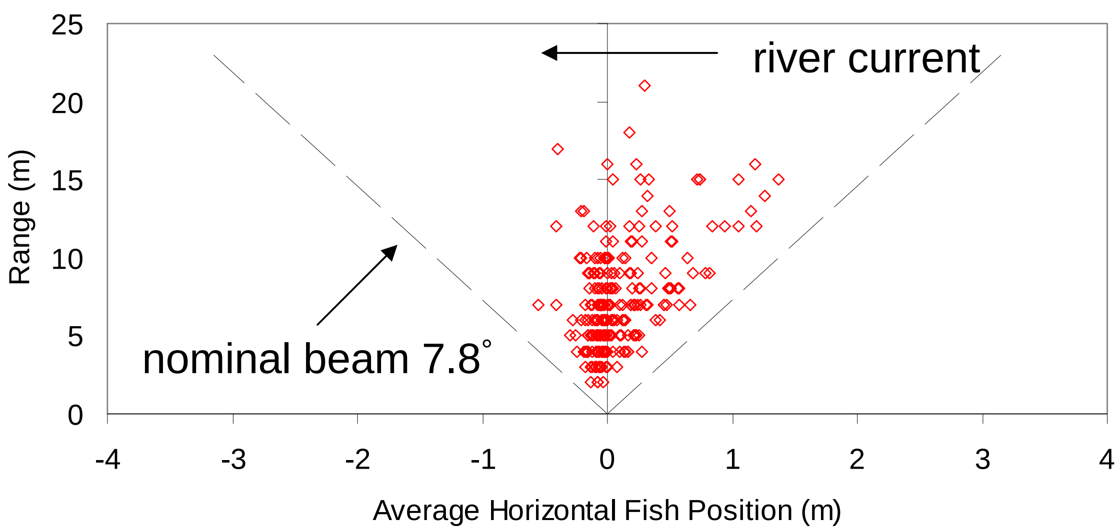


Figure 25. Average vertical position and range of tracked fish with the 3.8º nominal beam pitched -6.9º at 0.4 m deep (top), and average range and horizontal position (bottom), Miles Lake sonar site, Copper River, 25-26 June 2002.

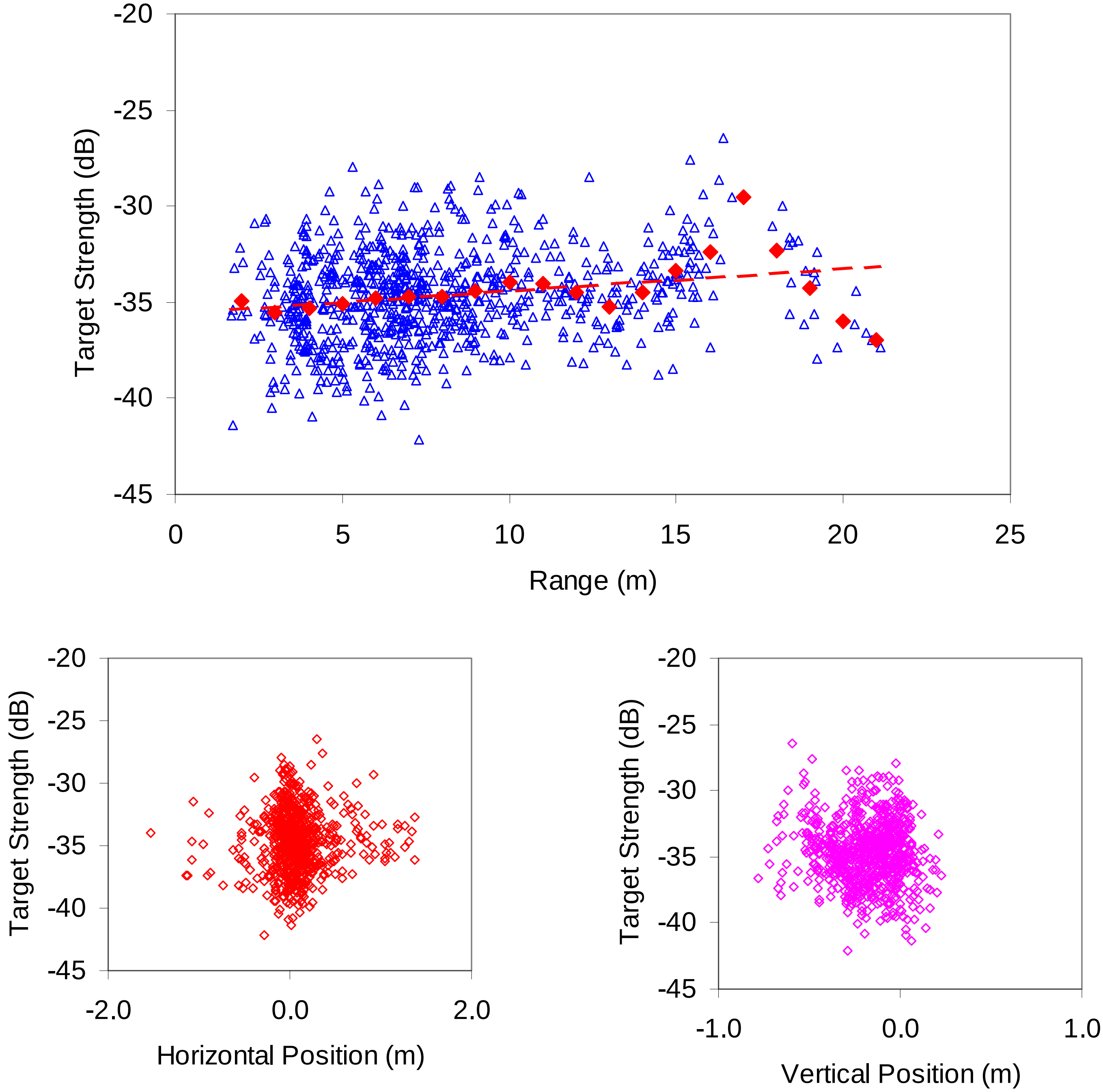


Figure 26. Split beam sonar measures of target strength by range for individual fish tracks (triangles) and average target strength per range bin (diamonds) (top) and target strength by horizontal (lower left) and vertical (lower right) position, Copper River Miles Lake sonar site, June 25-26, 2002.

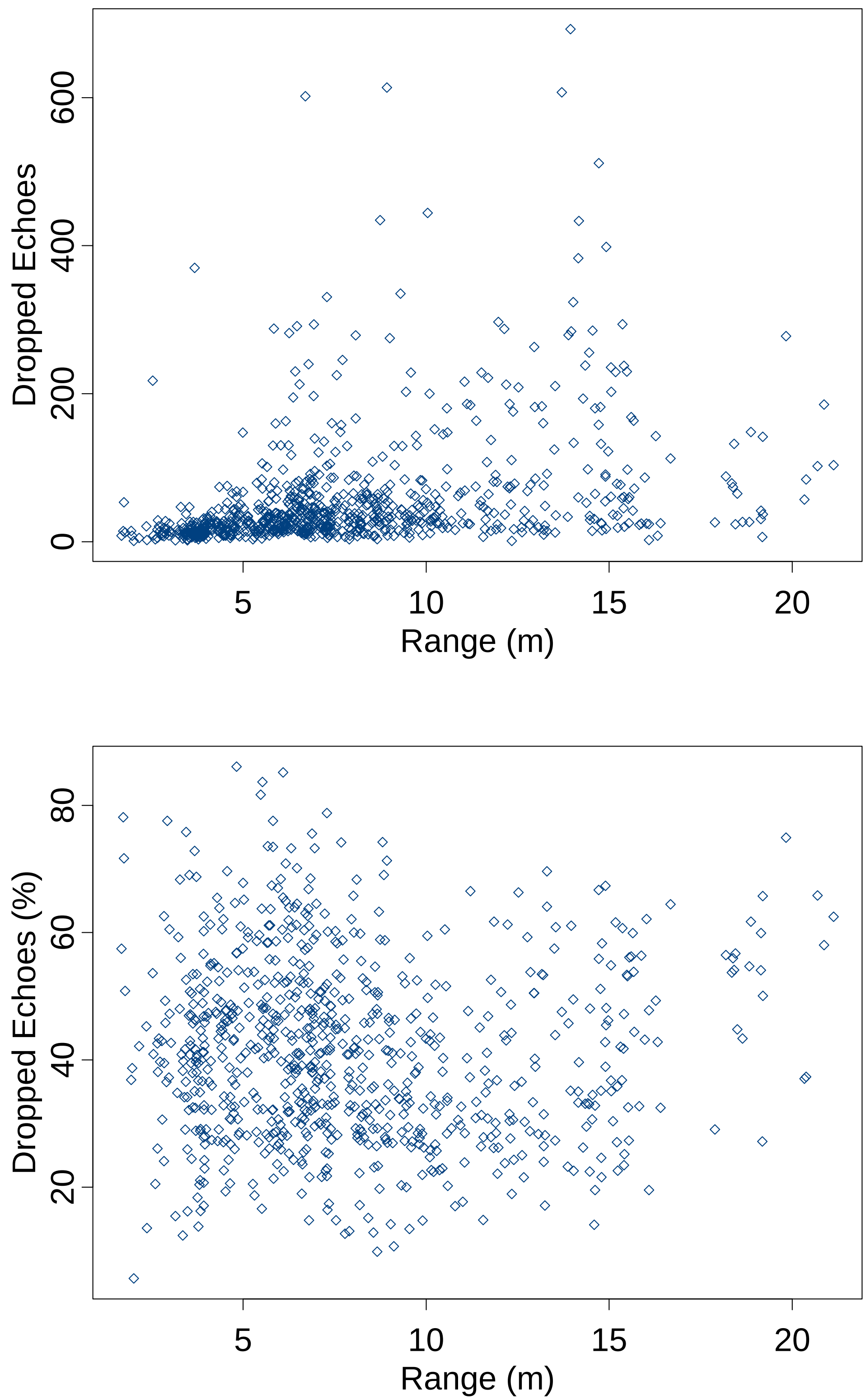


Figure 27. Number of dropped echoes per fish track (top) and the percentage of dropped echoes (bottom) by range for fish tracked at the Copper River Miles Lake sonar site with the split beam sonar, June 25-26, 2002.

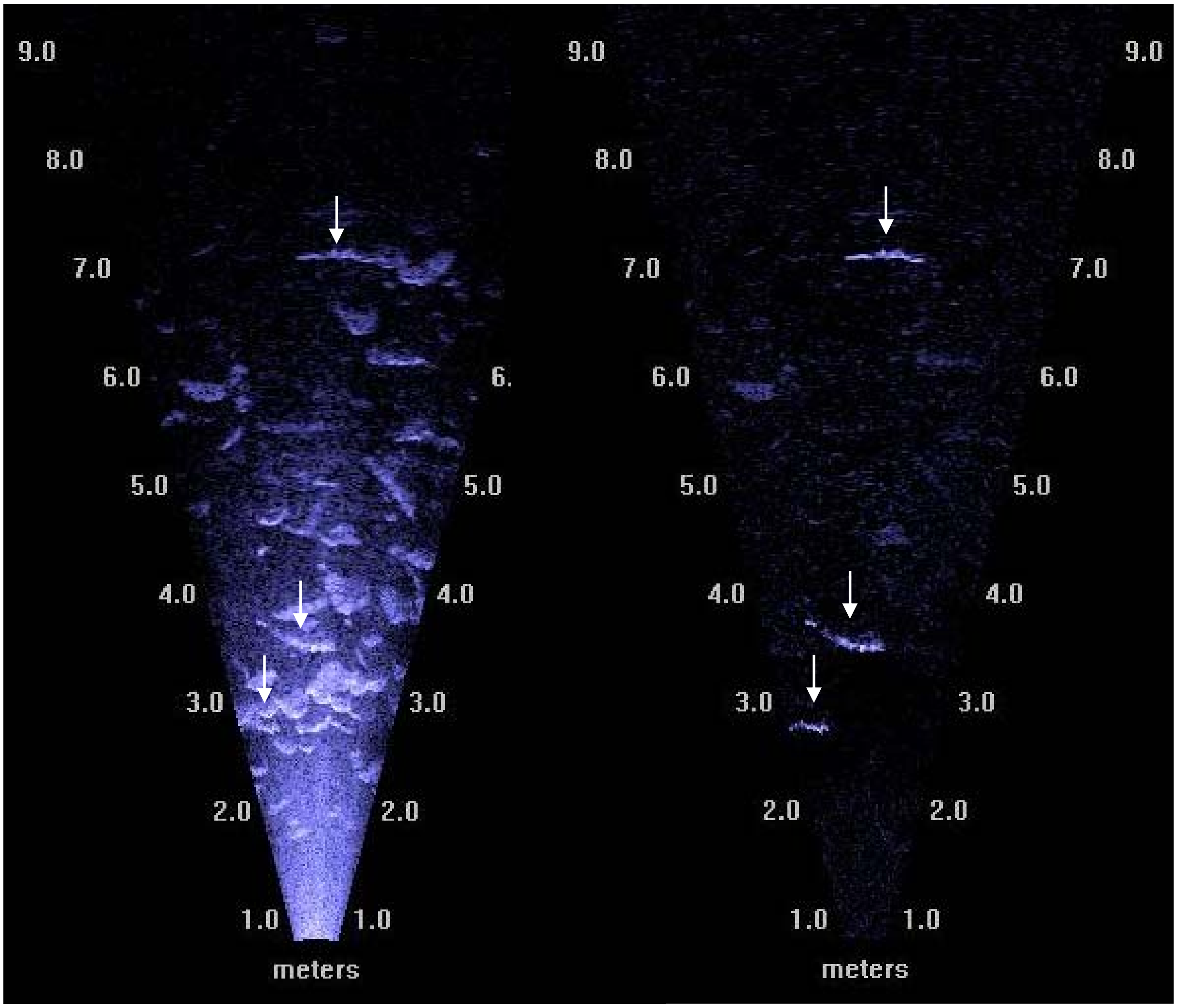


Figure 28. High frequency DIDSON image of three fish (noted with arrows) swimming over a rocky cobble background (left) and the same three fish with the static background removed (right), Copper River Miles Lake sonar site, June 27, 2002.

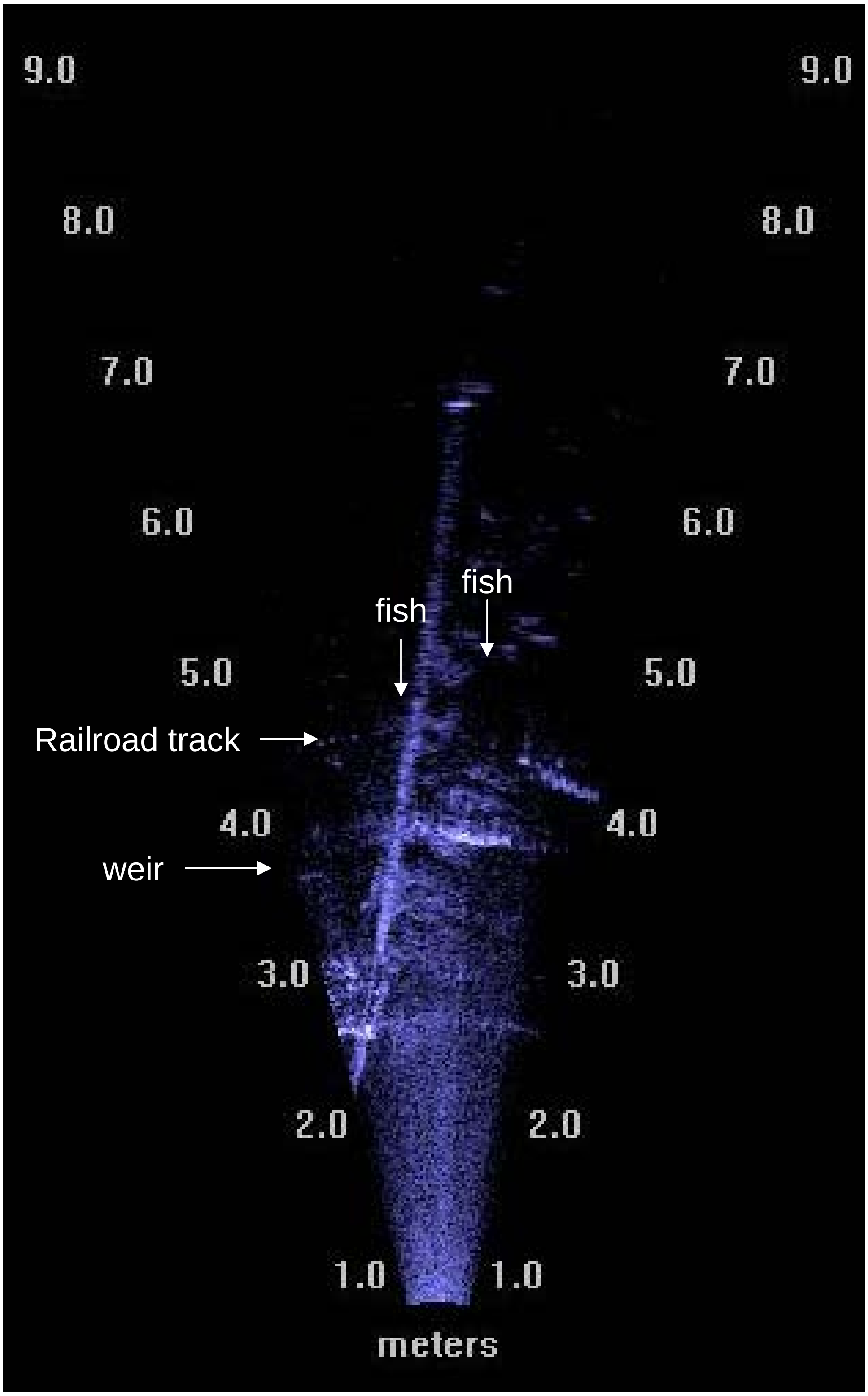


Figure 29. DIDSON image of the old concrete substrate at the Copper River Miles Lake sonar site showing the weir, railroad track, and two fish, June 28, 2002.

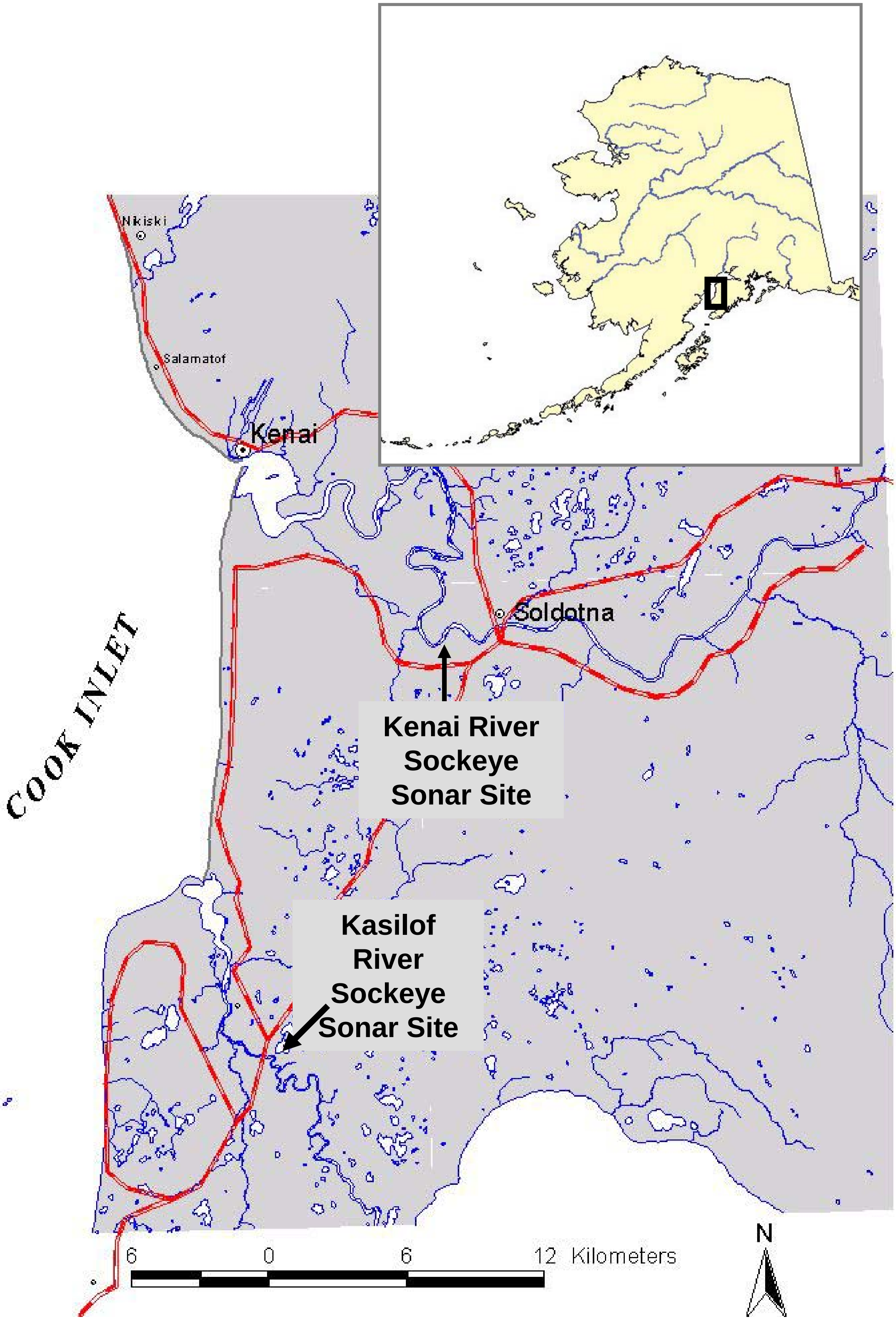


Figure 30. Location of the Kenai and Kasilof Rivers, Alaska.

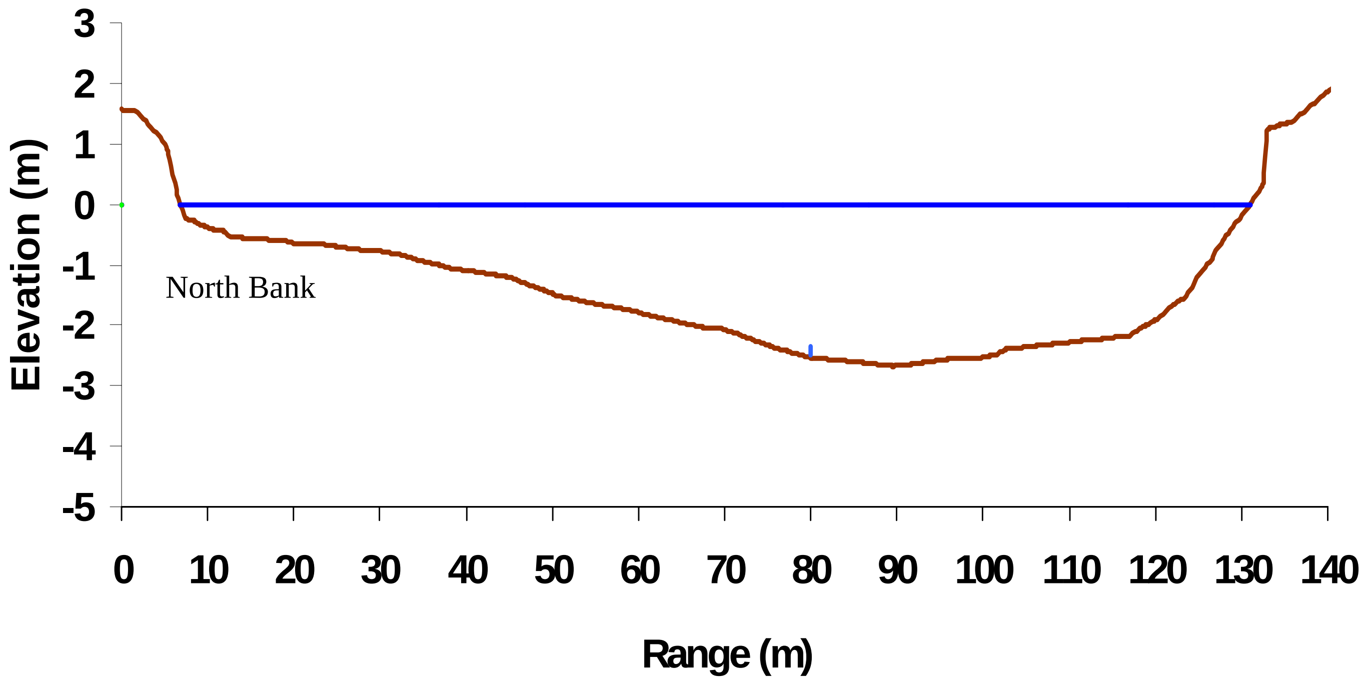


Figure 31. Kenai River bottom profile at the sockeye salmon sonar site, created July 2000.

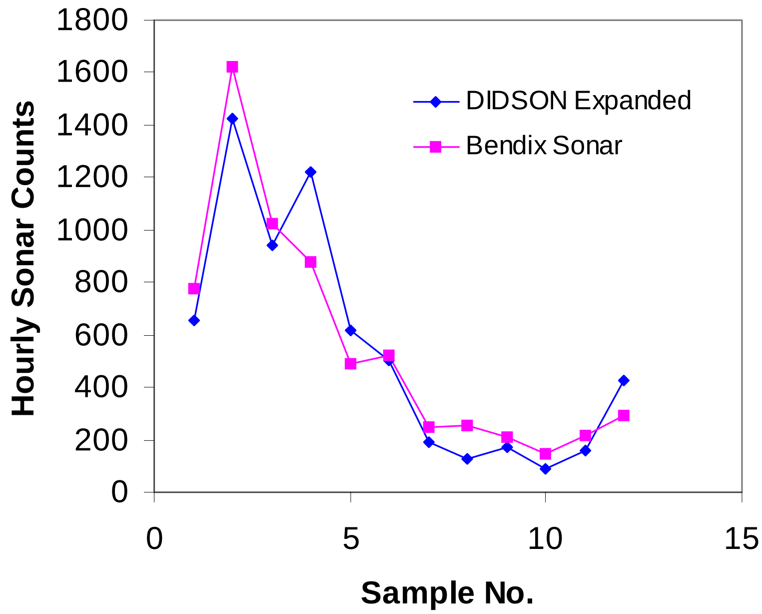


Figure 32. Time series of expanded fifteen minute DIDSON and full hour Bendix sonar salmon counts, Kenai River south bank, July 8-9, 2002.

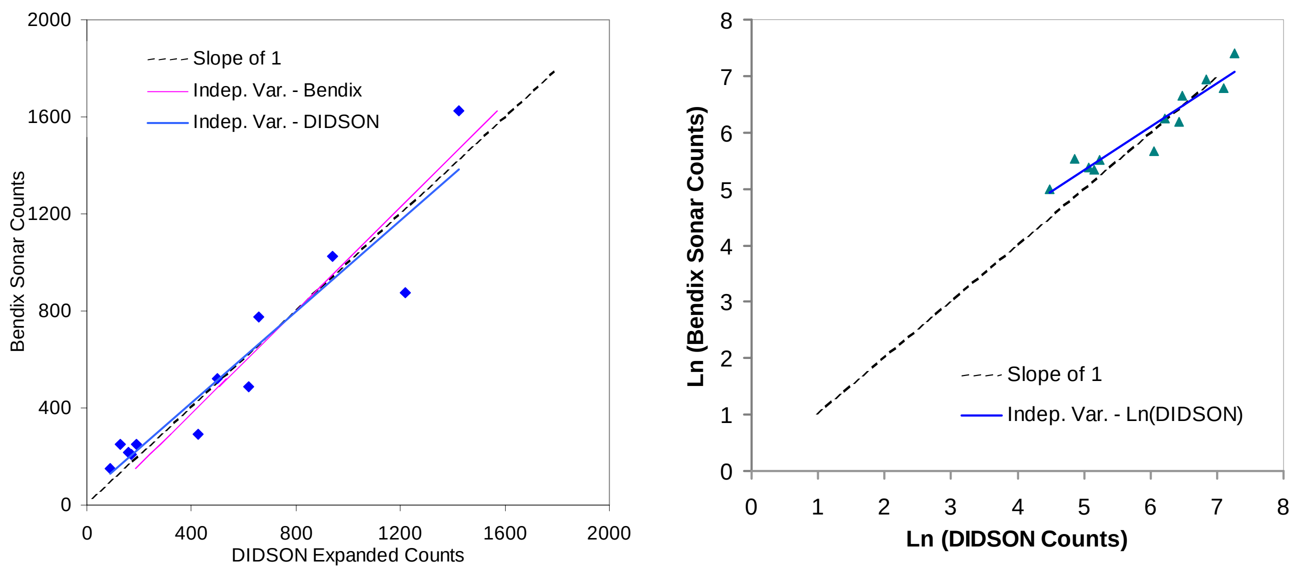


Figure 33. Full hour Bendix sonar counts compared against fifteen minute expanded DIDSON counts with regression lines using each counting method as the independent variable (left), and logarithmic transformed (ln) counts of the same comparison (right), Kenai River south bank, July 8-9, 2002.

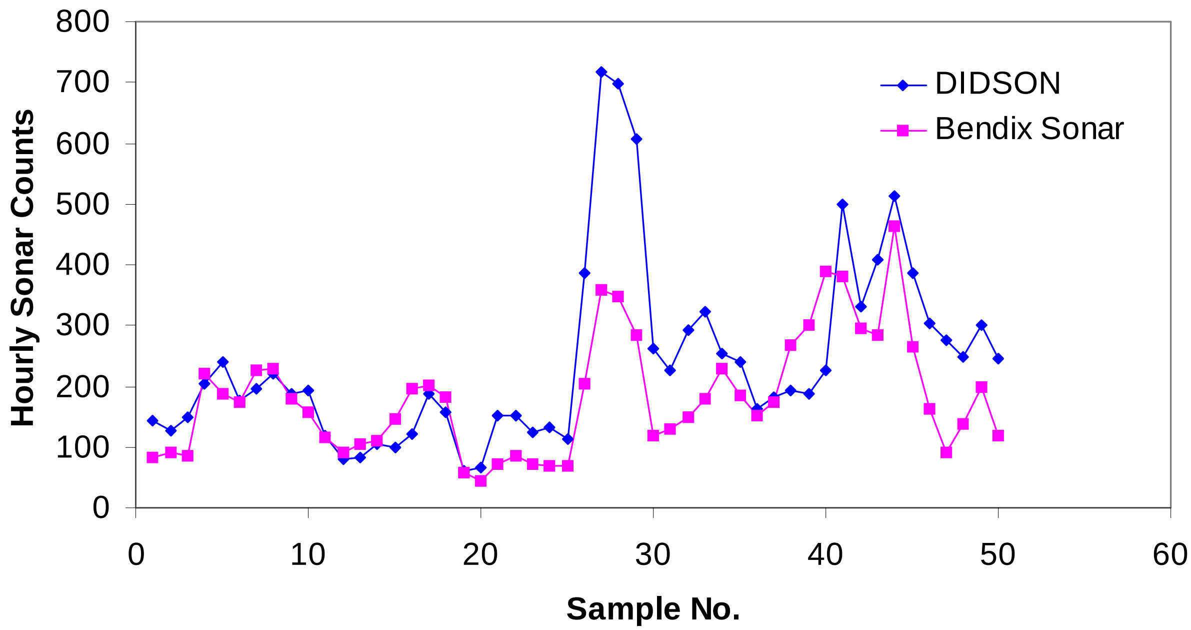


Figure 34. Time series of full hour DIDSON and Bendix sonar salmon counts, Kenai River south bank, 2002, 12-14 July 2002.

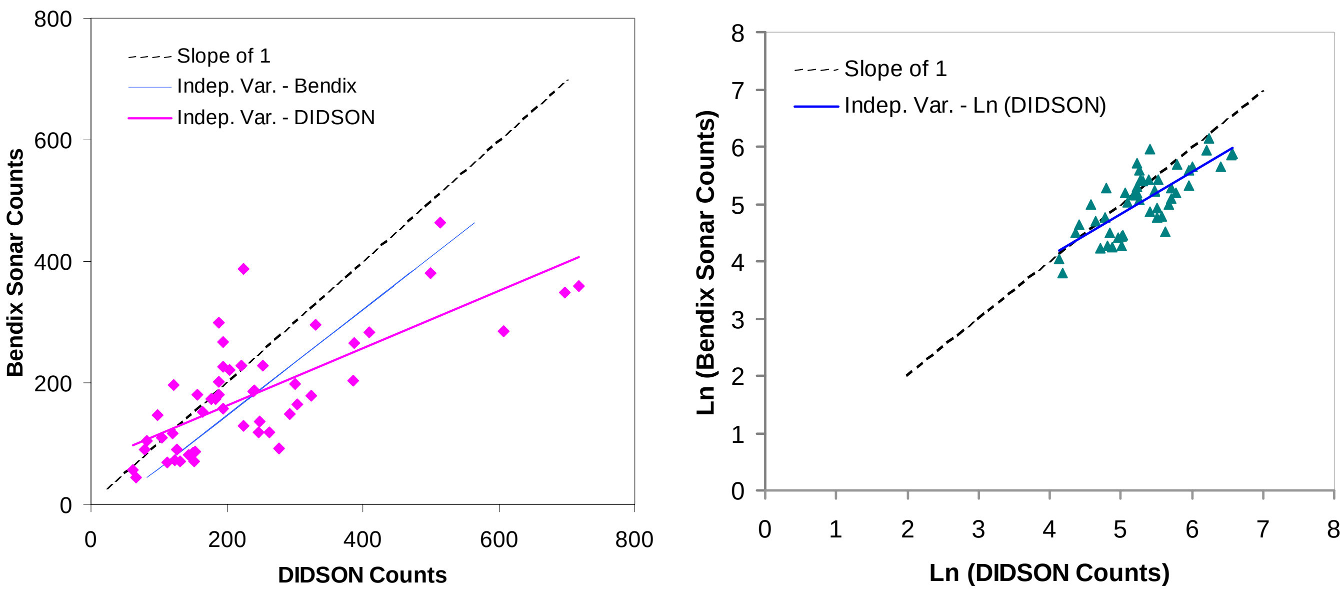
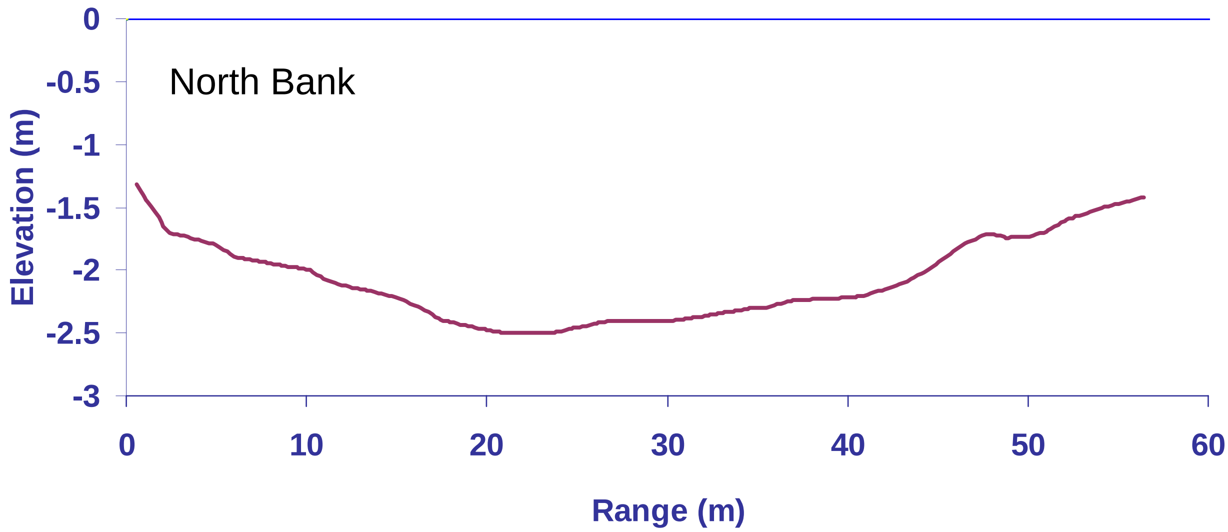


Figure 35. Full hour Bendix sonar counts compared against full hour DIDSON counts with regression lines using each counting method as the independent variable (left), and logarithmic transformed counts of the same comparison (right), Kenai River south bank, 12-14 July 2002.



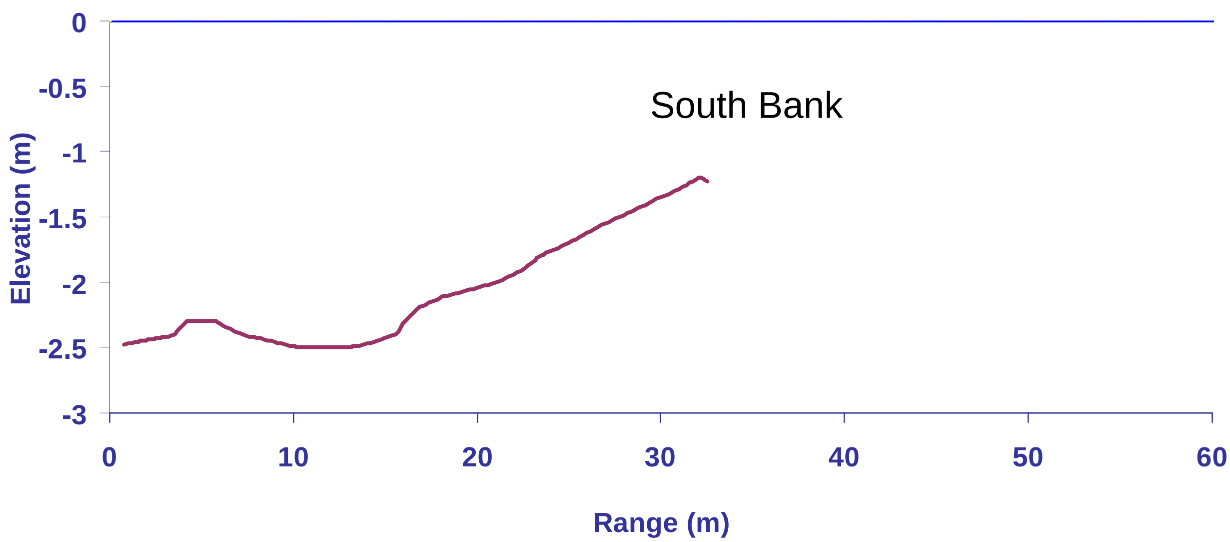


Figure 36. River bottom profile of the Kasilof River, north bank (top) extending across the river and south bank (bottom) stopping approximately mid-river, 2001.

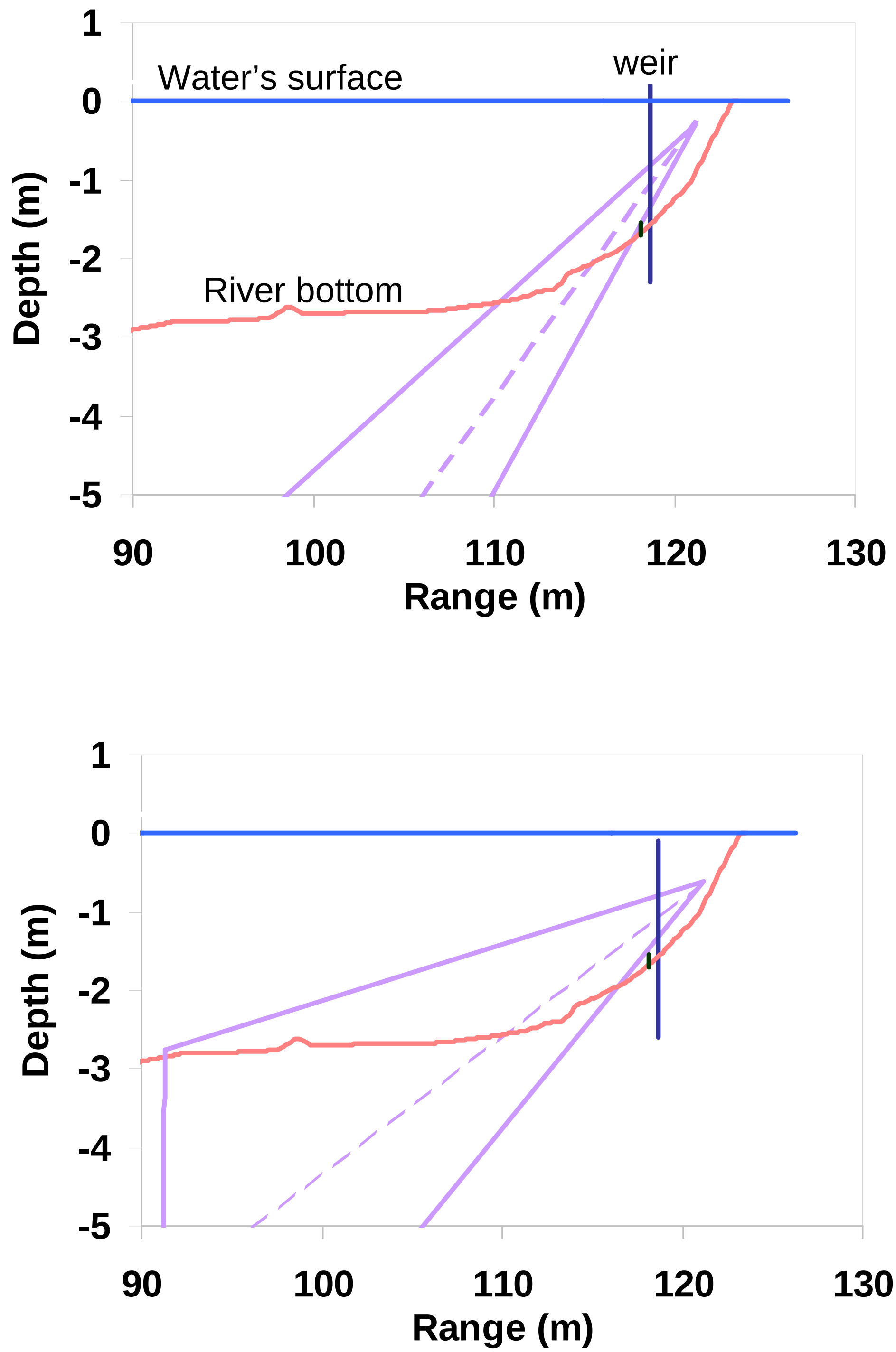


Figure 37. This extreme example shows the compromise between reducing shadowing effects by positioning the DIDSON transducer high on the mount with a severe downward pitch to sample fish nearshore (top) and lowering the transducer and aiming up to increase the range (bottom), Kenai River south bank profile.

APPENDICES

Appendix A: Laboratory calibrations for the split beam sonar.

EL201K32

BioSonics

XDUCER(1) S/N: DT6-45-200-4X8/15-004
SOUNDER S/N: DT5-96-032

SYSTEM CALIBRATION

Customer Name: Don Degen
(Company or Agency) ______
BioSonics Contact Person: ______

Date: 4/24/2002
Project #: P2820
Calibrator: Jie

RECEIVER/TANK PARAMETERS

Frequency 201 kHz
Temp of Tank 17.00 Deg. C
Xducer Seperation 1.20 m

Cal. Facility Biosonics Cal. Tank

CABLES

Cable S/N	141-02-1308	Cable Type	DECK	Cable Length	150'
Cable S/N		Cable Type		Cable Length	
Cable S/N		Cable Type		Cable Length	

STANDARD TRANSDUCER

EDO S/N 101
Ts 146.89 dB uPa/Vrms
Ss -202.24 dBv/uPA

CALIBRATION - SYSTEM RECEIVING SENSITIVITY

Volt into Standard, vs = 0.211 V
Vs = -13.51 dBv (RMS)

TL = 20 log R + aR = 1.58 dB (R = Rs meters)
Acoustic Level, L= 131.79 dB uPa
(L=Ts+Vs-TL at receiving transducer)

RECEIVER #1 SENSITIVITY

A/DC OUTPUT 80.85 dB Counts
VOUTPUT 12.13 dB V
Rcvr Sens @1M -119.67 dB V/uPa

Rcvr Sens in counts -50.94 dB counts/ uPa

Rcvr Noise Floor 12 Counts
Noise Strength (NS) -140.54 dB
(NS = Rcvr Noise Floor - SL - RS)

21.6 dB Counts
(Xmit set at -13dB)

Appendix A. Laboratory calculations for the split beam sonar.

EL201K32

BioSonics

XDUCER(1) S/N: DT6-45-200-4X8/15-004
SOUNDER S/N: DT5-96-032

SYSTEM CALIBRATION

RECEIVER #2 SENSITIVITY

A/DC OUTPUT 74.96 dB Counts
VOUTPUT 6.24 dB V
Rcvr Sens @1M -125.56 dB V/uPa

Rcvr Sens in counts -56.83 dB counts uPa

Rcvr Noise Floor 15 Counts
Noise Strength (NS) -132.72 dB
(NS = Rcvr Noise Floor - SL - RS)

23.5 dB Counts
(Xmit set at -13dB)

CALIBRATION SOURCE LEVEL

Pulse Width 0.400 ms

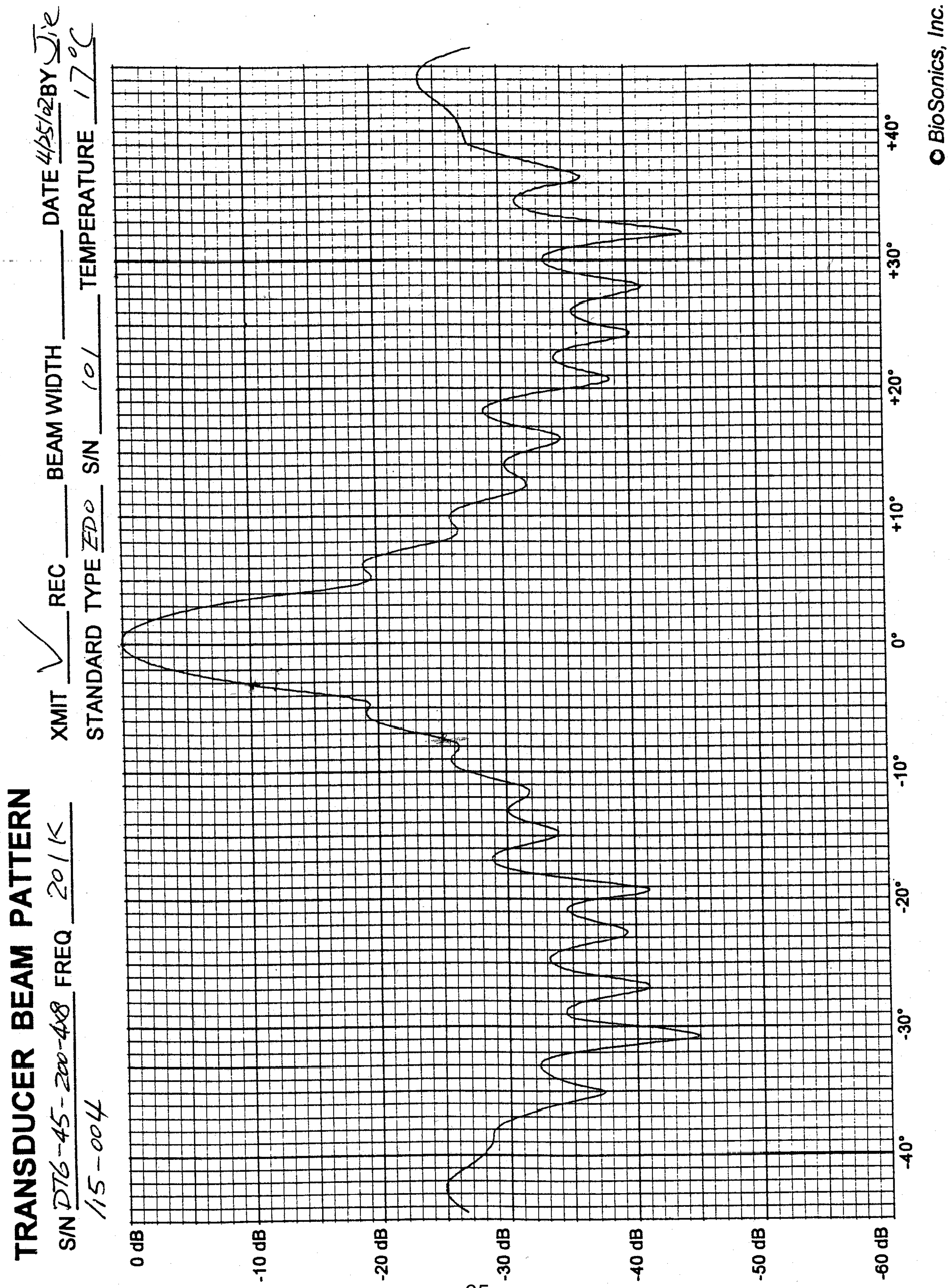
Vso = 20 Log (vrms out of standard)
SL = Vso - Ss + TL

TRANSMITTER SETTING		Vout STD XDUCER		Vso	-Ss+TL	SOURCE LEVEL	System Performance	
	dB	Vpp	Vrms	dBv	dBv	dBuPa@1m	(dB)	
			#VALUE!	#VALUE!	203.82	#VALUE!		
			#VALUE!	#VALUE!	203.82	#VALUE!		
			#VALUE!	#VALUE!	203.82	#VALUE!		
			#VALUE!	#VALUE!	203.82	#VALUE!		
Xmit set	**-13dB**	**8.20**	**2.90**	**9.25**	**203.82**	**213.07**		**93.40**

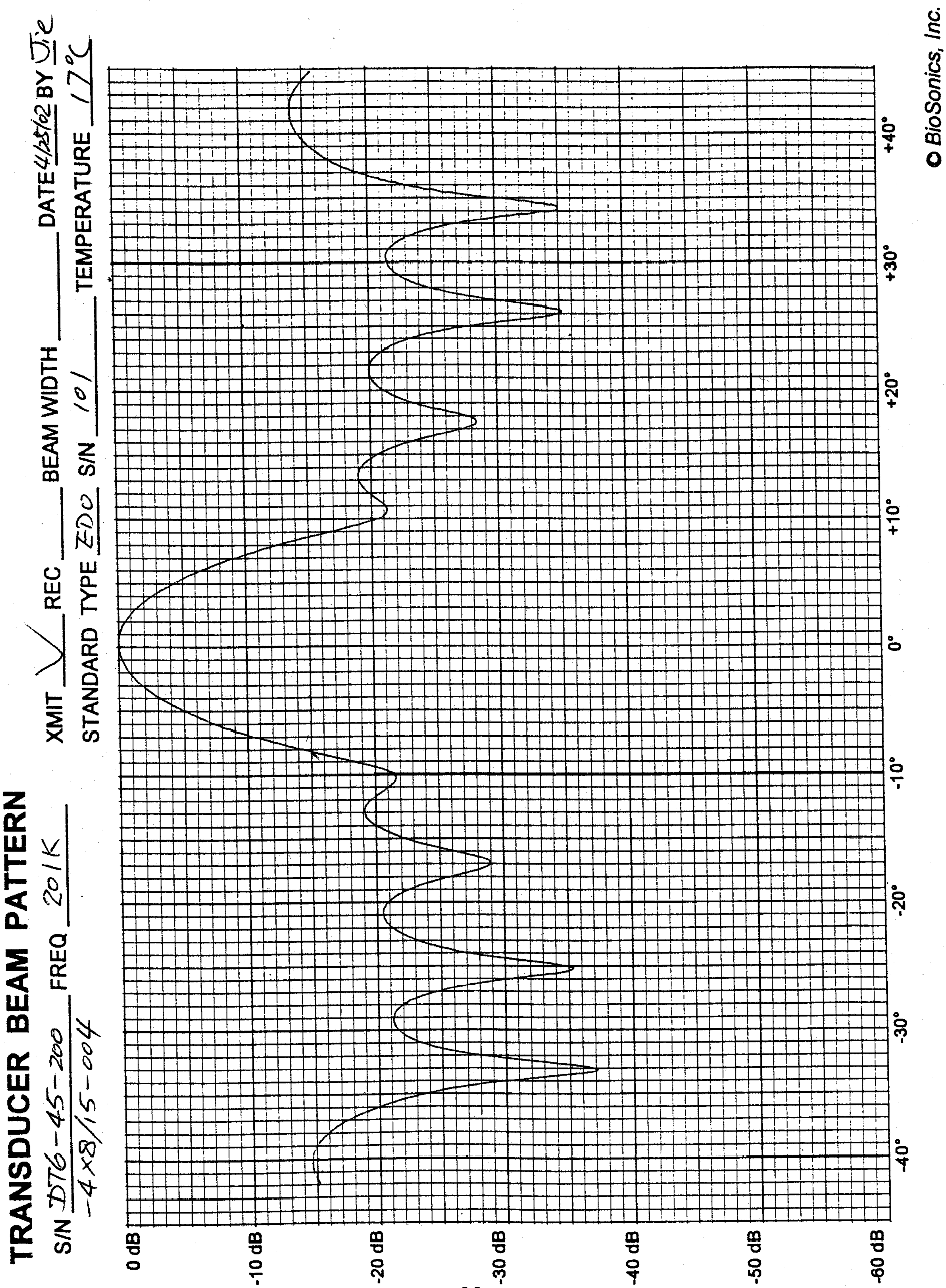
PHASE APCRTURE: +/- 8.3 degree

Comment:

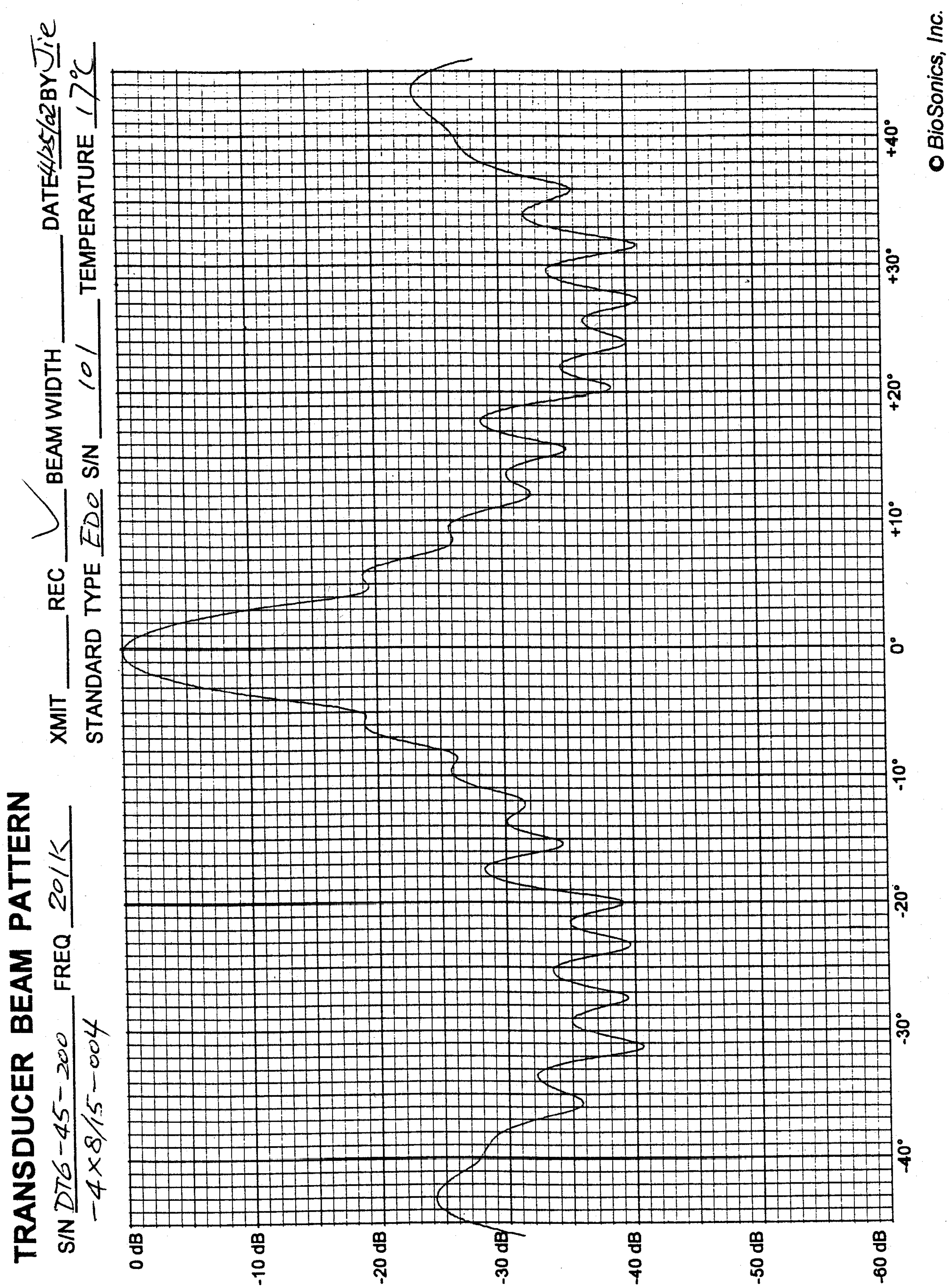
Appendix A. Laboratory calculations for the split beam sonar.



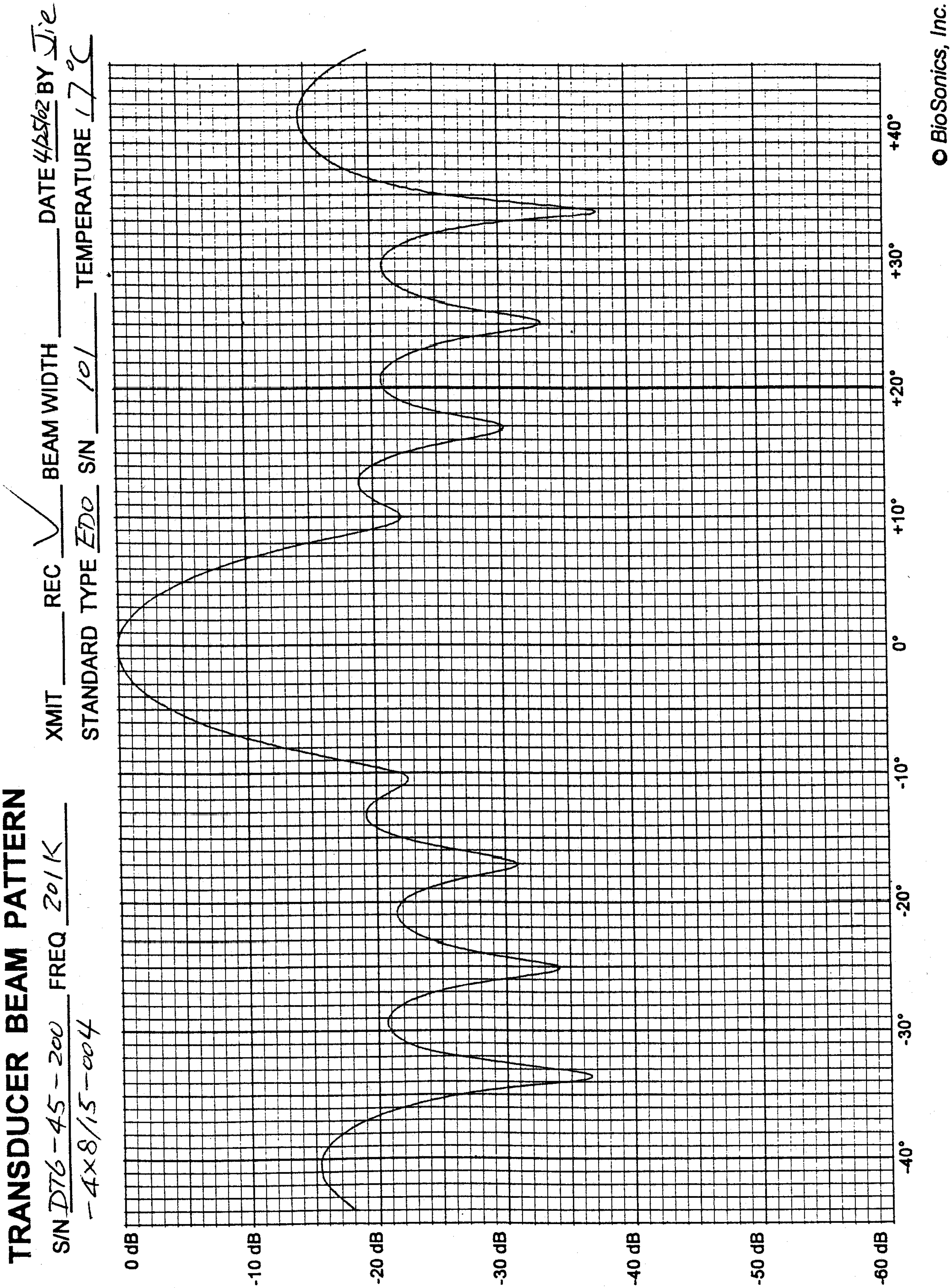
Appendix A. Laboratory calculations for the split beam sonar.



Appendix A. Laboratory calculations for the split beam sonar.



Appendix A. Laboratory calculations for the split beam sonar.



Appendix A. Laboratory calculations for the split beam sonar.
CC201K32

BioSonics

XDUCER(1) S/N: DT-45-200-0615-015
SOUNDER S/N: DT5-96-032

SYSTEM CALIBRATION

Customer Name: Don Degan
(Company or Agency) Aquacoustics, Inc.
BioSonics Contact Person: J.D.

Date: 4/25/2002
Project #: P2820
Calibrator: Jie

RECEIVER/TANK PARAMETERS

Frequency 201 kHz
Temp of Tank 17.00 Deg. C
Xducer Seperation 1.20 m

Cal. Facility Biosonics Cal. Tank

CABLES

Cable S/N	Cable Type	Cable Length
141-96-977	DECK	25'

STANDARD TRANSDUCER

EDO S/N 101
Ts 146.89 dB uPa/Vrms
Ss -202.24 dBv/uPA

CALIBRATION - SYSTEM RECEIVING SENSITIVITY

Volt into Standard, vs = 0.165 V
Vs = -15.65 dBv (RMS)

TL = 20 log R + aR = 1.58 dB (R = Rs meters)
Acoustic Level, L= 129.66 dB uPa
(L=Ts+Vs-TL at receiving transducer)

RECEIVER #1 SENSITIVITY

A/DC OUTPUT 77.48 dB Counts
VOUTPUT 8.76 dB V
Rcvr Sens @1M -120.90 dB V/uPa

Rcvr Sens in counts -52.18 dB counts/ uPa

Rcvr Noise Floor 12 Counts
Noise Strength (NS) -139.62 dB
(NS = Rcvr Noise Floor - SL - RS)

21.6 dB Counts
(Xmit set at -13dB)

Appendix A. Laboratory calculations for the split beam sonar.

CC201K32

BioSonics

XDUCER(1) S/N: DT-45-200-0615-015
SOUNDER S/N: DT5-96-032

SYSTEM CALIBRATION

RECEIVER #2 SENSITIVITY

A/DC OUTPUT 71.83 dB Counts
VOUTPUT 3.11 dB V
Rcvr Sens @1M -126.55 dB V/uPa

Rcvr Sens in counts -57.83 dB counts uPa

Rcvr Noise Floor 15 Counts
Noise Strength (NS) -132.03 dB
(NS = Rcvr Noise Floor - SL - RS)

23.5 dB Counts
(Xmit set at -13dB)

CALIBRATION SOURCE LEVEL

Pulse Width 0.400 ms

Vso = 20 Log (vrms out of standard)
SL = Vso - Ss + TL

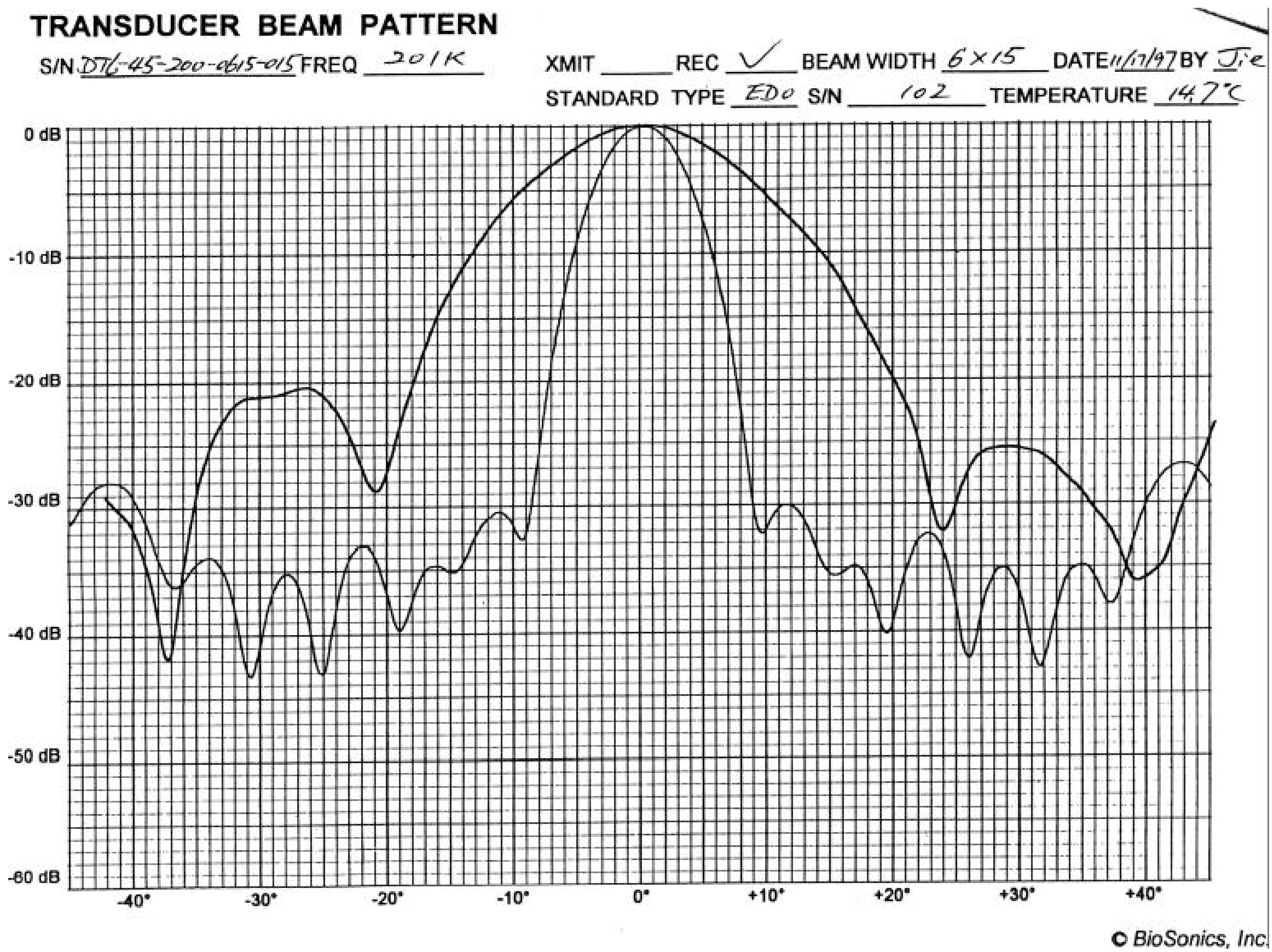
TRANSMITTER SETTING		Vout STD XDUCER		Vso	-Ss+TL	SOURCE LEVEL	System Performance	
	dB	Vpp	Vrms	dBv	dBv	dBuPa@1m	(dB)	
			#VALUE!	#VALUE!	203.82	#VALUE!		
			#VALUE!	#VALUE!	203.82	#VALUE!		
			#VALUE!	#VALUE!	203.82	#VALUE!		
			#VALUE!	#VALUE!	203.82	#VALUE!		
Xmit set	**-13dB**	**8.50**	**3.01**	**9.56**	**203.82**	**213.38**		**92.48**

PHASE APCRTURE: +/- 6.5 degree

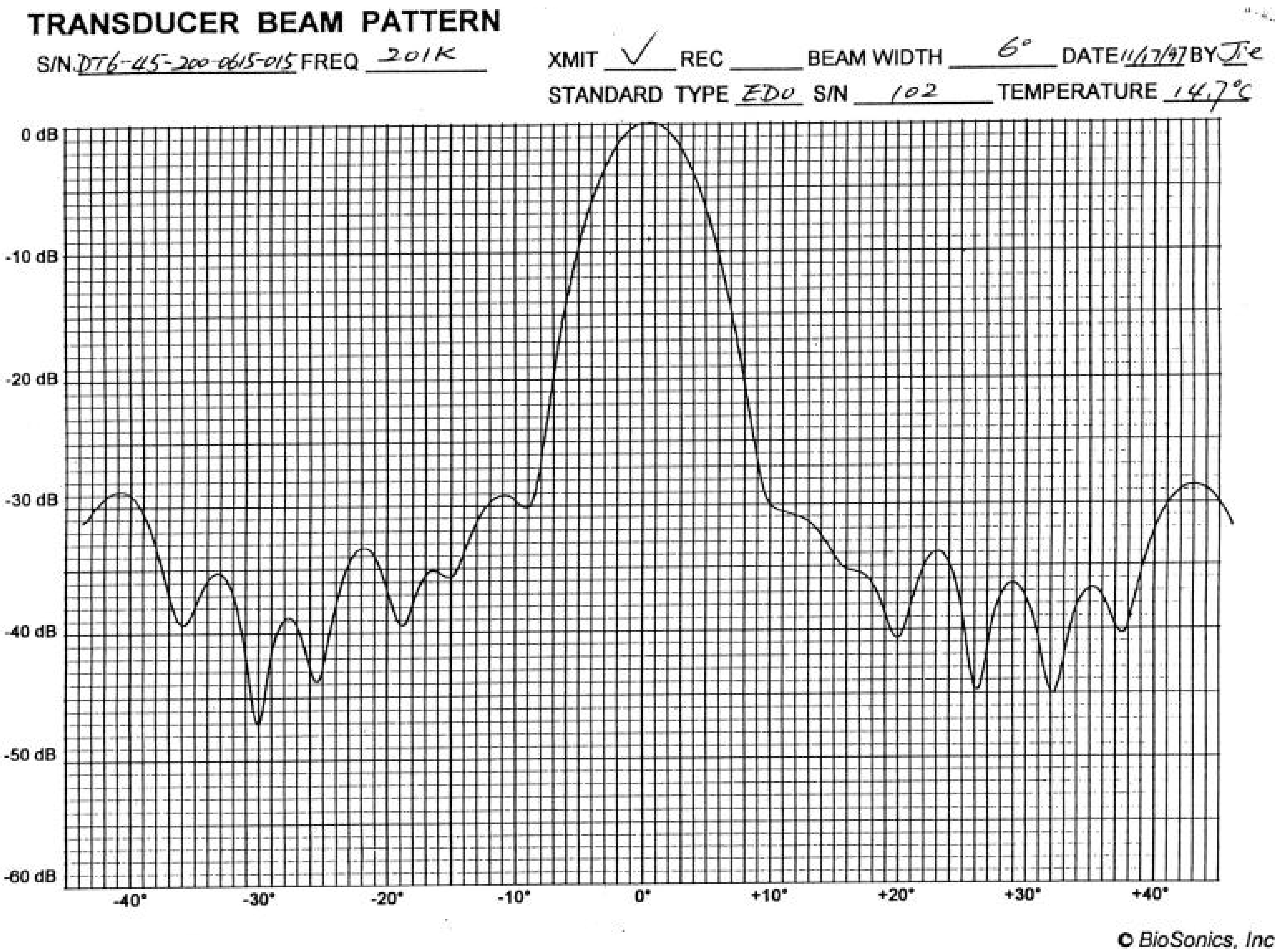
Comment:

4/26/2002

Appendix A. Laboratory calculations for the split beam sonar.



Appendix A. Laboratory calculations for the split beam sonar.



Appendix B. A modified likelihood ratio test for testing random effects.

In testing whether or not a random effect is equal to zero, we run into boundary problems. Much of the theory on maximum likelihood estimation does not hold when the true parameter value is on the boundary of the space. Testing to determine if a variance or a random effect is zero falls into this category. Fortunately, a modified likelihood ratio test can be used to test random effects. The likelihood ratio is calculated in the same manner, but the test statistic is compared to the following mixed chi-squared distribution:

$$\chi^2_{df1,df2} = \frac{1}{2}\chi^2_{df1} + \frac{1}{2}\chi^2_{df2}$$

where

> *df*1 = number of fixed effects in the null hypothesis, and
> *df*2 = number of fixed effects in the alternate hypothesis.

Appendix C. Field calibration and aiming protocol for the split beam sonar.

To field calibrate the split beam transducer:

1. Mount the transducer so it is no more than 3-4 inches off the ground (you should barely be able to stick the toe of your boot under it).
2. Wrap a 38.1 mm tungsten carbide sphere in a mesh bag using 25-30 lb monofilament line (monofilament line is invisible to the sonar beam). Tie a loop on the end of the line, far enough up so the knot will be above water level when the target is near the river bottom.
3. Attach the target to an extension pole and extend in front of the transducer just beyond the nearfield (1 m for a 6x10° 201 kHz split beam sonar) lowering it to approximately mid-way between the river's surface and bottom to avoid reverberation interference from either surface. Note: a loop can be tied on the end of the line to the extension pole then the target's loop can be drawn through the pole's loop making it easier to remove and add targets.
4. Position the transducer beam so the target is centered both vertically and horizontally.
5. Set the sonar parameters as you would for sampling, except the threshold should be set as low as possible. Collect 1,000 echoes or more from the target. Note: if fish targets are present, it may be necessary to raise and lower the target until the operator is assured the echoes are coming from the target.
6. Determine the average target strength of the target and compare to the laboratory calibration. Adjust the calibration parameters if necessary by changing the system gain. Document the target filename, the sonar parameters, and the average target strength in the logbook.

To aim the split beam transducer:

1. Measure the
    a. Distance from the river bottom to the bottom of the transducer
    b. Distance from river bottom to water's surface at the transducer
    c. Distance from transducer to shore
    d. Distance from transducer to the end of the weir
2. Wrap a salmon-size target (4 in diameter sphere partially filled with bb's) in a mesh bag using 50 lb or heavier monofilament line. Tie a loop on the end of the line, far enough up so the knot will be above water level when the target is near the river bottom.
3. Attach the salmon-size target to an extension pole and extend in front of the transducer beyond the nearfield (1 m for a 6x10° 201 kHz split beam sonar) Note: a loop can be tied on the end of the line to the extension pole, then the target's loop can be drawn through the pole's loop making it easier to remove and add targets.
4. Follow directions #2-6 above to document the target strength of the salmon-size target.
5. Position the target so a line drawn from the transducer mount to the target would perpendicularly bisect a line parallel to the river's current, then lower the target to approximately 4 inches off the river bottom.
6. Aim the split beam transducer so the target appears in the center of the beam horizontally and in the central portion of the lower half of the vertical beam. If the river bottom consists of a hard substrate, the transducer beam may have to be raised so the target rests closer to the

lower edge of the beam. If the river bottom is soft, the transducer may be lowered slightly moving the target closer to the central axis of the beam. Use the “Alt Print Screen” command to copy a picture showing the position of the target in the 2d graphs of HTI’s DEP program, then paste to either a drawing program or PowerPoint presentation to document the aim. Note: if fish targets are present, it may be necessary to raise and lower the target until the operator is assured the echoes are coming from the target.

7. Pull the target out and reposition once again to recheck the aim.

Appendix D. Kenai River south bank calibration schedule for 7/8-7/9 and 7/12-7/14, 2002 (Page 1 of 3).

LOCATION Kenai BANK South YEAR 2002

COUNTER MAKE/MODEL BENDIX SSS S/N 78x0001

Date	Obs	Time Begin	Time End	[A] Sonar Count	[B] Scope Count	[A/B] Calib Factor	Old Fish Vel	New Fish Vel	Number Sectors Monitored	Sensitivity	Counting Range	Comments Enter by Brandon (include shore to xducer distance)
7/8/2002	AP	1212	1222	145	132	109%	0.660	0.680	1-12	57	19	fish moving out
7/8/2002	AP	1222	1232	73	76	96%	0.680		1-12	57	18.5'	changed counting range to 19'
7/8/2002	SK	1324	1334	100	89		0.680	0.730	1-12	57	18.5	Cum. 647
7/8/2002	SK	1335	1340	54	52		0.730		1-12	57	18'	moving counting range in
7/8/2002	SK	1434	1440	102	90		0.730	0.750	1-12	57	18'	knig in front of
7/8/2002	SK	1540	1545	45	44		0.750		1-12	57	18'	sonar at 1413 hours
7/8/2002	SK	1606	1616	6670			0.750		1-12	57	18'	Dead range out to 3.15
7/8/2002	SK	1805	1815	72	100		0.450	0.550	1-12	57	18'	due to unexplainable
7/8/2002	DW/JN						0.550					trace in 1 and 2.
7/8/2002	DW/JN	1925	1929	164	156		0.550	0.590	1-12	57	20'	
7/8/2002	DW/JN	1932	1938	110	104		0.590	0.630	1-12	57	20'	
7/8/2002	DW/JN	1950	1956	119	100		0.360	0.750	1-12	57	20'	
7/8/2002	DW/JN	2000	2007	107	100		0.750		1-12	58	20'	Check Sens. 58V Dave moved
7/8/2002	DW/JN	2010	2018	105	100		0.750		1-12	58	18'	CR out so Increse sens.
7/8/2002	DW/JN	2127	2137	91	79		0.750	0.770	1-12	58	18'	Safety off
7/8/2002	DW/JN	2139	2149	108	96		0.770	0.800	1-12	58	18'	1281 since last calib.
7/8/2002	DW/JN	2335	2249	78	81		0.800		1-12	58	18'	
7/8/2002	DW/JN	2339	2349	96	92		0.800		1-12	58	18'	
7/8/2002	DW/JN	0038	0048	63	51		0.800	0.850	1-12	58	18'	Overcounting inside sect.
7/8/2002	DW/JN	0048	0058	58	57		0.850	0.860	1-12	58	18'	
7/9/2002	JN	0213	0223	29	35		0.860	0.830	1-12	58	20'	368 since last calib.
7/9/2002	JN	0223	0233	22	23		0.830	0.820	1-12	58	20'	slowing down
7/9/2002	BC	0709	0719	50	47	94%	0.820		1-12	58	20'	981 since last calib.
7/9/2002	BC	0904	0914	33	31		0.820		1-12	58	20'	1130 since last calib.
7/9/2002	BC	1011	1021	34	35		0.820		1-12	58	20'	
7/9/2002	BC	1207	1214	41	42		0.820		1-12	58	20'	397 since last calib.
7/9/2002	BC	1245	1255	21	18	85%	0.820	0.830	1-12	58	20'	
7/9/2002	BC	1407	1414	28	25		0.830		1-12	58	20'	
7/9/2002	BC	1420	1430	20	21		0.830		1-12	58	20'	
7/9/2002	BC	1520	1530	42	32	76%	0.830	0.840	1-12	58	20'	554 since last calib.
7/9/2002	BC	1532	1540	35	40		0.840	0.830	1-12	58	19'	
7/9/2002	AP	1732	1737	32	41	78%	0.830	0.750	1-12	58	19'	cum 550
7/9/2002	AP	1737	1747	91	88	96%	0.750	0.750	1-12	58	19'	
7/9/2002	AP	1845	1847	9	16		0.720		1-12	58	19'	
7/9/2002	AP	1847	1857	32	34		0.720		1-12	58	19'	
7/9/2002	JN	2014	2024	32	33	97%	0.720		1-12	58	19'	
7/9/2002	JN	2024	2034	52	45		0.720	0.730	1-12	58	19'	
7/9/2002	JN	2121	2131	12	12		0.730		1-12	58	19'	
7/9/2002	JN	2347	2357	52	43		0.730	0.760	1-12	58	19'	working on experimental 288's
7/9/2002	JN	2358	0009	34	27		0.760	0.775	1-12	58	19'	

Appendix D. Kenai River south bank calibration schedule for 7/8-7/9 and 7/12-7/14, 2002 (Page 2 of 3).

Date	Obs	Time Begin	Time End	[A] Sonar Count	[B] Scope Count	[A/B] Calib Factor	Old Fish Vel	New Fish Vel	Number Sectors Monitored	Sensitivity	Counting Range	Comments Enter by Brandon (include shore to xducer distance)
7/12/2002	JN	0005	0015	56	40		0.850	0.900	1-12	58	19'	inside Over counting, Outside undercounting
7/12/2002	JN	0016	0026	49	40		0.900		1-12	58	19'	1 fish counted 8X's
7/12/2002	JN	0203	0213	29	25		0.900		1-12	58	19'	411 since last calib.
7/12/2002	JN	0213	0223	8	7		0.900		1-12	58	19'	
7/12/2002	BC	0710	0720	7	7		0.900		1-12	58	19'	
7/12/2002	BC	0825	0835	3	4		0.900		1-12	58	19'	xducer 7' from shore
7/12/2002	BC	0909	0919	5	6		0.900		1-12	58	19'	passage rate very low
7/12/2002	BC	1033	1043	7	10		0.900	0.875	1-12	58	19'	approx. 20-30 fish/hour
7/12/2002	DW	1147	1157	30	22		0.875		1-12	60	22'	ckd sens. 4* DR= 2.5 CR=22'
7/12/2002	DW	1159	1209	11	16		0.875		1-12	53	23	(range = 26") - 2* DR=1.5 CR=23'
7/12/2002	DW	1213	1223	14	17		0.875		1-12	50	22	(range = 25' - AH DR 2.0 CR
7/12/2002	DW	1251	1306	23	28	82%	0.775	0.650	1-12	53	23	22' (range = 24') /// 2* CR 23' DR 1'
7/12/2002	DW	1306	1316	19	20		0.650		1-12	53	23	4* CR 22 DR 3'
7/12/2002	SK	1319	1329	12	12	100%	0.650		1-12	53	23	2*, DR 1.0'
7/12/2002	SK	1411	1421	18	16		0.650	0.675	1-12	53	23	
7/12/2002	SK	1505	1515	27	23	117%	0.675	0.725	1-12	53	23	
7/12/2002	SK	1615	1625	17	16		0.725		1-12	53	23	
7/12/2002	SK	1717	1727	8	8	100%	0.725		1-12	53	23	
7/12/2002	SK	1809	1816	19	17		0.725	0.730	1-12	53	23	
7/12/2002	JN/SK	1954	2004	17	15		0.730		1-12	53	23	
7/12/2002	JN/SK	2052	2102	12	13		0.730		1-12	53	23	
7/12/2002	JN/SK	2219	2229	9	5		0.730		1-12	53	23	
7/12/2002	JN	2229	2239	26	22		0.730		1-12	53	23	
7/13/2002	JN	0015	0025	13	10		0.730	0.750	1-12	53	23	
7/13/2002	JN	0204	0214	15	10		0.750	0.760	1-12	53	23	
7/13/2002	JN	0214	0224	14	10		0.760	0.780	1-12	53	23	
7/13/2002	BC	0722	0732	0	0		0.780		1-12	53	20	CR into 20', overcounting
7/13/2002	BC	0915	0925	10	10		0.780		1-12	53	20	in sect. 12
7/13/2002	BC	1003	1013	9	10		0.780		1-12	53	20	
7/13/2002	BC	1058	1058	4	4		0.780		1-12	53	20	
7/13/2002	BC	1205	1210	6	7		0.780		1-12	53	20	
7/13/2002	SK	1320	1330	9	8		0.780		1-12	53	20	really picking up
7/13/2002	SK	1404	1414	73	75		0.780		1-12	53	20	
7/13/2002	SK	1519	1529	61	62		0.780		1-12	53	20	
7/13/2002	SK	1703	1713	24	25		0.780		1-12	53	20	
7/13/2002	SK	1832	1842	21	17		0.780	0.800	1-12	53	20	
7/13/2002	SK	1845	1855	26	27		0.800	0.780	1-12	53	20	
7/13/2002	AP	2000	2010	22	25		0.720	0.720	1-12	53	20	cum. 175
7/13/2002	AP	2036	2106	55	54		0.720		1-12	53	20	cum.155 counting good
7/13/2002	AP	2214	2219	3	8		0.720	0.690	1-12	53	20	cum. 272
7/13/2002	AP	2210	2230	39	37	105%	0.690	0.690	1-12	53	20	
7/13/2002	AP	2330	2340	26	26	100%	0.690		1-12	53	20	cum. 171
7/14/2002	AP	0047	0057	17	18		0.690		1-12	53	20	cum. 182
7/14/2002	AP	0132	0137	11	16		0.690	0.720	1-12	53	20	
7/14/2002	AP	0229	0239	31	29		0.720		1-12	53	20	
7/14/2002	BC	0711	0721	55	43		0.720	0.750	1-12	53	20	1743 since last calib.

Appendix D. Kenai River south bank calibration schedule for 7/8-7/9 and 7/12-7/14, 2002 (Page 3 of 3).

Date	Obs	Time Begin	Time End	[A] Sonar Count	[B] Scope Count	[A/B] Calib Factor	Old Fish Vel	New Fish Vel	Number Sectors Monitored	Sensitivity	Counting Range	Comments Enter by Brandon (include shore to xducer distance)
7/14/2002	BC	0753	0758	28	31		0.750		1-12	53	20	
7/14/2002	BC	0911	0921	20	24		0.750	0.740	1-12	53	20	
7/14/2002	BC	1007	1017	15	20		0.740	0.700	1-12	53	20	
7/14/2002	BC	1131	1141	10	14		0.700	0.675	1-12	53	20	
7/14/2002	SK	1313	1323	9	9		0.675		1-12	53	20	
7/14/2002	SK	1445	1452	0	0		0.675		1-12	53	20	No fish passing
7/14/2002	SK	1614	1624	7	9		0.675		1-12	53	20	