Fishery Manuscript No. 07-08

The Feasibility of Using a Split-beam Sonar to Estimate Salmon Passage on the Kenai River as a Potential Replacement for an Echo-counting Bendix Sonar

by

April V. Smith

and

Suzanne Maxwell

December 2007

Alaska Department of Fish and Game **Division of Commercial Fisheries**

Symbols and Abbreviations

The following symbols and abbreviations, and others approved for the Système International d'Unités (SI), are used without definition in the following reports by the Divisions of Sport Fish and of Commercial Fisheries: Fishery Manuscripts, Fishery Data Series Reports, Fishery Management Reports, and Special Publications. All others, including deviations from definitions listed below, are noted in the text at first mention, as well as in the titles or footnotes of tables, and in figure or figure captions.

Weights and measures (metric)	
centimeter	cm
deciliter	dL
gram	g
hectare	ha
kilogram	kg
kilometer	km
liter	L
meter	m
milliliter	mL
millimeter	mm

Weights and measures (English)	
cubic feet per second	ft^3/s
foot	ft
gallon	gal
inch	in
mile	mi
nautical mile	nmi
ounce	oz
pound	lb
quart	qt
yard	yd

Time and temperature	
day	d
degrees Celsius	°C
degrees Fahrenheit	°F
degrees kelvin	K
hour	h
minute	min
second	s

Physics and chemistry	
all atomic symbols	
alternating current	AC
ampere	A
calorie	cal
direct current	DC
hertz	Hz
horsepower	hp
hydrogen ion activity (negative log of)	pH
parts per million	ppm
parts per thousand	ppt, ‰
volts	V
watts	W

General	
Alaska Administrative Code	AAC
all commonly accepted abbreviations	e.g., Mr., Mrs., AM, PM, etc.
all commonly accepted professional titles	e.g., Dr., Ph.D., R.N., etc.
at	@
compass directions:	
east	E
north	N
south	S
west	W
copyright	©
corporate suffixes:	
Company	Co.
Corporation	Corp.
Incorporated	Inc.
Limited	Ltd.
District of Columbia	D.C.
et alii (and others)	et al.
et cetera (and so forth)	etc.
exempli gratia (for example)	e.g.
Federal Information Code	FIC
id est (that is)	i.e.
latitude or longitude	lat. or long.
monetary symbols (U.S.)	$, ¢
months (tables and figures): first three letters	Jan,...,Dec
no data	ND
registered trademark	®
trademark	™
United States (adjective)	U.S.
United States of America (noun)	USA
U.S.C.	United States Code
U.S. state	use two-letter abbreviations (e.g., AK, WA)

Measures (fisheries)	
fork length	FL
mideye-to-fork	MEF
mideye-to-tail-fork	METF
standard length	SL
total length	TL

Mathematics, statistics	
all standard mathematical signs, symbols and abbreviations	
alternate hypothesis	H_A
base of natural logarithm	*e*
catch per unit effort	CPUE
coefficient of variation	CV
common test statistics	(F, t, χ^2, etc.)
confidence interval	CI
correlation coefficient (multiple)	R
correlation coefficient (simple)	r
covariance	cov
degree (angular)	°
degrees of freedom	df
expected value	*E*
greater than	>
greater than or equal to	≥
harvest per unit effort	HPUE
less than	<
less than or equal to	≤
logarithm (natural)	ln
logarithm (base 10)	log
logarithm (specify base)	log$_{2,}$ etc.
minute (angular)	'
not significant	NS
null hypothesis	H_O
percent	%
probability	P
probability of a type I error (rejection of the null hypothesis when true)	α
probability of a type II error (acceptance of the null hypothesis when false)	β
second (angular)	"
standard deviation	SD
standard error	SE
variance	
population	Var
sample	var

FISHERY MANUSCRIPT NO. 07-08

THE FEASIBILITY OF USING A SPLIT-BEAM SONAR TO ESTIMATE SALMON PASSAGE ON THE KENAI RIVER AS A POTENTIAL REPLACEMENT FOR AN ECHO-COUNTING BENDIX SONAR

by
April V. Smith
and
Suzanne Maxwell
Alaska Department of Fish and Game, Division of Commercial Fisheries, Soldotna

Alaska Department of Fish and Game
Division of Commercial Fisheries
333 Raspberry Road, Anchorage, Alaska, 99518

December 2007

The Division of Sport Fish Fishery Manuscript series was established in 1987 for the publication of technically-oriented results of several years' work undertaken on a project to address common objectives, provide an overview of work undertaken through multiple projects to address specific research or management goal(s), or new and/or highly technical methods. Since 2004, the Division of Commercial Fisheries has also used the Fishery Manuscripts series. Fishery Manuscripts are intended for fishery and other technical professionals. Fishery Manuscripts are available through the Alaska State Library and on the Internet: http://www.sf.adfg.state.ak.us/statewide/divreports/html/intersearch.cfm This publication has undergone editorial and peer review.

April V. Smith and Suzanne Maxwell,
Alaska Department of Fish and Game, Division of Commercial Fisheries,
43961 Kalifornsky Beach Rd., Suite B
Soldotna, AK, USA 99669

This document should be cited as:
Smith, A. V., and S. Maxwell. 2007. The feasibility of using a split-beam sonar to estimate salmon passage on the Kenai River as a potential replacement for an echo-counting Bendix Sonar. Alaska Department of Fish and Game, Fishery Manuscript No. 07-08, Anchorage.

TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF APPENDICES

ABSTRACT

A split-beam sonar was tested on the Kenai River as a potential replacement for an existing Bendix sonar used to enumerate migrating adult salmon. The Bendix is an echo-counting sonar deployed at a fixed location nearshore with the transducer beam directed perpendicular to current flow. We deployed 2 split-beam transducers along the Kenai River's north bank to sample a nearshore and offshore strata in 2001–2003. A single transducer was deployed along the Kenai's south bank in 2001. Hardware and software difficulties created numerous setbacks in both data collection and processing during each of the study years. Calibration and aiming protocols were developed to help standardize procedures and make it easier for technicians to correctly set up and operate the split-beam system. The information from the split-beam sonar was used to create diagnostic plots to determine whether the sonar was successfully detecting fish. Plots displaying the river bottom and vertical and range position of fish targets (fish-profile plots) showed that the split-beam 2-transducer configuration used on the north bank was adequate for detecting fish. On the south bank, the low numbers of fish detected by the split-beam sonar compared to the Bendix in 2001 made us reassess its use on this bank. A program developed to autotrack the split-beam sonar data failed because the riverine data was extremely noisy, and the split-beam signal processing removed many of the echoes needed to track the fish. A sampling period of 10 min/h was selected for the data collection. For each year of the study, paired data were collected between the Bendix echo-counting sonar and the new split-beam sonar. A visual count method was used for producing split-beam estimates. Regression analysis was used to evaluate the relationship between estimates generated by the 2 sonar systems. The relationship was not similar to 1. On the north bank, the difference between counts was most pronounced in 2002 and 2003. The 2001 count comparison was more similar. It was determined that the split-beam sonar was not the best replacement for the Bendix sonar. We began testing a dual frequency identification sonar (DIDSON) in 2002. The DIDSON is proving to be a better choice for the Bendix sonar replacement because of its wider viewing angles, higher resolution of fish targets, and ease of operation.

Key words: Split-beam, Bendix, sonar, salmon, Kenai River, hydroacoustic, sonar transition, Bendix replacement, Sockeye salmon, *Oncorhynchus nerka.*

INTRODUCTION

The Alaska Department of Fish and Game (ADF&G) began testing a modern split-beam sonar as a potential replacement for echo-counting, Bendix sonar counters, used to estimate adult salmon (*Oncorhynchus spp.)* passage. In 1977, a Bendix[1] side-scanning sonar (Bendix counter) was first employed at the Kenai River to replace a Bendix multiple transducer system, in use since 1968. The original sonar system used single-beam transducers deployed on the bottom of the river and arrayed in an upward-looking configuration (Namtvedt et al. 1979). The Bendix counter used a single transducer deployed near the river bank in a side-looking configuration. The salmon numbers produced by the counters soon became an integral part of the commercial fishery management program. The Bendix counters were used on many rivers in Alaska to estimate predominately sockeye *O. nerka* and chum *O. keto* salmon (Barton 2000; Chapell 2001; Westerman and Willette 2003a, b; Smith and Lewis 2006). In the Upper Cook Inlet area, commercial fishery managers are reliant on the daily, inseason escapement estimates of sockeye salmon to manage the fishery and set escapement goals. We tested the split-beam sonar at the existing Kenai River Mile 19 sonar site (Figure 1), devised sampling methods, and compared estimates from the old and new sonars.

The Bendix counter is a simple echo-counter that sums echoes that cross the threshold, and divides by an echo/fish criteria to obtain a count of passing salmon. The echo/fish criteria for most counters is hard-wired into the machine. The threshold setting depends on the bottom

[1] Product names used in this report are included for scientific completeness, but do not constitute a product endorsement.

profile and transducer aim. In general, the threshold is set as high as possible. On the Kenai River, a 515 kHz Bendix transducer alternately transmitting 4^{o} and 2^{o} beams is deployed in a fixed location along each bank and positioned perpendicular to the river's current. Bendix operators 'calibrate' the system periodically 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 oscilloscope count. The systems are low powered, drawing approximately 1 Watt. They are operated 24 h/d during the field season and produce estimates that are available to fishery managers hourly. Bendix transducers are positioned close to the river bottom 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. Ping rates and range settings are adjusted during the field season to account for changes in fish behavior and water level. Apportionment of sonar counts is conducted only when the daily fish wheel catch exceeds 10% of fish species other than sockeye salmon. Until this percentage is reached, 100% of the counts are allocated to sockeye salmon. Westerman and Willette (2003a, b) include more detailed information on the Bendix counters operations on the Kenai River.

In 1997, ADF&G began putting together a proposal for the Bendix replacement. Hydroacoustic Technology, Inc. (HTI), BioSonics, and Sci-fish bid on the proposal. The bid from BioSonics was accepted. The BioSonics split-beam system was tested across a 2-year period on the Wood River (BioSonics 1999a, 1999b). Several problems were discovered during the first year of testing. We learned that the BioSonics transducer was not a true split-beam, instead it consisted of 3 multiple beams, 1 used for amplitude, and the 3 in combination used for positional information. Unfortunately, BioSonics failed to correct for the parallax problem, resulting from the spacing between the beams. High power settings (1,000 Watts) and long pulse widths (0.4 ms) compounded the problem, resulting in poor positional information and poor resolution between closely spaced fish. In 1999, the power settings were lowered, and the pulse width was reduced to 0.2 ms; however, the parallax problem was not corrected until much later. Software development became a very large issue. BioSonics Visual Analyzer program uploaded the electronic echograms in speeds close to real time. Zooming in and out was also extremely slow, and BioSonics failed to provide any means to manually track and output information from the echogram. ADF&G opted out of the contract with BioSonics in early 2000, and selected HTI as the new vendor for the Bendix replacement. The HTI transducers were true split-beam systems so the parallax problem was not an issue. The HTI systems came with tracking software that had in part been developed by ADF&G's Division of Sport Fish and used to estimate Chinook salmon *O. tshawytscha* on the Kenai River (Miller and Burwen 2002).

Split-beam sonar uses timing differences in the arrival of echoes at the 4 transducer quadrants to determine the echo position and outputs time, amplitude, and dimensional information for each processed echo. This information allows the horizontal and vertical movement of fish to be plotted. The sole output of the Bendix counter is an hourly count by range sector. The additional information provided by the split-beam sonar can be used to track upstream and downstream movement of fish, test the transducer aim by observing the vertical position of fish, and alert the sonar operator to changes in fish swimming position that may necessitate reaiming the transducer. For example, if the transducer is aimed so the majority of fish are below the central axis of the beam and the operator observes fish moving primarily above the central axis, the aim of the transducer can be adjusted. The aim of the transducer is critical for detecting fish migration with both split-beam and single-beam systems. Salmon typically swim near the river bottom to take advantage of the reduced current flow and avoid surface drag. However, seasonal water level fluctuations can alter current flow and fish may move off bottom. The information provided by the split-beam sonar can be used to determine the effectiveness of the aim and monitor changes in fish behavior.

HTI split-beam sonar replaced earlier dual-beam sonar for estimating migrating Chinook salmon on the Kenai River (Miller and Burwen 2002) and chum salmon in the Chandalar River (Osborne and Melegari 2002). Both sites manually tracked fish echoes from electronic echograms using the HTI Trackman Program. The manual tracking method is too time-consuming a process for counting the high numbers of sockeye salmon. An automated method was required. A cooperative effort between the Department of Fisheries and Oceans (British Columbia, Canada), ADF&G, and HTI led to the development of an autotracking software program (ABTracker) using Blackman's algorithm (Blackman 1986). The state contracted Peter Withler to employ the algorithms and develop a software program capable of autotracking fish targets. The state also contracted Withler to provide an integrated tracking and editing program and leave the algorithms open to the public domain.

ADF&G began using Withler's software, Polaris, in 2000, for manual tracking only. At this stage, the autotracker was unable to track fish without also tracking noise from the river bottom. We discovered inseason that the Polaris program was not saving any of the edited data. Unable to get a hold of Withler, we were forced to switch to HTI's Echoscape program, which had replaced their earlier Trackman. Again, major bugs in the program invalidated the processed data. Neither the Polaris nor Echoscape developers were able to convince us that their programs would be workable in the near future. Later, we discovered a third software program, SonarData's Echoview (http://www.sonardata.com). SonarData integrated Withler's autotracking program and developed an editor to manually track and edit the echograms. The tracking and editing were completely integrated, making the program simpler to use. The integration also allowed much faster testing of autotracking parameters. The effects of changing parameters could be determined instantly instead of exporting tracked fish, importing into a second program, and analyzing the results. In 2002, ADF&G purchased Sonar Data's Echoview to process all the split-beam data.

The specific objectives for the replacement of the Bendix sonar are listed below.

1. Test and optimize parameters for the split-beam sonar.
    a. Field calibrate each transducer.
    b. Plot the vertical fish distribution.
    c. Determine the optimal beam size.
    d. Determine site-specific sampling parameters.
2. Compare paired HTI and Bendix estimates of sockeye salmon.

STUDY AREA

The Kenai River, located on the Kenai Peninsula in Southcentral Alaska (Figure 1), flows 132 km from its origin in Kenai Lake to Cook Inlet, draining 5,700 km^2 of glacial and clear water streams. The Bendix sonar site is located on a slight bend in the river, at river mile 19. At the site the river is ~120 m wide and it does not experience tidal influence, but water level gradually rises through the summer peaking in late July or early August. The slope of the river bottom from the north bank is flat with a 0.9^{o} slope out to 22 m (depending on water level) changing to 2.0^{o} beyond. The south bank river bottom is more steep nearshore with a 12.1^{o} slope out to 10 m from the bank, a 5.6^{o} slope from 10 to 15 m, and a 0.9^{o} slope beyond 15 m (Figure 2).

Kenai River sockeye, pink *O. gorbuscha*, Chinook, and coho *O. kisutch* salmon are harvested in commercial, sport, and subsistence/personal use fisheries. Sockeye salmon migrating past the sonar counters are destined for the higher reaches of the Kenai River and its tributaries and are not known to spawn downstream of the sonar site. The majority of Chinook salmon are in the river by the time sonar operations begin and they tend to migrate further offshore than sockeye salmon. Run timing for coho and pink salmon create an overlap with the end of the sockeye salmon run.

METHODS

TESTING THE SPLIT-BEAM SONAR

Equipment and Deployment

The HTI split-beam systems consisted of Model 241 (north bank) and Model 244 (south bank) digital echosounders, 200 kHz elliptical split-beam transducers, and Model 661H single-axis rotators with remote controllers and relative feedback. A BioSonics' attitude sensor was affixed to each transducer to provide absolute pitch, roll, and heading. Heading (magnetic compass bearing) was not used because of heavy distortion caused by the steel rotator and transducer housings. We used H-shaped mounts made from aluminum poles held together with slightly larger diameter aluminum poles welded into T-shapes (Figure 3). The rotator was attached to a hanging bracket on the mount, and the transducer was affixed to a metal plate mounted to the rotator. The BioSonics' attitude sensor was held on the side of the transducer using large metal hose clamps. Mounts were deployed nearshore at a fixed location with the sonar beam directed perpendicular to the current flow. The legs of the H-mounts were sandbagged to prevent the mounts, and thus the transducers from moving. During each of the 3 sampling years (2001–2003), 2 split-beam transducers, were deployed on the Kenai River north bank on the upstream side of the Bendix transducer, 3.05 m from the bank (Figure 4). A 4^{o} by 8^{o} HTI split-beam transducer was deployed for nearshore sampling and a 2^{o} by 6^{o} HTI split-beam transducer for offshore. Both transducers were connected to a single echosounder. In 2001, a 6^{o} by 10^{o} HTI split-beam transducer was deployed on the Kenai River south bank on the upstream side of the Bendix transducer, 3 m from the bank (Figure 5). A downstream weir was extended 0.61 m beyond the transducers to prevent fish from passing inshore of the sampling range. The split-beam transducers were positioned close to the river bottom with enough space to make small pitch adjustments without causing damage. The bottom portion of each transducer beam was aimed close along the river bottom. On each bank, a laptop computer with the HTI Digital Echo Processor (DEP) software installed controlled the echosounder and displayed the data (Figure 6). In 2001, all data were backed up on compact disc (CD) daily. In 2002 and 2003, external drives and CD's were used to archive data.

From surveys conducted in 2000, we created a bathymetry map in the vicinity of the sonar site that shows the deployment locations for the Bendix and HTI transducers (Figure 7).

Calibrations and Aiming

The HTI systems were calibrated at the HTI laboratory facility against a standard transducer using reciprocity techniques (Appendix A1). We field-calibrated the HTI system at the start of each field season using a 38.1 mm tungsten carbide sphere (calibration sphere) suspended outside the nearfield of each transducer in the center of the beam. The calibration sphere was moved vertically and horizontally through the beam to obtain echoes throughout each of the 4 split-beam transducer quadrants.

Prior to deploying the transducers, the attitude sensors were tested using a bubble level onshore. Once in the water, we aimed the nearshore transducers by suspending an approximate salmon-size target (10.16 cm plastic sphere filled with BB's) above the river bottom in front of the transducer. We adjusted the pitch of the transducer to match the slope of the river bottom and then fine tuned the aim by rotating the transducer until the target echoes in 2-dimensional position plots appeared just below the centerline of the beam. The offshore transducer was aimed by first matching the aim to the bottom slope. The plastic sphere was then lowered into the beam from the side of the boat using a pole and monofilament line. The target was lowered to the river bottom then pulled up approximately 4 in to test the aim. This technique was repeated at 2 or 3 offshore ranges.

Sonar Parameters

Although we desired as low a threshold as possible for the sonar system, the river was a noisy environment. Because the sound beam was squeezed between the river bottom and surface boundaries, sound reflecting off microscopic or macroscopic objects in the water and from the boundaries themselves bounced back to the receiver creating large numbers of unwanted echoes. In this report, unwanted echoes are referred to as noise regardless if their source is from ambient noise or sound reverberation. To enhance fish detection, we strove to obtain a minimum signal-to-noise ratio of 10 dB across the ensonified range. The sonar settings for transmit, receiver gain, and voltage threshold were adjusted to achieve as high a signal-to-noise ratio as possible while maintaining the lowest possible threshold. The pulse length was set small enough to provide maximum resolution of targets, but high enough that transmitted power levels were not compromised. The pulse repetition rate was set as high as range limitations would permit and the acoustic transmitter was capable of achieving. To obtain accurate target range (distance from transducer) measurements, the sound speed was calculated based on water temperature (MacLennan and Simmonds 1992) and input into the DEP program.

Split-beam Sonar Data Collection, Processing, and Analyses

Unlike the Bendix sonar, which operated 24 h/d during the field season, subsampling was required with the new split-beam system because of the large amount of time needed to process the data. A sample design was tested and the effects of subsampling on the estimated counts and the variance of these counts on a daily basis were found (Maxwell et al. *In prep*). To avoid any sampling bias due to potential diurnal fish behavioral patterns we sampled within each hour of the day. For the north bank HTI sampling, each hour was subdivided for each transducer. The echosounder was programmed in 2001 and 2002 to sample in 20-minute segments. The nearshore transducer sampled the first 40 minutes of the hour and the offshore sampled the remaining 20 minutes. In 2003, both transducers sampled for 30 minutes, the nearshore at the top of the hour and the offshore at the bottom.

For the south bank HTI sampling, the echosounder was programmed in 2001 to sample 20-minute segments each hour. All data was manually tracked and fish counts equaled the number of exported fish. The numbers of fish in the three 20-min/h segments were added to obtain an hourly estimate.

Inseason data was processed using first Polaris, then Echoscape. In 2002, we went into the season with Echoview. Discovering no serious flaws, we processed all the 2002 and 2003 data and went back and reprocessed all the 2001 data using Echoview.

We tested the autotracking program, the ABTracker, with small datasets from each transducer aim containing fish densities that were relatively high, but low enough that individual tracks could be visually distinguished on the echogram. Autotracked counts were compared with visual counts. Echoview was used for both autotracking and displaying fish tracks for visual counts. We originally intended to work with a few sample files to develop the needed parameters, and then track a broad range of files using these parameters. However, because of the large disparity in counts from the autotracking program compared to the visual counts, further autotracking was halted. Noise from the river bottom and the multi-pathed echoes from the fish interfered with the autotracking (Figure 8).

Although Echoview allowed us to process the data more quickly, without the autotracker, it was still too time-consuming to process 24 hours of data within a single day to obtain fish passage estimates. To trim the data to what could be processed daily, we manually tracked only the first 10 min/h of data from each transducer in 2003. Even this level of processing was too time-consuming to be performed daily. To further reduce the processing time, we visually counted the echogram fish traces (visual count) in the 10-min/h files using a tally counter and recorded the counts on a Microsoft Excel spreadsheet. Downstream targets were not subtracted from the count because the information was not available from a visual count. This method was used to count or recount the data from all 3 years (2001–2003). To obtain positional data from the fish traces we manually tracked fish echoes on electronic echograms (manual tracking) from the 10-min/h files. In 2001 and 2002, the first 10 minutes of the sampling period for each transducer was visually counted and manually tracked. In 2003, the last 10 minutes of the sampling period for the nearshore and the first 10 minutes of the offshore were visually counted. Dependent on crew scheduling, a full hour of data was collected daily from both HTI transducers and manually tracked.

The most powerful viewing tool from the positional data was a fish-profile plot. To create this plot, we plotted the river bottom profile in a range versus depth graph then converted the positional information from the fish echoes to the same coordinate system. The average position of each fish was plotted as a separate point. Each point was then ‘pitched’ to match the recorded pitch angle of the transducer that produced it. The averaged, pitched echoes were then plotted on the charts. The position of the nominal beam was overlaid resulting in a plot that showed the fish position in relation to both the transducer beam and the river bottom. This information was used to judge the effectiveness of the aiming pitch of the transducer. Ideally, we wanted to produce daily fish-profile plots inseason. With this tool, we would be able to adjust the aim as needed. For example, if fish targets were concentrated in the upper edge of the beam, the transducer could be pitched up. Daily plots would show whether fish were moving up off the river bottom, or moving offshore or inshore.

The average position of each target in the horizontal (upriver/downriver) and the vertical planes was displayed in separate plots. These plots provided information regarding the placement of the transducer. In the horizontal plane, there should be an equal number of echoes on the upstream side and the downstream side of the center axis. Appearance of echoes from tracked fish on only one side of the beam may signify shadowing or may indicate a problem with the transducer. If the track appears to progress diagonally through the beam it may indicate the transducer is tilted (or rolled) upstream or downstream. In the vertical plane, the echoes should be predominately located in the lower quadrant if fish are swimming along the river bottom. Movement up can indicate a change in fish behavior or shifting of the transducer that might necessitate an adjustment of the transducer pitch.

Average target strength, average velocity of the target as it progresses through the beam, and the average number of echoes per fish were also monitored. Changes in target strength could indicate a problem with the transducer sensitivity or the receiver card. Target strength values for individual echoes were calculated and plotted by first logging the data, and then obtaining an average in 1 m range bins by year and by transducer. Average fish velocity and the number of echoes per fish were parameters needed for the automated fish-tracking program. The velocity of a fish traveling through the beam was obtained by regressing the horizontal position of each echo within a fish track against time. The velocity of each fish track was then averaged in 1m range bins by year and by transducer and plotted. Individual echoes were averaged within a fish track then an overall average was obtained in 1 m range bins by year and transducer and plotted. These diagnostic tools assisted us in monitoring the sonar system and in making adjustments as needed. Without this information, a problem might go unnoticed and valuable data lost.

Comparing Bendix and Split-beam Sonar Estimates of Migrating Salmon

We collected paired HTI split-beam sonar and Bendix estimates along the north bank of the Kenai River across 3 field seasons (2001–2003). Paired HTI and Bendix data on the south bank were only collected in 2001. The Bendix sonar was operated 24 h/d. The setup and operations of the Bendix systems for the 2001–2003 field seasons are described in Davis (2002) and Westerman and Willette (2003a, b). To match the data between the 2 sonar systems, full hour Bendix counts were treated as individual samples and paired with 10 min/h HTI sonar visual counts multiplied by 6 to represent an hourly count. On the north bank, hourly HTI nearshore and offshore counts were summed to obtain a single hourly count.

Fish passage estimates from the 2 sonar systems were compared using time series and least squares regression techniques. The time series plots were used visually to compare differences by day. We used the regression analysis to test the hypothesis that the slopes between the paired Bendix and spit-beam sonar estimates were equal to 1. Because we could not assume that either method was without error, we calculated regression lines using each counting method as the independent variable to determine the extent of the variability from each sonar. Regression techniques were applied to daily and hourly samples. For the daily samples, the data for the entire day was summed to provide a single data point. For the hourly samples, each hour count was treated as an individual sample.

This was not a true blind comparison. Although different staff members monitored and obtained counts from each system, we made no effort to prevent an exchange of information between them. The potential bias from this sharing of information was unknown. In 2003, a 3-day lag in data processing from the HTI system was used to avoid potential biases.

RESULTS

TESTING THE SPLIT-BEAM SONAR

Equipment and Deployment

In 2001, numerous network crashes throughout the field season caused the connection between the HTI sonar and the controlling computer to be lost. Following the field season, it was learned that the Lantastic network used by the HTI system was not fully compatible with the computer's Windows 2000 operating system, even though the combined system was tested preseason by the vendor. The problem was resolved prior to the next field season.

In 2001, paired data were collected on the north bank from July 1 to July 31, except on July 7 and 8 when the HTI system shut down. The 2001 comparison did not include the offshore counts because there was so much missed data.

In 2001, paired data were collected on the south bank from July 5 to August 9, except on July 7 and 8 when the HTI system shut down. After examining the data and comparing with the Bendix, we determined the HTI system was not adequately detecting fish along this shore. No further testing was conducted with the split-beam system on this bank.

In 2002, paired data were collected from July 11 to August 14. A total of 6 days (July 26–30 and August 1) of HTI data were lost because of a malfunction with an external drive.

In 2003, paired data were collected from July 1 to August 10. The final data processing and analysis occurred during the fall of 2003.

Calibrations and Aiming

Field calibration results from the tungsten carbide are listed in Table 1 for each of the transducers used in this study. Field calibration results from the plastic sphere using the 200 kHz split-beam sonar can be found in Maxwell et al. (*In prep*). North bank nearshore echoes formed a diagonal from the lower upstream to the upper downstream portion of the beam in 2001, were concentrated in the downstream 3-quarters of the beam in 2002, and were distributed throughout the beam in 2003 (Figure 9). North bank offshore echoes were concentrated in the center of the beam in 2001 and throughout the beam in 2003 (Figure 10). No field calibration was performed on the north bank offshore transducer in 2002. For the south bank, the echoes formed a diagonal pattern in 2001 (Figure 11). The standard deviation of the field target strength measures included the theoretical target strength of –39.45 dB for each transducer in all years except the 2^o by 6^o (offshore) calibration in 2001. The theoretical target strength was calculated for the 38.1 mm tungsten carbide sphere at 0.2 ms and 10^oC for the 200 kHz transducers (Faran 1951).

To aim the transducers, we first examined the river bottom profile and matched the aim of the transducer to the slope of the river bottom using the pitch output from the attitude sensors. We fine-tuned the aim using the plastic sphere suspended just above the river bottom at a nearshore and offshore location. For the north bank nearshore, this resulted in a pitch $–2.2^o$ from level in 2001, 0.2^o to 0.4^o in 2002, and $–1.5^o$ in 2003. For the north bank offshore, the resulting pitch was $–1.0^o$ in 2001, $–0.5^o$ in 2002, and $–1.0^o$ to $–0.3^o$ in 2003. For the south bank, the resulting pitch ranged from $–8.1^o$ to $–9.1^o$ in 2001 depending on where the transducer was positioned.

Table 1.–Field calibration results for the 38.1 mm tungsten carbide sphere using the 200 kHz split-beam sonar, Kenai River.

Transducer	Year	Target Strength (dB)	# of Echoes	Range (m)
North Bank				
HTI 4°x8°	2001	-37.7 ± 2.8	1,996	2.7
HTI 4°x8°	2002	-38.6 ± 0.9	927	1.8
HTI 4°x8°	2003	-38.9 ± 1.5	2,684	1.7
HTI 2°x6°	2001	-43.2 ± 1.3	747	2.4
HTI 2°x6°	2002 [a]	ND	ND	ND
HTI 2°x6°	2003	-40.1 ± 4.1	1,464	7.6
South Bank				
HTI 6°x10°	2001	-37.2 ± 3.0	6,975	2.7

[a] No calibration was performed.

Sonar Parameters

The north bank and south bank split-beam sonar parameters for 2001–2003 are listed in Table 2.

Table 2.–Split-beam sonar parameters for the north and south bank operations on the Kenai River, 2001–2003.

	North Bank Nearshore			North Bank Offshore			South Bank
Parameters	**2001**	**2002**	**2003**	**2001**	**2002**	**2003**	**2001**
Sound speed	1460 m/s	1448 m/s	1448m/s	1460 m/s	1448 m/s	1448 m/s	1460 m/s
Water temp.	10°C	10°C	10°C	10°C	10°C	10°C	10°C
Receiver gain	-6 dB	-6 dB	-6 dB	-6 dB	-6 dB	-6 dB	-2 dB
Pulse repetition rate	15 pings/s	15 pings/s	15 ping/s	8 pings/s	8 pings/s	8 pings/s	15, 20 pings/s
Pulse width	0.2 ms	0.2 ms	0.2 ms	0.2 ms	0.2 ms	0.2 ms	1.25, 0.2 ms
Threshold	-40 dB	-45 dB	-40 dB	-43 dB	-41.2 dB	-40 dB	-40, -46, -43 dB
Transmit	2 dB	8 dB	8 dB	2 dB	8 dB	8 dB	2 dB
Effective beam width	5°x8°	8°x8°	5.5°x8°	3°x6°	5°x6°	4°x6°	7°x10°, 6°x10°
Max off-axis criteria	12 dB	13 dB	6 dB	12 dB	13dB	12 dB	12 dB
Absorption coefficient	0 dB/km	3.0 dB/km	3.0 dB/km	0 dB/km	3.0 dB/km	3.0 dB/km	0 dB/km

In 2001, the range of the north bank nearshore transducer was 0.6–30 m from the face of the transducer. The offshore range was 0.8–70 m throughout the season. In 2002, the initial range of the nearshore transducer was 1–30 m and the offshore range was 25–55 m. On July 23 at 0900 hours, the range of the nearshore transducer was shortened to 1–18 m and the offshore range was changed to 18–60 m to reduce noise and fit the nearshore beam better in the water column. In 2003, the range of the nearshore transducer was 1–27 m and the offshore range was 1–75 m.

In 2001, the initial range of the south bank transducer was 0.6–10 m from the face of the transducer. On July 13 at 1700 hours, the range of the transducer was shortened to 0.5–8.5 m. The ping rate was decreased to reduce overall reverberation coming off targets, and the threshold was decreased so extraneous noise was not recorded.

Split-beam Sonar Data Collection, Processing, and Analyses

The split-beam sonar data were displayed, tracked, and exported using Echoview. To obtain the needed diagnostic tools, we processed data by manually tracking the fish tracks electronically and saving the amplitude and positional echo data for each fish in Excel files.

The sampling schedule to manually track fish changed across the years. The 2001 data were tracked in 10 min/h samples; a total of 531 samples were tracked nearshore and 452 offshore. In 2002, all nearshore echoes were tracked and later cut into 10-min/h samples to correspond with the 2001 sampling method; 620 samples were tracked nearshore and 615 offshore. In 2003, a full hour of data was recorded daily from each transducer; a total of 32 h of data were manually tracked from the nearshore transducer and 11 h from the offshore. Upstream and downstream targets were distinguished by examining the horizontal position of echoes versus time (Figure 12). Because of the software difficulties, daily manual tracking of the data was only accomplished in 2003. For all prior years, the data was processed postseason.

In 2001, a total of 33,226 fish were tracked nearshore and 156 fish offshore on the north bank. The offshore transducer was repositioned and the pitch changed on July 20 at 0900 hours, so 2 fish-profile plots were made with this time period as the dividing factor. The nearshore plots from this year were crowded with targets filling the beam from edge to edge out to 10 m then the distribution narrowed to the beam center (Figure 13). Nearshore fish were tracked on the lower edge of the beam throughout the sampling range. Offshore fish were tracked near the lower edge from 25–35 m. No fish were detected past 35 m before July 20, but a few were detected after. For the south bank, data were recorded continuously in 20 min intervals. A total of 107,597 fish were tracked from 692 hours of data. The transducer was raised on the mount from 2 to 5 in from the river bottom on July 19 but the pitch stayed the same. The pitch changed on July 24 at 1500 hours, so 2 fish-profile plots were made with this as the dividing factor. The plots showed the targets filled the beam from edge to edge out to 10 m then distribution narrowed to the center of the beam out to 27 m (Figure 14). Nearshore fish were tracked on the lower edge of the beam throughout the sampling range.

In 2002, 2 fish-profile plots were produced because of a sampling range change that occurred on July 23 on the north bank. The offshore transducer maintained the same pitch throughout the season. From July 11–23, a total of 22,703 fish were tracked nearshore and 740 fish offshore. The nearshore sampling range terminated at 30 m and the offshore sampling range began at 25 m, which created an overlap of the sampling ranges at 25–30 m from the transducer. Fish passing through the nearshore beam were not tracked beyond the 25 m range due to extensive bottom noise interfering with our ability to track targets (Figure 15). The fish targets were concentrated in the lower edge of the nearshore beam from 4–19 m (Figure 16). From 19–25 m a lower fish density was observed. In the offshore beam, fish were on the lower edge from 26–37 m. From July 23–August 19, a total of 19,070 fish were tracked nearshore and 1,464 fish offshore. Fish targets were in the lower edge of the nearshore beam from 1–16 m and higher in the beam at ~13 m. Offshore fish were on the lower edge from 18–33 m with detection falling off after that. For both months, fish distribution remained slightly off the river bottom throughout the sampling range.

In 2003, the pitch remained the same for both transducers so only 1 fish-profile plot was created. A total of 21,811 fish were tracked nearshore and 140 fish offshore on the north bank. Nearshore fish were distributed in the beam from edge to edge at 1–4.5 m then were centered in the beam close to the river bottom from 4.5–24 m (Figure 17). Offshore fish were tracked high in the water column in the top of the beam from 19–31 m and in the lower edge of the beam from 27–30 m. The majority of the fish tracked were between 19–31 m, the area with no noise corruption. It became harder to distinguish fish echoes from the noise starting at 29 m (Figure 18). Fish targets were scattered through the beam out to the 75 m end range.

The average horizontal (upstream/downstream) and vertical positions of each fish track were calculated from the split-beam sonar angular data (Table 3). If the fish passed directly through the beam, the averaged horizontal position would be close to zero. If the fish were bottom-oriented, the averaged vertical position should be below the beam's center. North bank nearshore fish echoes were distributed around the center of the transducer beam in 2001 and 2003, and below the center line in 2002 (Figure 19). Offshore fish echoes were clustered below the transducer beam's center in 2001 and 2002, and throughout the beam in 2003 (Figure 20). For the south bank, fish echoes were centered below the centerline with targets spreading out as depth increased (Figure 21).

Table 3.–Average horizontal and vertical position of tracked fish from the split-beam sonar at the Kenai River.

Year	Transducer	Vertical (degrees)	Horizontal (degrees)
North Bank			
2001	Nearshore	0.29 ± 0.46 (s.d.)	-0.005 ± 0.83 (s.d.)
2002	Nearshore	-1.14 ± 0.43	-0.30 ± 0.86
2003	Nearshore	0.09 ± 0.40	-0.16 ± 0.75
2001	Offshore	-0.33 ± 0.26	0.05 ± 0.70
2002	Offshore	-0.78 ± 0.18	0.10 ± 0.82
2003	Offshore	0.38 ± 0.45	0.18 ± 0.80
South Bank			
2001	-	-1.09 ± 1.00	0.10 ± 1.00

The average horizontal position was within one standard deviation of zero for all transducers in all 3 years. The average vertical position of tracked fish was below the center of the nearshore beam in 2002 and the offshore beam in 2001 and 2002.

The average TS, velocity, and number of echoes per fish are summarized in Table 4 for all tracked fish echoes. For the north bank, the average TS values by year ranged from -33.0 to -28.7 dB. The TS of fish tracked from the nearshore transducer looked similar and remained fairly constant from the start of the range bin toward the end (Figure 22) in 2001 and 2003. In 2002, the nearshore TS increased through the mid range then decreased at far range. In 2001 and 2002, the offshore TS remained fairly stable throughout range. In 2003, the offshore TS was less consistent throughout the range. The velocity of tracked nearshore fish decreased toward the end range for all 3 years sampled (Figure 23). The offshore fish velocities were much more dynamic. The average number of echoes for fish from each transducer was highly variable for nearshore and offshore fish (Figure 24). As expected, the number of echoes for fish at close range to the transducer was low and increased with range. For all 3 years sampled, the number of echoes per fish in the nearshore beam increased with range then decreased toward the end range. The offshore echoes were more dynamic. For the south bank, the TS of tracked fish remained constant within 6 m of the transducer then increased out to the 10 m end range (Figure 25). The velocity of tracked fish on the south bank increased to mid range then leveled off. The number of echoes per fish in the beam remained constant throughout the 10 m range.

Table 4.–Average target strength, velocity, and numbers of echoes per tracked fish from the split-beam sonar at the Kenai River.

Year	Transducer	Target Strength (dB)	Velocity (m/s)	Echoes/Fish (#)	Files Tracked
North Bank					
2001	Nearshore	–32.2 ± 2.3 (s.d.)	0.16 ± 0.11(s.d.)	31.1 ± 24.1(s.d.)	10 min/h samples
2002	Nearshore	–29.1 ± 3.7	0.20 ± 0.11	44.6 ± 26.4	10 min/h samples
2003	Nearshore	–32.7 ± 3.7	0.14 ± 0.12	20.8 ± 13.2	1 h/d samples
2001	Offshore	–33.0 ± 2.6	0.23 ± 0.10	42.5 ± 24.3	10 min/h samples
2002	Offshore	–28.8 ± 3.0	0.23 ± 0.12	31.7 ± 17.4	10 min/h samples
2003	Offshore	–28.7 ± 2.7	0.24 ± 0.18	37.9 ± 29.8	1 h/d samples
South Bank					
2001	-	-31.8 ± 3.8	0.15 ± 0.27	15.7 ± 9.4	24 h/d samples

COMPARING BENDIX AND SPLIT-BEAM SONAR ESTIMATES OF MIGRATING SALMON

Daily Bendix and Split-beam Estimates Compared

Paired daily estimates of migrating fish from the HTI split-beam and Bendix sonar systems were compared for each of the sample years (2001–2003). Because we were interested in comparative data and not daily passage, we removed rather than extrapolated the blocks of missing data that extended beyond a couple of hours. Consequently, daily totals reported here do not always represent a complete day's estimate of salmon passage and will not match the numbers reported in the annual Kenai River sonar reports (Davis 2002; Westerman and Willette 2003a, b). In each case, the data were missing from the HTI system, not the Bendix. Single or double hours of missed data from the HTI system were interpolated by adding the hour prior to the missed data and the hour proceeding and dividing by 2.

North Bank

In 2001, 29 daily paired HTI and Bendix samples were compared. Out of the 531 nearshore HTI samples collected, 79 (14.9%) of the corresponding offshore files were lost due to system crashes, and 73 (July 1–8) were corrupted by surface noise for more than half their range (Figure 26, top). No fish were counted in the offshore during this time. On July 9, the aim of the offshore transducer was adjusted to reduce surface noise until only noise from the buoys appeared (Figure 26, bottom). Due to the missing and corrupted offshore data, only nearshore HTI data were used in 2001 for comparison with the Bendix data. To justify using only the nearshore counts, we plotted the percent of nearshore fish along with the total passage estimates using only the samples when offshore counts were recorded (Figure 27). Offshore fish passage accounted for only 0.55% of the total.

In 2002 and 2003, nearshore and offshore HTI visual count data were summed for each hour to obtain a single hourly estimate. A total of 29 paired samples were compared in 2002 and 41 in 2003.

Total fish passage estimates for the days sampled were most similar between the HTI and Bendix in 2001; the expanded HTI estimate of 220,284 and Bendix estimate of 225,781 differed by only 5,497 fish (2.5%). In 2002 and 2003, the differences between the 2 estimates were greater. In 2002, the expanded HTI estimates totaled 349,907 while the Bendix estimate totaled 283,204, a difference of 66,703 fish (23.6%). In 2003, the expanded HTI estimates totaled 626,256 while the Bendix estimate totaled 550,351, a difference of 75,905 fish (13.8%). In 2001, the HTI and Bendix estimates were very similar except during periods of peak passage (Figure 28). In 2002, more fish were counted daily with the HTI except at the start and end of the season. In 2003, more fish were counted daily with the HTI except for 1 peak midseason.

Range data produced from the HTI and Bendix systems were used to plot partial cross-river fish distributions. Distributions from both systems showed shore-oriented migration but the peak regions varied during each of the study years (Figures 29–31). The HTI peak regions were slightly wider and less peaked than Bendix in 2001–2002, but in 2003, the 2 distributions were more similar. Using the HTI visual count data (10 min/h counts) from 2001, which included offshore data, the nearshore estimate composed 99.5% of the total fish counted using this system. In 2002 and 2003, the nearshore estimates were 98.1% and 99.0% of the total, respectively (Figure 32). The percentage of offshore counts was higher during the start and end of the season when the fish passage was lowest. Using the HTI tracked fish dataset, and lumping nearshore and offshore fish together, the range where 95% and 99% of the fish traveled was within 13 m (95% point) and 21 m (99% point) from the transducer in 2001, 20 m and 28 m in 2002, and 13 m and 22 m in 2003. The range with the greatest concentration of fish was 5–7 m from the transducer during 2001–2002 and 3–5 m in 2003.

Regression results from the comparison of daily estimates between the 2 sonar systems showed the relationship in 2002 and 2003 was better than that in 2001 as evidenced by the higher r^2 and slope values (Table 5). The 95% confidence intervals show that the regression slope values obtained were not significantly close to 1 during any of the comparison years. However, the edges of the confidence intervals were close to 1. In 2002, the paired data contained the highest r^2 values. This was the same year the final estimates were the most different. Plotted regression lines show that the difference between the 2 sonar’s varied the most in 2001 and least in 2002 (Figure 33).

Table 5.–Regression results for the HTI split-beam and Bendix sonar comparison of daily counts.

Year	Bank	Regression Equation	S.E. (slope)	r^2	95% Confidence (Slope)
HTI as the independent (predictor) variable					
2001	North	*y = 0.67x+ 2707*	0.12	0.55	0.43-0.91
2002	North	*y = 0.73x + 937*	0.04	0.91	0.64-0.82
2003	North	*y = 0.86x + 363*	0.06	0.83	0.73-0.98
2001	South	*y = 0.16x + 1872*	0.03	0.48	0.10-0.22
Bendix as the independent variable					
2001	North	*y = 0.83x + 1159*	0.14	0.55	0.53-1.12
2002	North	*y = 1.25x – 136*	0.07	0.91	1.10-1.40
2003	North	*y = 0.97x+ 2264*	0.07	0.83	0.83-1.11
2001	South	*y = 3.06x+ 1330*	0.56	0.48	1.92-4.19

South Bank

In 2001, 34 daily HTI samples were compared to the daily Bendix estimate. Fish passage estimates for the days sampled were very different between the 2 systems with the HTI ensonifying fewer fish targets (Figure 34). The HTI estimate of 109,333 and Bendix total estimate of 288,727 differed by 179,394 fish (37.9%). Less fish were counted daily with the HTI through the entire season.

Regression results from the comparison of daily estimates between the 2 systems showed a large variation in the relationship evidenced by the low r^2 values (Table 5). When HTI was used as the predictor, the 95% confidence intervals show that the regression slope values were closer to zero than to 1. When Bendix was used as the predictor, the 95% confidence intervals show that the regression slope values obtained were substantially higher than 1. Plotted regression lines show the large difference between the 2 systems (Figure 35).

Range data from both systems showed shore-oriented fish migration but the peak regions varied (Figure 36). The HTI peak regions were slightly wider and less peaked than Bendix. From the HTI tracked fish dataset, the range where 95% and 99% of fish traveled was within 4 m and 6 m from the transducer, respectively. Both systems showed the greatest concentration of fish occurred within 2–3 m from the transducer.

Hourly Bendix and Split-beam Estimates Compared

North Bank

The paired data from the HTI and Bendix sonar systems resulted in a total of 555 h of data in 2001, 625 h in 2002, and 932 h in 2003. In this section, we treated the hourly data as individual samples and recalculated the regressions. The r^2 and slope values from the hourly samples were lower on average compared to the daily samples (Tables 5 and 6). Like the daily samples, the 95% confidence intervals from the hourly samples show the slope values to all be considerably different from 1. With the HTI as the predictor, the upper limits of the confidence intervals are well below 1. In 2002 and 2003, the slope values obtained when the HTI was used as the independent variable were higher each year for the hourly samples compared to the daily samples. Compared to the daily estimate, there was considerably more spread in the data points from the hourly estimates, and regression lines from the 2 predictors were more disparate from each other during each of the sample years (Figure 37).

Table 6.–Regression results for the HTI and Bendix sonar comparison of hourly counts along the north bank of the Kenai River.

Year	Regression Equation	S.E. (slope)	r^2	95% Confidence (Slope)
HTI as the independent (predictor) variable				
2001	$y = 0.50x + 212$	0.03	0.40	0.45-0.55
2002	$y = 0.62x + 104$	0.02	0.66	0.59-0.66
2003	$y = 0.70x + 120$	0.02	0.60	0.66-0.74
Bendix as the independent variable				
2001	$y = 0.81x + 61$	0.04	0.40	0.72-0.89
2002	$y = 1.05x + 83$	0.03	0.66	0.99-1.11
2003	$y = 0.86x + 163$	0.02	0.60	0.82-0.91

Because the inseason daily passage estimate has the most value to fishery managers, we calculated a regression slope from the hourly data for each day sampled to obtain a daily slope value. Daily slope values ranged between –1.2 and 2.1 (Figure 38). In 2001, the fish passage peaks were accompanied by higher daily regression slopes with the highest slope values calculated in the middle of the season, during high passage. In 2002, the highest and lowest slope values occurred during low passage. In 2003, the higher daily regression slope values varied between high and low passage with the highest slope values calculated during higher passage.

We collapsed the hourly data from across the field season by hour of the day to look for diurnal patterns in fish migration. The percentage of fish counted for each hour was surprisingly similar between the 2 systems, except in 2001, when the HTI was lower during the early morning when passage rates were less, and higher from 1400–2000 hours during the highest passage period (Figure 39). The lowest fish passage for both systems occurred at 0400 hours in all 3 years except in 2003 when the Bendix low shifted to 0800 hours. Periods of highest passage were more variable between years. The highest fish passage occurred from approximately 1800–2200 hours in all 3 years with variability within each year.

South Bank

Because of the large disparity between the daily estimates from the 2 south bank sonar systems, hourly estimates were not analyzed. However, the estimates were plotted by hour to display the diurnal migration pattern.

The percentage of fish passage by hour was similar between the 2 systems and no obvious difference in diurnal pattern was examined (Figure 40). The lowest fish passage occurred at 0400–0500 hours and the highest passage was at 1700 hours. The pattern of fish passage across a day was similar to what was seen on the north bank in 2001.

DISCUSSION

TESTING THE SPLIT-BEAM SONAR

Equipment, Calibrations, Aiming

During the first 2 years of operation, the network connecting the HTI sonar to the controller computer crashed frequently resulting in much lost data. Prior to the 2002 field season, HTI worked out the incompatibility problems making the system more stable. Software problems created many setbacks in the data processing. Moving from Withler's Polaris, to HTI's Echoscape, to SonarData's Echoview required reprocessing the data numerous times as the bugs were discovered, and Polaris and Echoscape deemed unusable in their current state. Although the Echoview program also contained a few problems, none prevented us from processing the data.

Field calibration results showed that measured target strength of the calibration sphere was within the standard deviation of the theoretical value except for the 2^o by 6^o in 2001. Although the echo patterns from the calibration sphere were not completely random, each quadrant contained numerous echoes. Therefore, there was no reason to suspect a problem with the transducers. In 2001, the echoes in the nearshore beam were distributed in a diagonal line from the upstream bottom quadrant to the downstream top quadrant on the north bank with the reverse pattern on the south bank (Figures 9 and 11). The most probable reason for this pattern was that the tungsten carbide sphere was being detected first on the river bottom in the upstream quadrant, and as it was slowly raised in the beam, the current pushed the target downstream. In 2002 and 2003, the target was moved more effectively through all 4 quadrants.

Aiming the transducers using the aiming protocol we devised (Appendix B1) gave us confidence in the positioning of the transducer beam. The protocol, which utilized both profile and sensor information, provided a means for technicians to re-aim the transducer successfully after a change in water level or disturbance to the transducer. Without this information, it would be difficult if not impossible to determine how well the beam was directed along the river's bottom. Using the echogram helps, but there are many situations where the echogram alone does not provide enough information to achieve an accurate aim, and can even provide misleading information. The transducer beam can bounce off the surface, hit the river bottom and return the signal to the transducer resembling river bottom. The user would think that the beam was aligned along the bottom when it was actually aimed high. The varying transducer pitch between study years was caused by differences in the transducer's distance from the river bottom, level starting position, and the transducer's distance from shore.

The fish-profile plots (Figures 13, 14, 16 and 17) were the most useful tools for determining split-beam system aim quality and for noticing possible target detection problems. However, daily plots are needed to make adjustments inseason as conditions change. Without this information, it is easy to miss problems that arise. Fish profile plots from the 4^o by 8^o HTI transducer data show fish targets at close range from one edge of the beam to the other indicating the beam width was not adequate. Another problem is the gap between the end range of the nearshore transducer and the effective start range of the offshore transducer.

The average target strength of fish tracked in the offshore transducer was much more variable compared to the nearshore for all 3 years. Offshore fish echoes are much more likely to be contaminated with echoes from the river bottom or surface than nearshore targets, which would create a more dynamic target strength.

In 2001, a 6^o by 10^o HTI transducer was deployed on the south bank of the Kenai River with the intent of conducting a comparison study with the Bendix on that bank. After examining the data and comparing with the Bendix, we determined the HTI system was not adequately detecting fish along this shore. We discovered that fish were dodging around the weir, being detected by the Bendix counter, but cutting in too closely to shore to be detected by the HTI system which was placed directly adjacent to the Bendix transducer. Because of successful preliminary tests conducted early in the season in 2002 with a dual-frequency identification sonar (DIDSON) (Maxwell and Gove 2004), we determined that the DIDSON would be more effective on the Kenai River south bank and discontinued further testing with the HTI split-beam sonar.

COMPARING BENDIX AND SPLIT-BEAM SONAR ESTIMATES OF MIGRATING SALMON

Although the HTI split-beam is a more modern system than the Bendix single-beam, the 2 are still subject to many of the same problems (i.e. narrow beams that fish can swim over or under if the bottom substrate is uneven, multi-pathing of echoes from fish, and interference of fish echoes with surface and bottom echoes). Features specific to the Bendix counter include a narrower nearshore beam and lower power (~1 Watt compared to 25 Watts). Both can lead to poor fish target detection. However, the Bendix is an echo-counter unable to distinguish between fish echoes and non-fish echoes if their amplitudes are similar. The real-time visual display from the Bendix oscilloscope used to calibrate the counter is poorer than the output from the split-beam system. Distinguishing fish from non-fish echoes is more difficult on the Bendix, and the Bendix counter has a greater potential to overcount fish. The combination of an undercount bias from poorer detection and overcount bias from counting noise echoes adds uncertainty to the Bendix count.

The HTI split-beam system required more time than the Bendix system for training technicians to operate the equipment and process the data. We found that although split-beam data processing was far more cumbersome than Bendix, we were able to keep up with daily counts by subsampling. Compared with the Bendix single transducer configuration, the HTI nearshore and offshore transducer configuration allowed a larger range to be sampled with less interference from the bottom. The echogram from the HTI system is electronically recorded, so a playback of fish passage is available, something not possible with the Bendix. During manual counting of fish tracks, the echogram can be scrolled through quickly to obtain a 10-minute subsample making it possible to report to fisheries managers an hourly escapement estimate. Subsampling the data was a necessity.

The autotracking program was not usable with the noisy split-beam data from the Kenai River. If the split-beam is to be used to estimate fish passage, a better method of visually counting the data would be to use a sonar system that constructs the echogram from the raw data and not the processed echo data. The echo data discards too many echoes making it difficult to count fish traces, especially during high passage. Manually tracking fish during high passage on the Kenai would create a lag in the daily processing of the data. Manual tracking was more subjective because each individual determined what was a fish from the positional data accompanying each track. Poor target tracking was caused by multi-path echoes, crosstalk, boat bubbles, and unknown sources of reverberation. Fish holding and backing into the beam from upstream caused messy echograms. During high passage rates fish tracks become more difficult to distinguish because of the high density of bank-oriented salmon and the resulting multiple echoes. It became difficult to detect and track fish close to the transducer.

The Bendix counts are an integral part of the fisheries management program. If the HTI system were to replace the Bendix, we would need to understand the relationship between fish counts from the 2 sonars. Although passage rates from the 2 sonars tracked each other fairly well, during peak passage the 2 were often different. In general, the HTI counts were higher during peak periods; however, the Bendix counts were higher during 2 of these peaks. The daily slope values displayed in Figure 38 are also highly variable. Because the differences between the 2 sonars are variable, and we don't understand the error from either system, more information would be necessary to convert to the HTI system.

In 2002, the HTI sonar was deployed late because of scheduling conflicts with the DIDSON tests. Testing of the new multiple-beam DIDSON sonar (Belcher et al. 2001, Belcher et al. 2002) in 2002 revealed many advantages that this sonar system has over traditional split-beam and single-beam systems. The DIDSON produces a video-like image creating moving fish targets that are generally easy to discern from static noise. The DIDSON's large vertical beam (14^{o}) creates some surface and bottom noise but provides better coverage close to the transducer where the majority of sockeye salmon passage occurs. DIDSON software includes a bottom subtraction feature that allows users to remove static river bottom structure from the image, thus improving the fish image and fish detection abilities. The wide horizontal beam (28.8º) increases the amount of time it takes a fish to traverse the beam, thus making direction of travel easy to determine. On the south bank, the standard DIDSON can be used to ensonify a longer range (30 m) without being limited by the slope change, and provide greater coverage near the transducer.

The north bank HTI system was deployed in 2002 and 2003 because the standard DIDSON was limited to 40 m and could not provide the range coverage of the split-beam sonar. The long, flat river bottom and narrow water column of the Kenai River north bank is not easily ensonified with traditional sonar, whether the system is a modern split-beam system or an older single-beam system. The 2 share many of the same problems. In 2003, ADF&G began researching newly developed long range DIDSON sonar that has a possible range of 90 m. We expected to experience numerous hardware and software problems with the new system, but were surprised to find we were able to operate the DIDSON with few problems and with an ease of operation unsurpassed by even the Bendix sonar. We are moving forward with research on this new system as a possible replacement for the Bendix systems.

ACKNOWLEDGMENTS

The HTI staff answered many concerns and questions about the split-beam system throughout the study years. ADF&G biologist Dave Westerman and technicians Bill Atwood and Oliver Murray spent long hours tracking and editing the sonar data and providing logistical support. The Kenai Bendix crew shared their boats, site, and bunkhouse. Lowell Fair, Regional Research Biologist, reviewed the manuscript.

REFERENCES CITED

Barton, L. H. 2000. Sonar estimation of fall chum salmon abundance in the Sheenjek River. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 3A00-27, Anchorage.

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., Dedham, Massachusetts.

Chapell, R. S. 2001. Anvik River chum salmon escapement studies, 1997-1999. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 2A01-12, Anchorage.

Davis, R. Z. 2002. Upper Cook Inlet salmon escapement studies 2001. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 2A02-17, Anchorage.

Faran, Jr. J. J. 1951. Sound scattering by solid cylinders and spheres. J. Acoust. Soc. Am., 23, pp. 405-418.

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

Maxwell, S. L., and N. E. Gove. 2004. The feasibility of estimating migrating salmon passage rates in turbid rivers using a Dual Frequency Identification Sonar (DIDSON) 2002. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 2A04-05, Anchorage.

Maxwell, S. L., D. Degan, A. V. Smith, L. McKinley, and N. E. Gove. *In prep*. The feasibility of using a split-beam sonar to estimate salmon passage on the Nushagak River as a potential replacement for an echo-counting Bendix Sonar. Alaska Department of Fish and Game, Fishery Manuscript, Anchorage.

Miller, J. D., and D. Burwen. 2002. Estimates of Chinook salmon abundance in the Kenai River using split-beam sonar, 2000. Alaska Department of Fish and Game, Fishery Data Series No. 02-09, Anchorage. http://www.sf.adfg.state.ak.us/FedAidPDFs/fds02-09.pdf

Namtvedt, T. B., N. V. Friese, and D. L. Waltemyer. 1979. Cook Inlet sockeye salmon studies. Alaska Department of Fish and Game, Division of Commercial Fisheries, Technical Report for the period July 1, 1977 to June 30, 1978, Anchorage.

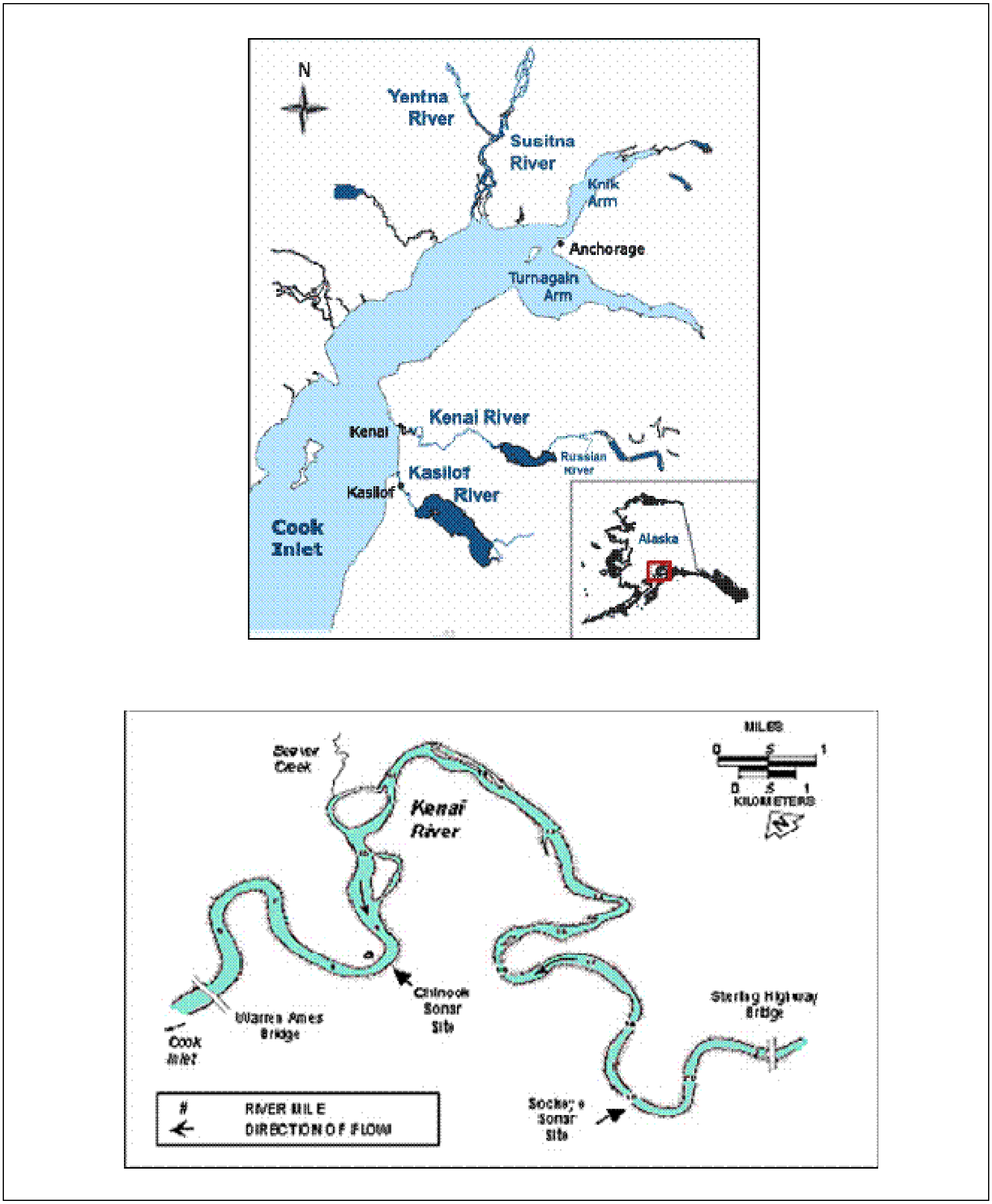
Osborne, B. M., and J. M. Melegari. 2002. Use of split-beam sonar to enumerate Chandalar River fall chum salmon, 2000. U.S. Fish and Wildlife Service, Fairbanks Fishery Resource Office, Alaska Fisheries Technical Report 61, Fairbanks, Alaska.

Smith, A. V., and B. Lewis. 2006. Copper River hydroacoustic salmon enumeration studies 2002-2004. Alaska Department of Fish and Game, Fishery Data Series No. 06-41, Anchorage. http://www.sf.adfg.state.ak.us/FedAidPDFs/fds06-41.pdf

Westerman, D. L. and T. M. Willette. 2003a. Upper Cook Inlet salmon escapement studies 2002. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 2A03-24, Anchorage.

Westerman, D. L. and T. M. Willette. 2003b. Upper Cook Inlet salmon escapement studies 2003. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 2A04-03, Anchorage.

FIGURES



Note: The sonar site is located at river mile 19 on the Kenai River in the city of Soldotna.

Figure 1.–Map of the Kenai River, Alaska.

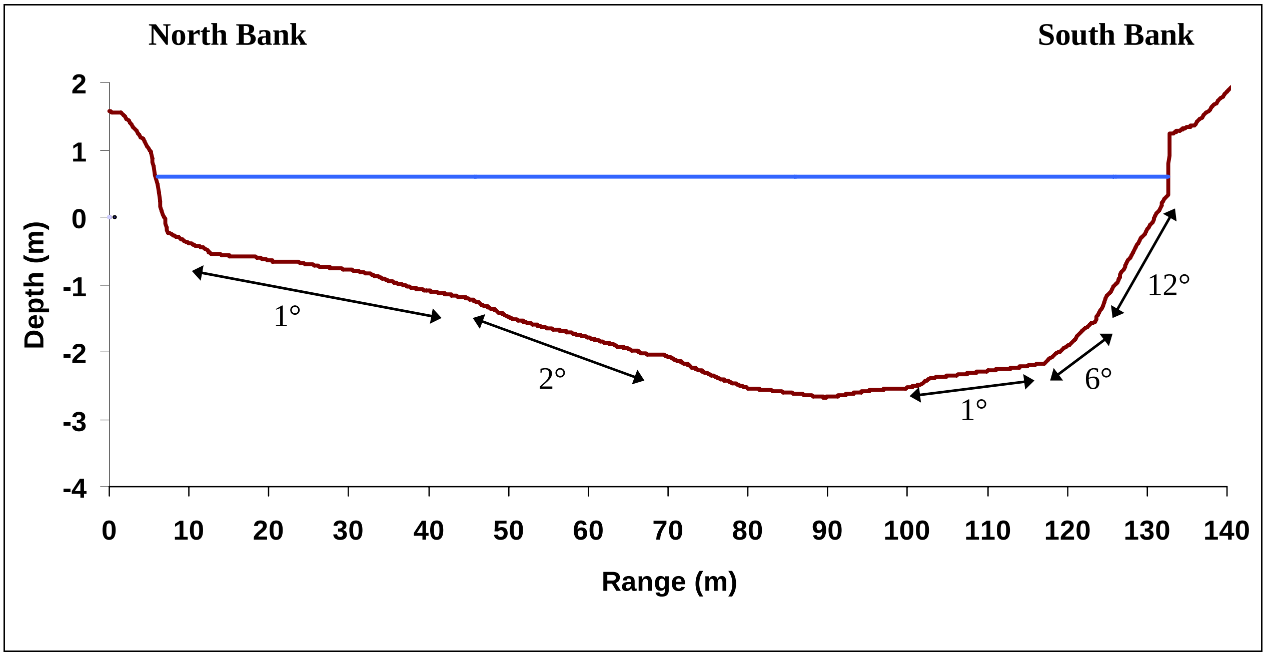


Figure 2.–River bottom profile of the Kenai River at the RM 19 sonar site with the slope changes labeled for each bank.

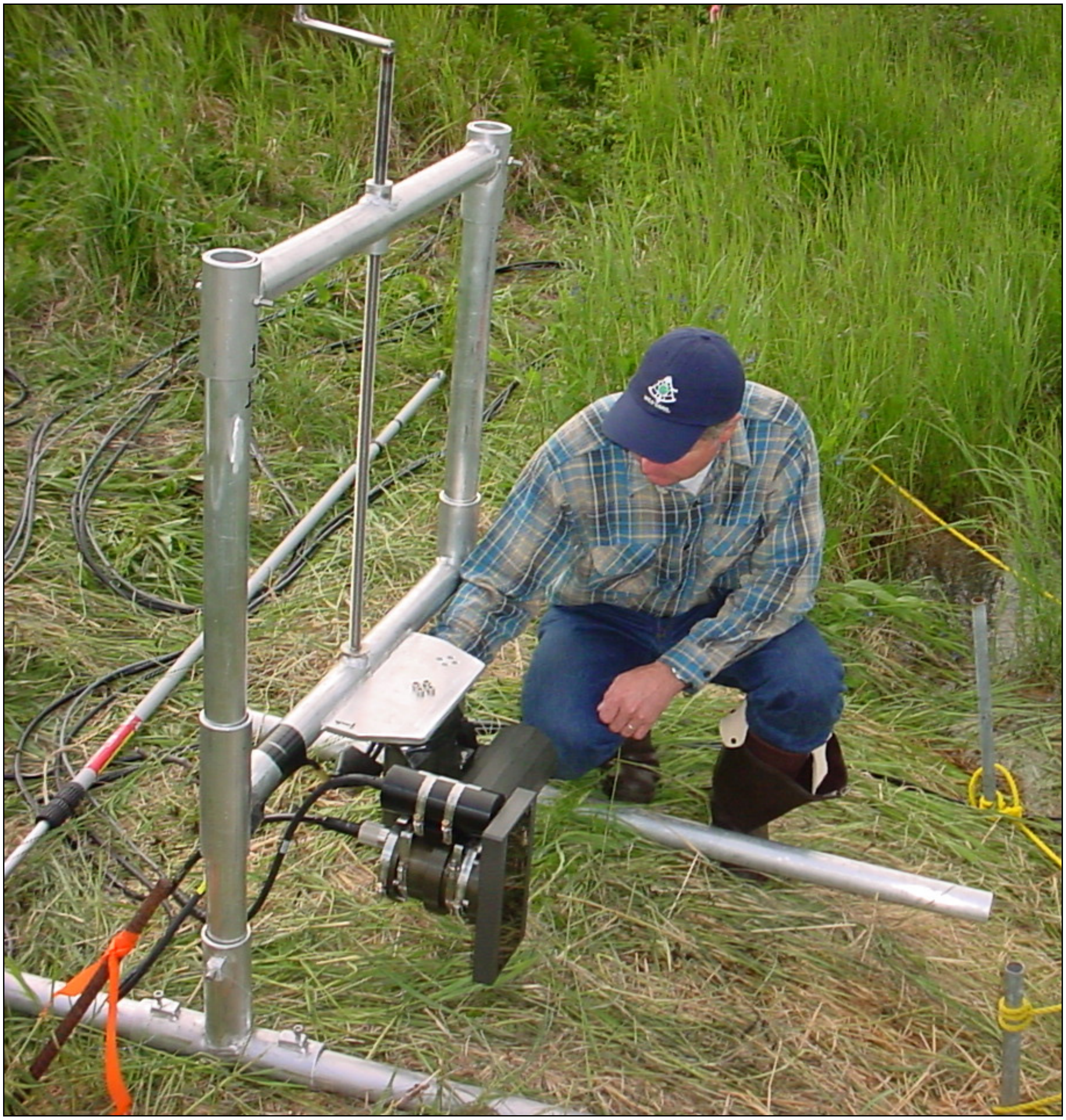


Figure 3.–H-mount made from aluminum poles with 2 single axis rotators, a 2^{o} by 6^{o} HTI transducer, and a BioSonics' attitude sensor used on the north bank of the Kenai River.

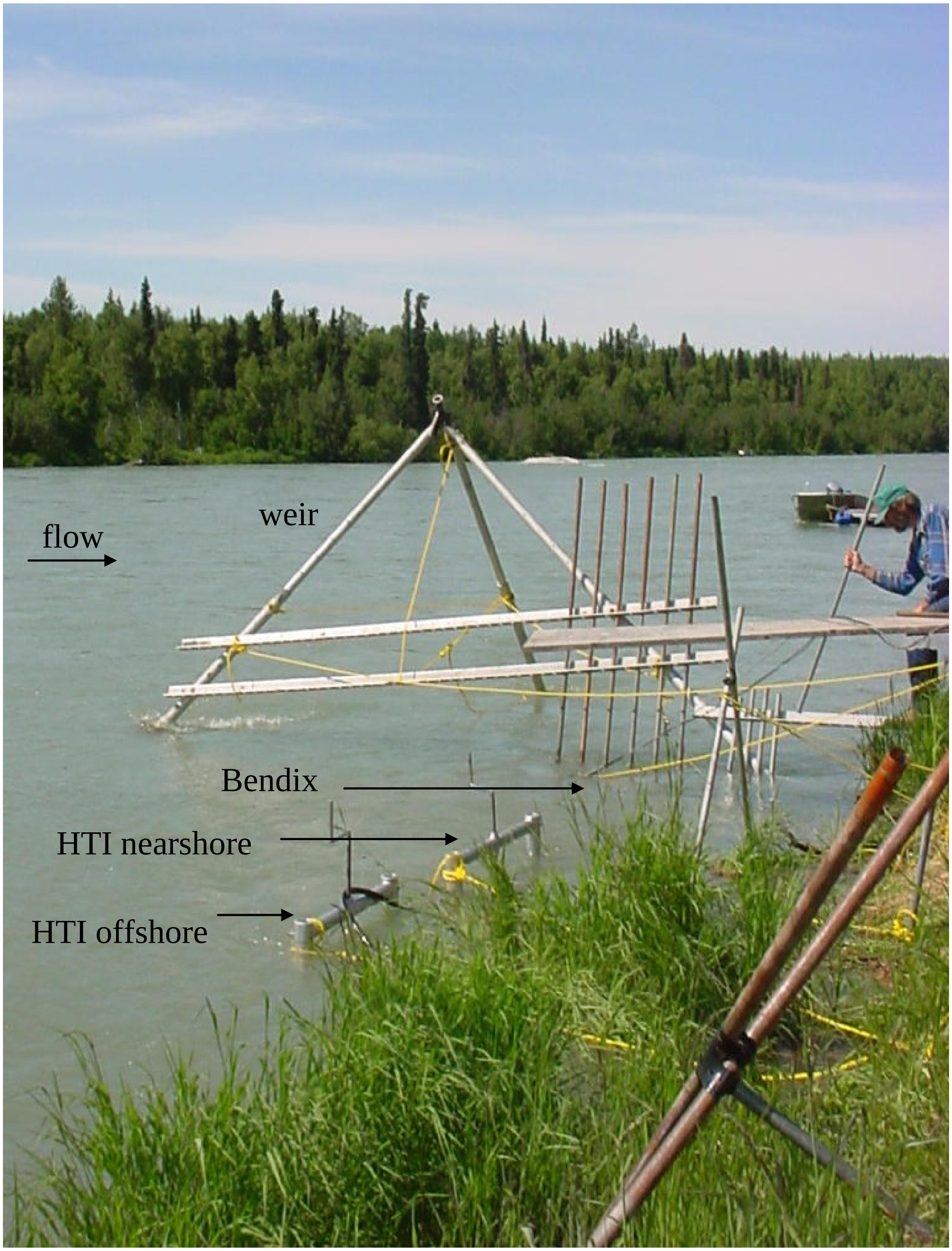


Figure 4.–Nearshore and offshore HTI split-beam transducers deployed side-by-side upstream of the Bendix transducer along the north bank of the Kenai River.

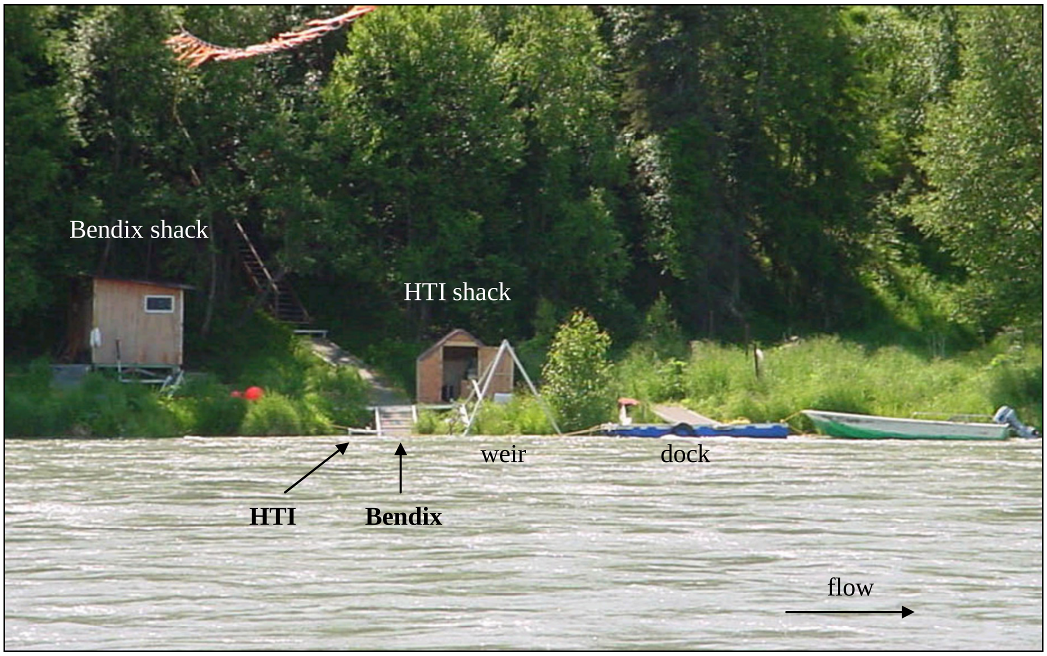
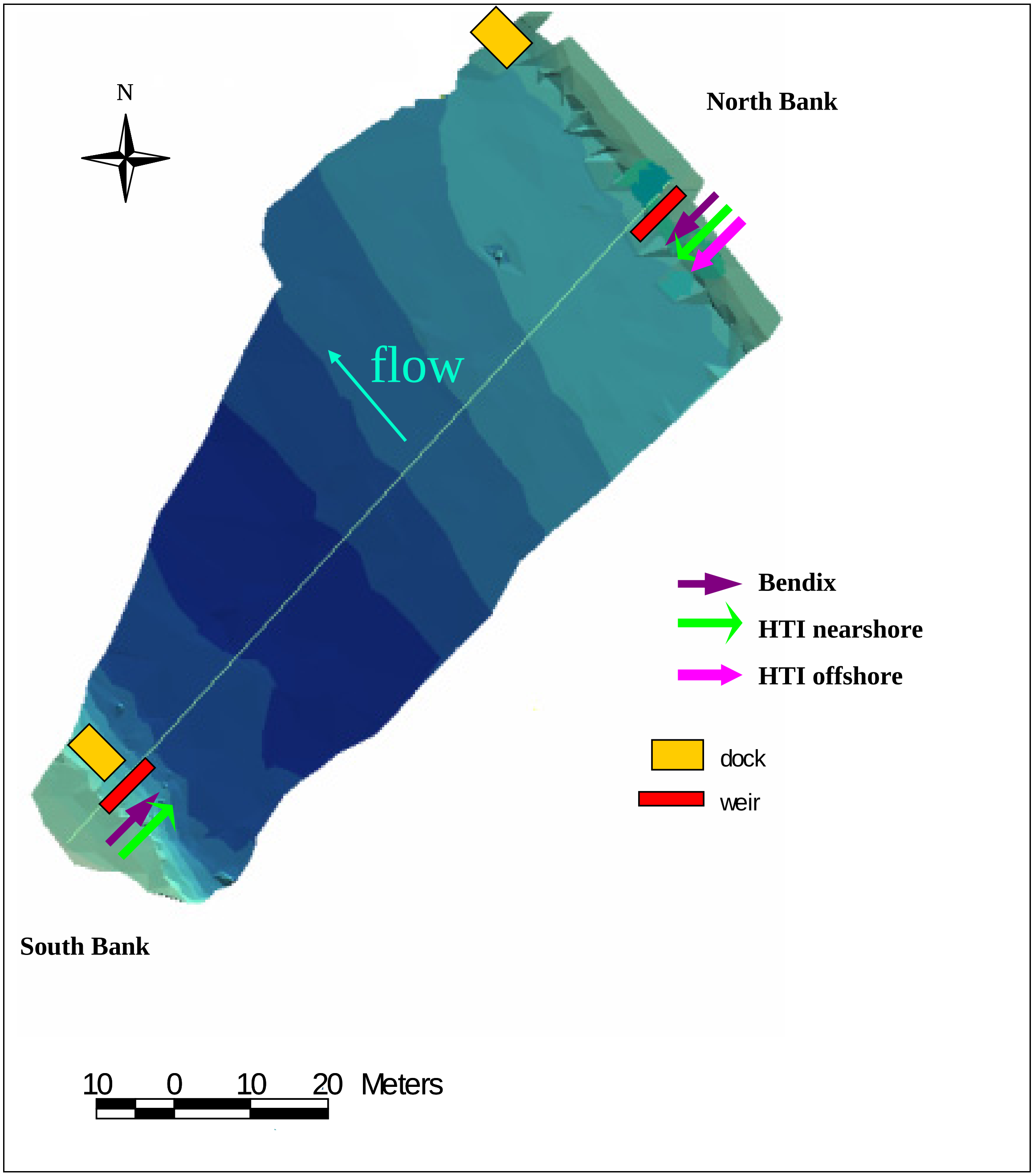


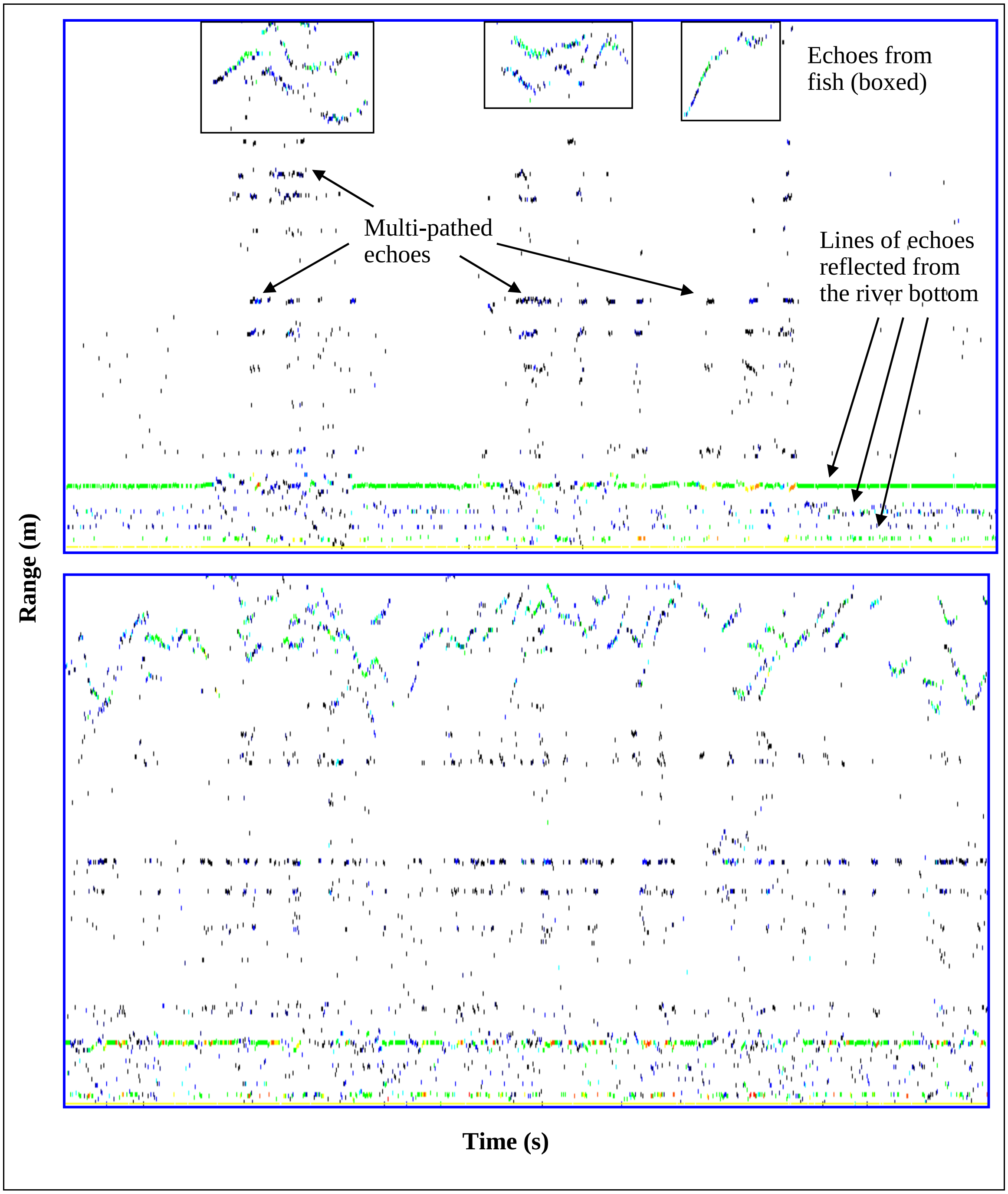
Figure 5.–The Kenai River south bank sonar site and the location of the HTI split-beam transducer deployed just upstream of the Bendix transducer.

Figure 6.–Topside equipment used on the Kenai River north bank included a HTI echosounder, a HTI rotator control box, and a laptop computer used to control the echosounder and display data.



Note: The Bendix and split-beam sonar deployment sites marked for each bank.

Figure 7.–Bathymetry map of the Kenai River at the river mile 19 sonar site.



Note: The end range for this echogram is 8.75 m.

Figure 8.–A low (top) and high (bottom) fish passage echogram from the south bank split-beam transducer showing fish echoes, reflections off the river bottom, and multi-path echoes, Kenai River, 17 July 2001.

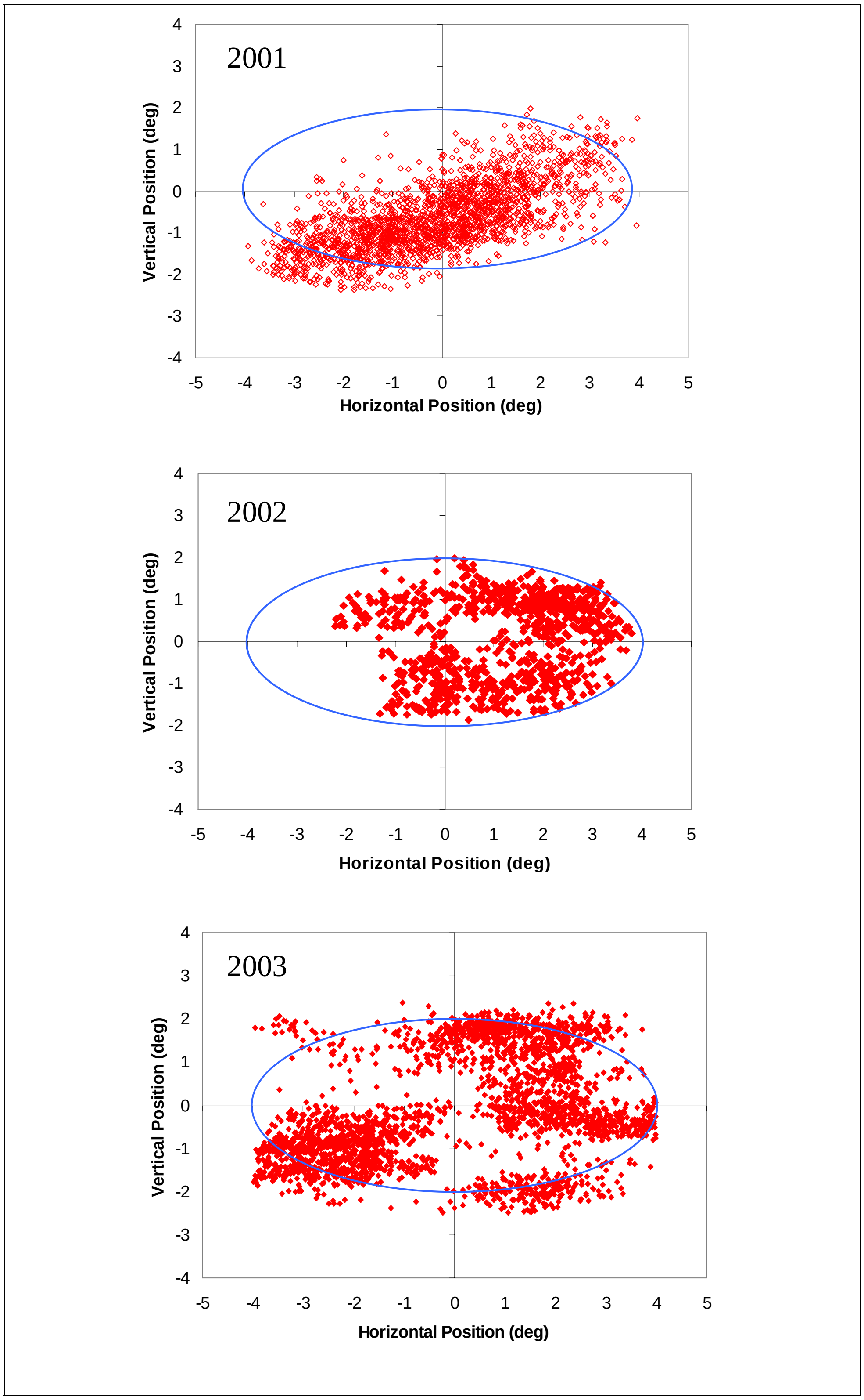


Figure 9.–Position of the 38.1 mm tungsten carbide sphere during calibration of the 4° by 8° split-beam transducer with the nominal beams overlaid, Kenai River north bank, 2001–2003.

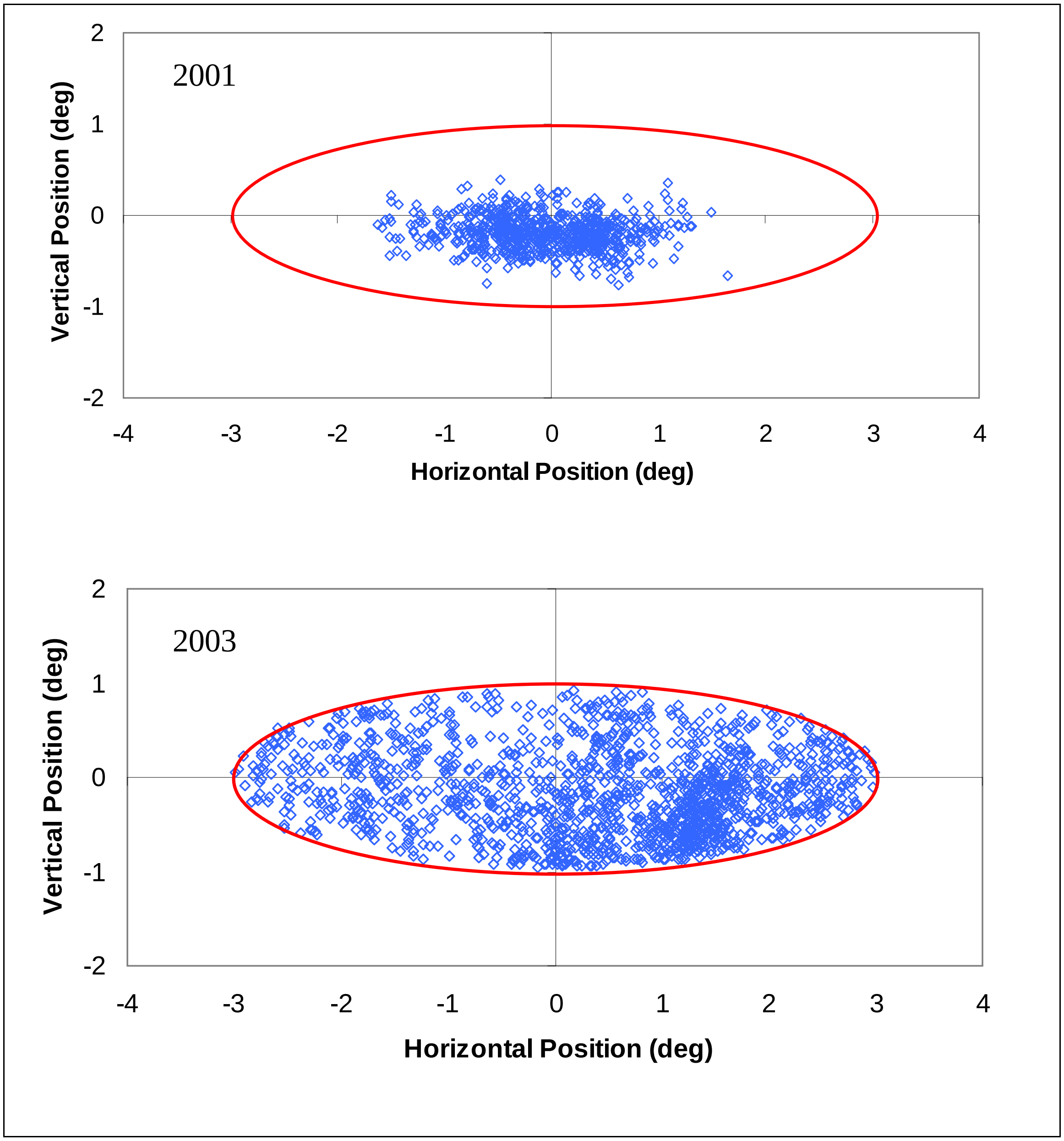


Figure 10.–Position of the 38.1 mm tungsten carbide sphere during calibration of the 2° by 6° split-beam transducer with the nominal beams overlaid, Kenai River north bank, 2001 and 2003.

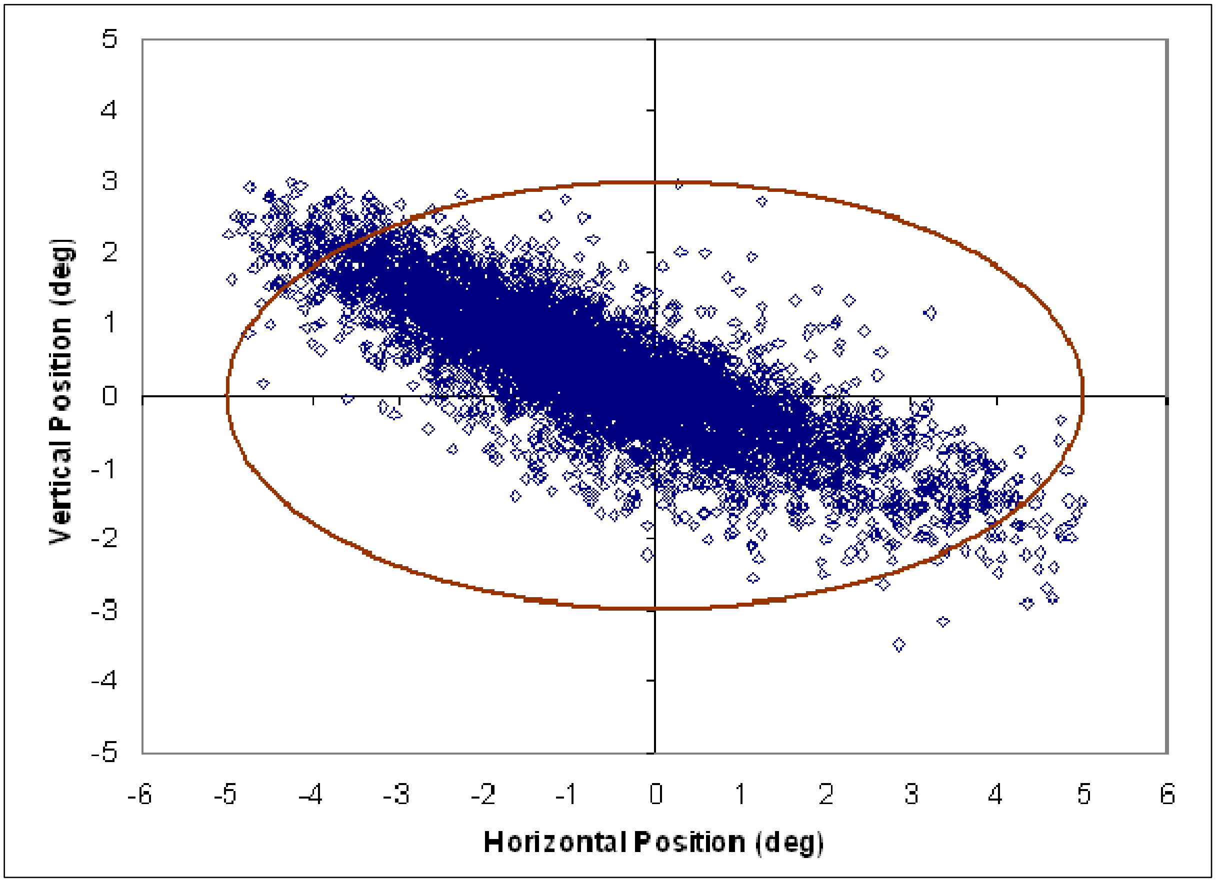


Figure 11.–Position of the 38.1 mm tungsten carbide sphere during calibration of the 6º by 10º split-beam transducer with the nominal beams overlaid, Kenai River south bank, 2001.

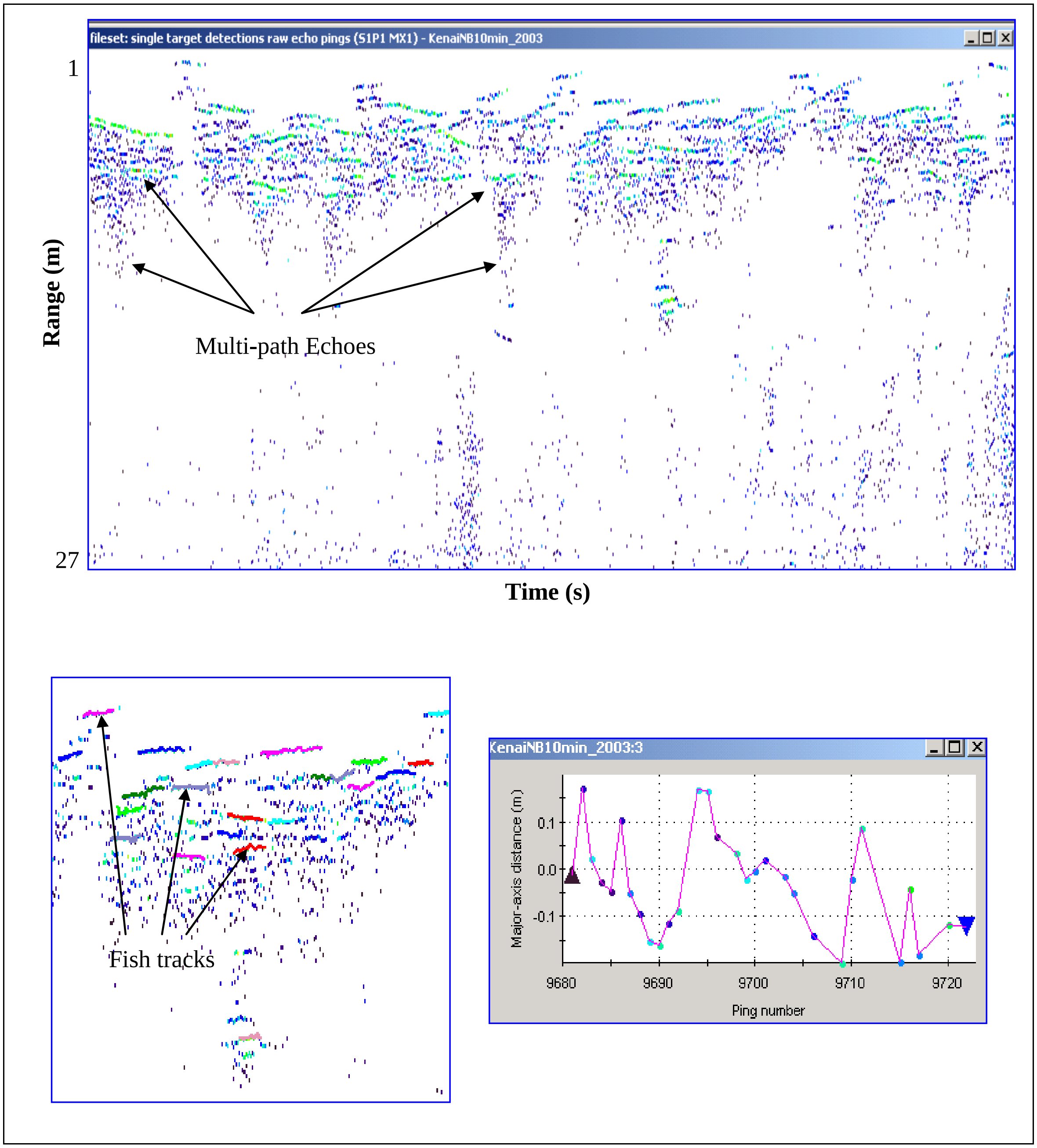


Figure 12.–Fish traveling through the beam of the spit-beam transducer produced multi-path echoes (top) reflected from boundary layers. Tracked fish echoes mixed in with noise (bottom left) and 2 upstream fish tracked as 1 (bottom right), Kenai River north bank, July 16, 2003.

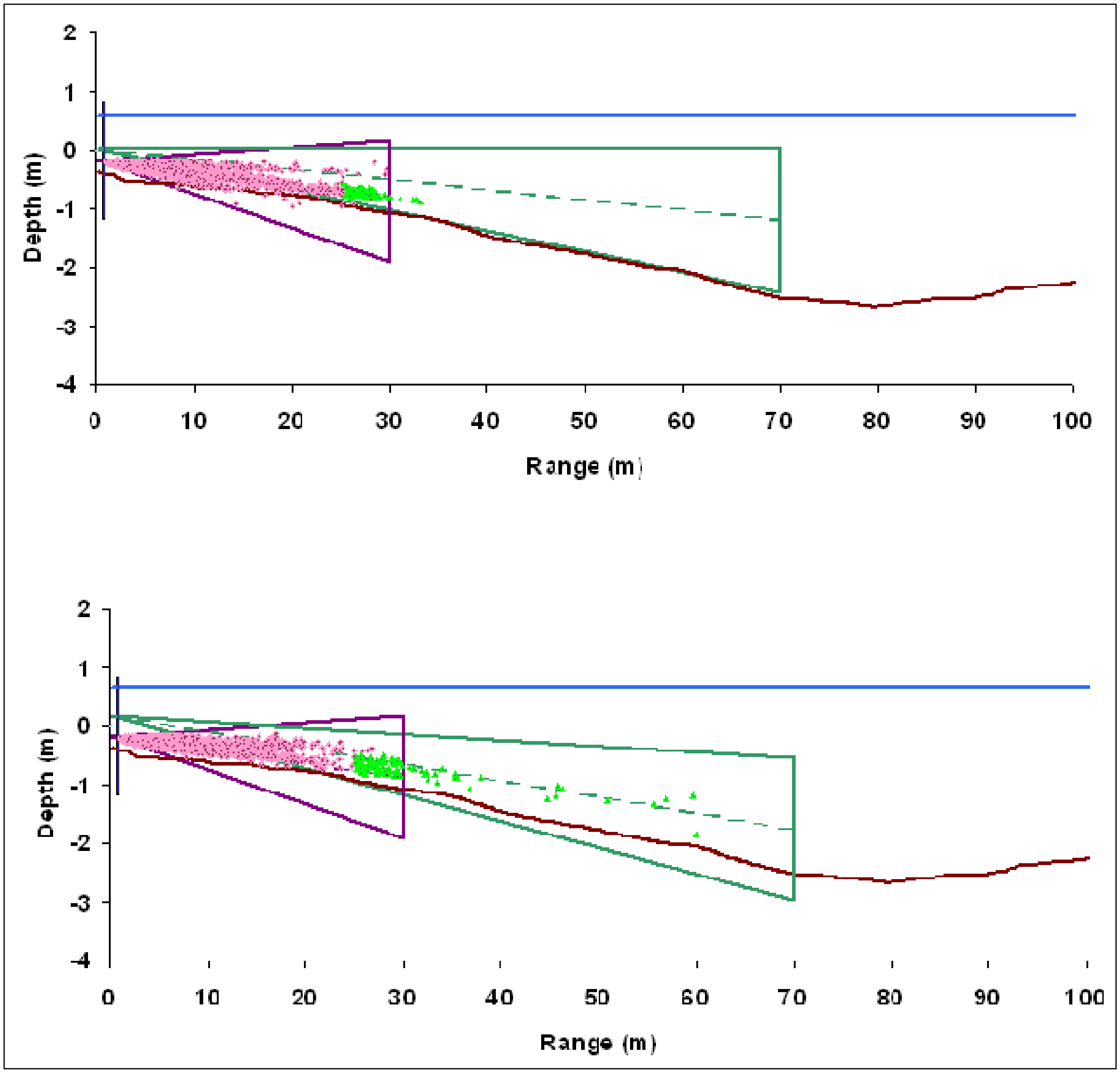


Figure 13.–The average range and vertical position of each tracked fish in relation to the split-beam nominal beams and river bottom profile, July 1–20 (top) and July 20–31 (bottom), Kenai River north bank, 2001.

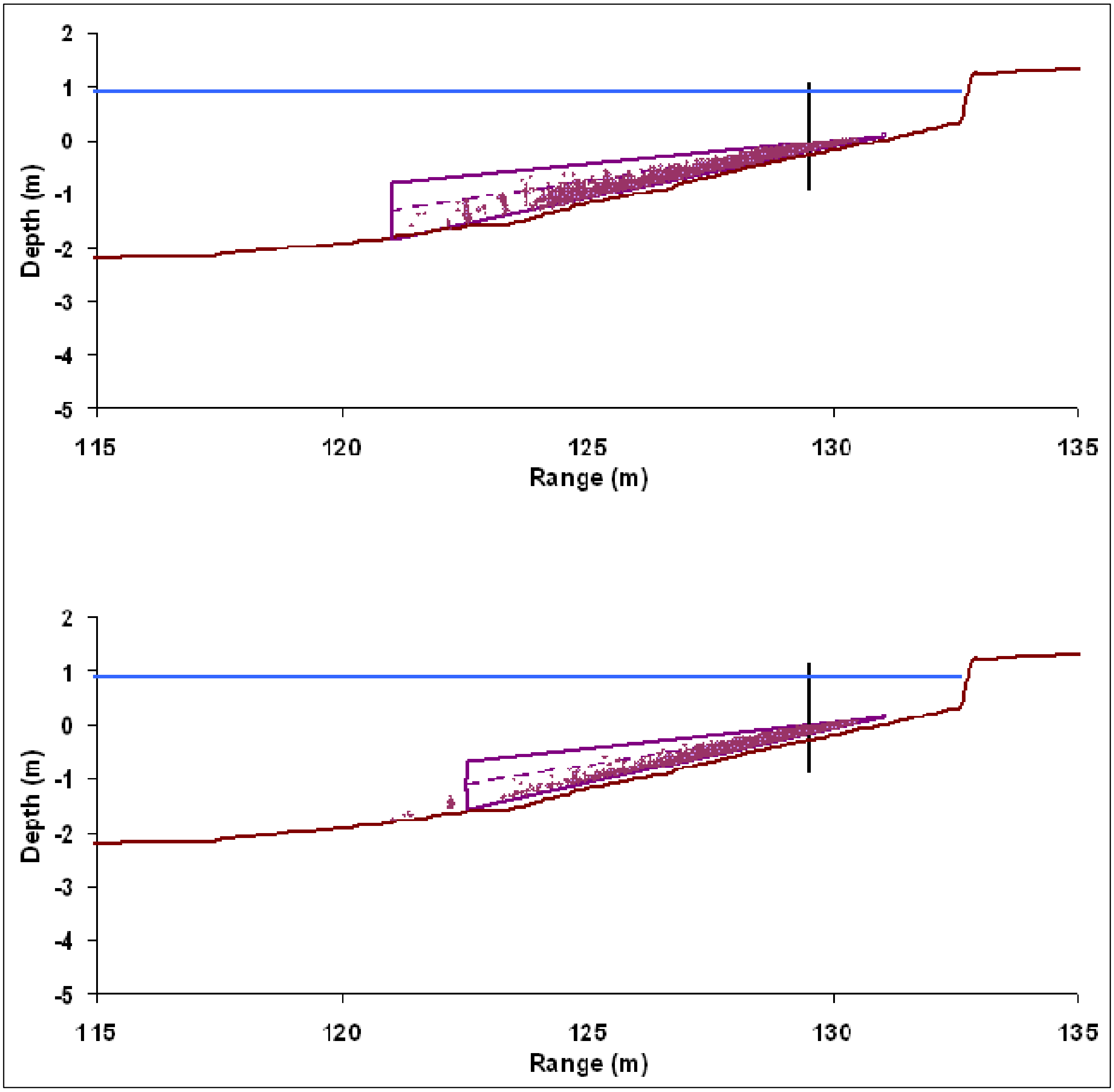
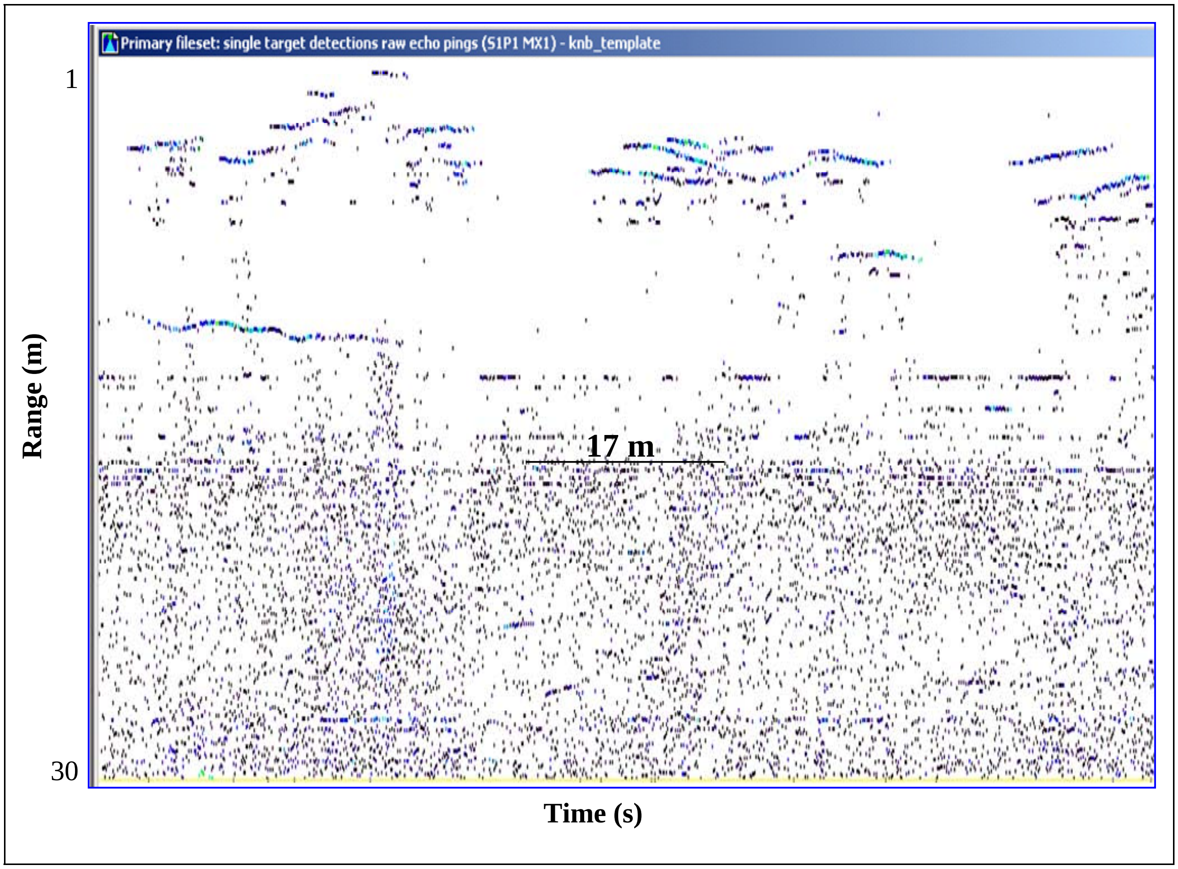


Figure 14.–The average range and vertical position of each tracked fish in relation to the slit-beam nominal beam and river bottom profile July 3–24 (top) and July 25–August 9 (bottom), Kenai River south bank, 2001.



Note: The noise starts at 17 m and end range is at 30 m.

Figure 15.–Echogram from July 23 at 0700 hours, prior to the change in range on the split-beam nearshore transducer, Kenai River north bank, 2002.

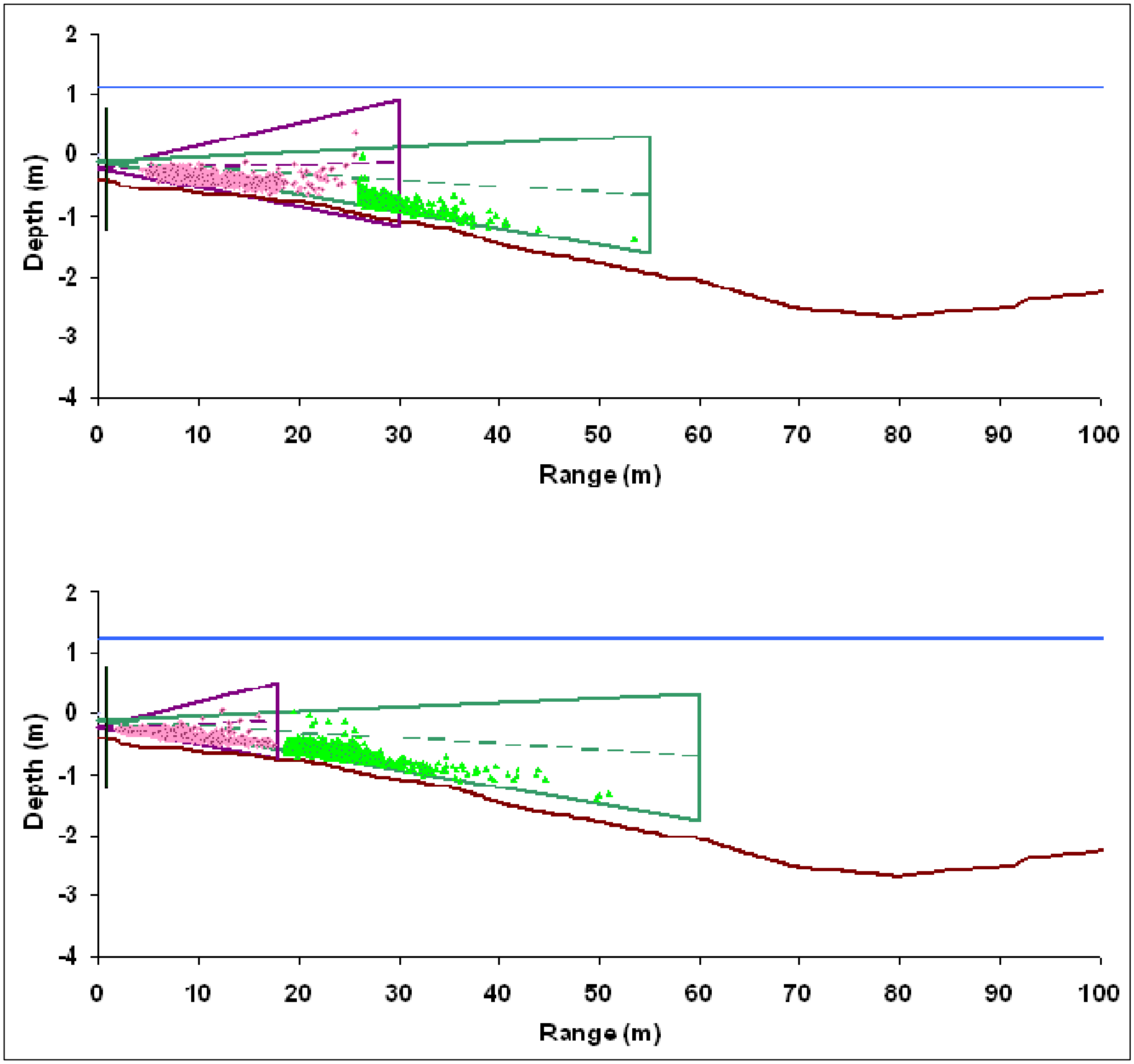


Figure 16.–The average range and vertical position of each tracked fish in relation to the split-beam nominal beams (nearshore and offshore) and river bottom profile, July 11–23 (top) and July 23–August 19 (bottom), Kenai River north bank, 2002.

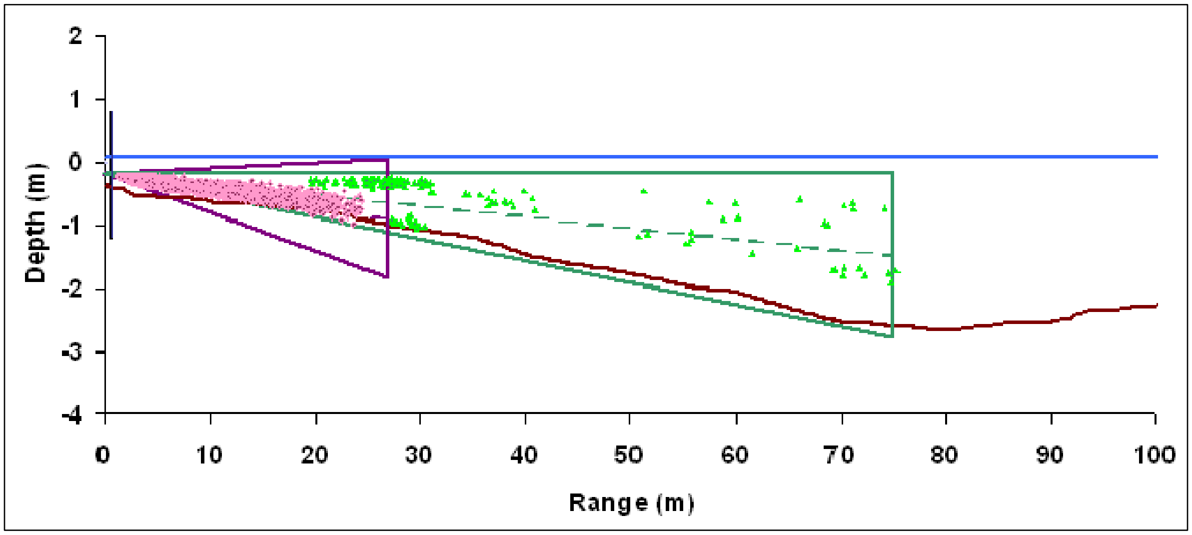
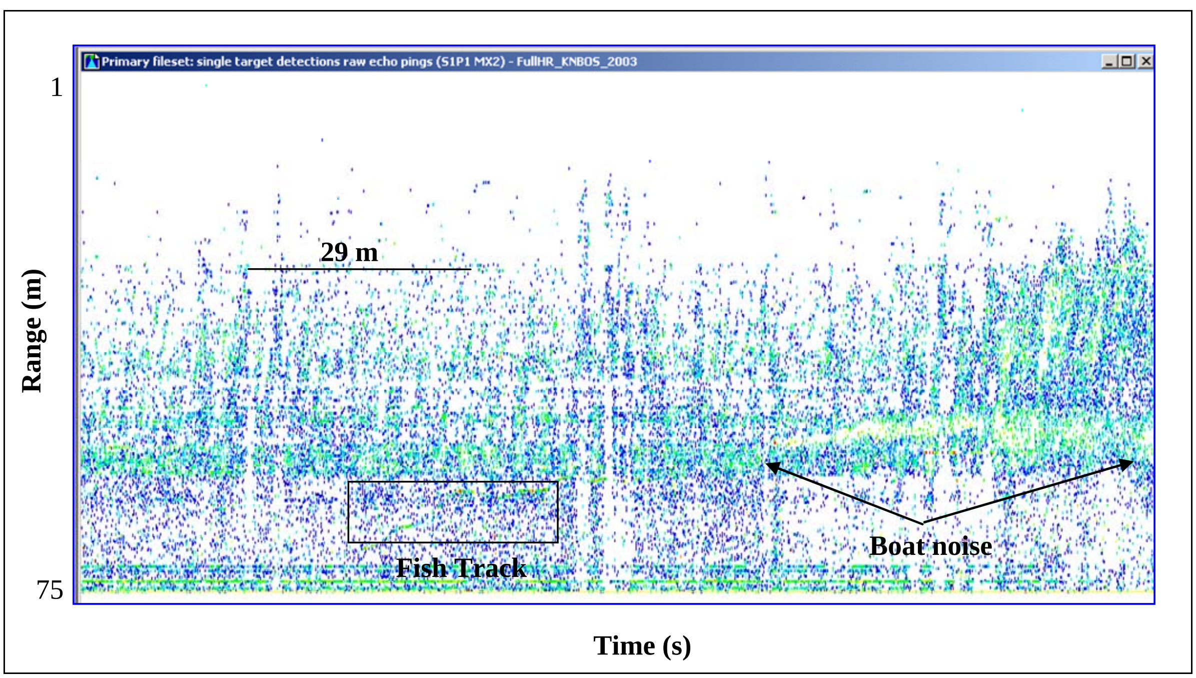


Figure 17.–The average range and vertical position of each tracked fish in relation to the split-beam nominal beams (nearshore and offshore) and river bottom profile, July 1–August 10, Kenai River north bank, 2003.



Note: The noise starts at 29 m.

Figure 18.–Offshore echogram with a sampling range of 1–75 m, Kenai River north bank, July 24, 2003.

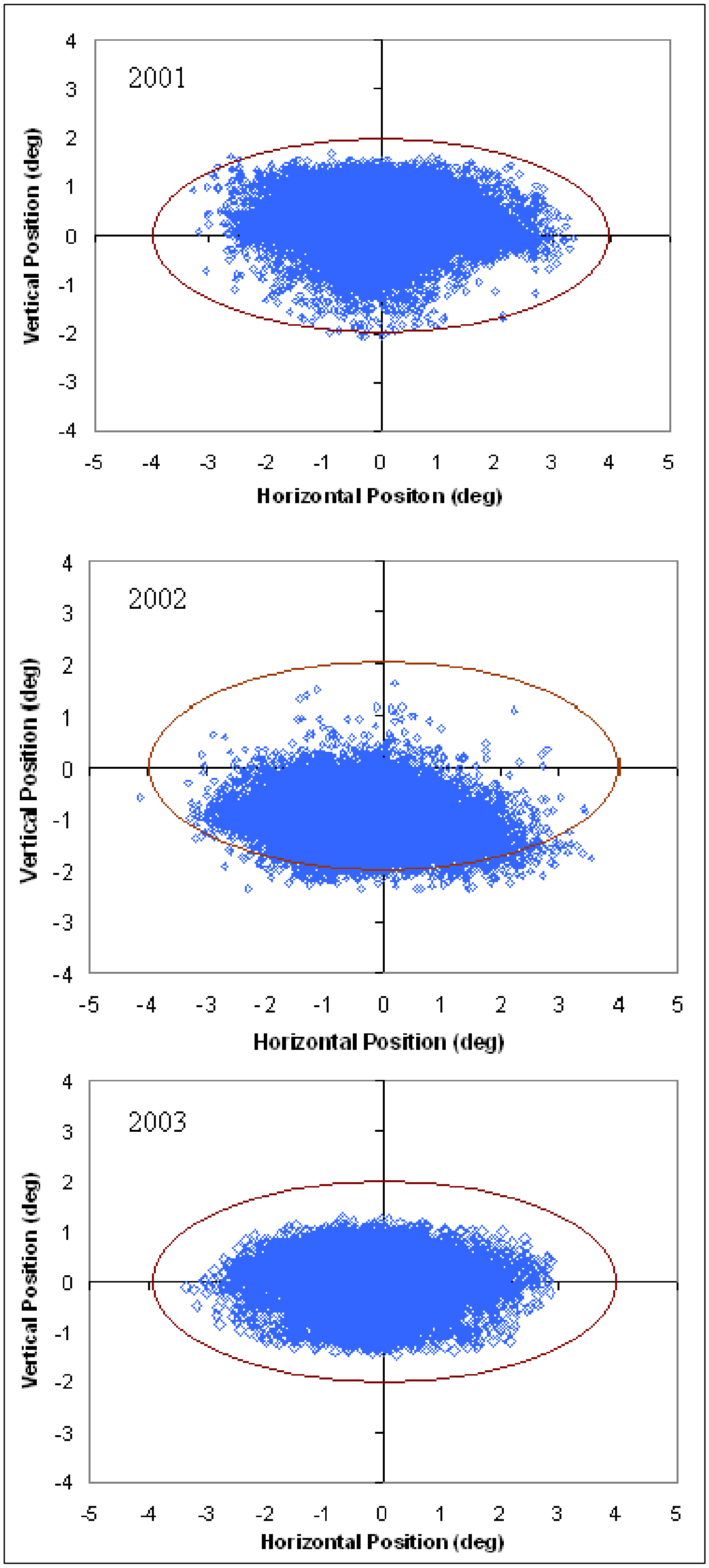


Figure 19.–The average horizontal and vertical position of fish detected by the split-beam nearshore transducer with the nominal beam overlaid, Kenai River north bank, 2001–2003.

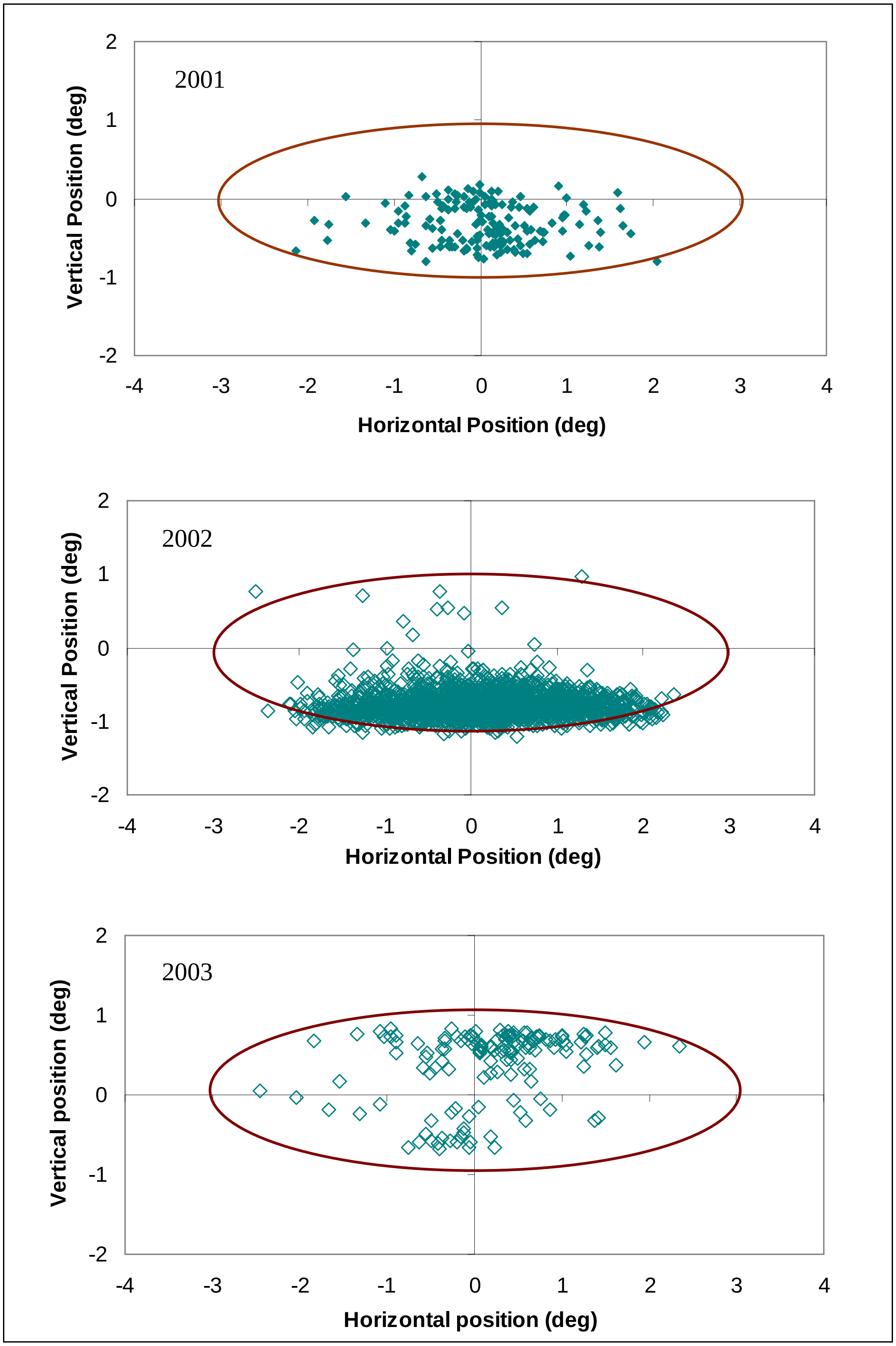


Figure 20.–The average horizontal and vertical position of fish detected by the split-beam offshore transducer with the nominal beam overlaid, Kenai River north bank, 2001–2003.

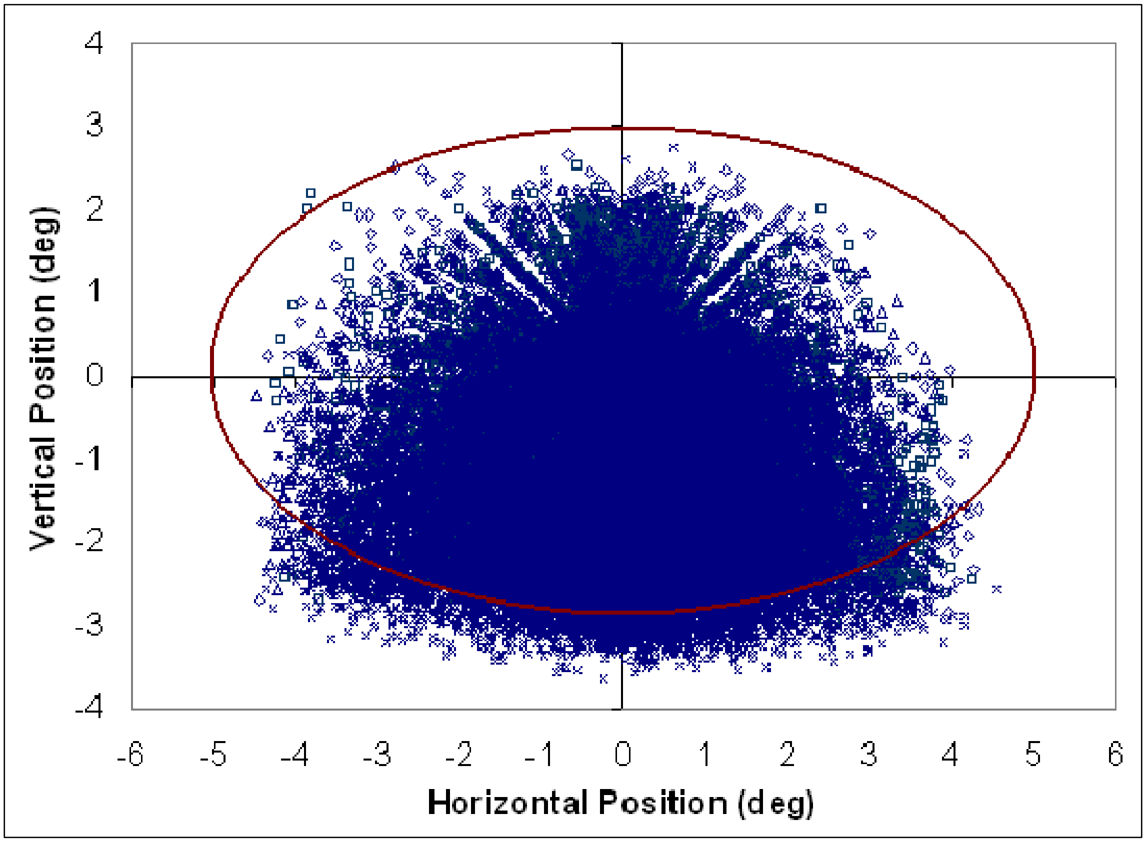


Figure 21.–The average horizontal and vertical position of fish detected by the split-beam transducer with the nominal beam overlaid, Kenai River south bank, 2001.

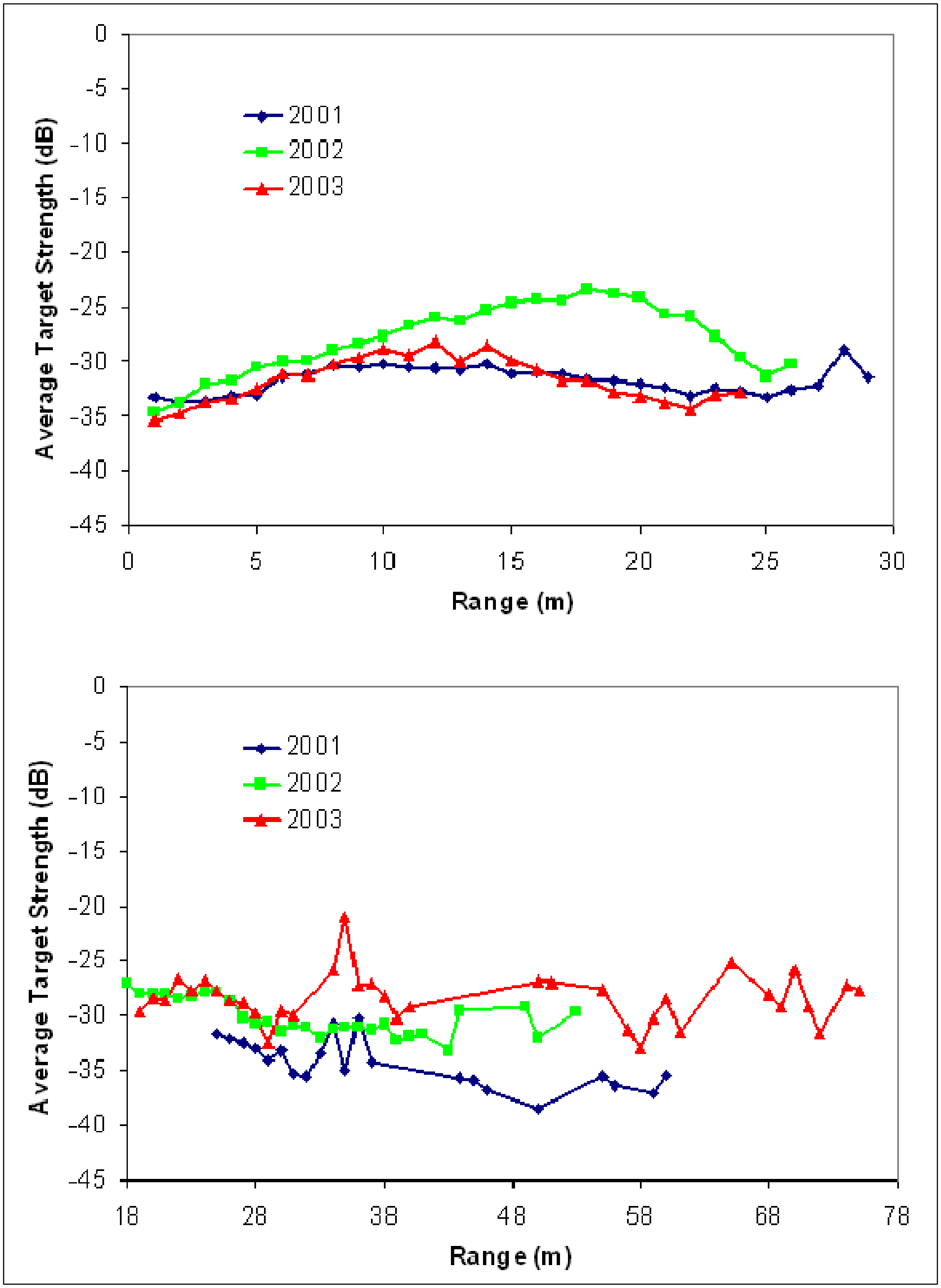


Figure 22.–Average target strength by range for tracked fish nearshore (top) and offshore (bottom) from the spilt-beam sonar, Kenai River north bank, 2001–2003.

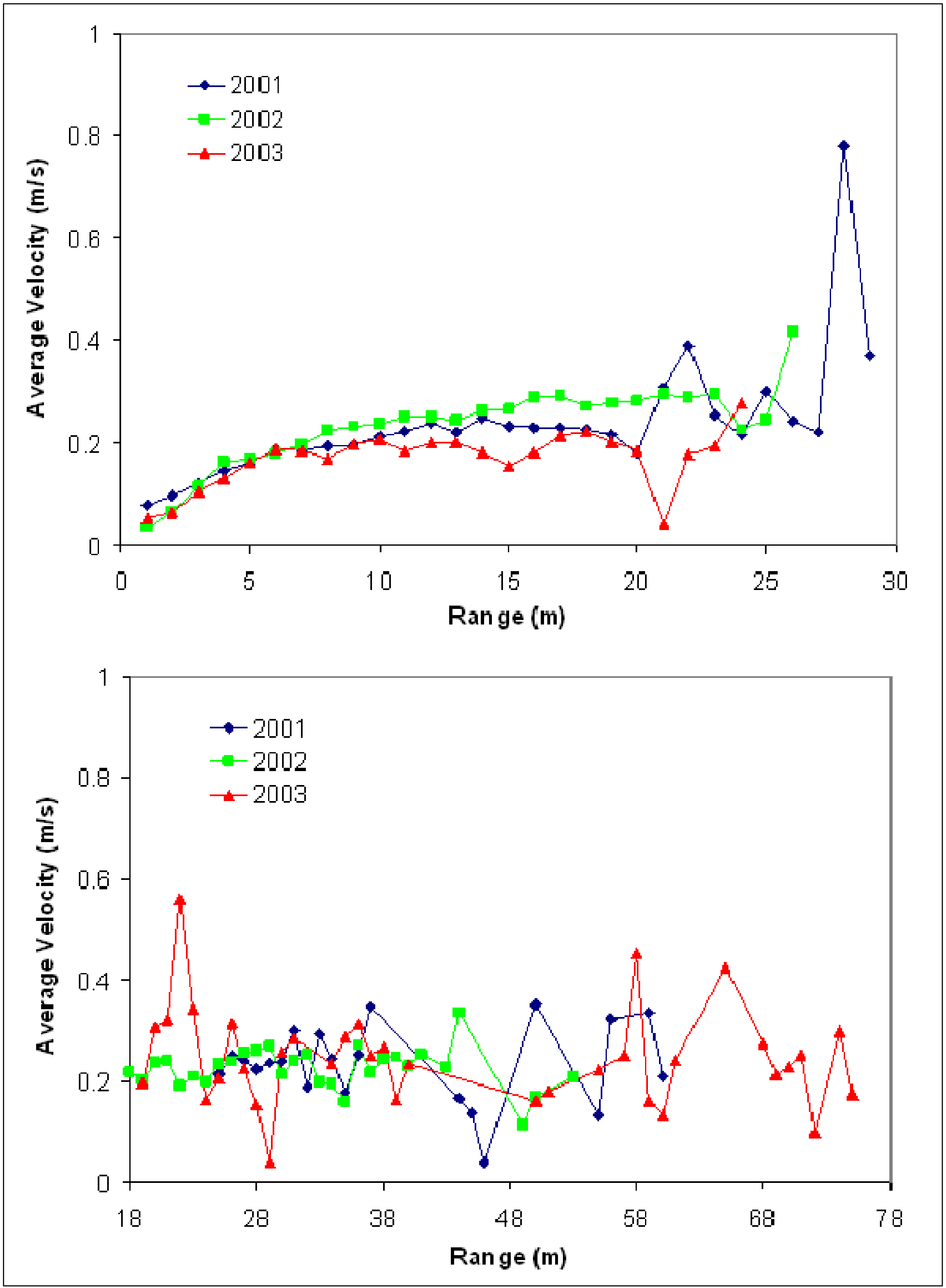
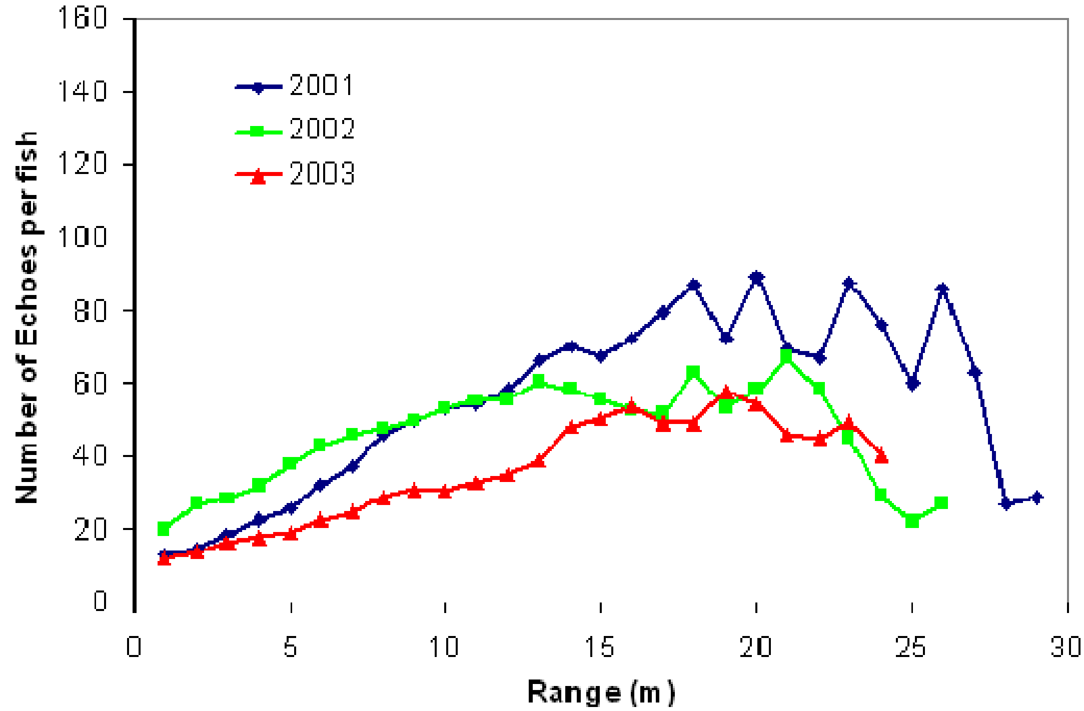


Figure 23.–Average velocity by range for tracked fish nearshore (top) and offshore (bottom) from the spilt-beam sonar, Kenai River north bank, 2001–2003.



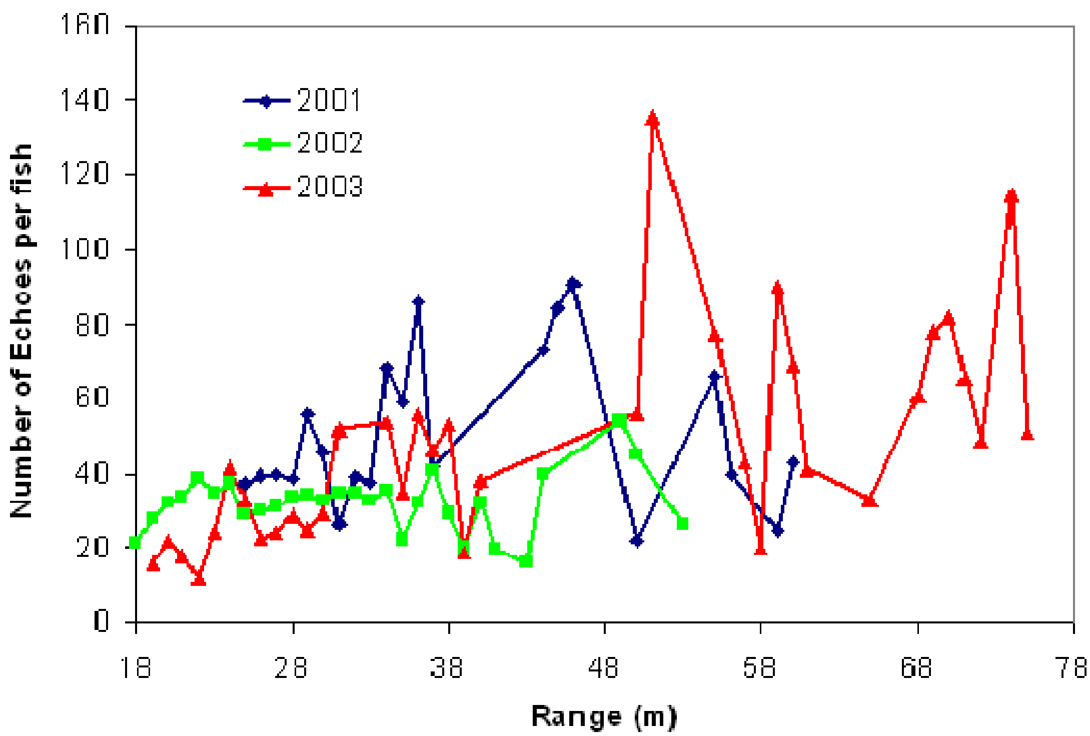


Figure 24.–The number of echoes per tracked fish by range bin for nearshore (top) and offshore (bottom) split-beam transducers, Kenai River north bank, 2001–2003.

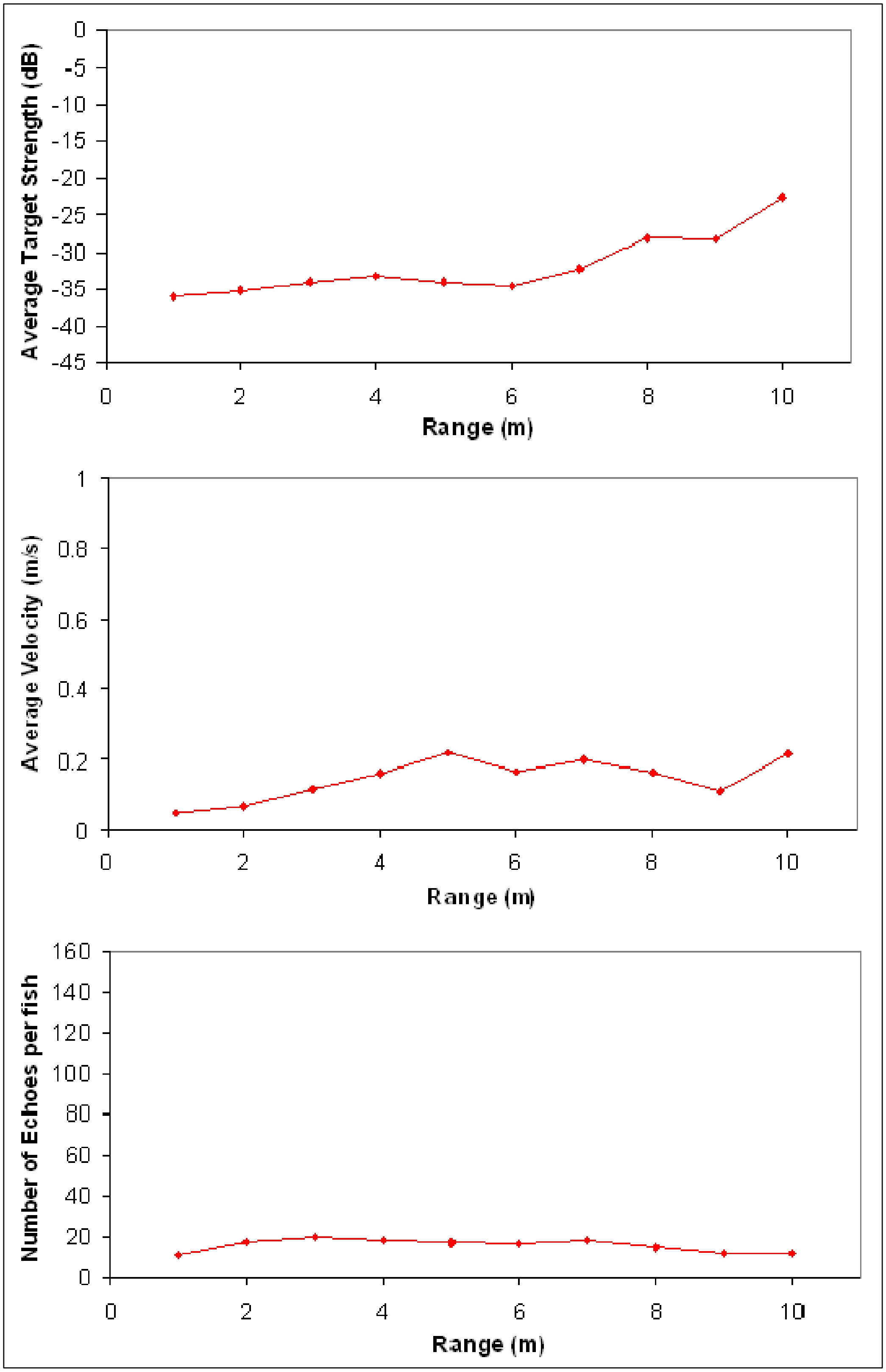


Figure 25.–Average target strength (top), velocity (middle), and number of echoes (bottom) by range for tracked fish from the split-beam transducer, Kenai River south bank, 2001.

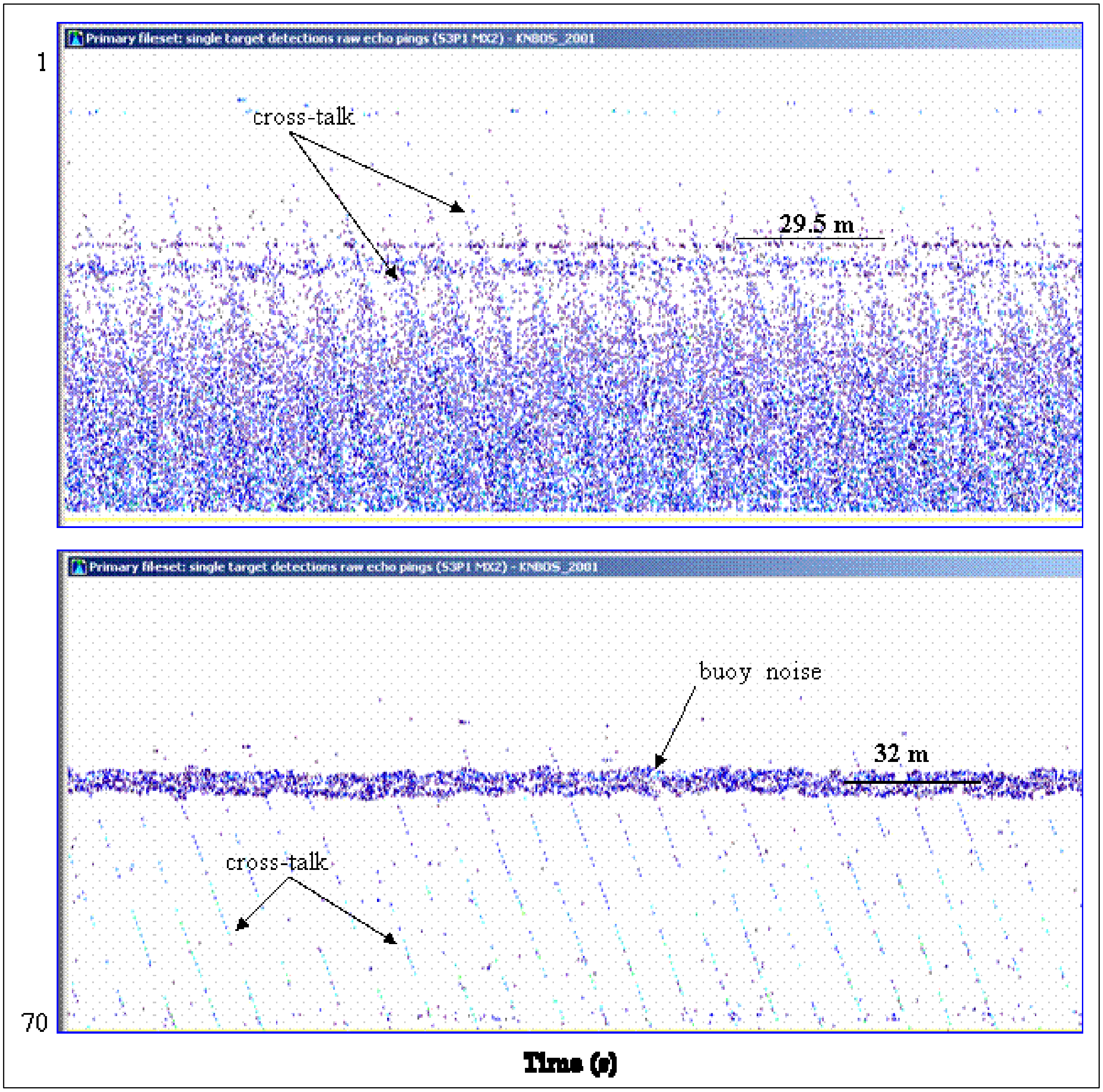


Figure 26.–Echogram from the split-beam offshore transducer with an end range of 70 m (top). Noise and cross-talk (diagonal lines) from the transducer on the opposite bank begins at 29.5 m. Echogram on July 9 after the pitch was lowered with noise from surface buoys at 32 m and cross-talk (bottom), Kenai River north bank, 2001.

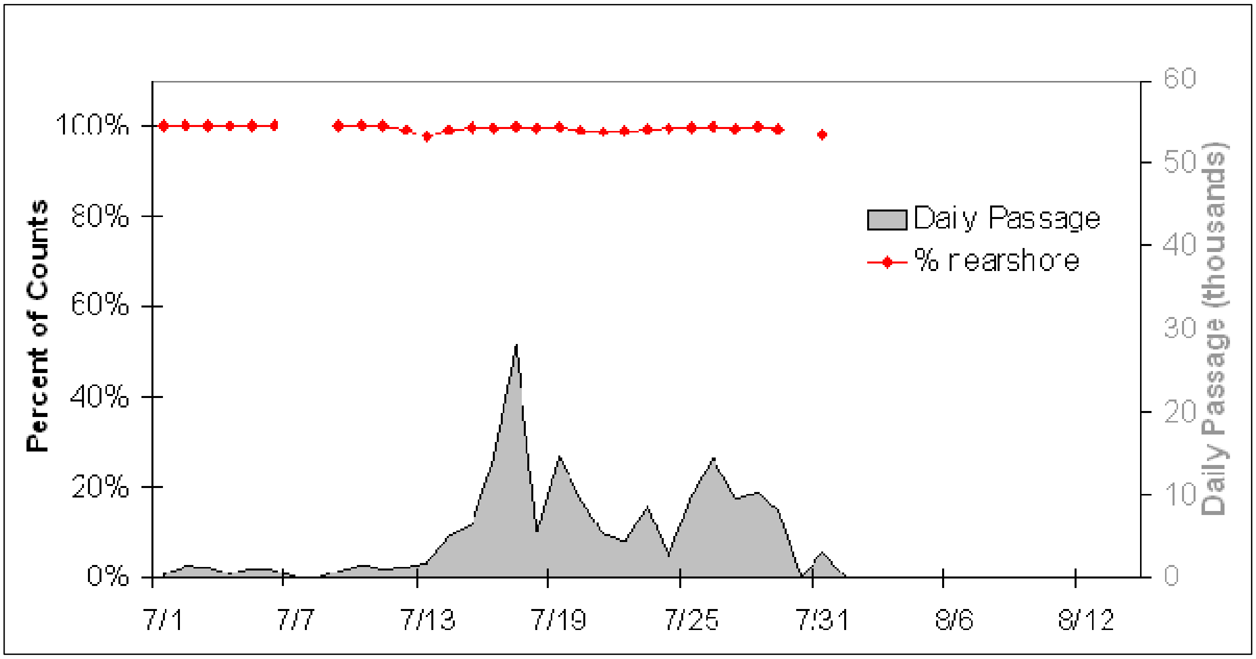


Figure 27.–Percentage of split-beam nearshore fish counts and passage estimates by day, Kenai River north bank, 2001.

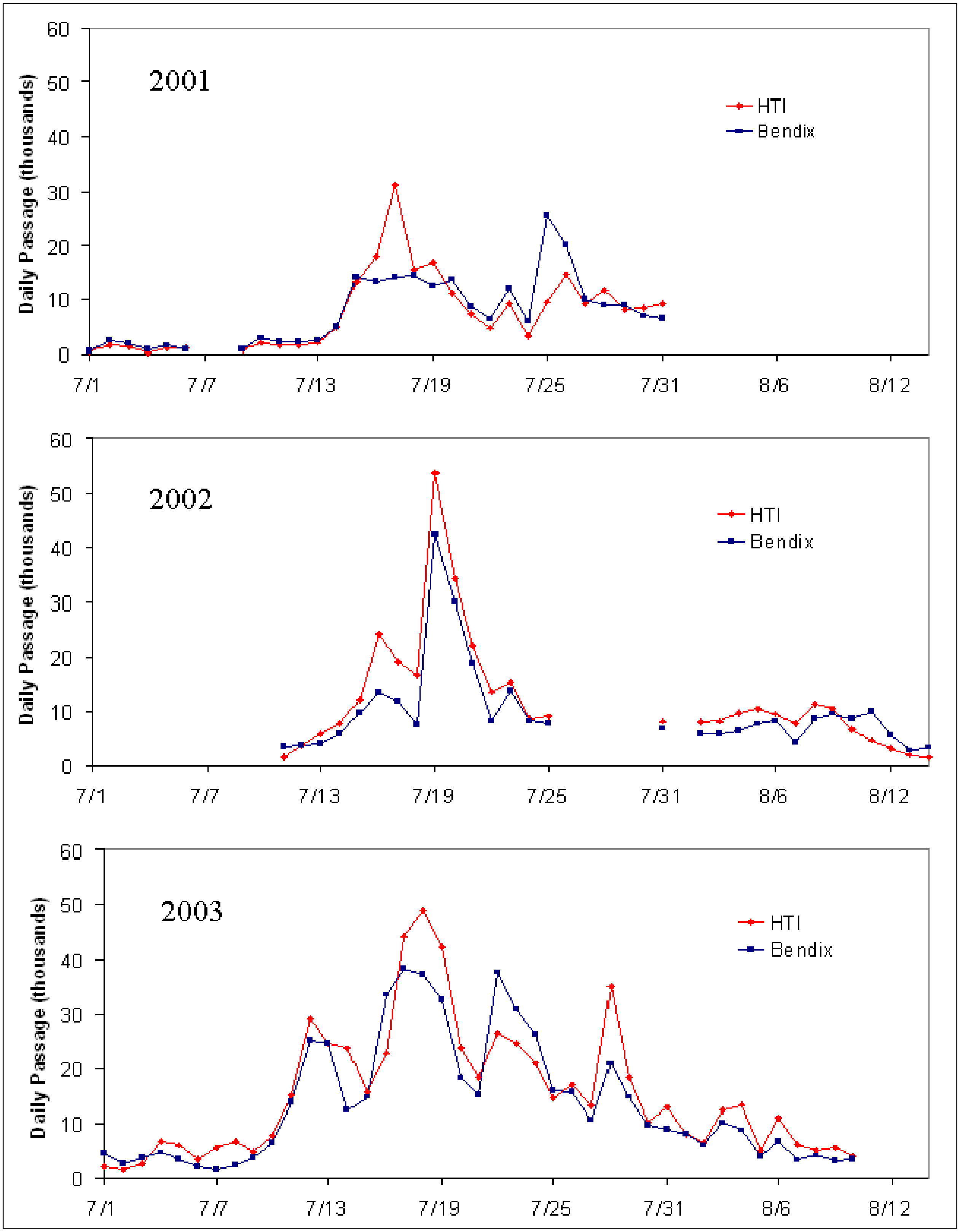


Figure 28.–Daily passage estimates from the HTI and Bendix systems, Kenai River north bank, 2001–2003.

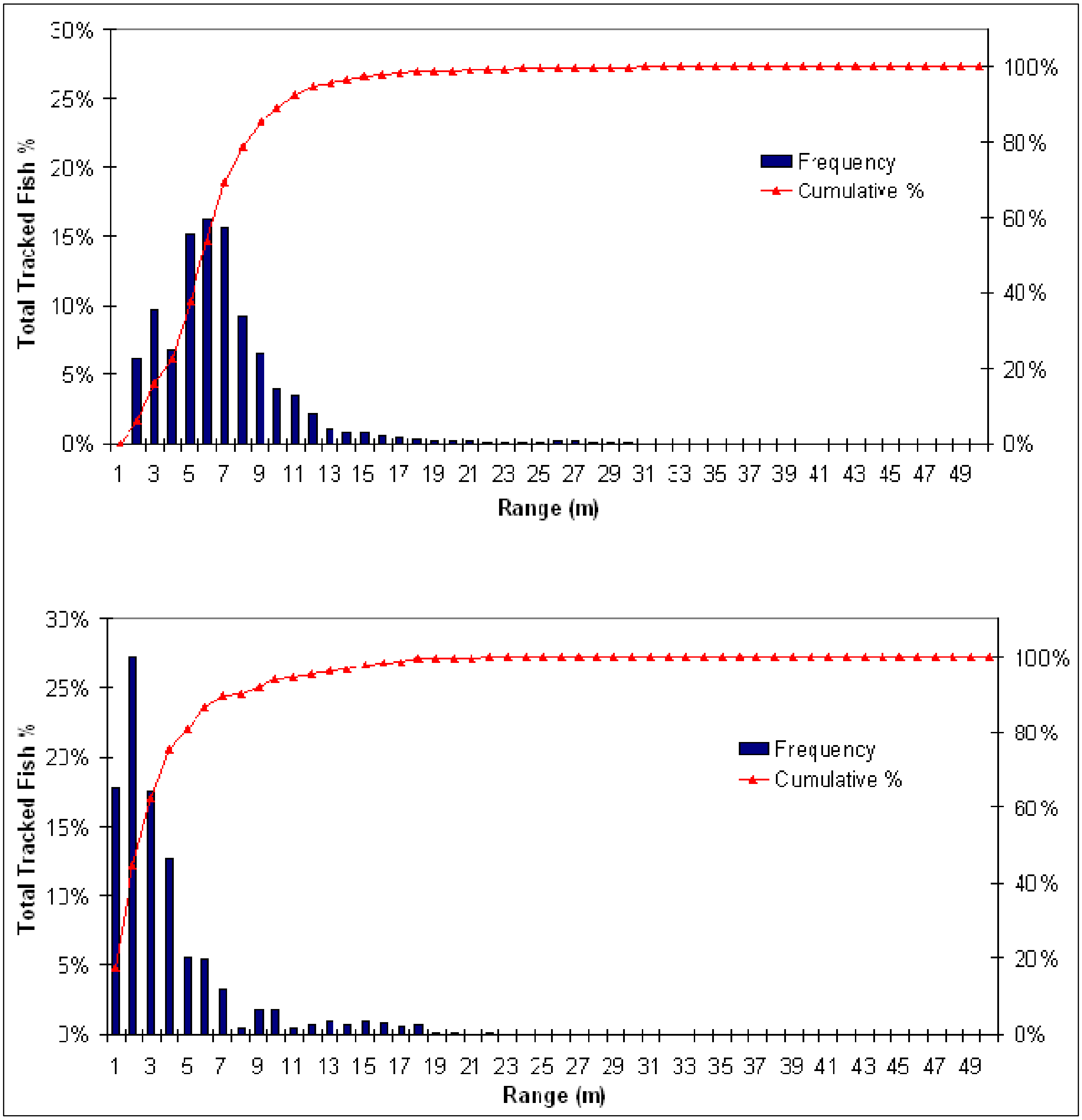


Figure 29.–Range distributions of tracked fish from the HTI (top) and Bendix (bottom) sonar systems, Kenai River north bank, 2001.

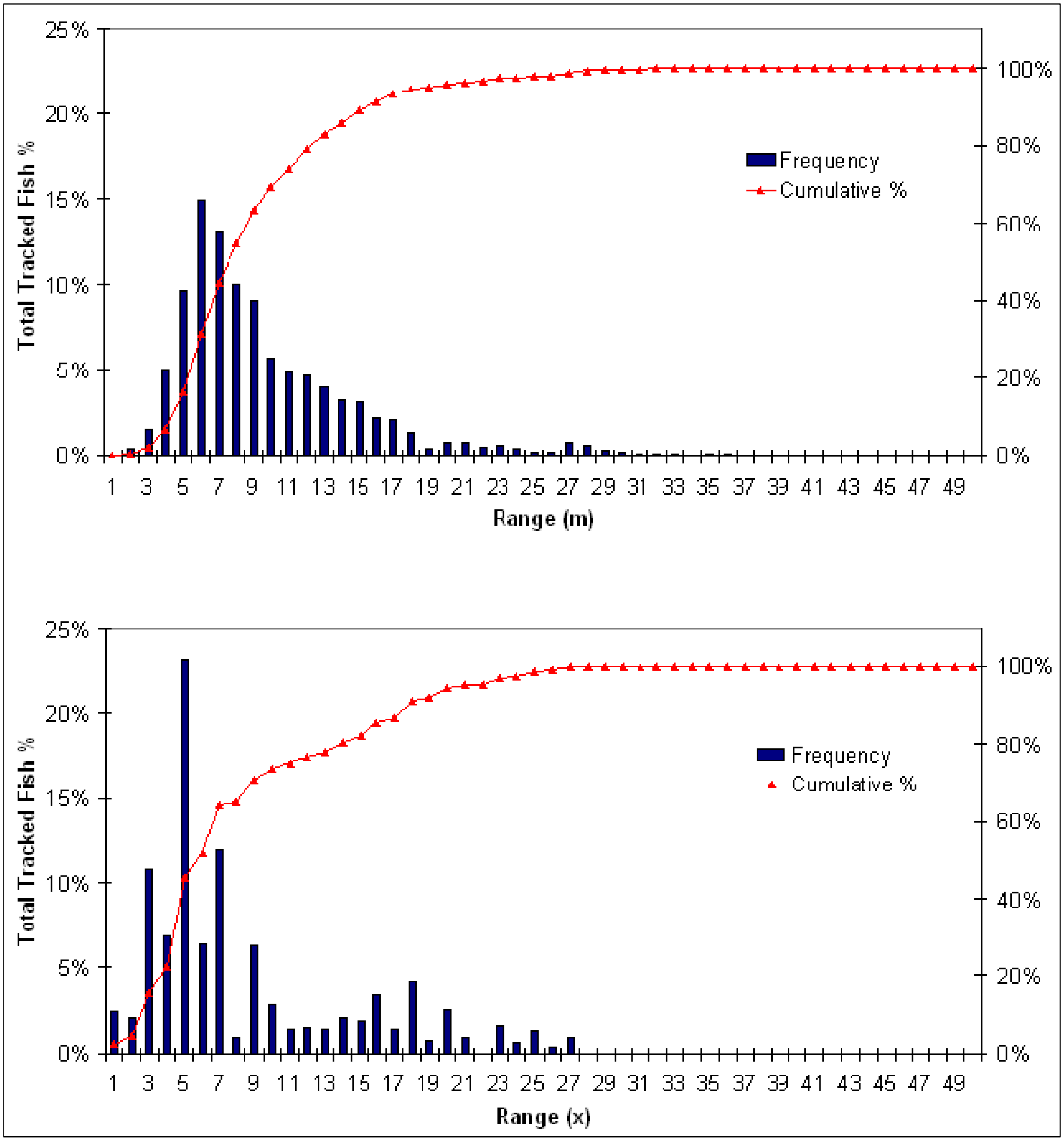


Figure 30.–Range distributions of tracked fish from the HTI (top) and Bendix (bottom) sonar systems, Kenai River north bank, 2002.

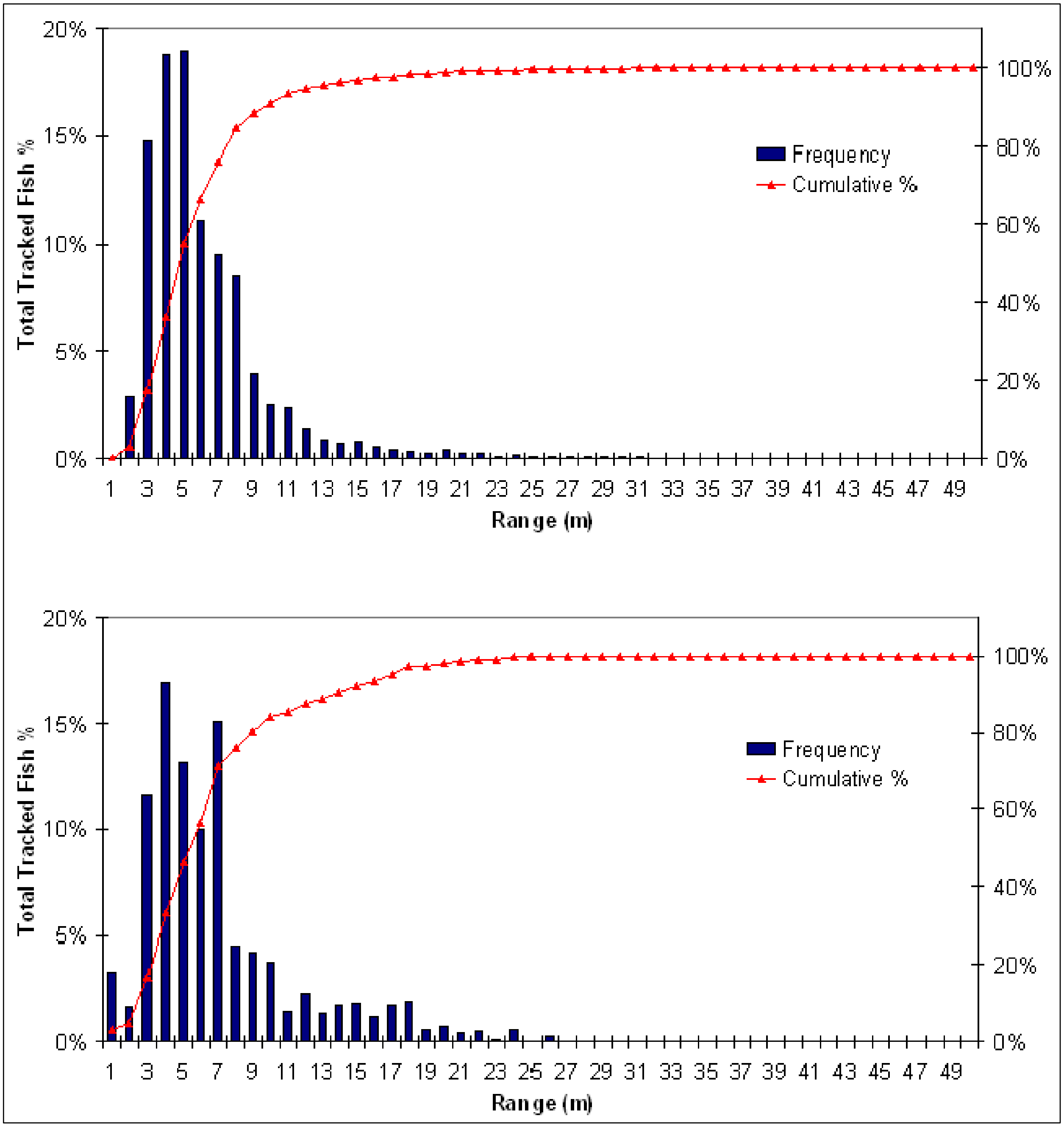


Figure 31.–Range distributions of tracked fish from the HTI (top) and Bendix (bottom) sonar systems, Kenai River north bank, 2003.

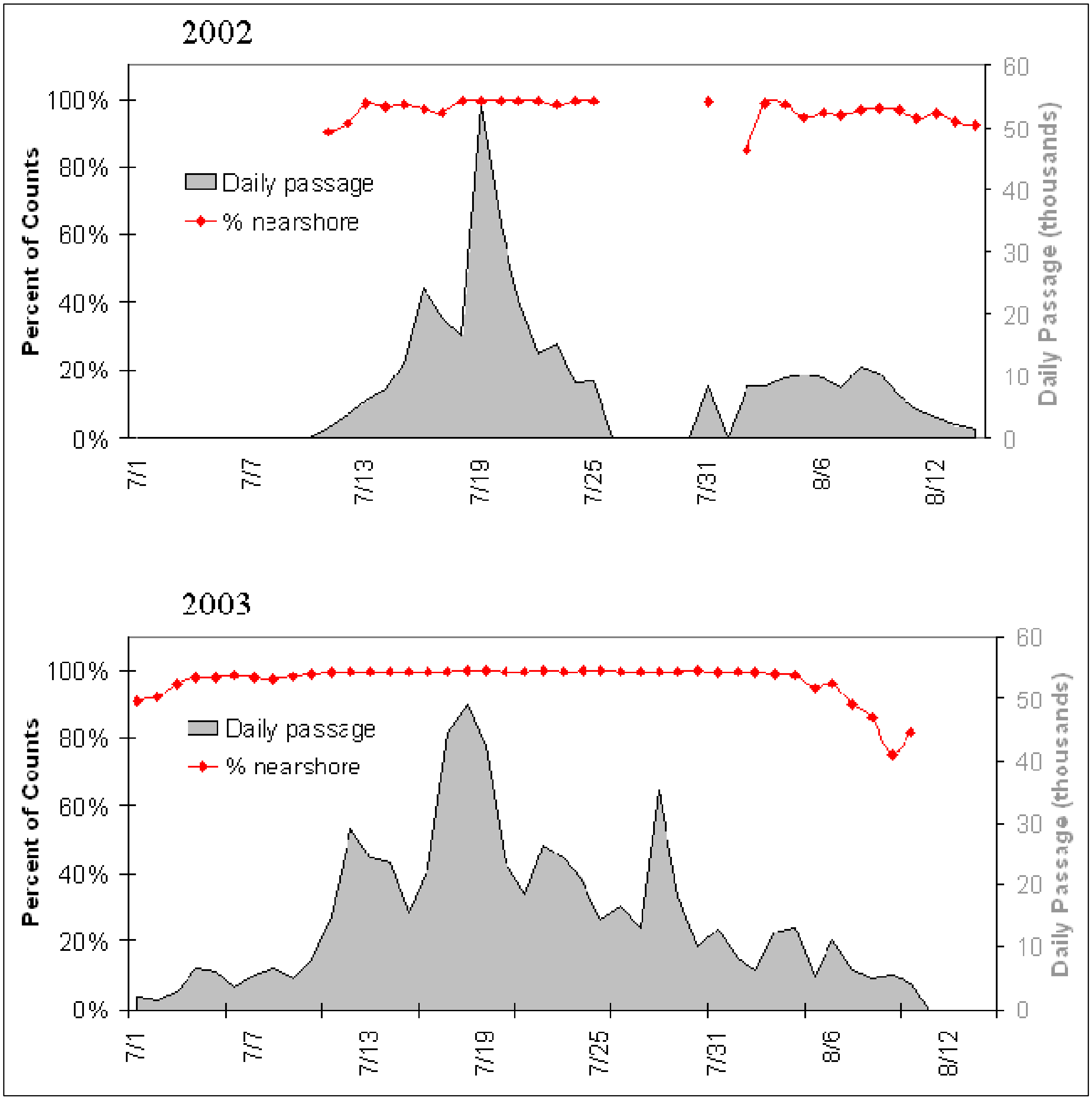
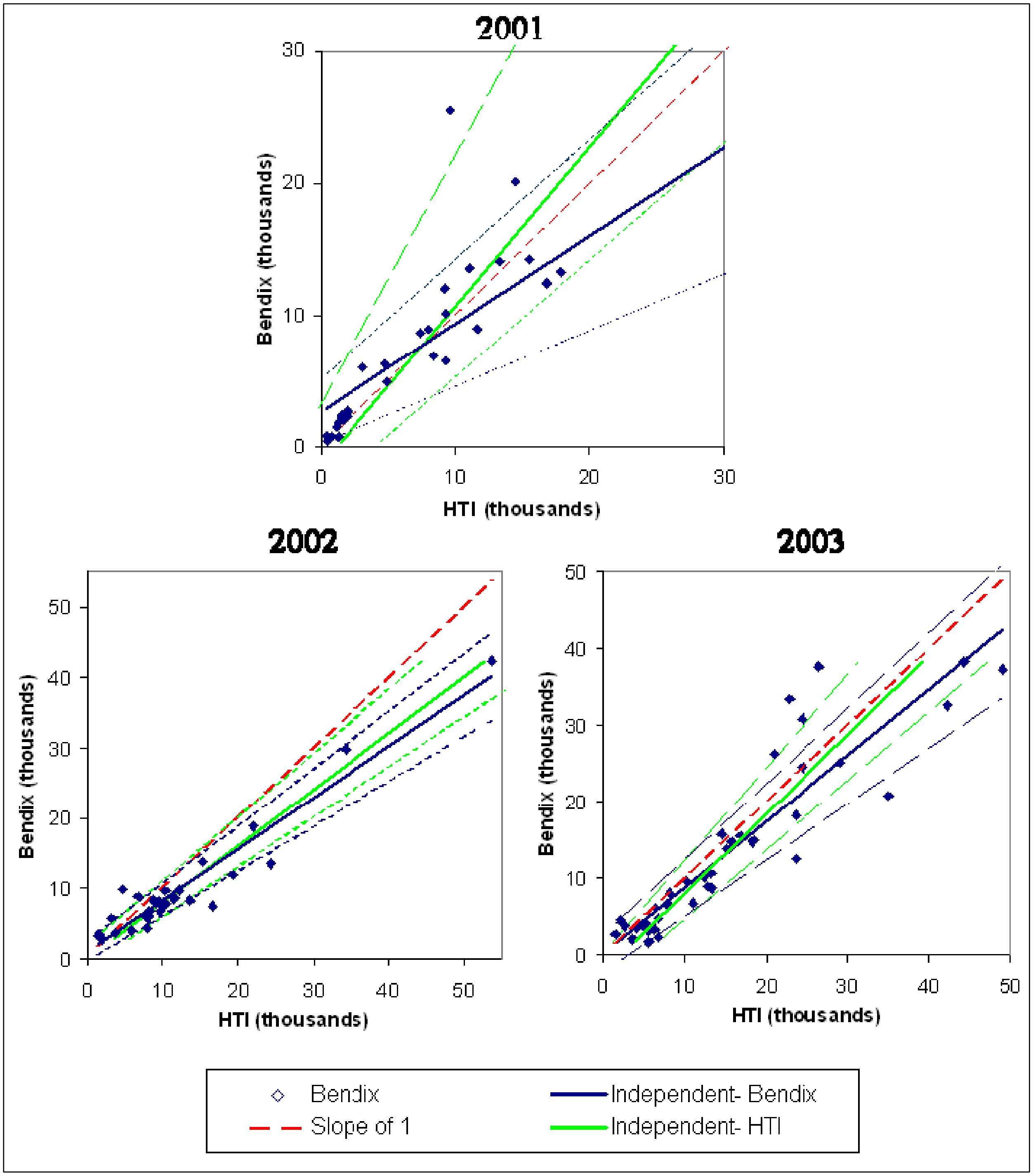


Figure 32.–Percentage of split-beam nearshore fish counts and passage estimates by day, Kenai River north bank, 2002–2003.



Note: The diagonally dashed line in the center represents a slope of 1.

Figure 33.–Daily fish passage regression plots with regression lines (solid lines) and 95% confidence intervals (dashed lines) using each variable as the independent variable from paired HTI and Bendix datasets, Kenai River north bank, 2001–2003.

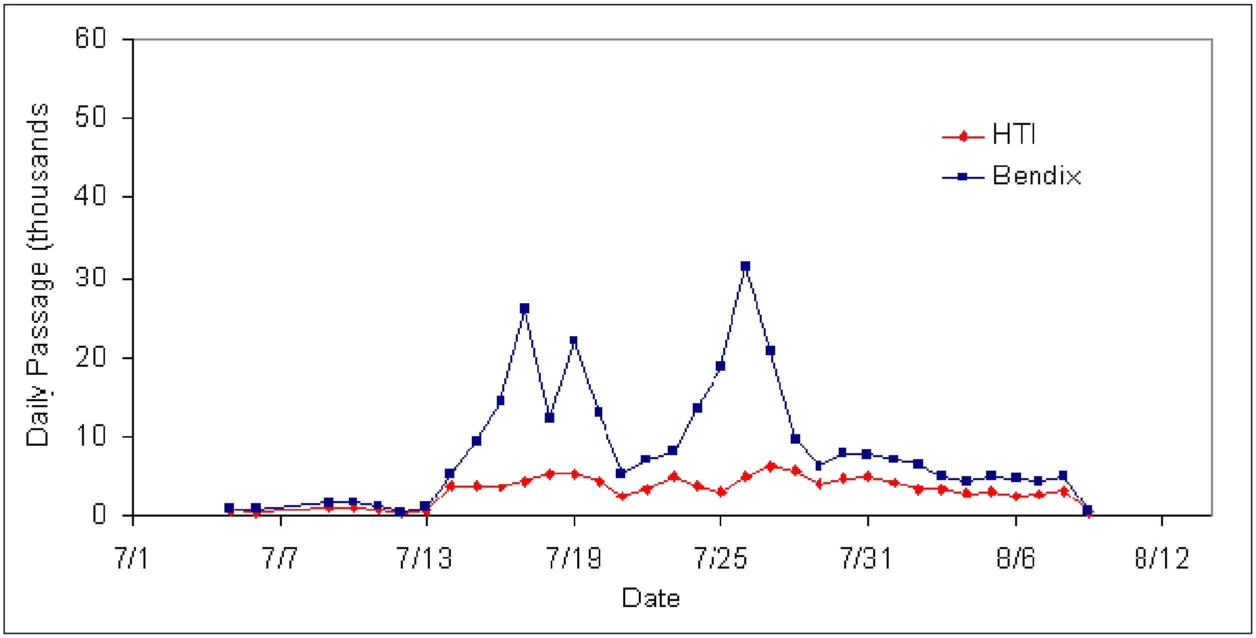
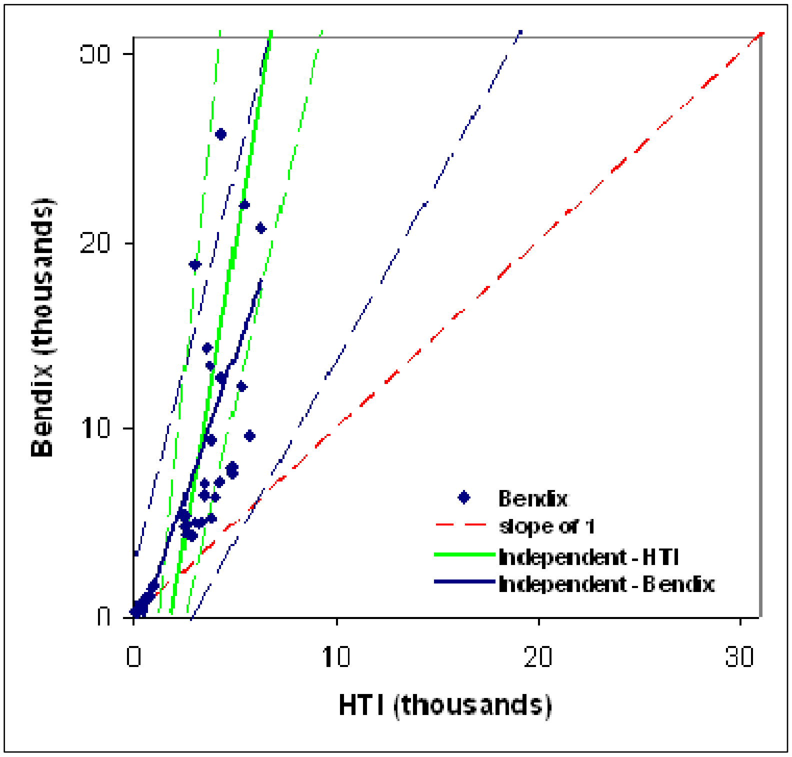


Figure 34.–Daily fish passage estimates from the HTI and Bendix systems, Kenai River south bank, 2001.



Note: The dashed line in the center diagonally represents a slope of 1.

Figure 35.–Daily fish passage regression plot with regression lines (solid lines) and 95% confidence intervals (dashed lines) using each variable as the independent variable from paired HTI and Bendix datasets, Kenai River south bank, 2001.

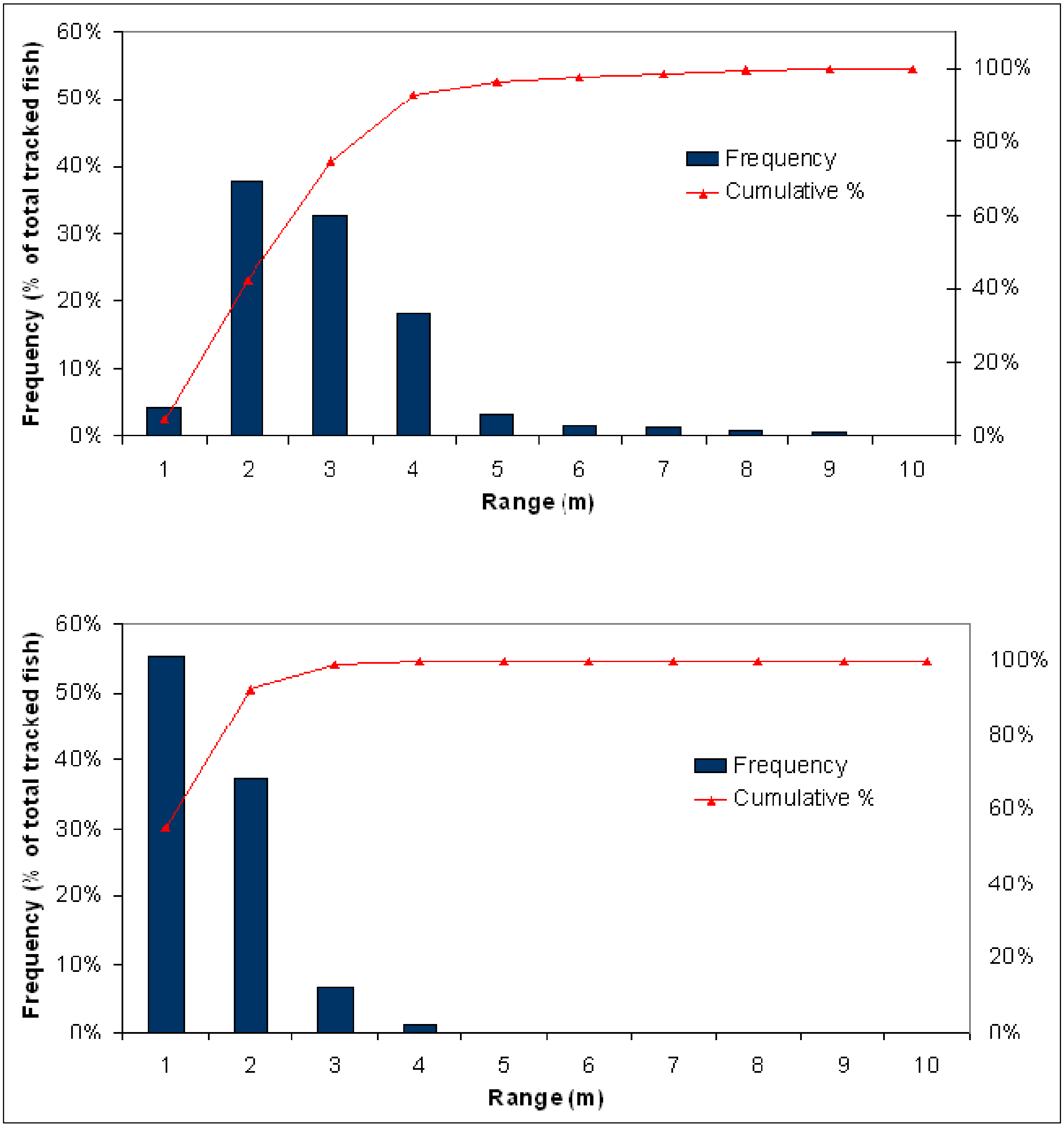


Figure 36.–Range distributions of tracked fish from the HTI (top) and Bendix (bottom) sonar systems, Kenai River south bank, 2001.

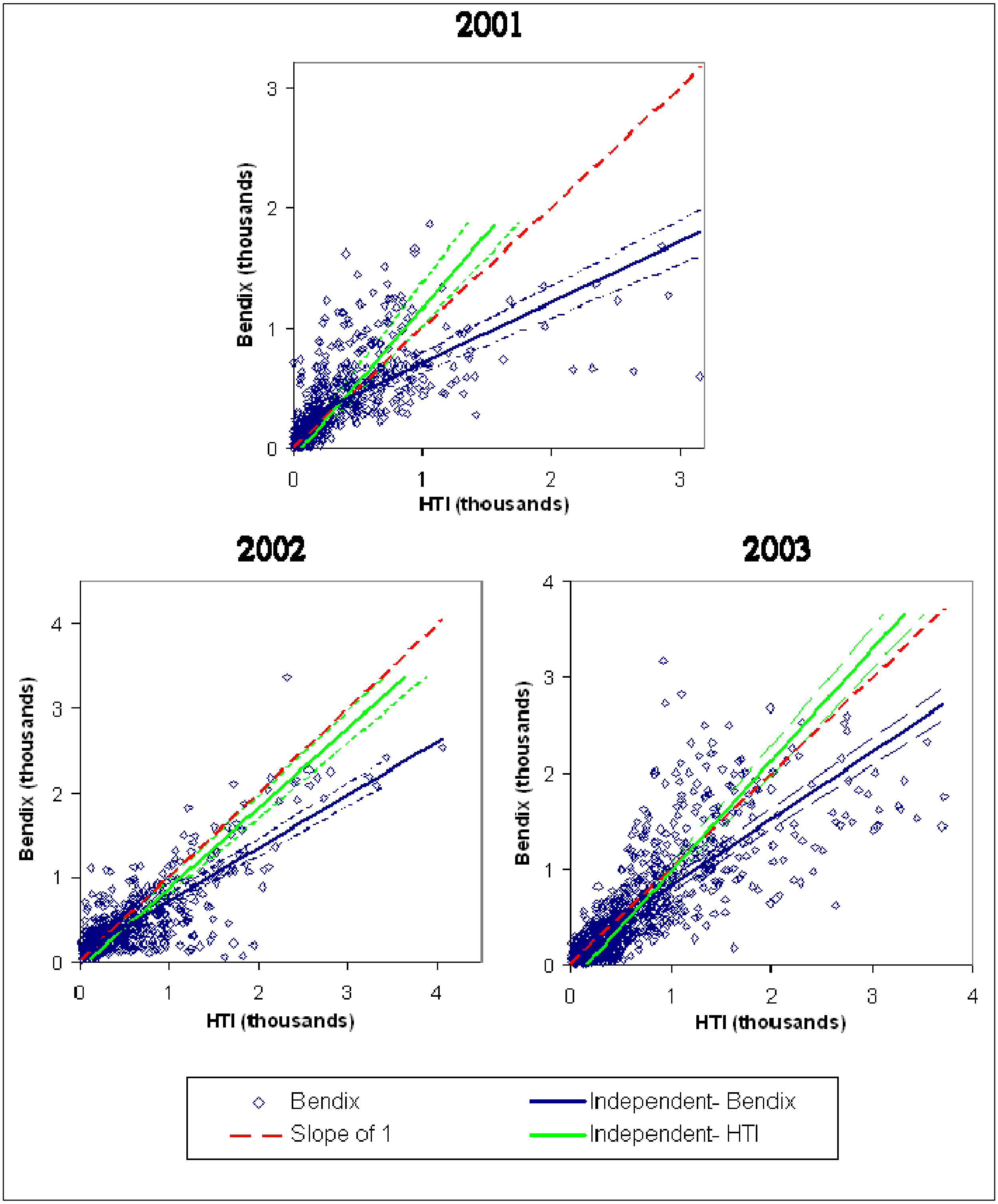
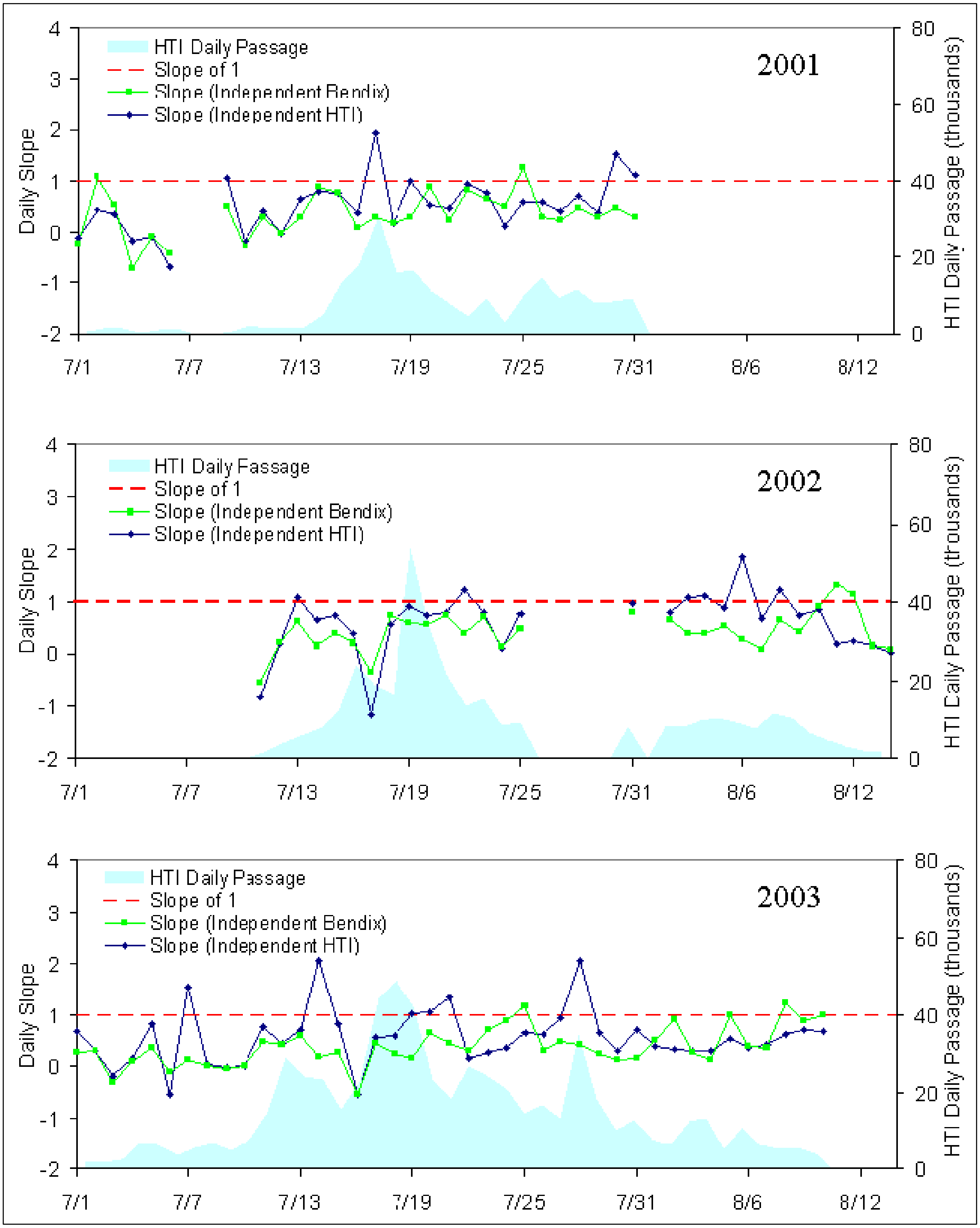


Figure 37.–Hourly passage estimate regression plots with regression lines and confidence intervals (dashed lines) using each variable as the independent variable from paired HTI and Bendix datasets, Kenai River north bank, 2001–2003.



Note: The HTI daily passage estimates are shown for reference purposes

Figure 38.–Slope values from daily regressions of the hourly HTI and Bendix sonar data with each variable used as the independent variable, Kenai River north bank, 2001–2003.

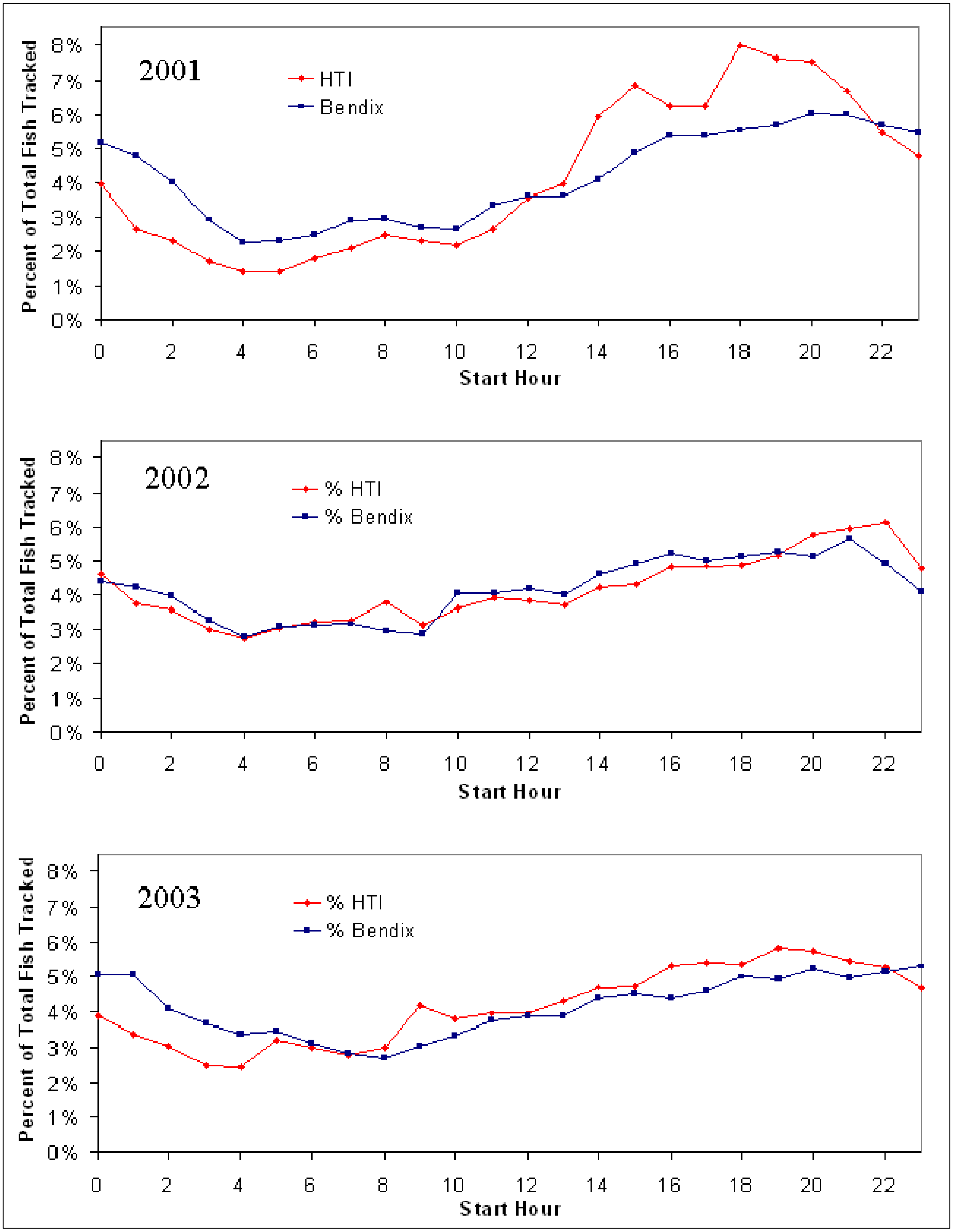


Figure 39.–HTI and Bendix estimated fish passage summed per hour across the field season, Kenai River north bank, 2001–2003.

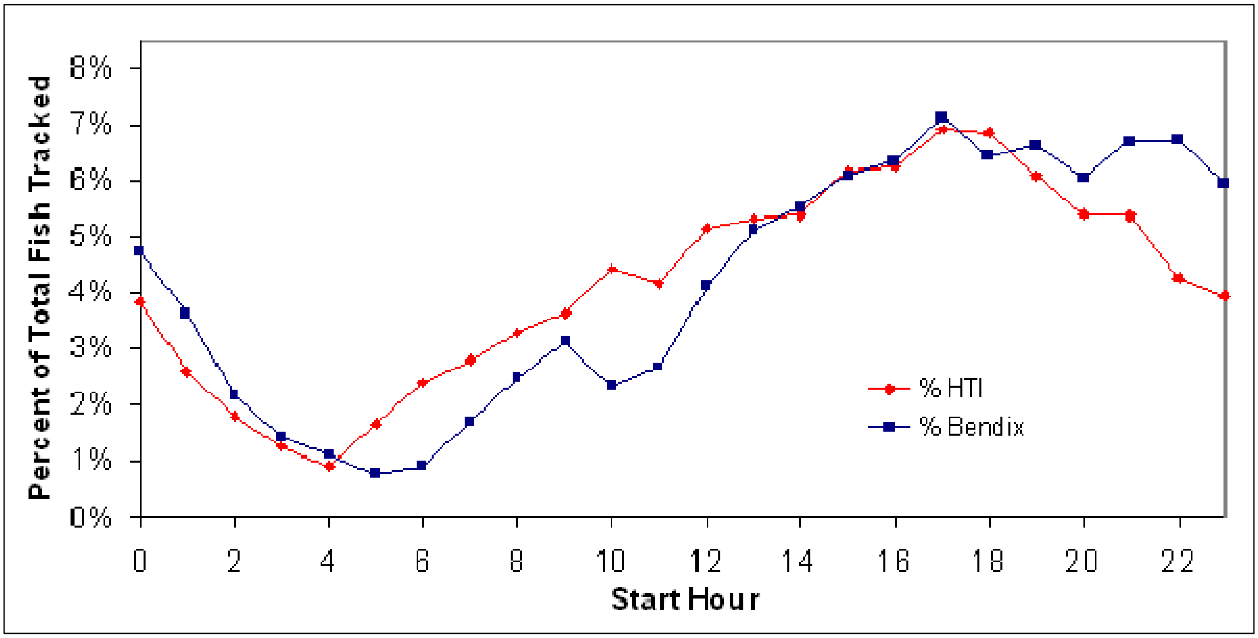


Figure 40.–HTI and Bendix estimated fish passage summed per hour across the field season, Kenai River south bank, 2001.

APPENDIX A. LABORATORY CALIBRATIONS

Appendix A1.–Laboratory calibration for the 4^o by 8^o split-beam transducer used with the Model 241 split-beam system.

200 KHz — 4X8 Degree —200ft
S/N 1405203

-continued-

Hydroacoustic Technology Inc.

HTI

Standard Sphere Calibration

		Freq	200 KHz
Customer	ADFG MAXWELL	Transducer S/N	1405203
Project Name	KENAI REMOTE	Beam Width	4X8 Deg
Calibration Location	HTI-Impulse	Echo Sounder S/N	1320757
Customer Contact	SUSIE MAXWELL	Model #	241
Calibrated by	BK, GH, MA	Calibration Date	06/05/02
		Calibration File	203S757 .xls
Sphere Type	38.1 mm Tungsten-carbide	Cable Length	200 Feet

FILE NAME RAW / MDB	RX Gain dB	TVG Gain dB	TX Pwr dBW	PW ms	Pulse Type	Chirp BW KHz	Range m	Echoes #	TS dB	Std. DEV dB
S1561003	-6	0	14	0.40	NORM	0.0	6.09	508	-39.59	0.83
S1561005	-6	0	14	5.00	CHIRP	10.0	6.03	305	-40.41	0.74
S1561006	-6	0	14	2.50	CHIRP	10.0	6.03	324	-40.53	0.85
S1561008	-6	0	14	1.25	CHIRP	10.0	6.08	289	-40.20	0.59

-continued-

Hydroacoustic Technology, Inc.

HTI

Hydroacoustic System Calibration

		Frequency (kHz)	200
Customer	ADF&G	Transducer S/N	1405203
Project Name	Kenai Remote	Beam Width	4x8
Calibration Location	HTI-Impulse	Echo Sounder S/N	1320757
Customer Contact	Susie Maxwell	Model #	241
Calibrated by	BK, GH	Calibration Date	04-Jun-02
		G1+SL20 =	49.63 dB

Echo Sounder

Arguments to: TVG	1 2 0 42 0 3 1	Arguments to: RX	0
Arguments to: TRIG	00/10	Arguments to: REP	100 10
Arguments to: TX	1-2 to 1-20	Arguments to: MUX	1
Arguments to:FILTER	3	Arguments to:	

Frequency	200 kHz	Band Width	n/a kHz
Receiver Gain (Rg)	0 dB	Pulse Width	0.5 msec
TVG Full Range	n/a m	Blanking Control	3
TVG Crossover	11.22 m	Blanking Min	1 m
TVG Cal Rng (Rcal)	11.22 m	Blanking Max	2 m
Alpha (a)	0 dB/km	Rel Noise (wet)	-36 dBV
RCAL @ T 0 42 TX 1 20	not measured Vdet40		(T 0 82 .. CWFILT 4)

Cable

Cable S/N	1302029	Cable Length	200 ft
Cable Type	Split-beam	Mux Port	2

Standard Transducer

Type	ITC-5323	Ts =	124.1 dBuPa/V
S/N	007	Ss =	-223.84 dBv/uPa
Last Calibration	Nov 25, 2000 PAS		
		Preamp Gain 20=	13.39 dB
LP Filter	100 x 1k	Equiv. Ss20 =	-210.45 dBv/uPa
HP Filter	300 x 1k		
		Preamp Gain 40=	33.34 dB
		Equiv. Ss40 =	-190.5 dBv/uPa

Air and Water Parameters

Air Temperature	62 °F	Calibration Depth	4.57 m
Water Temperature	55 °F	Separation (Rs)	6.1 m

Filename: 203S757.xls

Page 1

-continued-

Hydroacoustic Technology, Inc.

HTI

Receiving Sensitivity

Transducer S/N 1405203
Sounder S/N 1320757

Voltage Into Standard Vs (Generator at 23 dBm)
Vs= 6.24 *volts (rms)*
Vs= 15.90 dBVrms

Transmission Loss TL = 20 log Rs + aRs
TL = 15.71 dB
Acoustic Level L = Ts + Vs - TL
L = 124.30 dB/uPa

Sum Channel Detected 12 kHz Output
Calibration Readings
v12kHz = 0.498 *volts (rms)*
Vdet = -3.05 dB Vdet
TVG Gain G(40) = (40 log Rcal + 2a Rcal)
G(40) = 42.00 dB

Vdet = V12kHz + 3.01 dB
Sensitivity at Rcal Gx = Vdet - L
Gx = -127.34 dB/uPa@Rcal
Sensitivity at 1 m G1 = Gx - G(40) - Rg
G1 = -169.34 dB/uPa @ 1m

Up Channel Detected 12 kHz Output
Calibration Readings
v12kHz = 0.238 *volts (rms)*
Vdet = -9.46 dB Vdet
TVG Gain G(40) = (40 log Rcal + 2a Rcal)
G(40) = 42.00

Sensitivity at Rcal Gx = Vdet - L
Gx = -133.75 dB/uPa@Rcal
Sensitivity at 1 m G1 = Gx - G(40) - Rg
G1 = -175.75 dB/uPa @ 1m

Left Channel Detected 12 kHz Output
Calibration Readings
v12kHz = 0.243 *volts (rms)*
Vdet = -9.28 dB Vdet
TVG Gain G(40) = (40 log Rcal + 2a Rcal)
G(40) = 42.00 dB

Sensitivity at Rcal Gx = Vdet - L
Gx = -133.57 dB/uPa@Rcal
Sensitivity at 1 m G1 = Gx - G(40) - Rg
G1 = -175.57 dB/uPa @ 1m

20 Log R Channel Detected Output
Calibration Readings
vdet = 0.681 *volts (peak)*
Vdet = -3.34 dBV (det)
TVG Gain G(20) = (20 log Rcal + 2a Rcal)
G(20) = 21.00 dB

Sensitivity at Rcal Gx = Vdet - L
Gx = -127.63 dB/uPa@Rcal
Sensitivity at 1 m G1 = Gx - G(20) - Rg
G1 = -148.63 dB/uPa @ 1m

Transmission Loss TL = 20 log Rs + aR
TL = 15.71 dB
Source Level SL = Vso - Ss + TL-Pre-Amp

Transmit Power (dB)	Standard Transducer Vso (FFT) dBV (+20)	Standard Transducer Vso (FFT) dBV (+40)	Source Level (dBuPa @ 1 m)
20.0	-7.19		218.97
14.0	-12.81		213.35
8.0		0.94	207.14
2.0		-5.31	200.89

Filename: 203S757.xls Page 2

-continued-

Sum Detected Voltage vs Power and Gain

Hydroacoustic Technology, Inc.

HTI

Transducer S/N 1405203

Sounder S/N 1320757

Power Level 20	Vdet = SL + TS + G1 + Rg	Target Strength (dB)						
		-65	-60	-55	-50	-45	-40	-35
Receiver Gain (dB)	-18	0.021	0.038	0.068	0.121	0.214	0.381	0.678
	-12	0.043	0.076	0.135	0.241	0.428	0.761	1.353
	-6	0.085	0.152	0.270	0.480	0.854	1.518	2.700
	0	0.170	0.303	0.539	0.958	1.704	3.030	5.388
	6	0.340	0.604	1.075	1.912	3.399	6.045	>
	12	0.678	1.206	2.145	3.814	6.782	>	>
	18	1.353	2.407	4.279	7.610	>	>	>
	24	2.700	4.802	8.539	>	>	>	>

Power Level 14	Vdet = SL + TS + G1 + Rg	Target Strength (dB)						
		-65	-60	-55	-50	-45	-40	-35
Receiver Gain (dB)	-18	0.011	0.020	0.036	0.063	0.112	0.200	0.355
	-12	0.022	0.040	0.071	0.126	0.224	0.398	0.708
	-6	0.045	0.079	0.141	0.251	0.447	0.795	1.413
	0	0.089	0.159	0.282	0.502	0.892	1.586	2.820
	6	0.178	0.316	0.563	1.001	1.779	3.164	5.627
	12	0.355	0.631	1.123	1.997	3.550	6.314	>
	18	0.708	1.260	2.240	3.984	7.084	>	>
	24	1.413	2.514	4.470	7.949	>	>	>

Power Level 8	Vdet = SL + TS + G1 + Rg	Target Strength (dB)						
		-65	-60	-55	-50	-45	-40	-35
Receiver Gain (dB)	-18	0.005	0.010	0.017	0.031	0.055	0.098	0.174
	-12	0.011	0.020	0.035	0.062	0.110	0.195	0.347
	-6	0.022	0.039	0.069	0.123	0.219	0.389	0.692
	0	0.044	0.078	0.138	0.246	0.437	0.776	1.381
	6	0.087	0.155	0.276	0.490	0.871	1.549	2.755
	12	0.174	0.309	0.550	0.978	1.738	3.091	5.497
	18	0.347	0.617	1.097	1.950	3.468	6.168	>
	24	0.692	1.231	2.188	3.892	6.921	>	>

Power Level 2	Vdet = SL + TS + G1 + Rg	Target Strength (dB)						
		-65	-60	-55	-50	-45	-40	-35
Receiver Gain (dB)	-18	0.003	0.005	0.008	0.015	0.027	0.048	0.085
	-12	0.005	0.009	0.017	0.030	0.053	0.095	0.169
	-6	0.011	0.019	0.034	0.060	0.107	0.190	0.337
	0	0.021	0.038	0.067	0.120	0.213	0.378	0.672
	6	0.042	0.075	0.134	0.239	0.424	0.755	1.342
	12	0.085	0.151	0.268	0.476	0.847	1.506	2.677
	18	0.169	0.300	0.534	0.950	1.689	3.004	5.342
	24	0.337	0.599	1.066	1.895	3.370	5.994	>

Filename: 203S757.xls

Page 3

-continued-

Hydroacoustic Technology Inc.

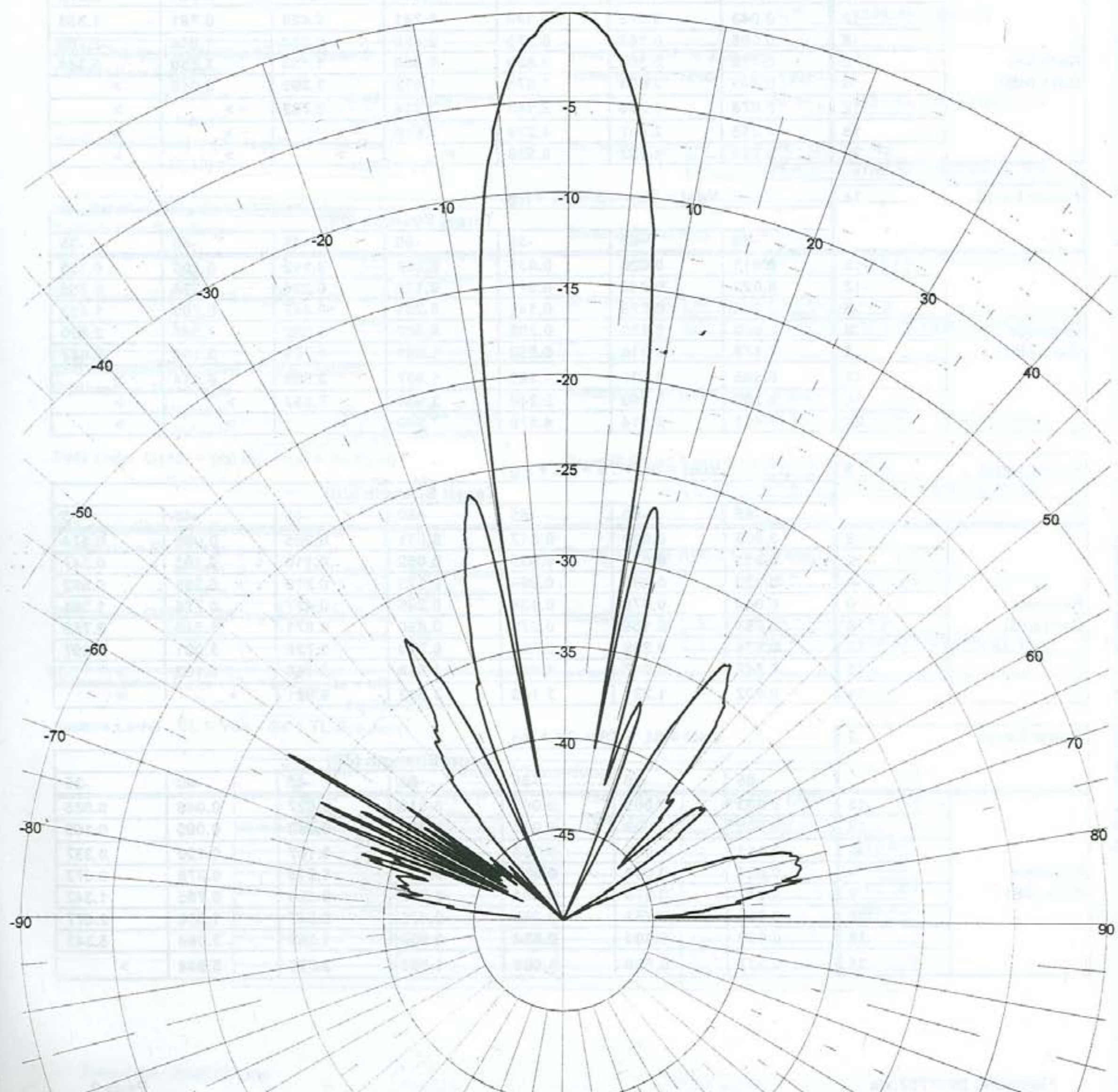
Collected By: BK, GH
Date June 05, 2002
Time 9:34:53
Sounder S/N 1320757 241
Transducer S/N 1405203 4x8
Cable S/N 1302029 200'

Depth 4.57 m
Sep. Dist. 6.1 m
Water Temp 55 F
Bandwidth N/A Hz

-3dB Beamwidth = 7.85 Deg
BoreSite = 14.71 dBv @ 185.88 RAM Deg
Largest Left Side Lobe = -26.11 dB @ -13.19 Deg
Largest Right Side Lobe = -26.84 dB @ 12.42 Deg

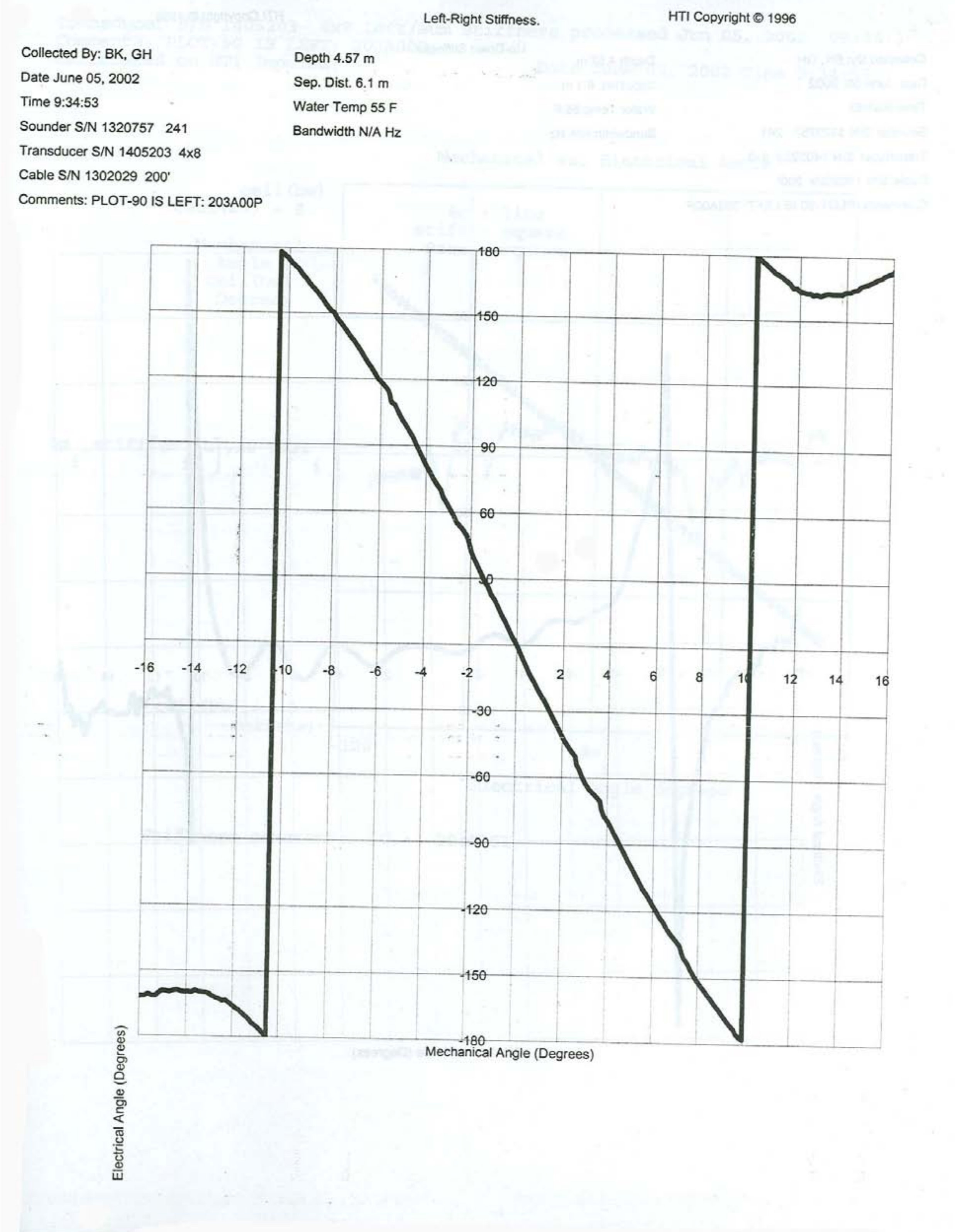
Processes: Clip=C Smooth=S Boresite=B Normalize=N
Performed: C,C,S,N,N,B,B,

Comments: PLOT-90 IS LEFT: 203A00P



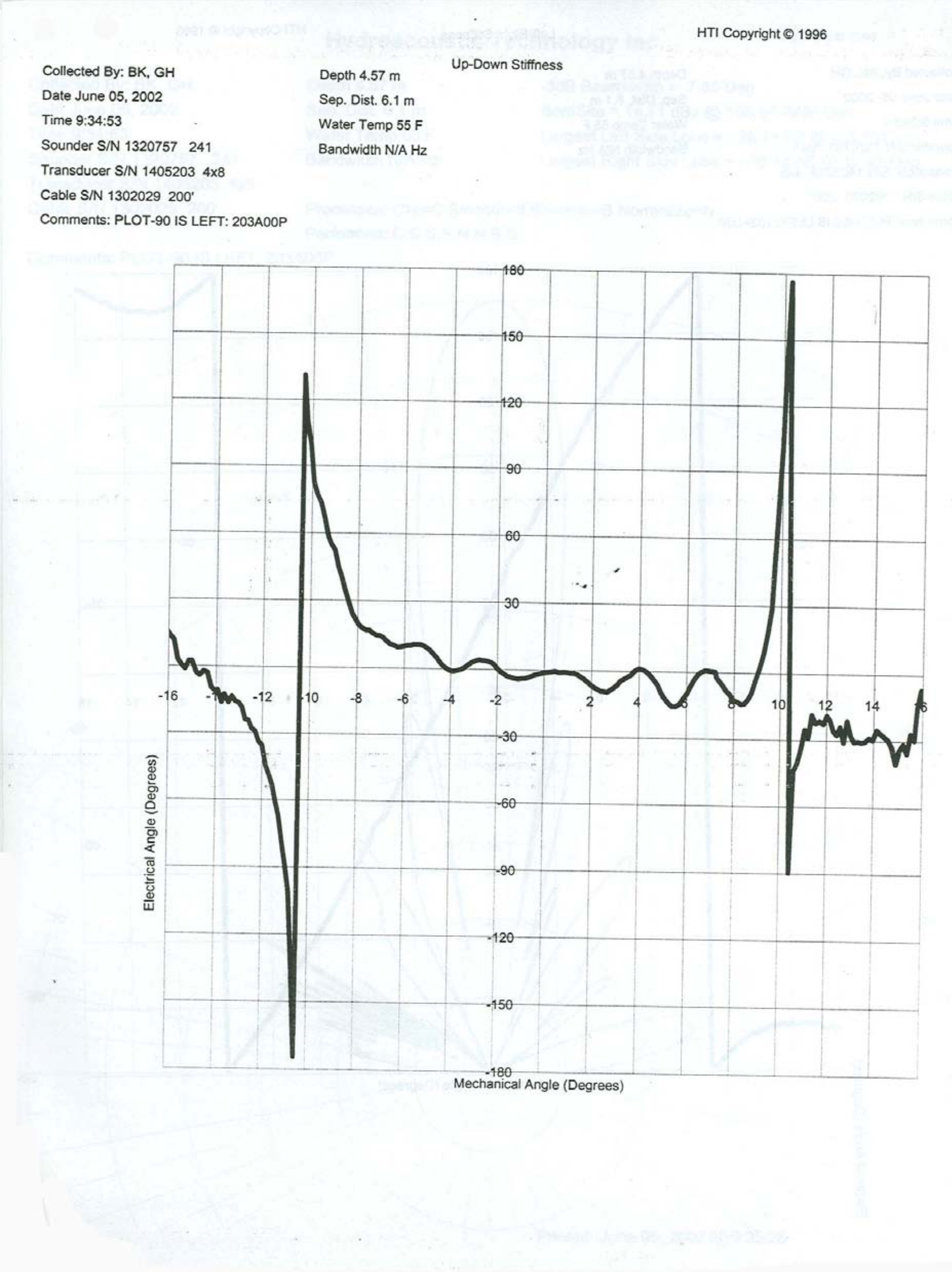
Printed: June 05, 2002 @ 9:35:26

-continued-


Left-Right Stiffness.
HTI Copyright © 1996
Collected By: BK, GH
Date June 05, 2002
Time 9:34:53
Sounder S/N 1320757 241
Transducer S/N 1405203 4x8
Cable S/N 1302029 200'
Comments: PLOT-90 IS LEFT: 203A00P
Depth 4.57 m
Sep. Dist. 6.1 m
Water Temp 55 F
Bandwidth N/A Hz
180
150
120
90
60
30
-30
-60
-90
-120
-150
-180
-16
-14
-12
-10
-8
-6
-4
-2
2
4
6
8
10
12
14
16
Mechanical Angle (Degrees)
Electrical Angle (Degrees)

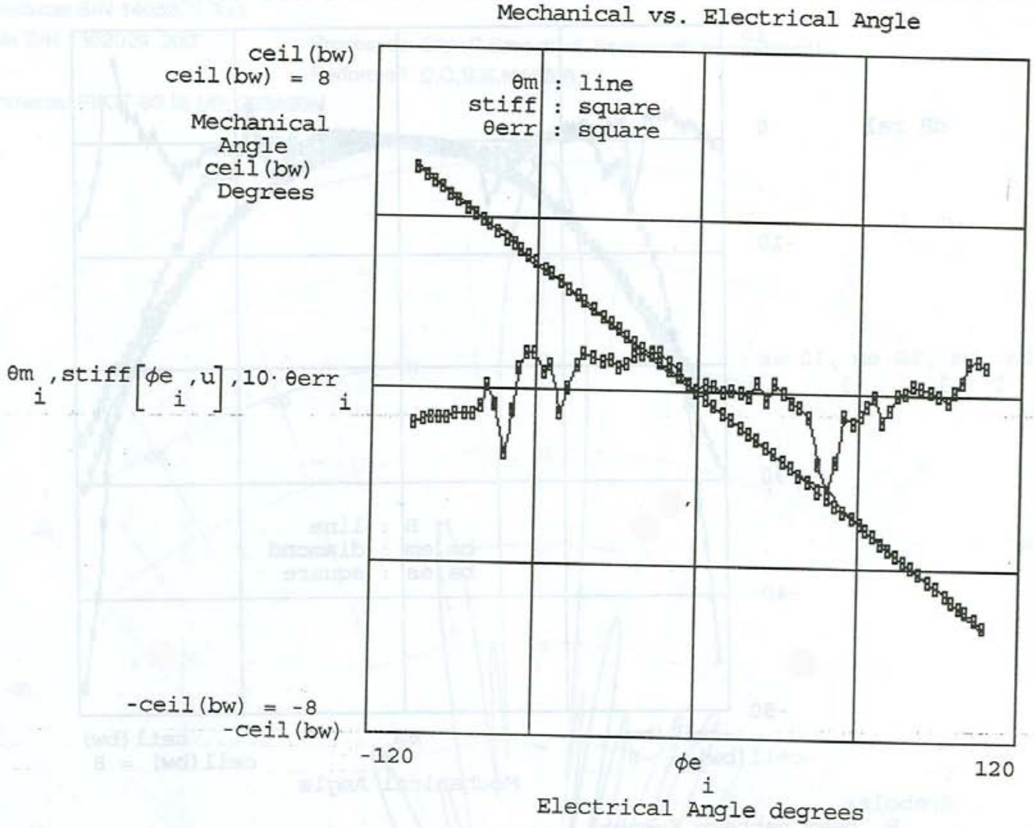
-continued-

Appendix A1.–Page 8 of 16.



-continued-

Transducer S/N 1405203 4x8 Left/Sum Stiffness processed Jun 05, 2002 09:36:3
Comments: PLOT-90 IS LEFT: 203A00P
Calibrated on HTI Impulse: Date June 05, 2002 Time 9:34:53

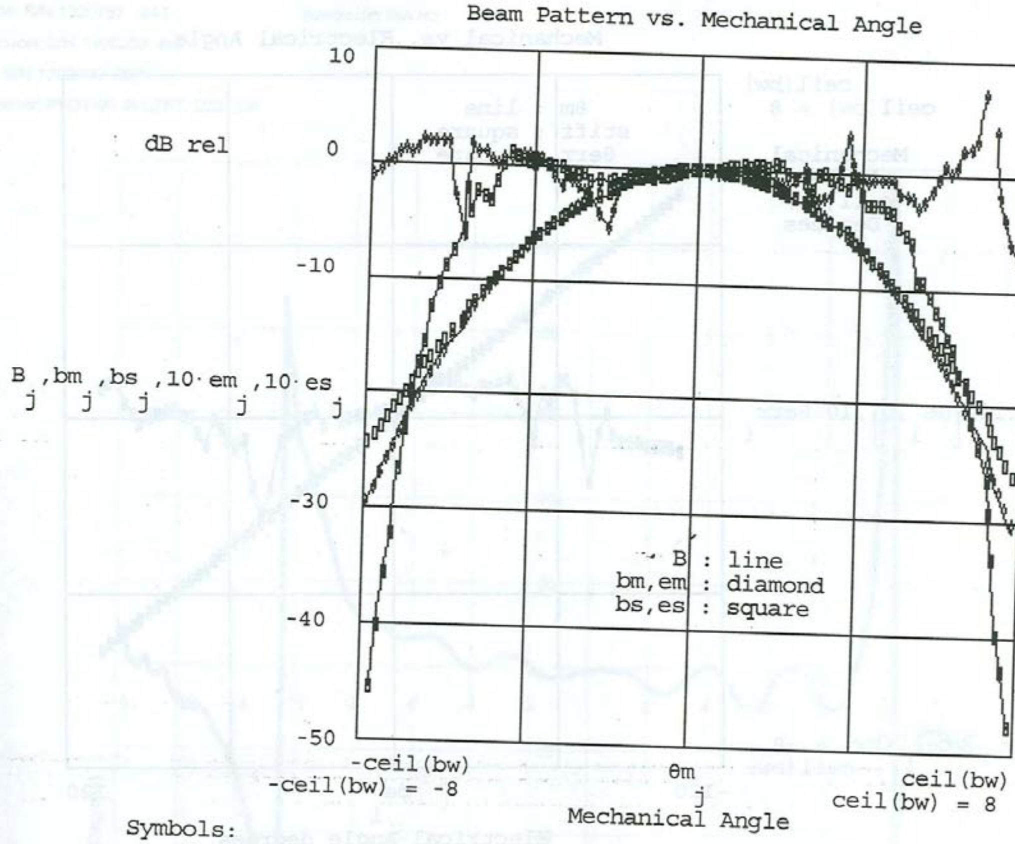


Stiffness constant: U = -20.2351

-continued-

Transducer S/N 1405203 4x8 Left/Sum Stiffness processed Jun 05, 2002 09:36:3
Comments: PLOT-90 IS LEFT: 203A00P
Calibrated on HTI Impulse:

Date June 05, 2002 Time 9:34:53



Symbols:
- B beam pattern factor
- θm mechanical angle
- ϕe electrical angle

Beam pattern fit plot:
- B: pattern plotted against mechanical angle, θm
- bm: fit of pattern, θm -> bm
- bs: pattern predicted from stiffness, ϕe -> θm' -> bm

Beam fit coefficients:

Measured beamwidth: bw = 7.688
Beamwidth from fit: bw_fit = 7.667

$$c = \begin{bmatrix} 0 \\ 0.000419 \\ -0.388096 \\ -0.001472 \\ -0.001474 \end{bmatrix} \begin{matrix} a \\ b \\ c \\ d \\ e \end{matrix}$$

-continued-

Hydroacoustic Technology Inc. Copyright © 1996

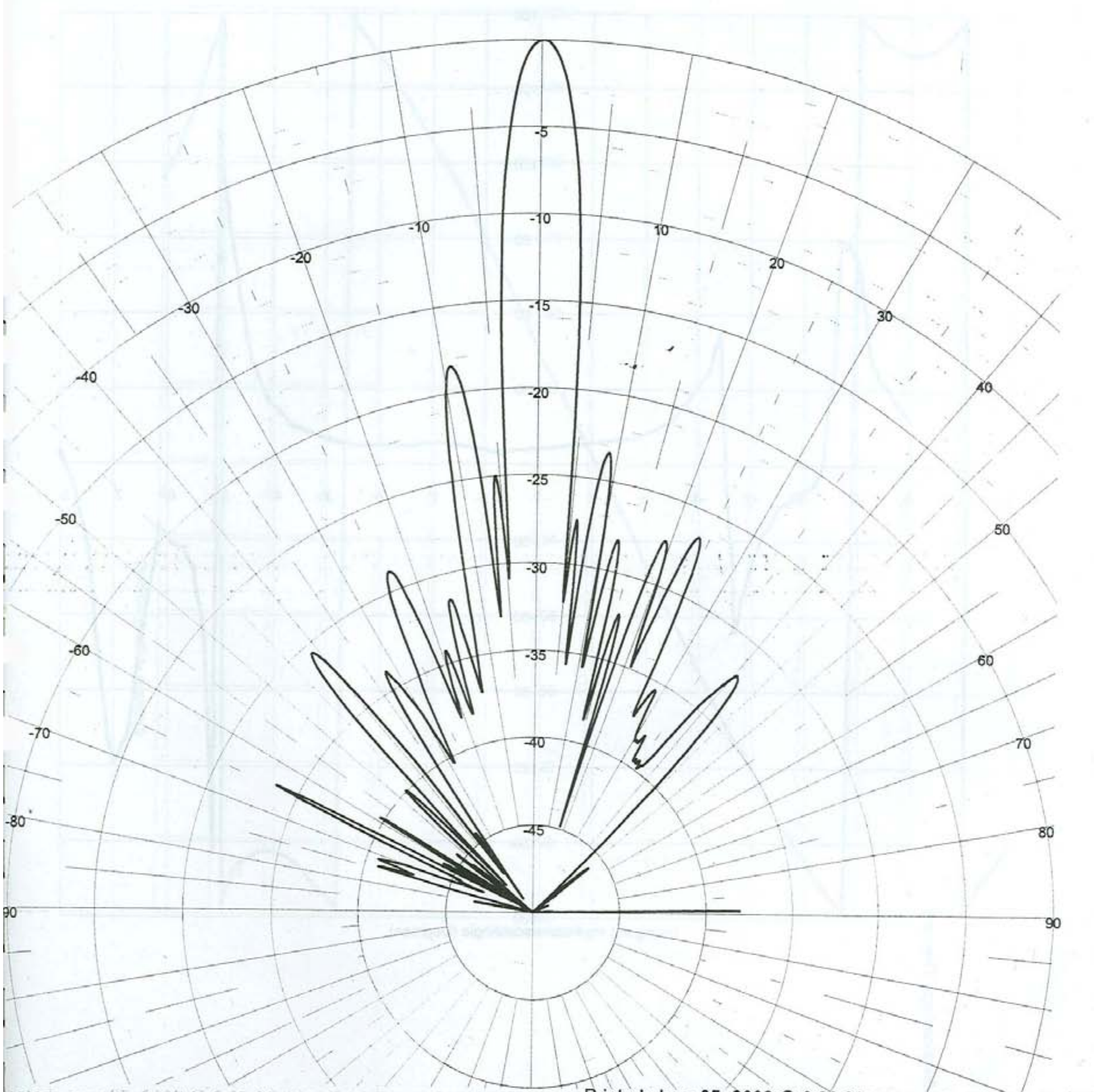
Collected By: BK, GH
Date June 05, 2002
Time 9:39:1
Sounder S/N 1320757 241
Transducer S/N 1405203 4x8
Cable S/N 1302029 200'

Depth 4.57 m
Sep. Dist. 6.1 m
Water Temp 55 F
Bandwidth N/A Hz

-3dB Beamwidth = 3.90 Deg
BoreSite = 14.64 dBv @ 186.20 RAM Deg
Largest Left Side Lobe = -18.45 dB @ -9.20 Deg
Largest Right Side Lobe = -23.38 dB @ 8.88 Deg

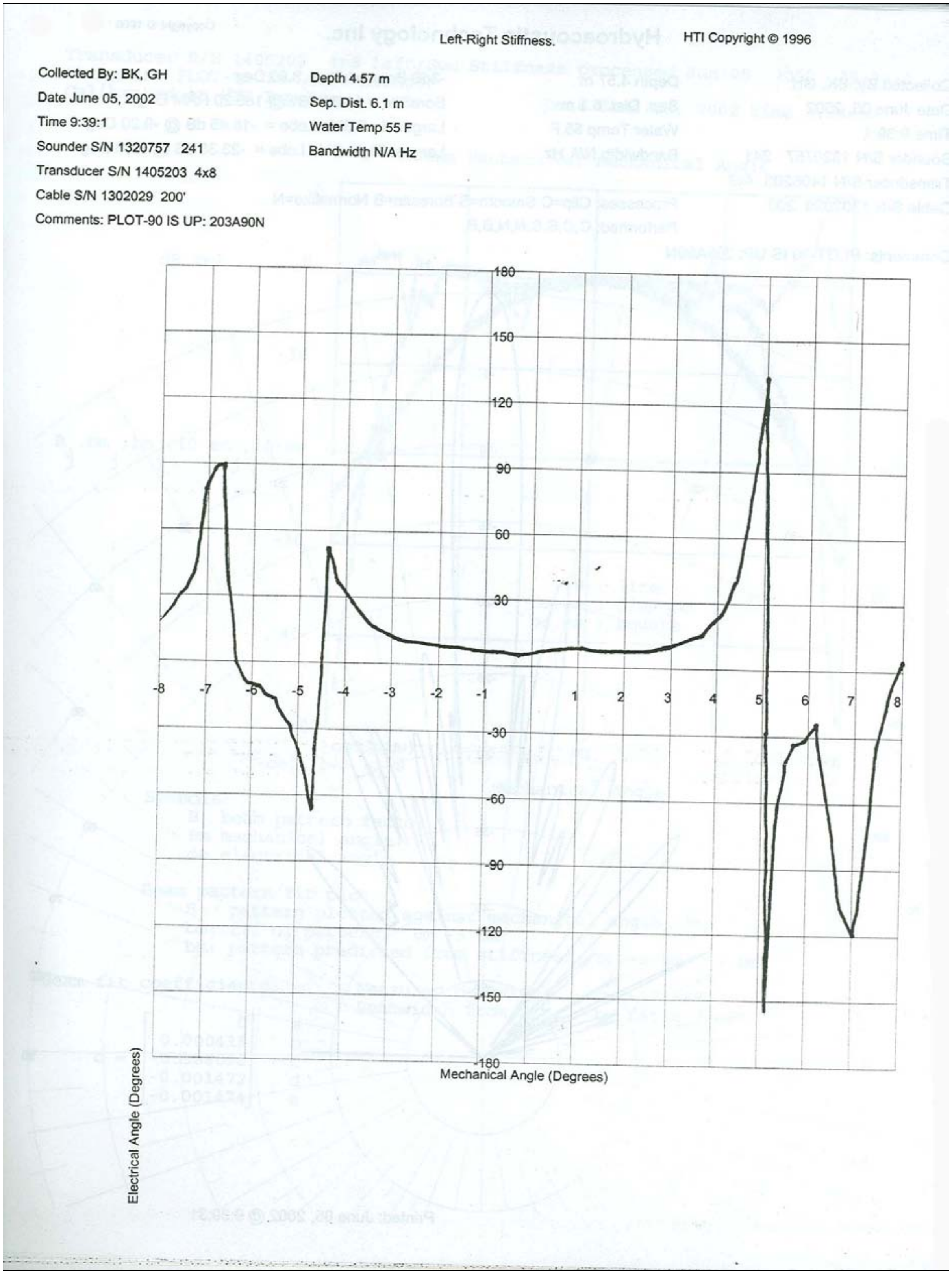
Processes: Clip=C Smooth=S Boresite=B Normalize=N
Performed: C,C,S,S,N,N,B,B,

Comments: PLOT-90 IS UP: 203A90N

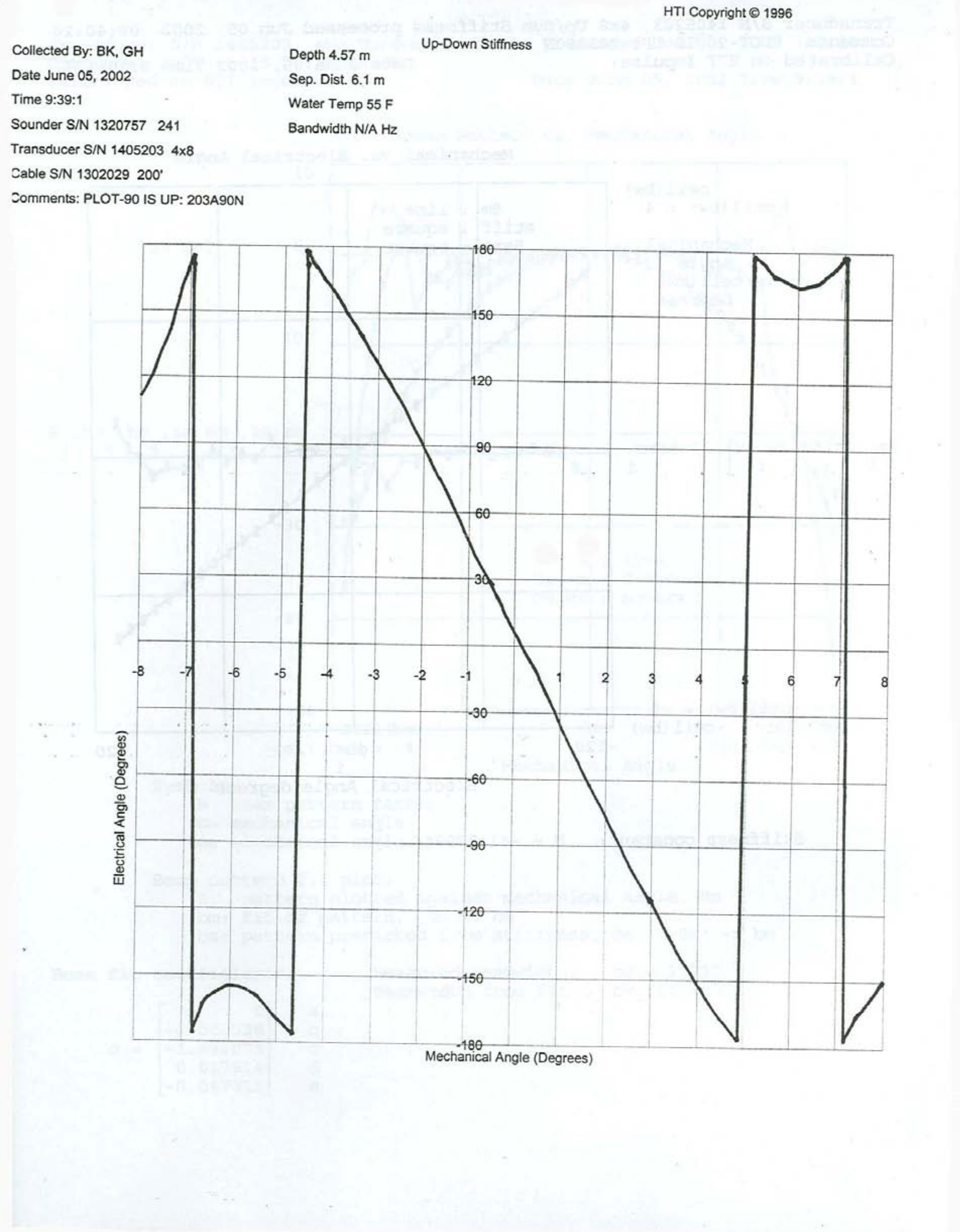


Printed: June 05, 2002 @ 9:39:31

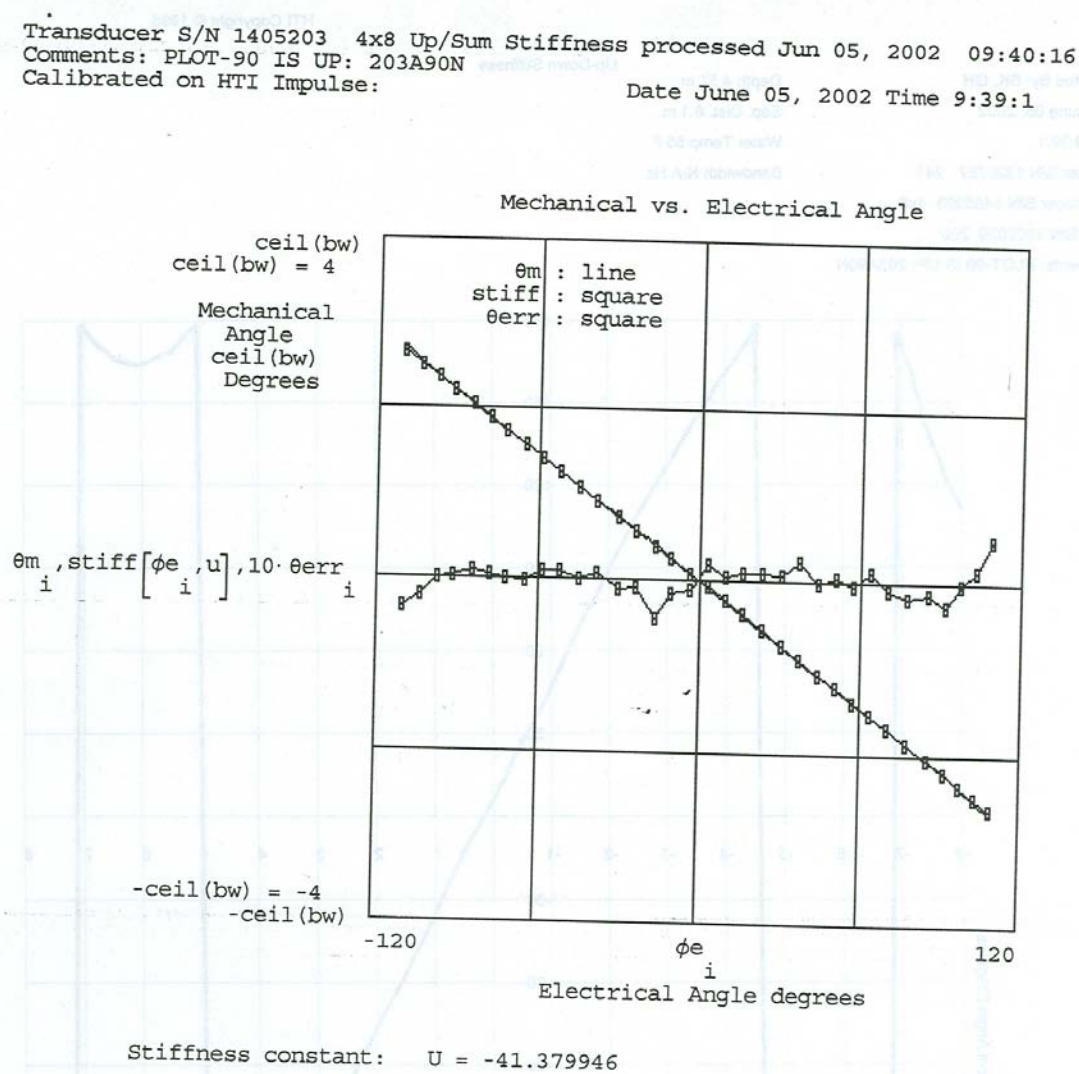
-continued-


Left-Right Stiffness.
HTI Copyright © 1996
Collected By: BK, GH
Date June 05, 2002
Time 9:39:1
Sounder S/N 1320757 241
Transducer S/N 1405203 4x8
Cable S/N 1302029 200'
Comments: PLOT-90 IS UP: 203A90N
Depth 4.57 m
Sep. Dist. 6.1 m
Water Temp 55 F
Bandwidth N/A Hz
180
150
120
90
60
30
-30
-60
-90
-120
-150
-180
-8
-7
-6
-5
-4
-3
-2
-1
1
2
3
4
5
6
7
8
Mechanical Angle (Degrees)
Electrical Angle (Degrees)

-continued-

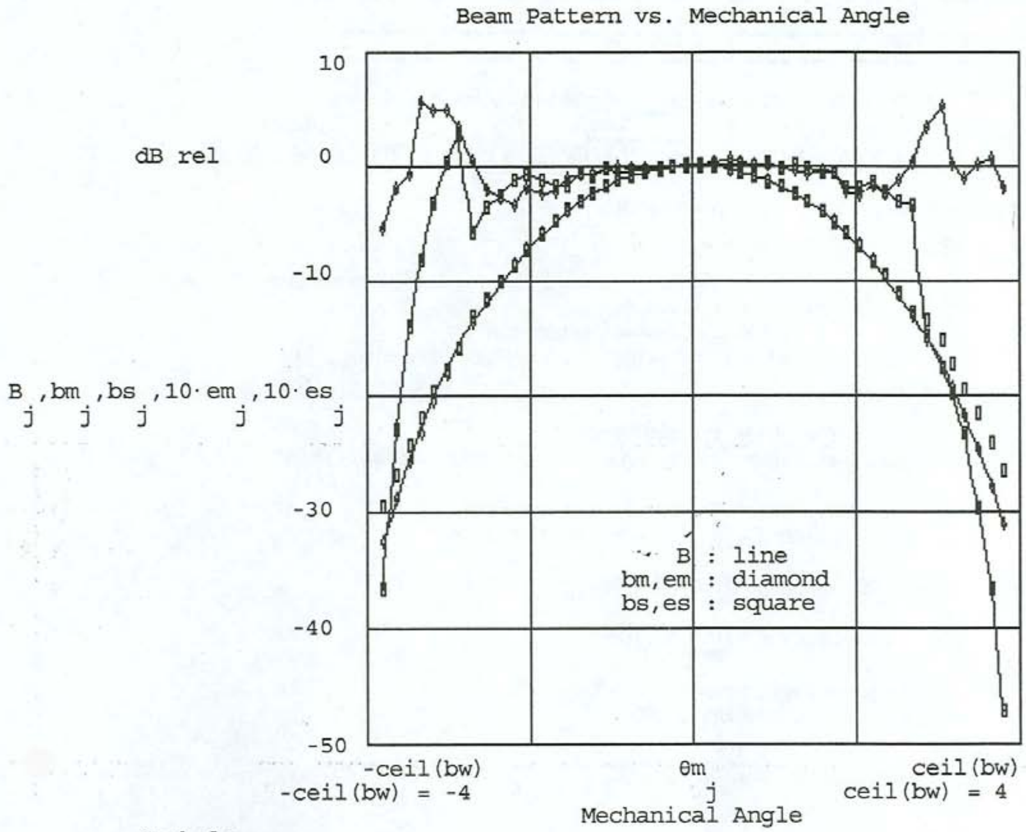

HTI Copyright © 1996
Up-Down Stiffness
Collected By: BK, GH
Date June 05, 2002
Time 9:39:1
Sounder S/N 1320757 241
Transducer S/N 1405203 4x8
Cable S/N 1302029 200'
Comments: PLOT-90 IS UP: 203A90N
Depth 4.57 m
Sep. Dist. 6.1 m
Water Temp 55 F
Bandwidth N/A Hz
Electrical Angle (Degrees)
Mechanical Angle (Degrees)

-continued-


Transducer S/N 1405203 4x8 Up/Sum Stiffness processed Jun 05, 2002 09:40:16
Comments: PLOT-90 IS UP: 203A90N
Calibrated on HTI Impulse:
Date June 05, 2002 Time 9:39:1
Mechanical vs. Electrical Angle
ceil(bw)
ceil(bw) = 4
Mechanical Angle ceil(bw) Degrees
θm : line
stiff : square
θerr : square
θm_i ,stiff[φe_i ,u],10·θerr_i
-ceil(bw) = -4
-ceil(bw)
-120
120
φe_i
Electrical Angle degrees
Stiffness constant: U = -41.379946

-continued-

Transducer S/N 1405203 4x8 Up/Sum Stiffness processed Jun 05, 2002 09:40:16
Comments: PLOT-90 IS UP: 203A90N
Calibrated on HTI Impulse: Date June 05, 2002 Time 9:39:1



Symbols:
B beam pattern factor
θm mechanical angle
ϕe electrical angle

Beam pattern fit plot:
B: pattern plotted against mechanical angle, θm
bm: fit of pattern, θm -> bm
bs: pattern predicted from stiffness, ϕe -> θm' -> bm

Beam fit coefficients:

Measured beamwidth: bw = 3.732
Beamwidth from fit: bw_fit = 3.8

$$c = \begin{bmatrix} 0 \\ -0.000526 \\ -1.498075 \\ 0.017914 \\ -0.047215 \end{bmatrix} \begin{matrix} a \\ b \\ c \\ d \\ e \end{matrix}$$

-continued-

Squared Beam Pattern Factor Calculation for Rectangular Transducer Element

For XD: s/n 1405203 | 200 KhZ, 4X8

Actual 3dB beamwidth from beamfit - using coefficients

Vertical Plane:	3.80 °	4.253067 Ly/Lambda
Horizontal Plane:	7.67 °	2.109137 Lx/Lambda

Find squared beam pattern factor (b^2(theta,phi)):

Where:

Lx = transducer element size (wavelengths) in one plane
lambda = wavelength
BW = 3 dB one-way beamwidfth
constant1 = 0.1410112 is empirically determined

First find Lx/lambda and Ly/lambda:

Lx / lambda = constant / sin(BW/2)
10Log(b^2(theta,phi)) = 10Log((1/(Lx/lambda)) * (1/(Ly/lambda))) - 11.572

b^2(theta,phi) = Squared Beam Pattern Factor
constant2 = -11.572 is empirically derived

10Log(b^2(theta,phi)) = -21.1001

b^2(theta,phi) = 0.007762

These equations were developed by J. Ehrenberg, after those expressed in Urick, 1963

Appendix A2.–Laboratory calibration for the 2^o by 6^o split-beam transducer used with the Model 241 split-beam system.

200 KHz — 2X6 Degree —200ft
S/N 1405201

-continued-

Hydroacoustic Technology Inc.

HTI

Standard Sphere Calibration

		Freq	200 KHz
Customer	ADFG MAXWELL	Transducer S/N	1405201
Project Name	KENAI REMOTE	Beam Width	2X6 Deg
Calibration Location	HTI-Impulse	Echo Sounder S/N	1320757
Customer Contact	SUSIE MAXWELL	Model #	241
Calibrated by	BK, GH, MA	Calibration Date	06/05/02
		Calibration File	201S757 .xls
Sphere Type	38.1 mm Tungsten-carbide	Cable Length	200 Feet

FILE NAME RAW / MDB	RX Gain dB	TVG Gain dB	TX Pwr dBW	PW ms	Pulse Type	Chirp BW KHz	Range m	Echoes #	TS dB	Std. DEV dB
S1560850	-6	0	14	0.40	NORM	0.0	6.08	507	-38.94	0.83
S1560852	-6	0	14	5.00	CHIRP	10.0	6.02	269	-39.91	0.81
S1560853	-6	0	14	2.50	CHIRP	10.0	6.02	259	-39.42	0.61
S1560855	-6	0	14	1.25	CHIRP	10.0	6.03	288	-39.23	0.59

-continued-

Hydroacoustic Technology, Inc.

HTI

Hydroacoustic System Calibration

Customer	ADF&G	Frequency (kHz)	200
Project Name	Kenai Remote	Transducer S/N	1405201
Calibration Location	HTI-Impulse	Beam Width	2x6
Customer Contact	Susie Maxwell	Echo Sounder S/N	1320757
Calibrated by	BK, GH	Model #	241
		Calibration Date	04-Jun-02
		G1+SL20 =	51.23 dB

Echo Sounder

Arguments to: TVG	1 2 0 42 0 3 1	Arguments to: RX	0
Arguments to: TRIG	00/10	Arguments to: REP	100 10
Arguments to: TX	1-2 to 1-20	Arguments to: MUX	1
Arguments to:FILTER	3	Arguments to:	

Frequency	200 kHz	Band Width	n/a kHz
Receiver Gain (Rg)	0 dB	Pulse Width	0.5 msec
TVG Full Range	n/a m	Blanking Control	3
TVG Crossover	11.22 m	Blanking Min	1 m
TVG Cal Rng (Rcal)	11.22 m	Blanking Max	2 m
Alpha (a)	0 dB/km	Rel Noise (wet)	-34.4 dBV
RCAL @ T 0 42 TX 1 20	not measured Vdet40		(T 0 82 .. CWFILT 4)

Cable

Cable S/N	1302022	Cable Length	200 ft
Cable Type	Split-beam	Mux Port	1

Standard Transducer

Type	ITC-5323	Ts =	124.1 dBuPa/V
S/N	007	Ss =	-223.84 dBv/uPa
Last Calibration	Nov 25, 2000 PAS		
		Preamp Gain 20=	13.39 dB
LP Filter	100 x 1k	Equiv. Ss20 =	-210.45 dBv/uPa
HP Filter	300 x 1k		
		Preamp Gain 40=	33.34 dB
		Equiv. Ss40 =	-190.5 dBv/uPa

Air and Water Parameters

Air Temperature	62 °F	Calibration Depth	4.57 m
Water Temperature	55 °F	Separation (Rs)	6.1 m

Filename: 201S757.xls

Page 1

-continued-

Hydroacoustic Technology, Inc.

HTI

Receiving Sensitivity

Transducer S/N 1405201

Sounder S/N 1320757

Voltage Into Standard Vs (Generator at 23 dBm)

Vs= 6.24 *volts (rms)*

Vs= 15.90 dBVrms

Transmission Loss TL = 20 log Rs + aRs

TL = 15.71 dB

Acoustic Level L = Ts + Vs - TL

L = 124.30 dB/uPa

Sum Channel Detected 12 kHz Output

Calibration Readings

v12kHz = 0.449 *volts (rms)*

Vdet = -3.95 dB Vdet

TVG Gain G(40) = (40 log Rcal + 2a Rcal)

G(40) = 42.00 dB

Vdet = V12kHz + 3.01 dB

Sensitivity at Rcal Gx = Vdet - L

Gx = -128.24 dB/uPa@Rcal

Sensitivity at 1 m G1 = Gx - G(40) - Rg

G1 = -170.24 dB/uPa @ 1m

Up Channel Detected 12 kHz Output

Calibration Readings

v12kHz = 0.221 *volts (rms)*

Vdet = -10.10 dB Vdet

TVG Gain G(40) = (40 log Rcal + 2a Rcal)

G(40) = 42.00

Sensitivity at Rcal Gx = Vdet - L

Gx = -134.40 dB/uPa@Rcal

Sensitivity at 1 m G1 = Gx - G(40) - Rg

G1 = -176.40 dB/uPa @ 1m

Left Channel Detected 12 kHz Output

Calibration Readings

v12kHz = 0.229 *volts (rms)*

Vdet = -9.79 dB Vdet

TVG Gain G(40) = (40 log Rcal + 2a Rcal)

G(40) = 42.00 dB

Sensitivity at Rcal Gx = Vdet - L

Gx = -134.09 dB/uPa@Rcal

Sensitivity at 1 m G1 = Gx - G(40) - Rg

G1 = -176.09 dB/uPa @ 1m

20 Log R Channel Detected Output

Calibration Readings

vdet = 0.625 *volts (peak)*

Vdet = -4.08 dBV (det)

TVG Gain G(20) = (20 log Rcal + 2a Rcal)

G(20) = 21.00 dB

Sensitivity at Rcal Gx = Vdet - L

Gx = -128.38 dB/uPa@Rcal

Sensitivity at 1 m G1 = Gx - G(20) - Rg

G1 = -149.38 dB/uPa @ 1m

Transmission Loss TL = 20 log Rs + aR

TL = 15.71 dB

Source Level SL = Vso - Ss + TL-Pre-Amp

Transmit Power (dB)	Standard Transducer		Source Level (dBuPa @ 1 m)
	Vso (FFT) dBV (+20)	Vso (FFT) dBV (+40)	
20.0	-4.69		221.47
14.0	-10.62		215.54
8.0		2.81	209.02
2.0		-4.06	202.14

Filename: 201S757.xls

Page 2

-continued-

Sum Detected Voltage vs Power and Gain

Hydroacoustic Technology, Inc.

HTI

Transducer S/N 1405201

Sounder S/N 1320757

Power Level 20

Vdet = SL + TS + G1 + Rg

Receiver Gain (dB)	Target Strength (dB) -65	-60	-55	-50	-45	-40	-35
-18	0.026	0.046	0.082	0.145	0.258	0.459	0.815
-12	0.051	0.091	0.163	0.289	0.515	0.915	1.627
-6	0.103	0.183	0.325	0.577	1.027	1.826	3.246
0	0.205	0.364	0.648	1.152	2.048	3.643	6.477
6	0.409	0.727	1.292	2.298	4.087	7.268	>
12	0.815	1.450	2.579	4.586	8.155	>	>
18	1.627	2.893	5.145	9.150	>	>	>
24	3.246	5.773	>	>	>	>	>

Power Level 14

Vdet = SL + TS + G1 + Rg

Receiver Gain (dB)	Target Strength (dB) -65	-60	-55	-50	-45	-40	-35
-18	0.013	0.023	0.041	0.073	0.130	0.232	0.412
-12	0.026	0.046	0.082	0.146	0.260	0.462	0.822
-6	0.052	0.092	0.164	0.292	0.519	0.922	1.640
0	0.103	0.184	0.327	0.582	1.035	1.840	3.272
6	0.206	0.367	0.653	1.161	2.064	3.671	6.528
12	0.412	0.732	1.303	2.316	4.119	7.325	>
18	0.822	1.462	2.599	4.622	8.219	>	>
24	1.640	2.916	5.186	9.222	>	>	>

Power Level 8

Vdet = SL + TS + G1 + Rg

Receiver Gain (dB)	Target Strength (dB) -65	-60	-55	-50	-45	-40	-35
-18	0.006	0.011	0.019	0.035	0.062	0.109	0.194
-12	0.012	0.022	0.039	0.069	0.123	0.218	0.388
-6	0.024	0.044	0.077	0.138	0.245	0.435	0.774
0	0.049	0.087	0.154	0.275	0.489	0.869	1.545
6	0.097	0.173	0.308	0.548	0.975	1.733	3.083
12	0.194	0.346	0.615	1.094	1.945	3.459	6.150
18	0.388	0.690	1.227	2.182	3.881	6.901	>
24	0.774	1.377	2.449	4.354	7.743	>	>

Power Level 2

Vdet = SL + TS + G1 + Rg

Receiver Gain (dB)	Target Strength (dB) -65	-60	-55	-50	-45	-40	-35
-18	0.003	0.005	0.009	0.016	0.028	0.050	0.088
-12	0.006	0.010	0.018	0.031	0.056	0.099	0.176
-6	0.011	0.020	0.035	0.062	0.111	0.197	0.351
0	0.022	0.039	0.070	0.125	0.221	0.394	0.700
6	0.044	0.079	0.140	0.248	0.442	0.786	1.397
12	0.088	0.157	0.279	0.496	0.881	1.567	2.787
18	0.176	0.313	0.556	0.989	1.759	3.128	5.562
24	0.351	0.624	1.110	1.973	3.509	6.240	>

Filename: 201S757.xls

Page 3

-continued-

Hydroacoustic Technology Inc. Copyright © 1996

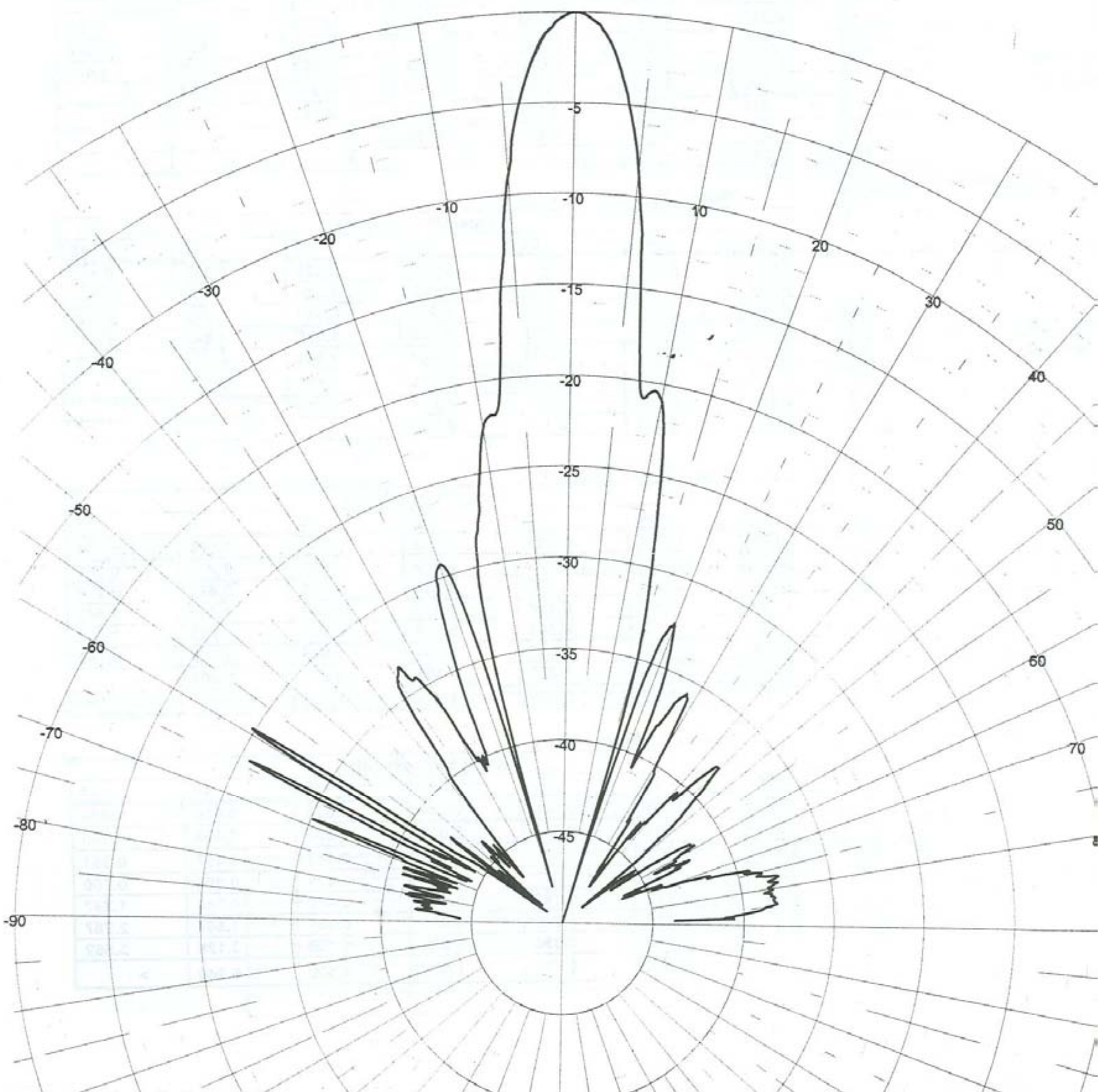
Collected By: BK, GH
Date June 05, 2002
Time 7:57:23
Sounder S/N 1320757 241
Transducer S/N 1405201 2x6
Cable S/N 1302022 200'

Depth 4.57 m
Sep. Dist. 6.1 m
Water Temp 55 F
Bandwidth N/A Hz

-3dB Beamwidth = 6.30 Deg
BoreSite = 13.81 dBv @ 186.36 RAM Deg
Largest Left Side Lobe = -20.76 dB @ -7.57 Deg
Largest Right Side Lobe = -20.43 dB @ 9.09 Deg

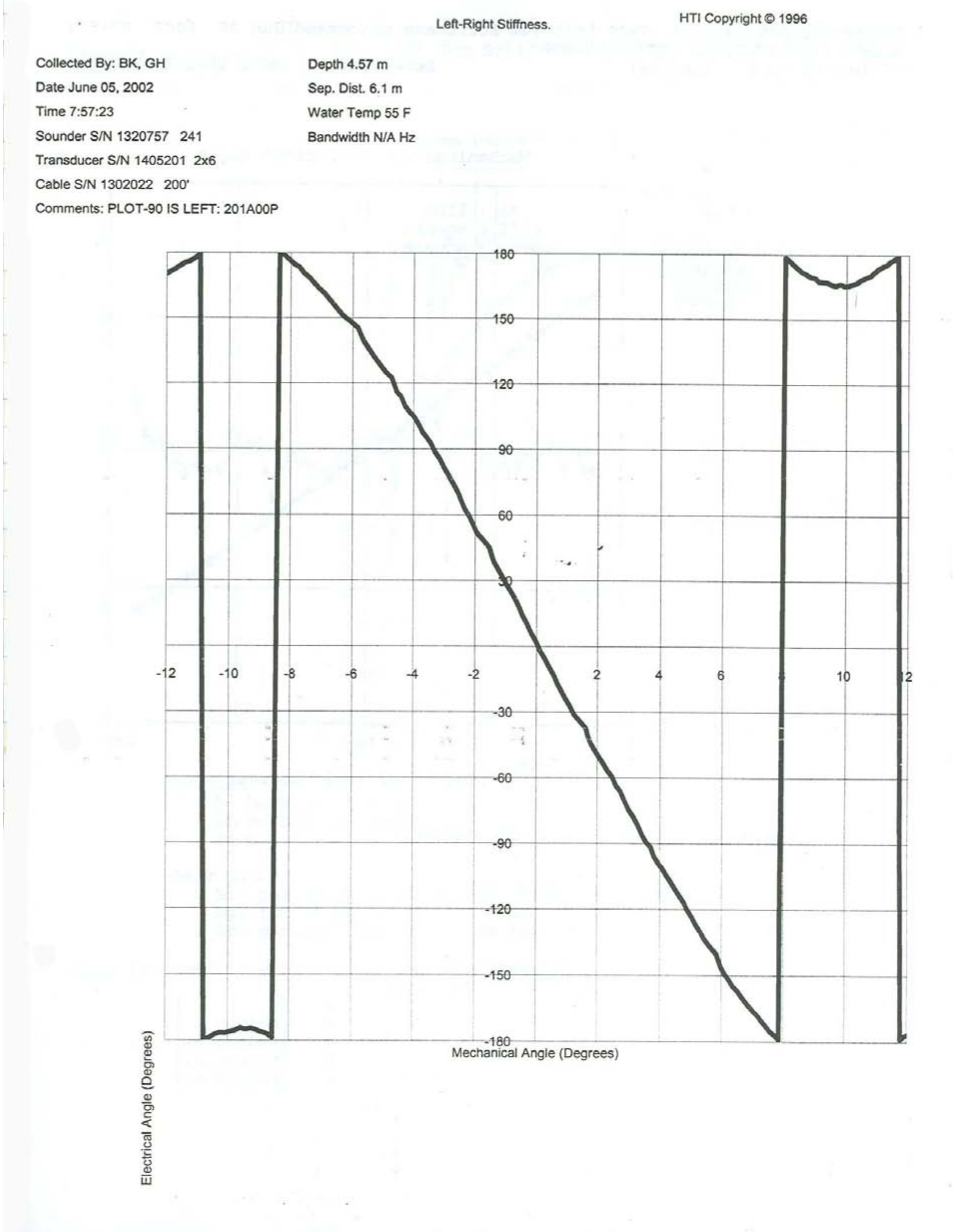
Processes: Clip=C Smooth=S Boresite=B Normalize=N
Performed: C,C,S,S,N,N,B,B,B,B,

Comments: PLOT-90 IS LEFT: 201A00P



Printed: June 05, 2002 @ 9:0:32

-continued-

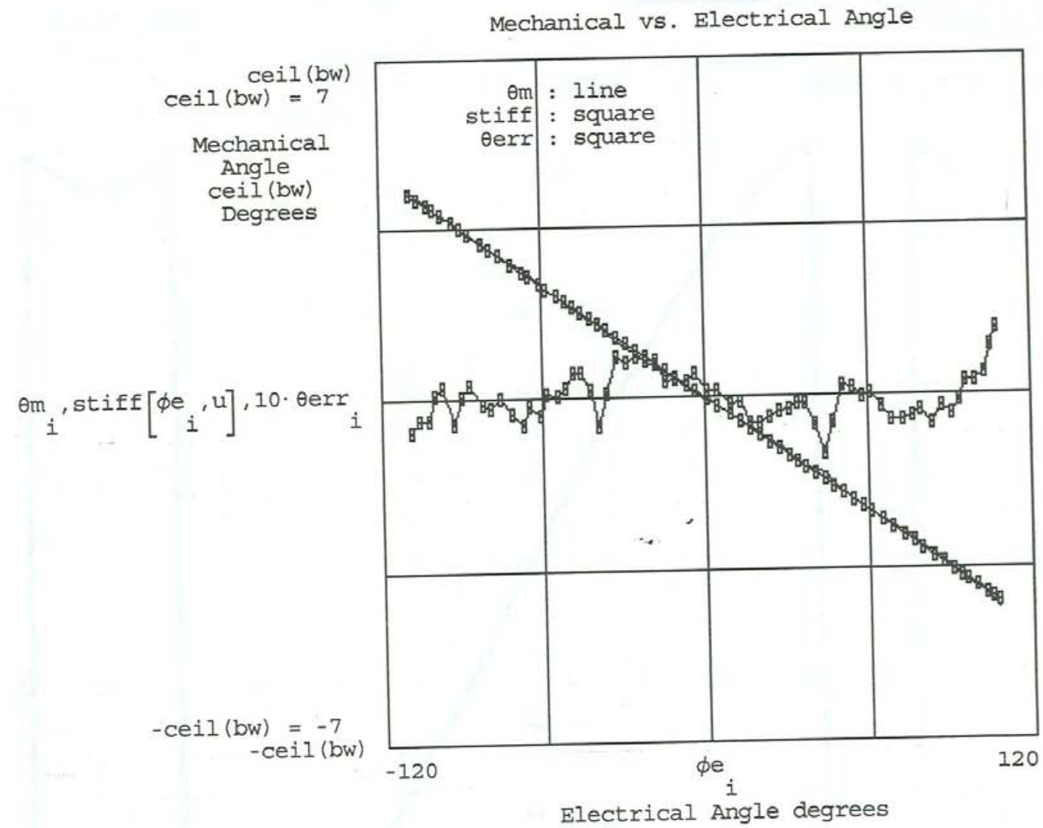


Left-Right Stiffness.
HTI Copyright © 1996
Collected By: BK, GH
Date June 05, 2002
Time 7:57:23
Sounder S/N 1320757 241
Transducer S/N 1405201 2x6
Cable S/N 1302022 200'
Comments: PLOT-90 IS LEFT: 201A00P
Depth 4.57 m
Sep. Dist. 6.1 m
Water Temp 55 F
Bandwidth N/A Hz
Electrical Angle (Degrees)
Mechanical Angle (Degrees)

-continued-

Transducer S/N 1405201 2x10 Left/Sum Stiffness processed Jun 05, 2002 07:59:
Comments: PLOT-90 IS LEFT: 201A00P
Calibrated on HTI Impulse:

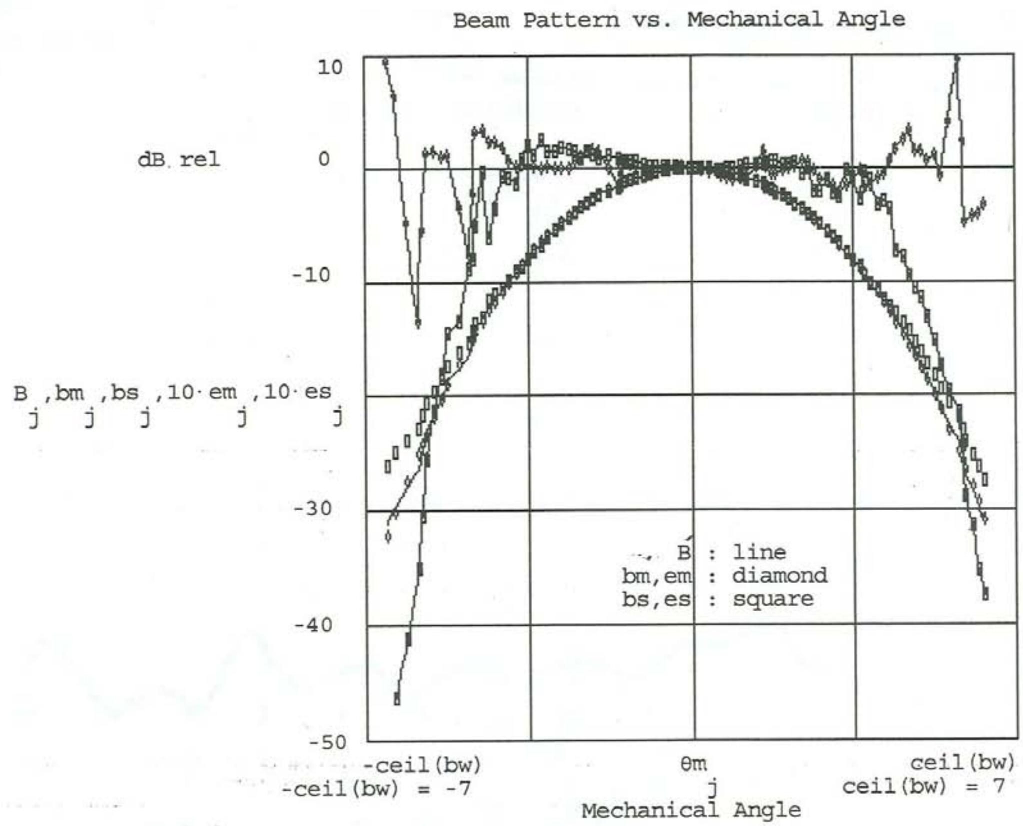
Date June 05, 2002 Time 7:57:23



Stiffness constant: U = -25.776218

-continued-

Transducer S/N 1405201 2x10 Left/Sum Stiffness processed Jun 05, 2002 07:59:
Comments: PLOT-90 IS LEFT: 201A00P
Calibrated on HTI Impulse: Date June 05, 2002 Time 7:57:23



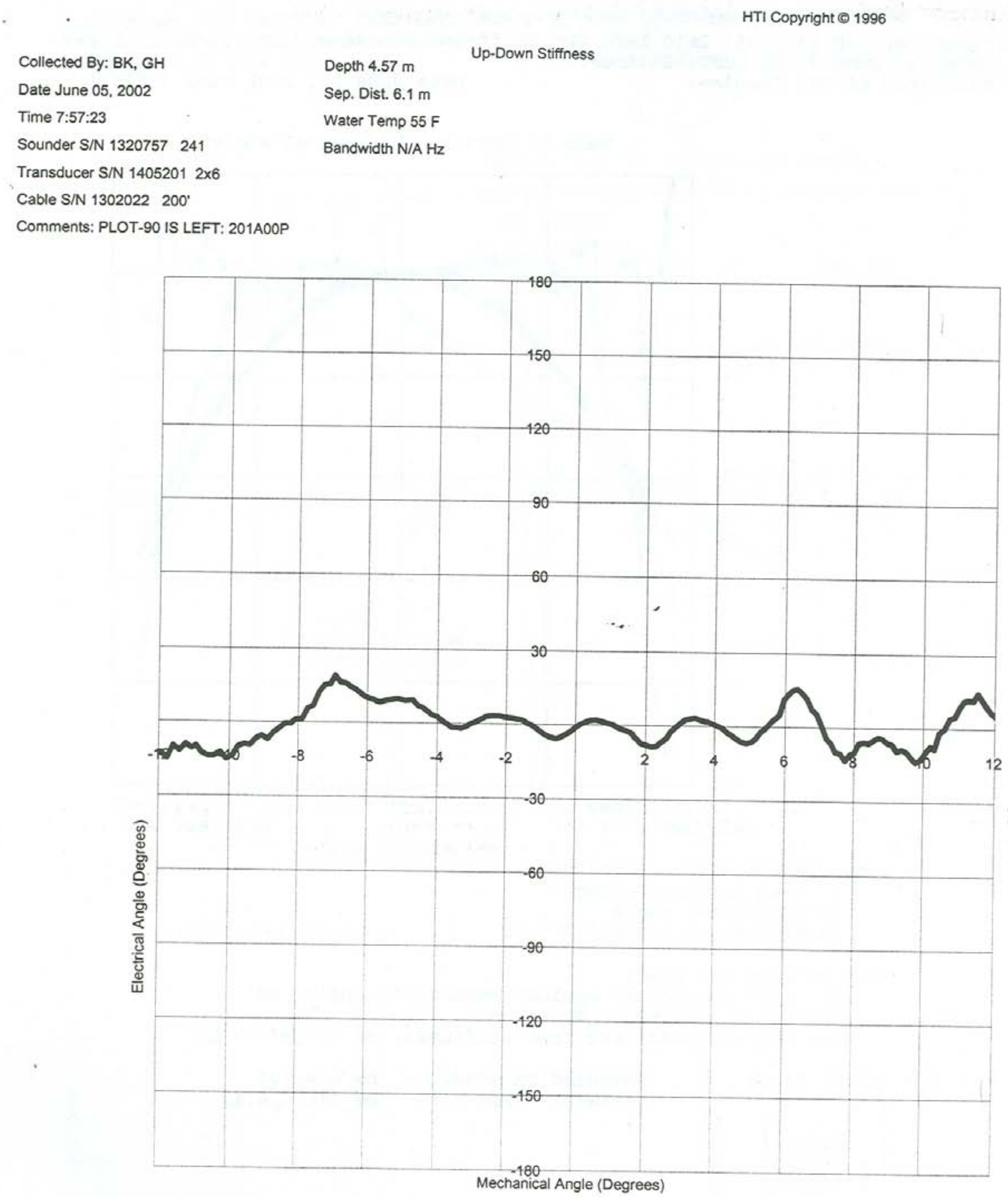
Symbols:
B beam pattern factor
θm mechanical angle
ϕe electrical angle

Beam pattern fit plot:
B: pattern plotted against mechanical angle, θm
bm: fit of pattern, θm -> bm
bs: pattern predicted from stiffness, ϕe -> θm' -> bm

Beam fit coefficients: Measured beamwidth: bw = 6.101
Beamwidth from fit: bw_fit = 6.13

$$c = \begin{bmatrix} 0 \\ 0.000054 \\ -0.605047 \\ -0.002214 \\ -0.003823 \end{bmatrix} \begin{matrix} a \\ b \\ c \\ d \\ e \end{matrix}$$

-continued-


HTI Copyright © 1996
Up-Down Stiffness
Collected By: BK, GH
Date June 05, 2002
Time 7:57:23
Sounder S/N 1320757 241
Transducer S/N 1405201 2x6
Cable S/N 1302022 200'
Comments: PLOT-90 IS LEFT: 201A00P
Depth 4.57 m
Sep. Dist. 6.1 m
Water Temp 55 F
Bandwidth N/A Hz
Electrical Angle (Degrees)
Mechanical Angle (Degrees)

-continued-

Hydroacoustic Technology Inc. Copyright © 1996

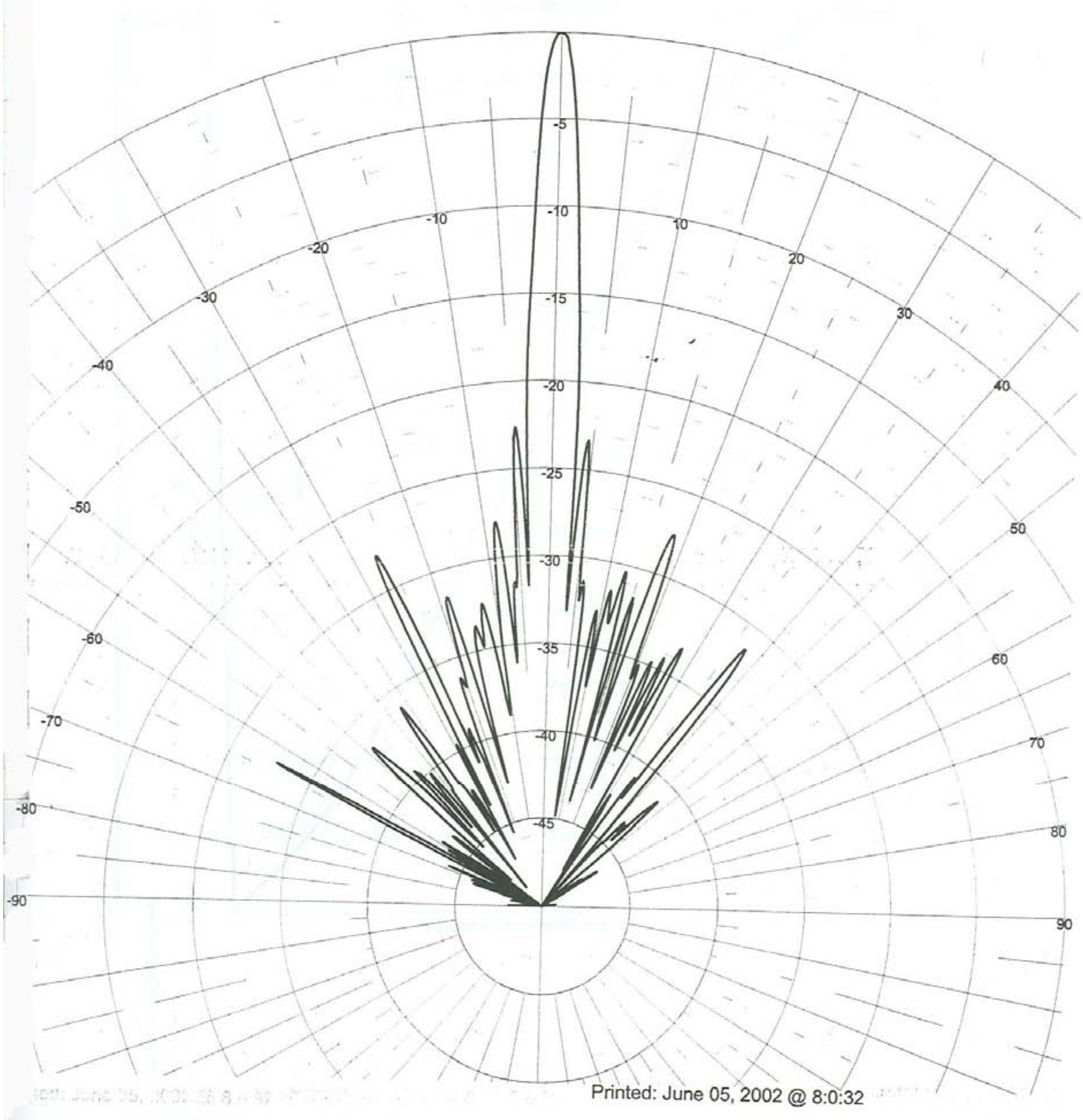
Collected By: BK, GH
Date June 05, 2002
Time 7:59:41
Sounder S/N 1320757 241
Transducer S/N 1405201 2x6
Cable S/N 1302022 200'

Depth 4.57 m
Sep. Dist. 6.1 m
Water Temp 55 F
Bandwidth N/A Hz

-3dB Beamwidth = 2.16 Deg
BoreSite = 13.75 dBv @ 186.43 RAM Deg
Largest Left Side Lobe = -21.88 dB @ -3.09 Deg
Largest Right Side Lobe = -22.62 dB @ 2.95 Deg

Processes: Clip=C Smooth=S Boresite=B Normalize=N
Performed: C,C,S,S,N,N,B,B,

Comments: PLOT-90 IS UP: 201A90N



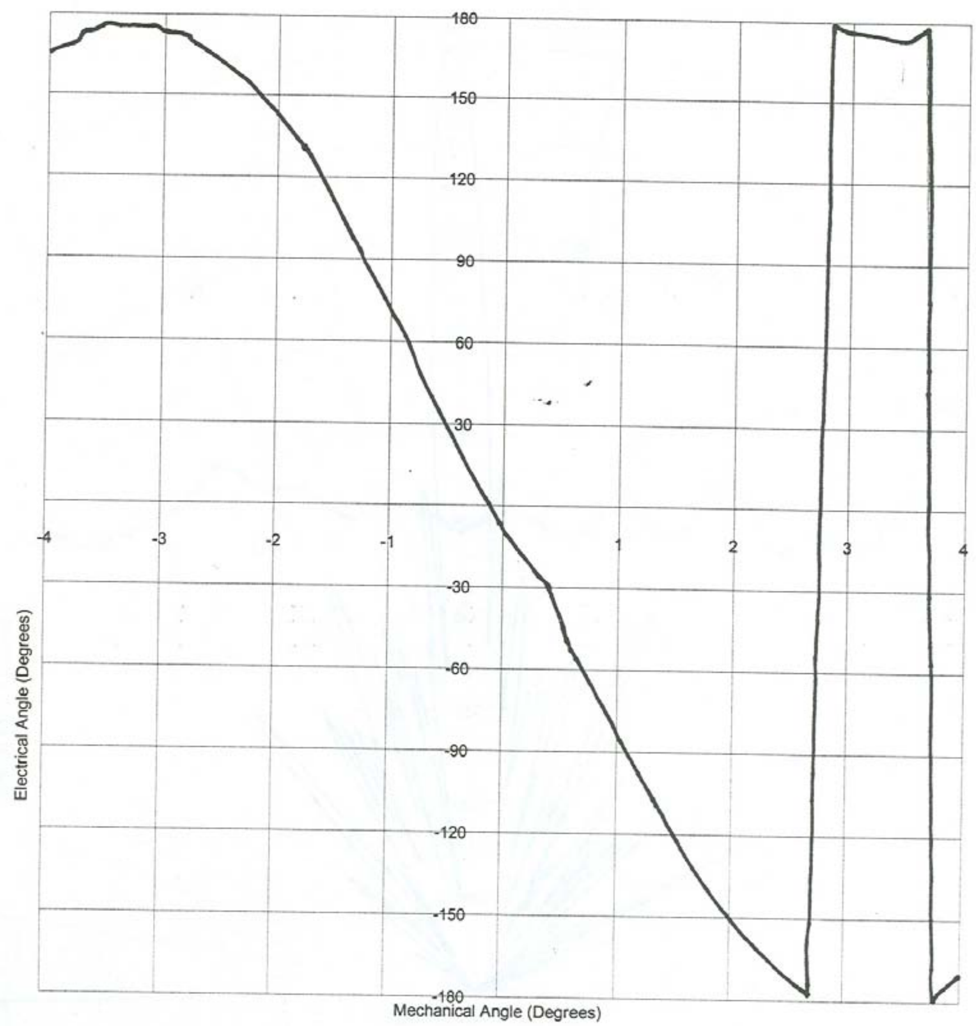
-continued-

HTI Copyright © 1996

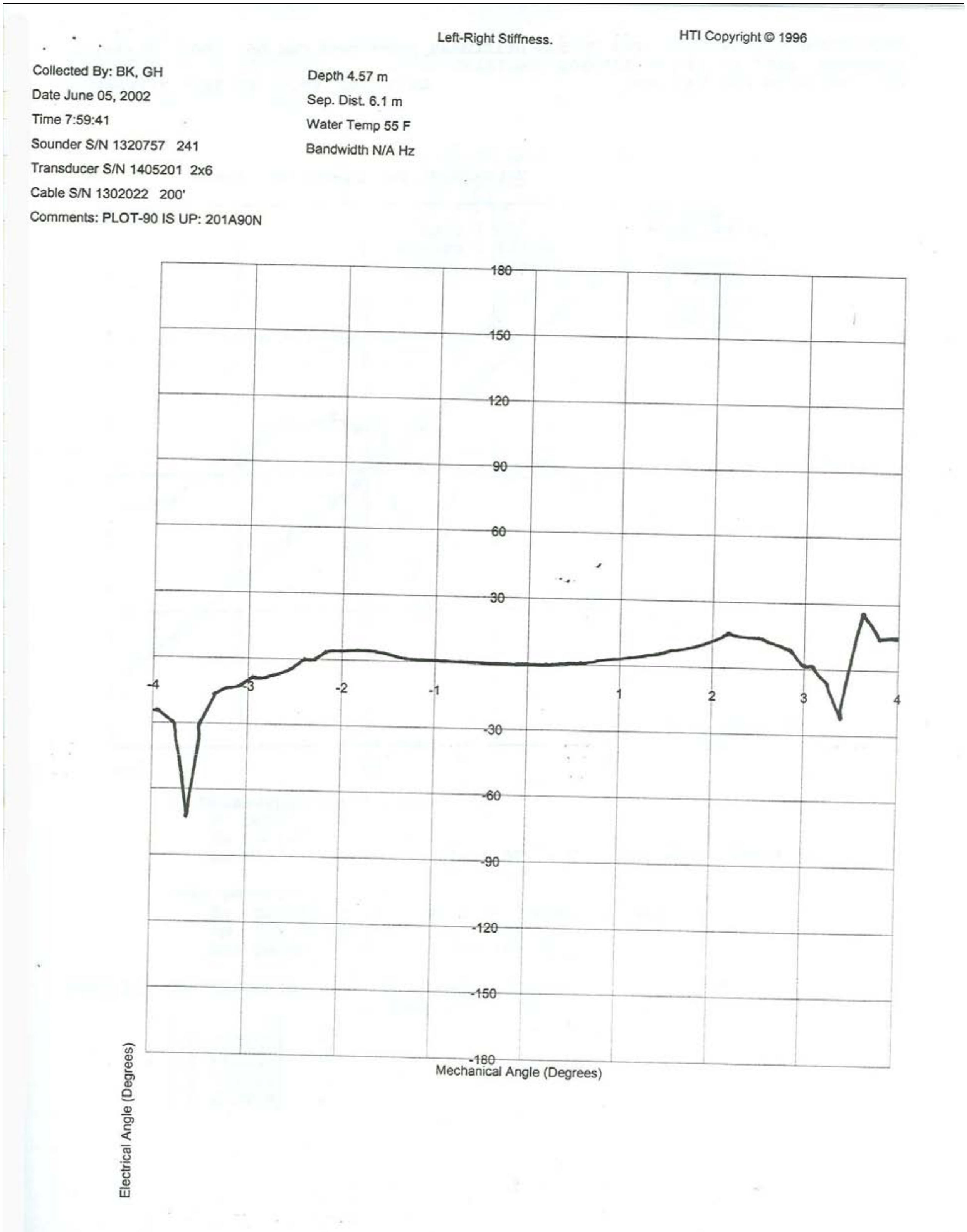
Up-Down Stiffness

Collected By: BK, GH
Date June 05, 2002
Time 7:59:41
Sounder S/N 1320757 241
Transducer S/N 1405201 2x6
Cable S/N 1302022 200'
Comments: PLOT-90 IS UP: 201A90N

Depth 4.57 m
Sep. Dist. 6.1 m
Water Temp 55 F
Bandwidth N/A Hz

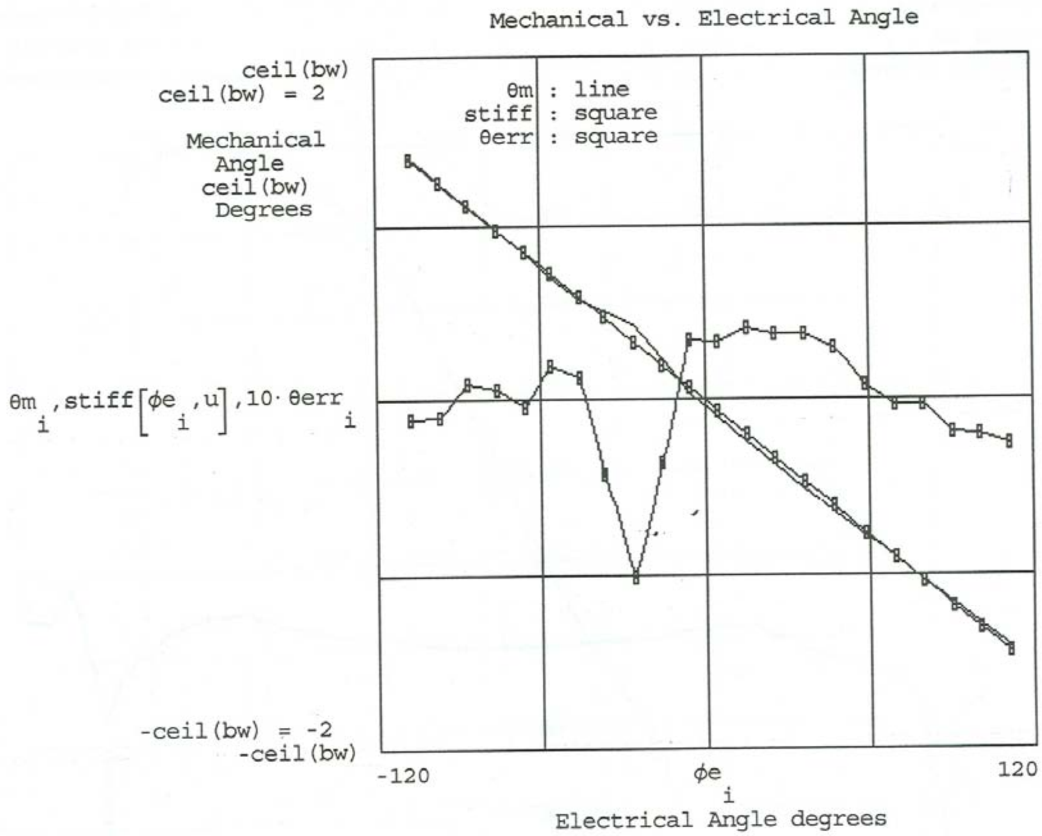


-continued-


Left-Right Stiffness.
HTI Copyright © 1996
Collected By: BK, GH
Date June 05, 2002
Time 7:59:41
Sounder S/N 1320757 241
Transducer S/N 1405201 2x6
Cable S/N 1302022 200'
Comments: PLOT-90 IS UP: 201A90N
Depth 4.57 m
Sep. Dist. 6.1 m
Water Temp 55 F
Bandwidth N/A Hz
180
150
120
90
60
30
-30
-60
-90
-120
-150
-180
-4
-3
-2
-1
1
2
3
4
Mechanical Angle (Degrees)
Electrical Angle (Degrees)

-continued-

Transcducer S/N 1405201 2x6 Up/Sum Stiffness processed Jun 05, 2002 08:26:33
Comments: PLOT-90 IS UP: 201A90N
Calibrated on HTI Impulse: Date June 05, 2002 Time 7:59:41

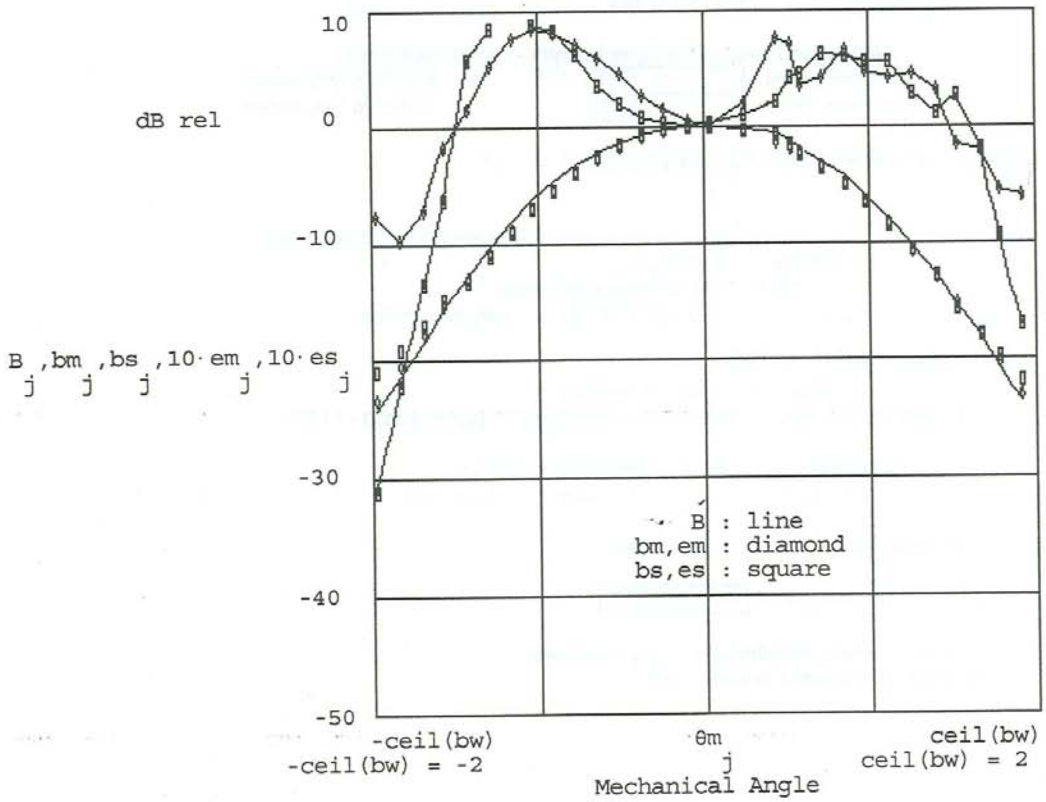


Stiffness constant: U = -76.869633

-continued-

Transducer S/N 1405201 2x6 Up/Sum Stiffness processed Jun 05, 2002 08:26:33
Comments: PLOT-90 IS UP: 201A90N
Calibrated on HTI Impulse: Date June 05, 2002 Time 7:59:41

Beam Pattern vs. Mechanical Angle



Symbols:
B beam pattern factor
θm mechanical angle
φe electrical angle

Beam pattern fit plot:
B: pattern plotted against mechanical angle, θm
bm: fit of pattern, θm -> bm
bs: pattern predicted from stiffness, φe -> θm' -> bm

Beam fit coefficients:

Measured beamwidth: bw = 1.999
Beamwidth from fit: bw_fit = 1.896

$$c = \begin{bmatrix} 0 \\ -0.010868 \\ -6.884655 \\ -0.054354 \\ 0.209459 \end{bmatrix} \begin{matrix} a \\ b \\ c \\ d \\ e \end{matrix}$$

-continued-

Squared Beam Pattern Factor Calculation for Rectangular Transducer Element

For XD: s/n 1405201 | 200 KhZ, 2X6

Actual 3dB beamwidth from beamfit - using coefficients

Vertical Plane:	1.90 °	8.522906	Ly/Lambda
Horizontal Plane:	6.13 °	2.63726	Lx/Lambda

Find squared beam pattern factor (b^2(theta,phi)):

Where:

Lx = transducer element size (wavelengths) in one plane
lambda = wavelength
BW = 3 dB one-way beamwidfth
constant1 = 0.1410112 is empirically determined

First find Lx/lambda and Ly/lambda:
Lx / lambda = constant / sin(BW/2)
10Log(b^2(theta,phi)) = 10Log((1/(Lx/lambda)) * (1/(Ly/lambda))) - 11.572

b^2(theta,phi) = Squared Beam Pattern Factor
constant2 = -11.572 is empirically derived

10Log(b^2(theta,phi)) = -25.0894

b^2(theta,phi) = 0.003098

These equations were developed by J. Ehrenberg,
after those expressed in Urick, 1963

Appendix A3.–Laboratory calibration for the 6° by 10° split-beam transducer used with the Model 244 split-beam system.

200 KHz — 6X10 Degree —50ft
S/N 926449

		Freq	200	KHz
Customer	ADF&G	Transducer S/N	926449	
Project Name	MAXWELL-KENAI	Beam Width	6X10	Deg
alibration Location	HTI-Impulse	Echo Sounder S/N	1224538	
Customer Contact	SUSIE MAXWELL	Model #	244L	
Calibrated by	GH, BK	Calibration Date	17-Jun-01	
		Calibration File	449S538	.xls
Sphere Type	38.1 mm Tungsten-carbide	Cable Length	50	Feet

FILE NAME RAW / MDB	RX Gain dB	TVG Gain dB	TX Pwr dBW	PW ms	Pulse Type	Chirp BW KHz	Range m	Echoes #	TS dB	Std. DEV dB
S1680729	-12	0	20	0.40	NORM	0.0	6.14	491	-39.43	1.21
S1680733	-12	0	10	0.40	NORM	0.0	6.09	200	-39.63	0.40
S1680735	-12	0	10	5.00	CHIRP	10.0	6.05	296	-39.86	0.66
S1680736	-12	0	10	1.25	CHIRP	10.0	6.05	308	-40.21	0.59

-continued-

Hydroacoustic Technology, Inc.

HTI

Hydroacoustic System Calibration

Customer	ADF&G Maxwell	Frequency (kHz)	200
Project Name	Kenai River Roadside	Transducer S/N	926449
Calibration Location	HTI-Impulse	Beam Width	6x10
Customer Contact	S. Maxwell	Echo Sounder S/N	1224538
Calibrated by	GH, BK	Model #	244L
		Calibration Date	17-Jun-01
		G1+SL25 =	49.93 dB

Echo Sounder

Arguments to: TVG	1 2 0 42 0 3 1	Arguments to: RX	0
Arguments to: TRIG	00/10	Arguments to: REP	100 10
Arguments to: TX	1-24 to 1-33	Arguments to: MUX	1
Arguments to:FILTER	3	Arguments to:	

Frequency	200 kHz	Band Width	n/a kHz
Receiver Gain (Rg)	0 dB	Pulse Width	0.5 msec
TVG Full Range	n/a m	Blanking Control	3
TVG Crossover	11.22 m	Blanking Min	1 m
TVG Cal Rng (Rcal)	11.22 m	Blanking Max	2 m
Alpha (a)	0 dB/km	Rel Noise (wet)	-22.5 dBV
RCAL @ T 0 42 TX 1 20	not measured Vdet40		(T 0 82 .. CWFILT 4)

Cable

Cable S/N	927753	Cable Length	50 ft
Cable Type	Split-beam	Mux Port	1

Standard Transducer

Type	ITC-5323	Ts =	124.1 dBuPa/V
S/N	007	Ss =	-223.84 dBv/uPa
Last Calibration	Nov 25 ,2000 PAS		
LP Filter	100 x 1k	Preamp Gain 20=	13.39 dB
HP Filter	300 x 1k	Equiv. Ss20 =	-210.45 dBv/uPa
		Preamp Gain 40=	33.34 dB
		Equiv. Ss40 =	-190.5 dBv/uPa

Air and Water Parameters

Air Temperature	65 °F	Calibration Depth	4.57 m
Water Temperature	55 °F	Separation (Rs)	6.1 m

Filename: 449S538.xls

Page 1

-continued-

Hydroacoustic Technology, Inc.

HTI

Receiving Sensitivity

Transducer S/N 926449

Sounder S/N 1224538

Voltage Into Standard Vs (Generator at 23 dBm)

Vs= 6.27 *volts (rms)*

Vs= 15.95 dBVrms

Transmission Loss TL = 20 log Rs + aRs

TL = 15.71 dB

Acoustic Level L = Ts + Vs - TL

L = 124.34 dB/uPa

Sum Channel Detected 12 kHz Output

Calibration Readings

v12kHz = *0.598* *volts (rms)*

Vdet = -1.46 dB Vdet

TVG Gain G(40) = (40 log Rcal + 2a Rcal)

G(40) = 42.00 dB

Vdet = V12kHz + 3.01 dB

Sensitivity at Rcal Gx = Vdet - L

Gx = -125.80 dB/uPa@Rcal

Sensitivity at 1 m G1 = Gx - G(40) - Rg

G1 = -167.80 dB/uPa @ 1m

Up Channel Detected 12 kHz Output

Calibration Readings

v12kHz = *0.292* *volts (rms)*

Vdet = -7.68 dB Vdet

TVG Gain G(40) = (40 log Rcal + 2a Rcal)

G(40) = 42.00

Sensitivity at Rcal Gx = Vdet - L

Gx = -132.02 dB/uPa@Rcal

Sensitivity at 1 m G1 = Gx - G(40) - Rg

G1 = -174.02 dB/uPa @ 1m

Left Channel Detected 12 kHz Output

Calibration Readings

v12kHz = *0.301* *volts (rms)*

Vdet = -7.42 dB Vdet

TVG Gain G(40) = (40 log Rcal + 2a Rcal)

G(40) = 42.00 dB

Sensitivity at Rcal Gx = Vdet - L

Gx = -131.76 dB/uPa@Rcal

Sensitivity at 1 m G1 = Gx - G(40) - Rg

G1 = -173.76 dB/uPa @ 1m

20 Log R Channel Detected Output

Calibration Readings

vdet = *0.812* *volts (peak)*

Vdet = -1.81 dBV (det)

TVG Gain G(20) = (20 log Rcal + 2a Rcal)

G(20) = 21.00 dB

Sensitivity at Rcal Gx = Vdet - L

Gx = -126.15 dB/uPa@Rcal

Sensitivity at 1 m G1 = Gx - G(20) - Rg

G1 = -147.15 dB/uPa @ 1m

Transmission Loss TL = 20 log Rs + aR

TL = 15.71 dB

Source Level SL = Vso - Ss + TL - Pre-Amp

Transmit Power (dB)	Standard Transducer Vso (FFT) dBV (+20)	Vso (FFT) dBV (+40)	Source Level (dBuPa @ 1 m)
25.0	-8.43		217.73
20.0	-11.56		214.60
15.0	-16.88		209.28
10.0	-22.50		203.66
5.0		-8.13	198.08
0.0		-15.62	190.59
-5.0		-24.38	181.83

Filename: 449S538.xls

Page 2

-continued-

Sum Detected Voltage vs Power and Gain

Hydroacoustic Technology, Inc.

HTI

Transducer S/N 926449

Sounder S/N 1224538

Power Level 25 — Vdet = SL + TS + G1 + Rg

Receiver Gain (dB)	TS -65	-60	-55	-50	-45	-40	-35
-18	0.022	0.039	0.070	0.125	0.222	0.395	0.702
-12	0.044	0.079	0.140	0.249	0.443	0.788	1.401
-6	0.088	0.157	0.280	0.497	0.884	1.572	2.796
0	0.176	0.314	0.558	0.992	1.764	3.137	5.578
6	0.352	0.626	1.113	1.979	3.519	6.258	>
12	0.702	1.249	2.221	3.949	7.022	>	>
18	1.401	2.492	4.431	7.879	>	>	>
24	2.796	4.971	8.840	>	>	>	>

Power Level 20 — Vdet = SL + TS + G1 + Rg

Receiver Gain (dB)	TS -65	-60	-55	-50	-45	-40	-35
-18	0.015	0.028	0.049	0.087	0.155	0.275	0.490
-12	0.031	0.055	0.098	0.174	0.309	0.550	0.977
-6	0.062	0.110	0.195	0.347	0.617	1.096	1.950
0	0.123	0.219	0.389	0.692	1.230	2.188	3.890
6	0.245	0.436	0.776	1.380	2.455	4.365	7.762
12	0.490	0.871	1.549	2.754	4.897	8.709	>
18	0.977	1.738	3.090	5.495	9.772	>	>
24	1.950	3.467	6.166	>	>	>	>

Power Level 15 — Vdet = SL + TS + G1 + Rg

Receiver Gain (dB)	TS -65	-60	-55	-50	-45	-40	-35
-18	0.008	0.015	0.027	0.047	0.084	0.149	0.265
-12	0.017	0.030	0.053	0.094	0.167	0.298	0.530
-6	0.033	0.059	0.106	0.188	0.334	0.594	1.057
0	0.067	0.119	0.211	0.375	0.667	1.186	2.108
6	0.133	0.237	0.421	0.748	1.330	2.366	4.207
12	0.265	0.472	0.839	1.493	2.654	4.720	8.394
18	0.530	0.942	1.675	2.978	5.296	9.418	>
24	1.057	1.879	3.342	5.942	>	>	>

Power Level 10 — Vdet = SL + TS + G1 + Rg

Receiver Gain (dB)	TS -65	-60	-55	-50	-45	-40	-35
-18	0.004	0.008	0.014	0.025	0.044	0.078	0.139
-12	0.009	0.016	0.028	0.049	0.088	0.156	0.277
-6	0.017	0.031	0.055	0.098	0.175	0.311	0.553
0	0.035	0.062	0.110	0.196	0.349	0.621	1.104
6	0.070	0.124	0.220	0.392	0.697	1.239	2.203
12	0.139	0.247	0.440	0.782	1.390	2.472	4.395
18	0.277	0.493	0.877	1.559	2.773	4.931	8.769
24	0.553	0.984	1.750	3.111	5.533	9.839	>

Filename: 449S538.xls

Page 3

-continued-

Hydroacoustic Technology Inc.

Copyright © 1996

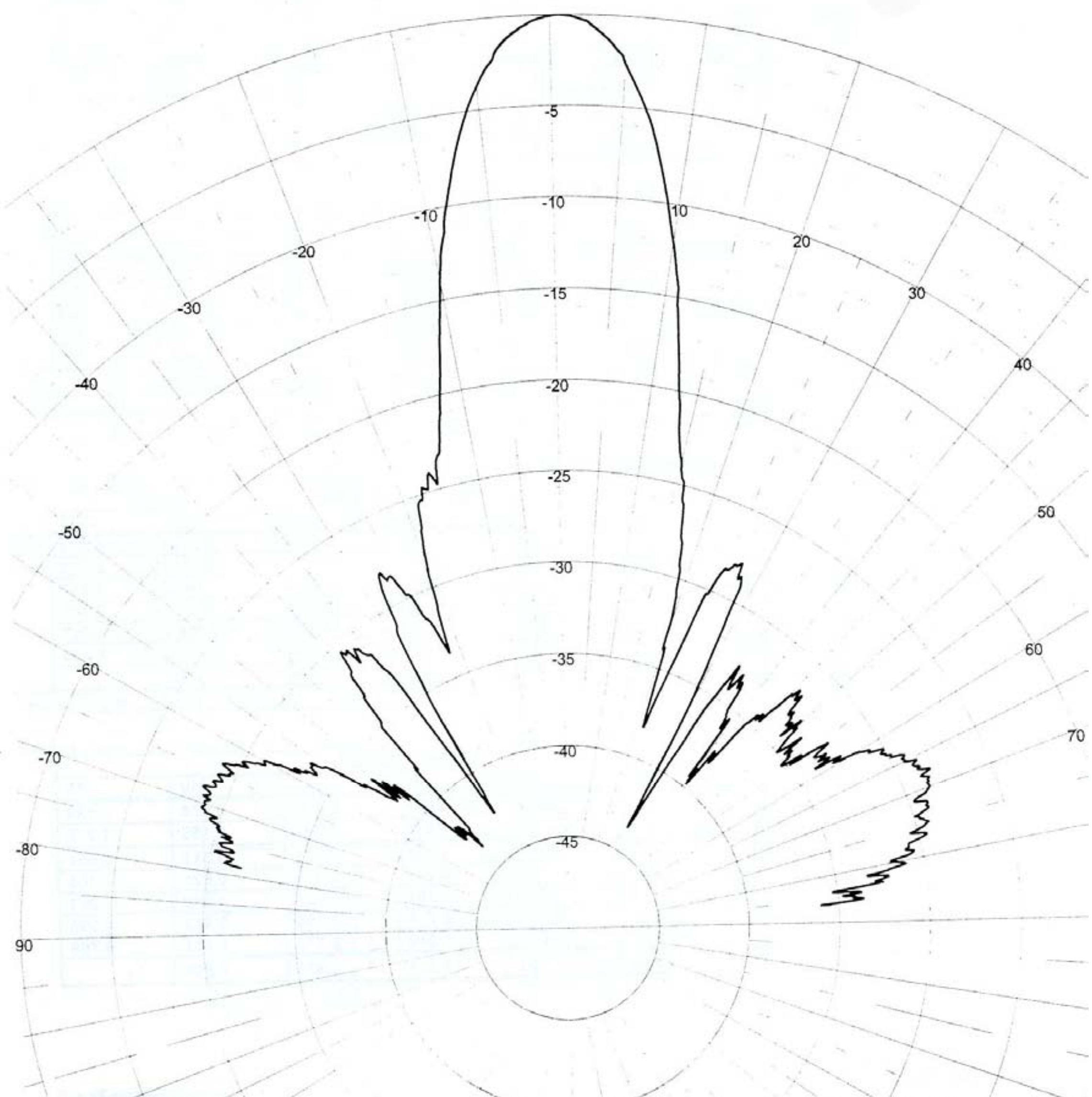
Collected By: GH, ES
Date May 30, 2001
Time 13:36:7
Sounder S/N 1224538 244
Transducer S/N 926449 6x10
Cable S/N 927752 50'

Depth 4.57 m
Sep. Dist. 6.1 m
Water Temp 55 F
Bandwidth N/A Hz

-3dB Beamwidth = 9.93 Deg
BoreSite = 4.55 dBv @ 185.59 RAM Deg
Largest Left Side Lobe = -28.06 dB @ -26.87 Deg
Largest Right Side Lobe = -27.93 dB @ 27.01 Deg

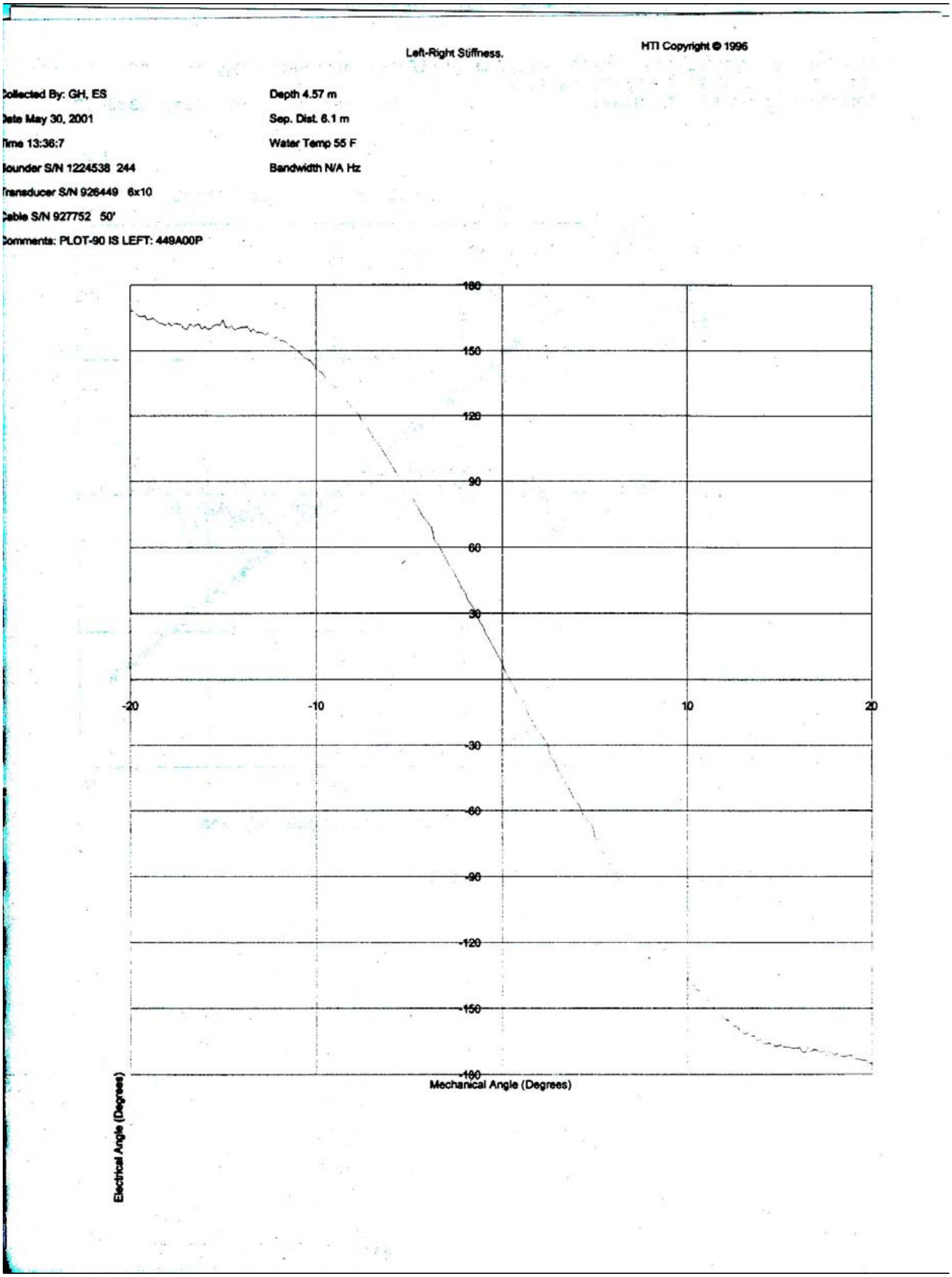
Processes: Clip=C Smooth=S Boresite=B Normalize=N
Performed: C,C,S,S,N,N,

Comments: PLOT-90 IS LEFT: 449A00P



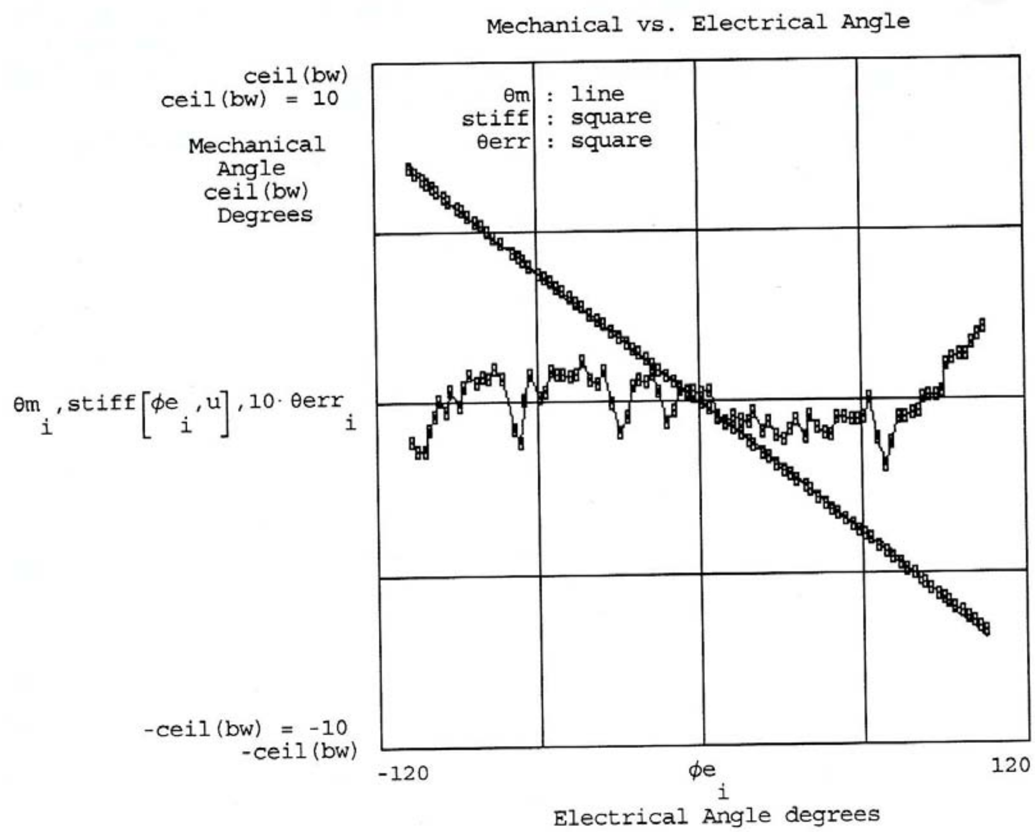
Printed: May 30, 2001 @ 13:37:37

-continued-


Left-Right Stiffness.
HTI Copyright © 1996
Collected By: GH, ES
Date May 30, 2001
Time 13:36:7
Sounder S/N 1224538 244
Transducer S/N 926449 6x10
Cable S/N 927752 50'
Comments: PLOT-90 IS LEFT: 449A00P
Depth 4.57 m
Sep. Dist. 6.1 m
Water Temp 55 F
Bandwidth N/A Hz
180
150
120
90
60
30
-20
-10
10
20
-30
-60
-90
-120
-150
-180
Mechanical Angle (Degrees)
Electrical Angle (Degrees)

-continued-

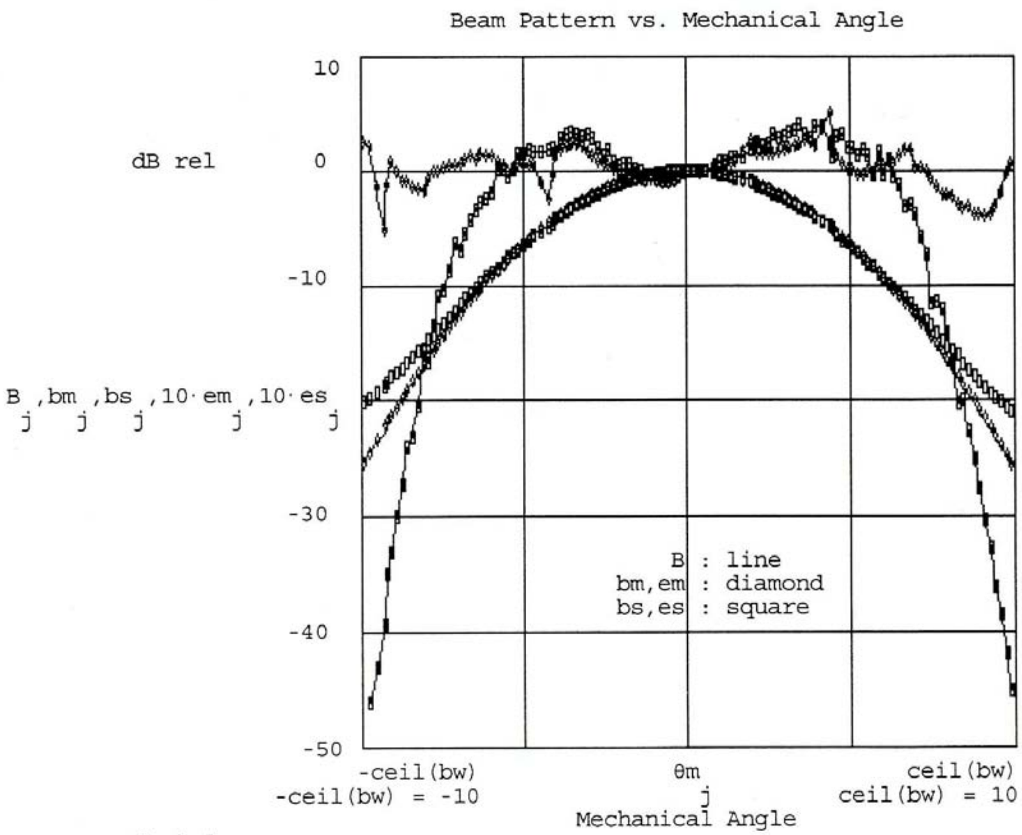
Transducer S/N 926449   6x10 Left/Sum Stiffness processed May 30, 2001 13:38:
Comments: PLOT-90 IS LEFT: 449A00P
Calibrated on HTI Impulse: Date May 30, 2001 Time 13:36:7



Stiffness constant: U = -15.603302

-continued-

```
Transducer S/N 926449   6x10 Left/Sum Stiffness processed May 30, 2001  13:38:
Comments: PLOT-90 IS LEFT: 449A00P
Calibrated on HTI Impulse:                     Date May 30, 2001 Time 13:36:7
```



Symbols:
- B beam pattern factor
- θm mechanical angle
- φe electrical angle

Beam pattern fit plot:
- B: pattern plotted against mechanical angle, θm
- bm: fit of pattern, θm -> bm
- bs: pattern predicted from stiffness, φe -> θm' -> bm

Beam fit coefficients: Measured beamwidth: bw = 9.729
                          Beamwidth from fit: bw_fit = 9.692

$$c = \begin{bmatrix} 0 \\ -0.000042 \\ -0.255398 \\ -0.000103 \\ -0.00004 \end{bmatrix} \begin{matrix} a \\ b \\ c \\ d \\ e \end{matrix}$$

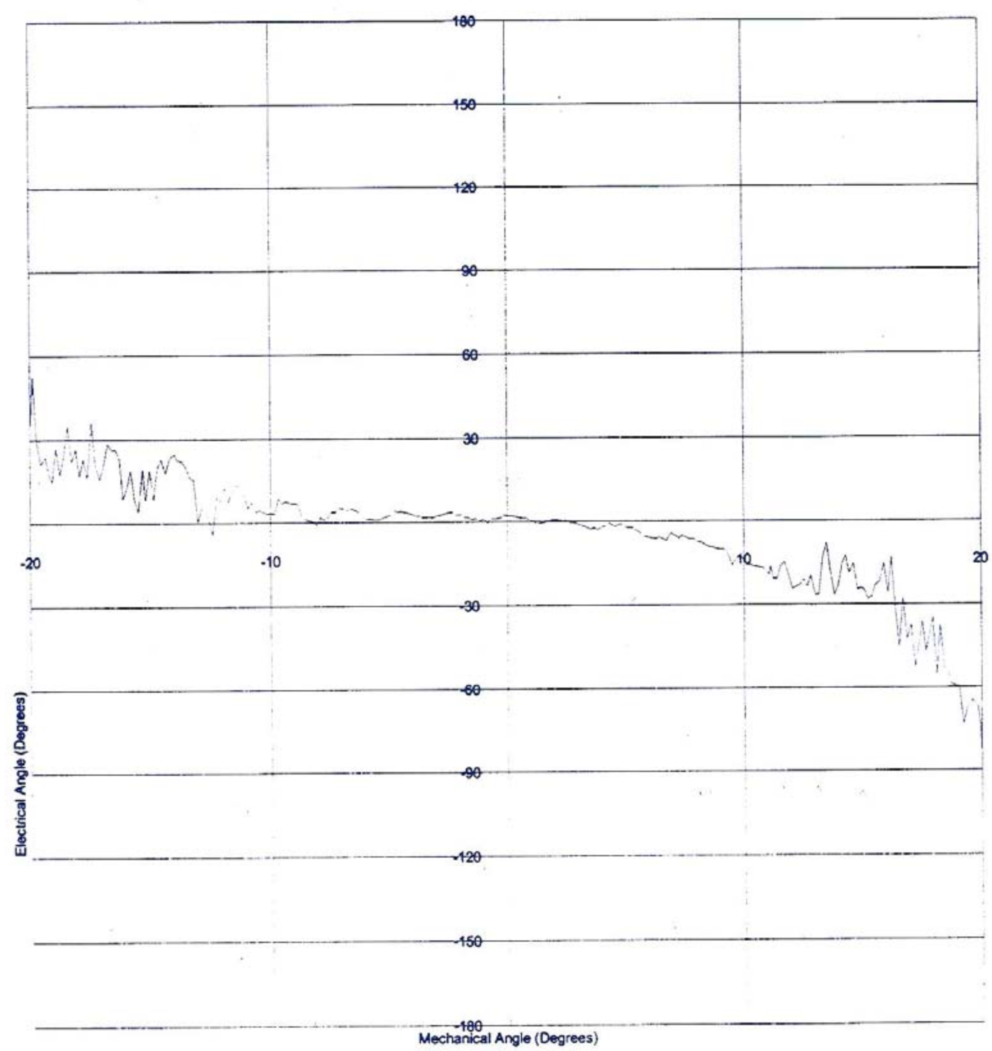
-continued-

HTI Copyright © 1996

Up-Down Stiffness

Collected By: GH, ES
Date May 30, 2001
Time 13:36:7
Sounder S/N 1224538 244
Transducer S/N 926449 6x10
Cable S/N 927752 50'
Comments: PLOT-90 IS LEFT: 449A00P

Depth 4.57 m
Sep. Dist. 6.1 m
Water Temp 55 F
Bandwidth N/A Hz



-continued-

Hydroacoustic Technology Inc.

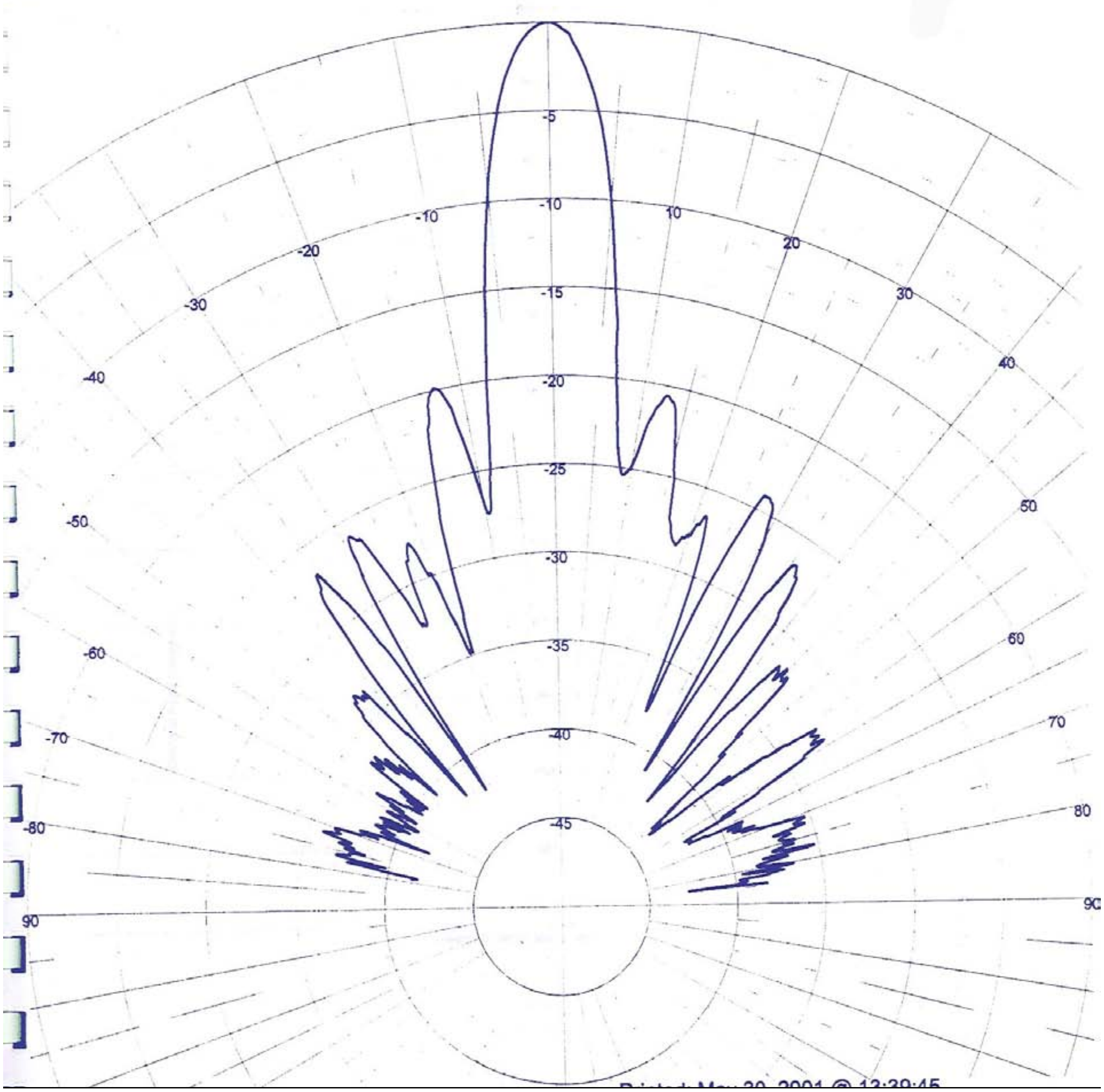
Collected By: GH, ES
Date May 30, 2001
Time 13:39:11
Sounder S/N 1224538 244
Transducer S/N 926449 6x10
Cable S/N 927752 50'

Depth 4.57 m
Sep. Dist. 6.1 m
Water Temp 55 F
Bandwidth N/A Hz

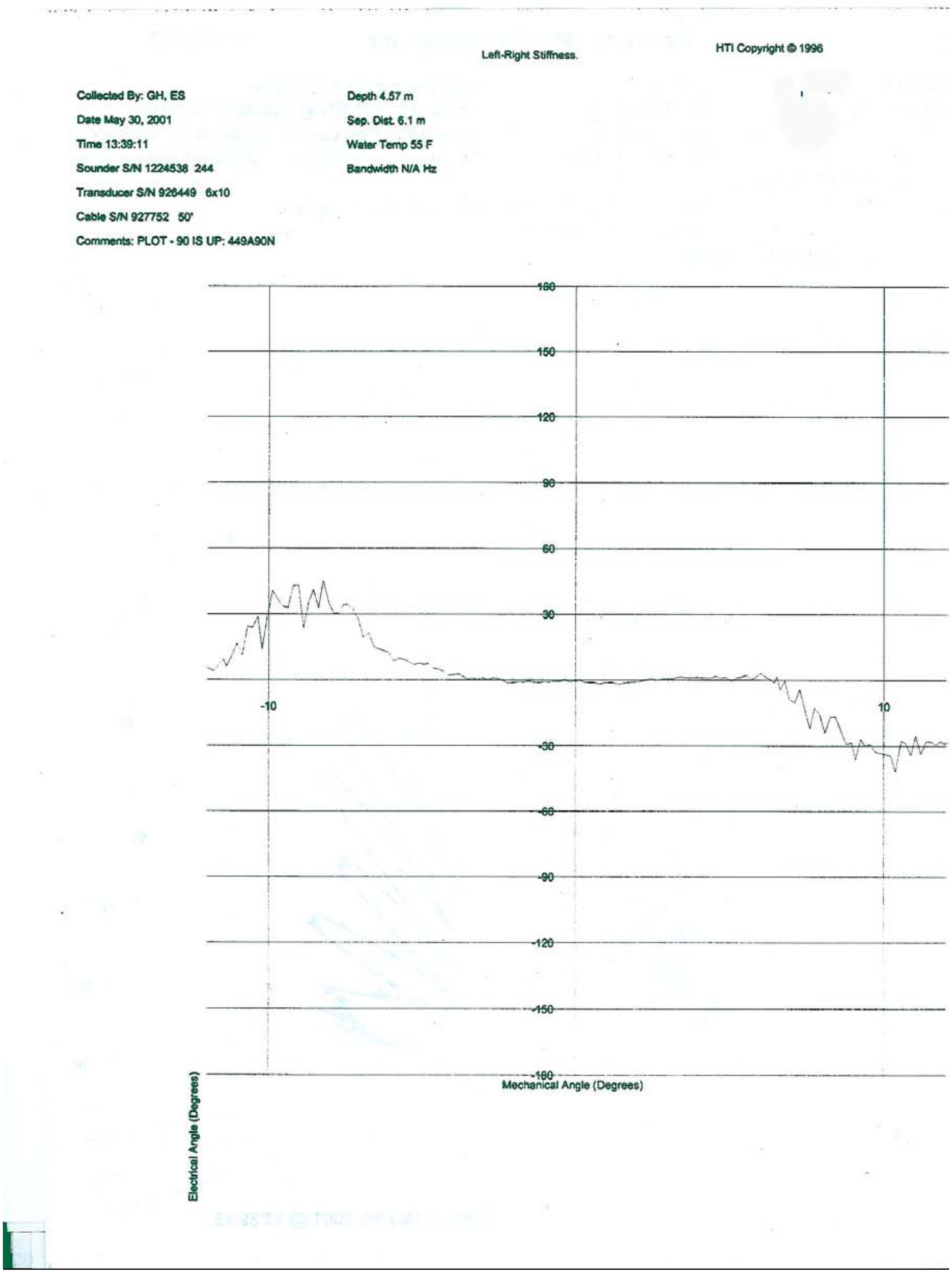
-3dB Beamwidth = 5.90 Deg
BoreSite = 4.70 dBv @ 185.48 RAM Deg
Largest Left Side Lobe = -19.88 dB @ -12.99 Deg
Largest Right Side Lobe = -20.54 dB @ 12.65 Deg

Processes: Clip=C Smooth=S Boresite=B Normalize=N
Performed: C,C,S,S,N,N,B,B,

Comments: PLOT - 90 IS UP: 449A90N

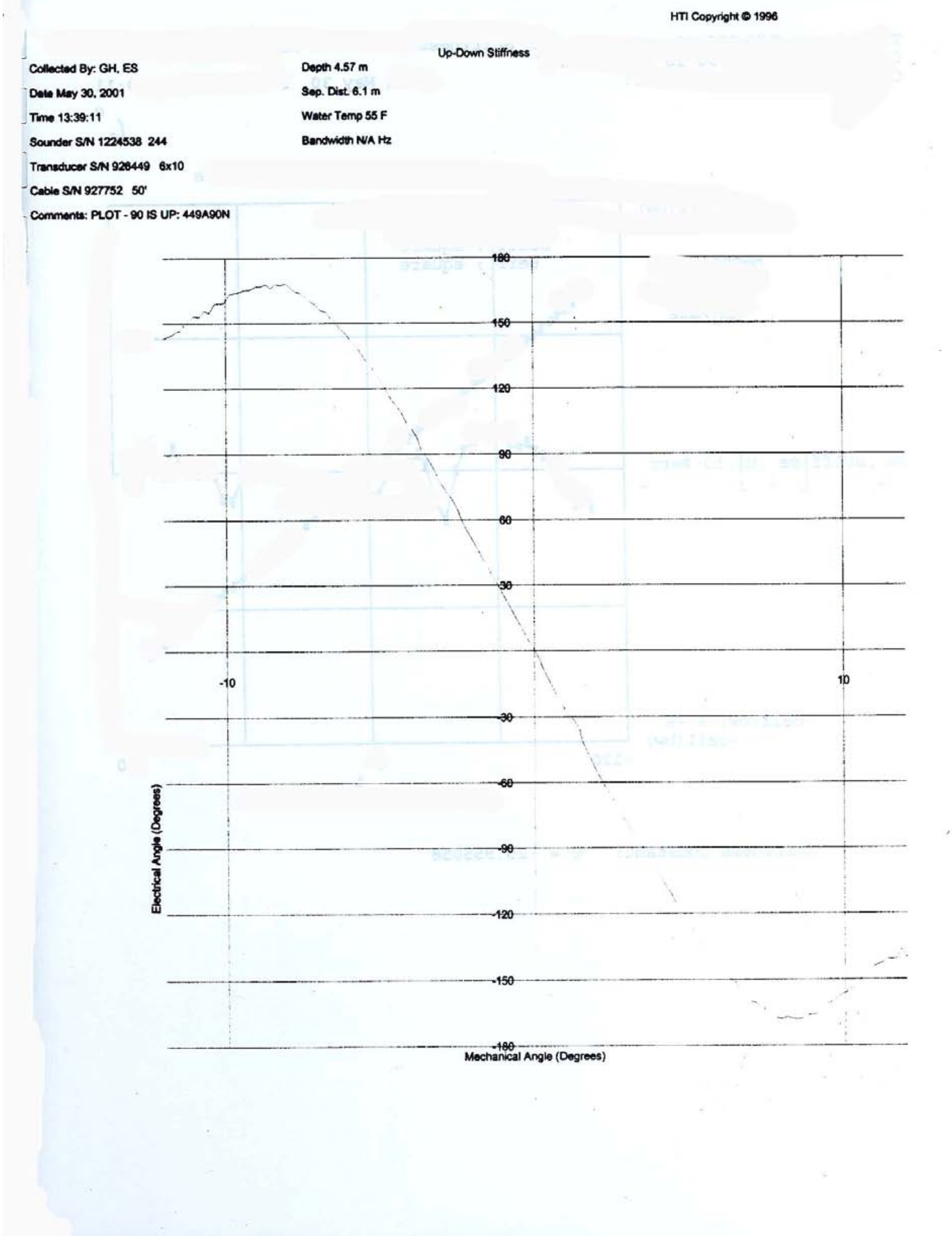


-continued-



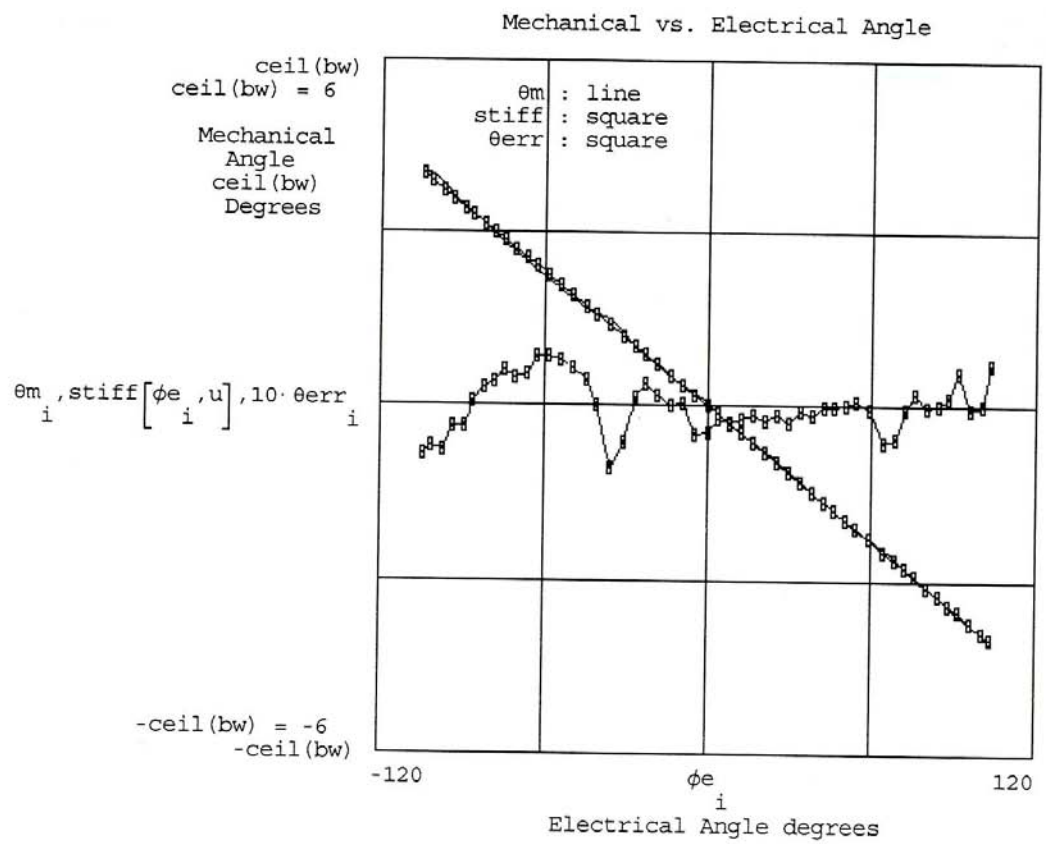
Left-Right Stiffness.
HTI Copyright © 1996
Collected By: GH, ES
Date May 30, 2001
Time 13:39:11
Sounder S/N 1224538 244
Transducer S/N 926449 6x10
Cable S/N 927752 50'
Comments: PLOT - 90 IS UP: 449A90N
Depth 4.57 m
Sep. Dist. 6.1 m
Water Temp 55 F
Bandwidth N/A Hz
180
150
120
90
60
30
-10
10
-30
-60
-90
-120
-150
-180
Mechanical Angle (Degrees)
Electrical Angle (Degrees)

-continued-


HTI Copyright © 1996
Up-Down Stiffness
Collected By: GH, ES
Date May 30, 2001
Time 13:39:11
Sounder S/N 1224538 244
Transducer S/N 928449 6x10
Cable S/N 927752 50'
Comments: PLOT - 90 IS UP: 449A90N
Depth 4.57 m
Sep. Dist. 6.1 m
Water Temp 55 F
Bandwidth N/A Hz
180
150
120
90
60
30
-10
10
-30
-60
-90
-120
-150
-180
Electrical Angle (Degrees)
Mechanical Angle (Degrees)

-continued-

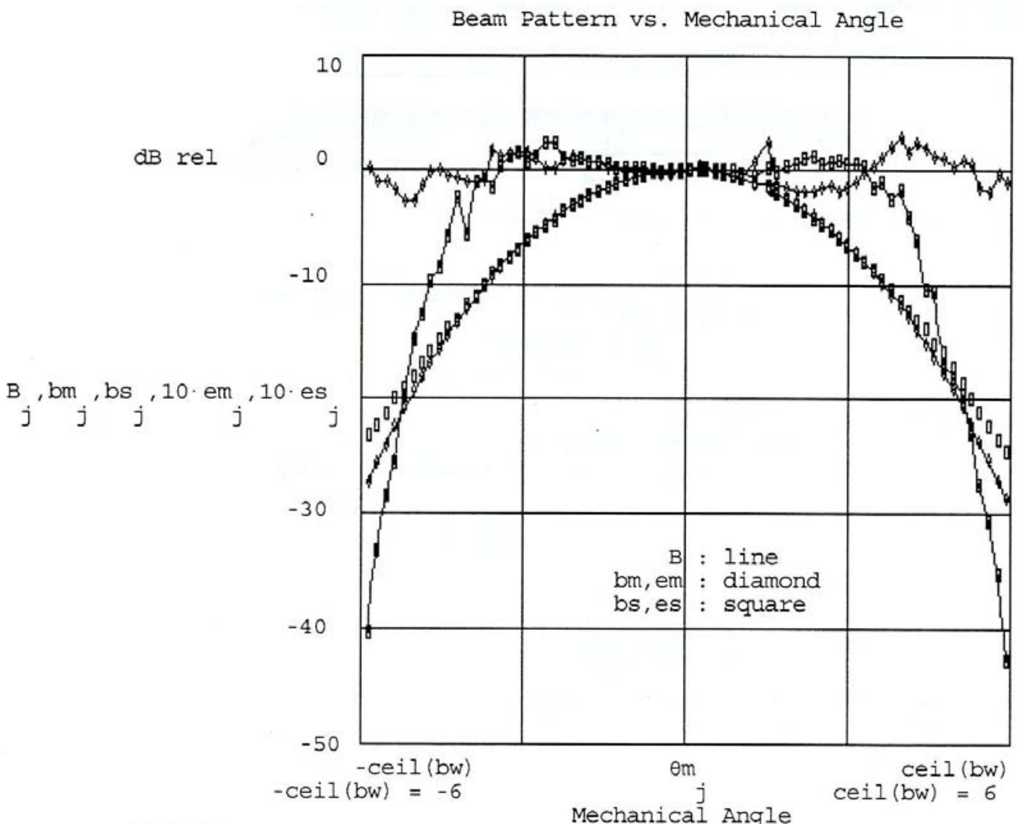
Transducer S/N 926449 6x10 Up/Sum Stiffness processed May 30, 2001 13:40:28
Comments: PLOT - 90 IS UP: 449A90N
Calibrated on HTI Impulse: Date May 30, 2001 Time 13:39:11



Stiffness constant: U = -25.955058

-continued-

Transducer S/N 926449 6x10 Up/Sum Stiffness processed May 30, 2001 13:40:28
Comments: PLOT - 90 IS UP: 449A90N
Calibrated on HTI Impulse: Date May 30, 2001 Time 13:39:11



Symbols:
- B beam pattern factor
- θm mechanical angle
- ϕe electrical angle

Beam pattern fit plot:
- B: pattern plotted against mechanical angle, θm
- bm: fit of pattern, θm -> bm
- bs: pattern predicted from stiffness, ϕe -> θm' -> bm

Beam fit coefficients: Measured beamwidth: bw = 5.765
Beamwidth from fit: bw_fit = 5.773

$$c = \begin{bmatrix} 0 \\ 0.000059 \\ -0.696865 \\ -0.002058 \\ -0.003074 \end{bmatrix} \begin{matrix} a \\ b \\ c \\ d \\ e \end{matrix}$$

-continued-

Squared Beam Pattern Factor Calculation for Rectangular Transducer Element

For XD: s/n 926449 | 200 KhZ, 6 x 10

Actual 3dB beamwidth from beamfit - using coefficients

Vertical Plane:	**5.73** °	2.819717	Ly/Lambda
Horizontal Plane:	**9.69** °	1.669209	Lx/Lambda

Find squared beam pattern factor (b^2(theta,phi)):

Where:

Lx = transducer element size (wavelengths) in one plane
lambda = wavelength
BW = 3 dB one-way beamwidfth
constant1 = 0.1410112 is empirically determined

First find Lx/lambda and Ly/lambda:
Lx / lambda = constant / sin(BW/2)
10Log(b^2(theta,phi)) = 10Log((1/(Lx/lambda)) * (1/(Ly/lambda))) - 11.572

b^2(theta,phi) = Squared Beam Pattern Factor
constant2 = -11.572 is empirically derived

10Log(b^2(theta,phi)) = -18.2992

b^2(theta,phi) = **0.014794**

These equations were developed by J. Ehrenberg,
after those expressed in Urick, 1963

APPENDIX B. FIELD CALIBRATION AND AIMING PROTOCOL

Appendix B1.–Field calibration and aiming protocol for the split-beam sonar.

To field calibrate and aim the split-beam transducer, the protocol listed below was followed.

To field calibrate the split-beam transducer:

1. Mount the transducer so it is no more than 3-4 in off the ground (you should barely be able to stick the toe of your boot under it).
2. Wrap a 1 ½ in tungsten carbide sphere in a mesh bag using 25-30 lb 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 target to an extension pole and extend in front of the transducer just beyond the near field (1 m for a 6x10^{o} 200 kHz split-beam) 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 1000 pings 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. Document the target filename, the sonar parameters, and the average target strength in the logbook.

To aim the split-beam transducer:

1. Measure
    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.

-continued-

3. Attach the salmon-size target to an extension pole and extend in front of the transducer beyond the near field (1 m for a 6x10^{o} 200 kHz split-beam) 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 and then lower the target to approximately 4 in 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.
7. 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.

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