Fish and standard-sphere target-strength measurements obtained with a dual-beam and split-beam echo-sounding system

Jimmie J. Traynor and John E. Ehrenberg


A new echo-sounding system, which has both dual-beam and split-beam target-strength measurement capability, is described. A method of calibrating this system using a tungsten carbide standard sphere is presented. Comparisons of target-strength measurements using the dual-beam and split-beam techniques are presented for the calibration sphere as well as fish targets. The target-strength measurements for 40-cm walleye pollock (Theragra chalcogramma) ranging from −29.8 to −31.5 dB/kg compare favorably with previous in situ estimates as well as estimates based on swimbladder measurements.

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Introduction

The importance of knowledge about the target-strength characteristics of the surveyed fish population to the accuracy of acoustic assessments using echo integration is well known. Recently, there has been a concerted effort by many researchers to obtain in situ target-strength measurements of fish in their natural environments. Because of their often superior performance (Ehrenberg, 1979), direct assessment techniques have frequently been chosen. The dual-beam technique has been applied by many researchers (e.g., Traynor and Ehrenberg, 1979; Traynor and Williamson, 1983; Dickie et al., 1984). Foote et al. (1985, 1986) describe the first applications of a split-beam direct target-strength measurement system to fish target-strength measurement. The purpose of the present paper is: (1) to describe a new echo-sounding system which has both split-beam and dual-beam target-strength measurement capability, (2) to describe the analysis procedure and the calibration technique used with that system, and (3) to present comparisons of dual-beam and split-beam target-strength measurements made from walleye pollock (Theragra chalcogramma) in the eastern Bering Sea.

Background

The difficulty with in situ target-strength measurement is that the voltage level out of an echo sounder is a function of both the acoustic size of the fish as measured by target strength and the position of the fish in the transducer beam. A single-beam echo-sounder output level in dB for an acoustic echo reflected from an individual fish is expressed by:

\[ V_0 = SL + G_R + TS + 2B(\theta,\phi) - 40 \log(R) - 2\alpha R + G_{TVG} \]

where SL is the transmitted source level, \( G_R \) is the fixed receiving gain from transducer input to sounder output, \( 40 \log(R) + 2\alpha R \) is the spreading and absorption loss, \( G_{TVG} \) is the time-varied-gain of the sounder, TS is the target strength of the individual fish located at angular coordinates \((\theta,\phi)\), and \( B(\theta,\phi) = 10 \log(b(\theta,\phi)) \) is the transducer beam-pattern factor. The source level and gain can be measured during calibration or measured using standard targets. The range-dependent loss can be removed with the time-varied-gain. However, the relative contribution of TS and B(\(\theta,\phi\)) to the output level cannot be determined for a given echo level using a single-beam echo-sounding system.

Various techniques for separating the beam-pattern effect from the target strength using a collection of echo levels have been developed. A review of these indirect target-strength estimation methods is contained in the paper by Ehrenberg (1983a). All of the indirect techniques are susceptible to numerical and statistical errors and do not work well in many cases of interest. An alternative to the indirect method is to remove the
beam-pattern effect for each individual echo. In so doing, many of the problems encountered in the indirect techniques are avoided. Direct removal of the beam-pattern factor from individual echoes requires a more complex acoustic system than the standard single-beam system.

There are two techniques used at present for implementing the direct target-strength estimation technique: the dual beam and the split beam. In the dual-beam technique, the acoustic signal is transmitted using a narrow-beam transducer. The echoes reflected from single fish are received simultaneously on the narrow-beam and wide-beam transducers. The beam-pattern factor for the individual fish echoes can be estimated from the difference of the narrow- and wide-beam outputs in dB (Ehrenberg, 1983a). The estimated beam-pattern factor can then be removed from narrow-beam output to produce a direct estimate of target strength.

The applied split-beam technique uses a transducer segmented into four quadrants. All four quadrants are driven simultaneously for transmission. The backscattered signal from an individual fish is received by each quadrant separately. The individual outputs are combined to form a full beam and two half-beam sets. The angular location of the fish is determined from the phases of the signals for the transducer half-beam pairs. Once the angular location of the target has been measured, B(θ, ϕ) for the fish can be calculated and removed from the echo level output to produce an estimate of fish target strength. The dual-beam and split-beam techniques have been described in greater detail in the paper by Ehrenberg (1983a). It has been shown that, in theory, the split beam will have superior performance to the dual beam in the presence of noise. However, the split beam is more difficult to implement and more sensitive to hardware inaccuracy.

Table 1. Description of beam segments.

<table>
<thead>
<tr>
<th>Beam description</th>
<th>TVG</th>
<th>Use</th>
<th>Output signal</th>
</tr>
</thead>
<tbody>
<tr>
<td>A+C</td>
<td>40 logR+2 R</td>
<td>Split-beam phase measurement</td>
<td>10 kHz</td>
</tr>
<tr>
<td>B+D</td>
<td>40 logR+2 R</td>
<td>Split-beam phase measurement</td>
<td>10 kHz</td>
</tr>
<tr>
<td>A+B</td>
<td>40 logR+2 R</td>
<td>Split-beam phase measurement</td>
<td>10 kHz</td>
</tr>
<tr>
<td>C+D</td>
<td>40 logR+2 R</td>
<td>Split-beam phase measurement</td>
<td>10 kHz</td>
</tr>
<tr>
<td>E</td>
<td>40 logR+2 R</td>
<td>Dual-beam, wide-beam amplitude</td>
<td>Detected</td>
</tr>
<tr>
<td>A+B+C+D+E</td>
<td>40 logR+2 R</td>
<td>Dual-beam, split-beam, narrow-beam amplitude</td>
<td>Detected</td>
</tr>
<tr>
<td>A+B+C+D+E</td>
<td>40 logR+2 R</td>
<td>Echo integration</td>
<td>Detected</td>
</tr>
</tbody>
</table>

System specifications:

- Frequency: 38 kHz
- Nominal pulsedwidth: 0.6 ms
- Bandpass filter width (to −3 dB points): 4.5 kHz
- Sum (narrow) beamwidth (to −3 dB points): 6 deg.
- Wide beamwidth (to −3 dB points): 25 deg.
- Source level (dB|μ micropascal ref. 1 m): 218 dB

System description

The echo-sounding system provides appropriate signals for echo integration, as well as dual-beam and split-beam target-strength analyses (Fig. 1). The transmitter is a 5-kW pulse amplifier (Instruments, Inc. Model SPG-4B). The receiving system is a prototype instrument constructed by BioSonics, Inc. The transducer (Fig. 2) was modified from a dual-beam transducer and is constructed using 79 individual ceramic elements, each approximately 13 mm in diameter. All elements are used during pulse transmission, while the elements are separated into five receiving segments. The center seven elements are separated to provide the signal for the wide beam of the dual-beam system. The remaining 72 elements are separated to form the four quadrants, consisting of 18 elements each, used to produce the split-beam signals. Five transmit/receive switches, housed in the transducer, are used to protect the receiving circuitry during pulse transmission. On reception, the signal from each transducer segment is amplified by a preamplifier in the transducer and relayed on separate conductors through the cable to the echo sounder. In the receiving hardware, the segments are combined prior to time-varied-gain (TVG) control to form four half-beams for split-beam analysis and a sum beam. The sum-beam signal, used for both echo-integration and target-strength analyses, is provided to separate receiving circuits with appropriate TVG functions. See Table 1.

Dual-beam target-strength measurements and echo-integration measurements are completed using a Hewlett Packard 1000-F computer. Single targets are accepted on the basis of half-amplitude pulsedwidth in the narrow beam. The analytical procedures have been well

1Reference to trade name does not imply endorsement by the National Marine Fisheries Service, NOAA.
Figure 1. System block diagram.
The split-beam phase measurement is accomplished using a prototype split-beam digital processor (SBDP) manufactured by BioSonics, Inc. The SBDP has been described by Hsieh (1986). The processor has, as hardware inputs, the synchronization pulse for the system and the outputs of the four half-beam receivers, heterodyned to 10 kHz, and the detected sum beam, all with 40 logR + 2αR TVG control. Operator inputs include sum-beam noise threshold, half-amplitude pulsewidth acceptance window, and depth range to be analyzed. An additional pulsewidth acceptance window can be specified, i.e., the pulsewidth at the threshold. If this pulsewidth is greater than the acceptance window, the target is labeled as a multiple target, but is recorded. During subsequent analysis, the operator may choose to use this information to reject the target as not being from a single-fish target.

The first step of the process is the acceptance of single targets in the sum-beam channel satisfying the pulsewidth and noise threshold criteria. The sampling rate for the sum-beam channel in the SBDP is 40 kHz. Next, the phase difference between pairs of the two sets of transducer half-beams [(A+B,B+D) and (A+B,C+D)] is estimated by the method of quadrature sampling cross-correlation (Ehrenberg, 1981). The quadrature sampling cross-correlation method for measuring the phase differences was selected over the easier-to-implement technique using hard limiters because the latter are prone to amplitude-dependent errors. The heterodyned signals from each pair of half-beams are sampled at 40 kHz to provide quadrature samples (90° apart on the 10 kHz signal) of each waveform. To assure that the phase calculations carried out below are accurate, the quadrature samples for each half-beam are obtained simultaneously by the analogue to digital converter in the SBDP. For either set of half-beams, quadrature samples, S(i,j), for the two half-beams can be expressed as:

\[ S(i,1) = E(t) \cos(wt+p), \quad \text{and} \]
\[ S(i,2) = E(t) \cos(wt+p+D), \]

where \( i \) is the sample number, \( j \) is the half-beam designator, \( E(t) \) is the signal envelope, \( w \) is the operating frequency, \( t \) is the sample time, \( p \) is a random phase angle, and \( D \) is the phase difference between the two signals. It can be shown that the phase difference, \( D \), can be estimated as (Ehrenberg, 1983b):

\[ D = \arctan \frac{S(i,1)S(i+1,2) - S(i,2)S(i+1,1)}{S(i,1)S(i+1,1) + S(i,2)S(i+1,2)}. \]

For the above calculations, it is assumed that the envelope level \( E(t) \) is varying slowly relative to the carrier frequency. If there was no noise in the signals, the two split-beam signals could be quadrature sampled at any point in the received pulse to obtain measurements of \( D \). However, since the signal does contain noise, the best estimate of \( D \) is obtained by using the quadrature samples taken near the peak amplitude of the target in the sum beam. One could use more than one quadrature pair within each half-beam to calculate \( D \); however, Ehrenberg (1983b) has shown that increasing the number of samples within the pulse does not significantly improve the precision of the phase-difference estimate.

System calibration

Before and after each cruise, the equipment is calibrated using standard calibration techniques to estimate the transmitting and receiving characteristics of the system. The amplitude characteristics of the receiver are monitored in the field using a calibration oscillator located in the transducer, and set, during initial calibration of the system, to be equivalent to a known intensity at the transducer face. Changes in receiving-system characteristics can be observed by monitoring changes in the level of the calibration oscillator signal output for any beam or segment. The calibration oscillator has three levels of attenuation so that the entire TVG range can be monitored. The calibration signal is used to measure deviations from ideal TVG correction using analysis software for the split-beam and dual-beam target-strength measurement and the integration channels. The calibration oscillator operates on remote control using two logic lines between the receiver and transducer which turn the oscillator on or off and switch between the three levels used for calibration.

In addition to monitoring amplitude calibration, the calibration oscillator is also used to monitor phase stability in the receiving circuitry and to correct for any
constant phase offset between the split-beam half-beams. The SBDP measured the phase difference of the calibration signal between the pairs in each set of split-beam half-beams at 4 ms (3 m) intervals to a range of 300 m. This phase difference represents the phase offset between the two half-beams, which is then used to adjust phase-difference calculations made for fish targets using Equation (3).

One procedure for estimating beam-pattern effect from split-beam phase measurements is to convert the electrical phase measurements to mechanical degrees and to estimate the beam-pattern effect on the basis of the known beam-pattern directivity. Because of potential inaccuracies in this procedure, conversion for the present system is accomplished by completing a special calibration procedure to allow the direct conversion of electrical phase-angle measurements to beam-pattern directivity values. Using a calibration facility (University of Washington, Applied Physics Laboratory, Seattle, Washington) capable of providing signal pulses at a known delay and at known angles from the acoustic axis, a constant intensity pulse is provided to the split-beam transducer on a 15 by 15 grid from -3.5 to +3.5 degrees in two directions, perpendicular to one another, with each point separated from the next by 0.5 degrees. At each location, approximately 15 phase measurements are made and the voltage of the constant intensity pulse is measured. From the voltage measured, the beam-pattern directivity effect \( b \) can be determined for each of the data points on the observation grid. These data are then used to produce an empirical relationship between the two phase angles measured by the split-beam system \((x, y)\) and the one-way directivity effect determined from the measured voltages, using a multiple regression procedure:

\[
b(x, y) = A(0) + A(1)x + A(2)y + A(3)x + \ldots + A(18)x^5 + A(19)y^5 + A(20)x^4y^5 \quad (4)
\]

where the \( A(i) \)s are least-squares regression coefficients. This relationship can then be used to estimate the beam-pattern effect for any returned phase angles, \( x \) and \( y \). In practice, we have used a separate regression for values of \( b \) greater than 0.5 (\( B > -3 \text{ dB} \)) because the beam-pattern directivity surface is relatively flat in this region. Thus, we can obtain a better fit of the data in this region than if all data are used. Since a value of \(-3 \text{ dB} \) is typically used as the beam-pattern directivity.

Figure 3. Map of the study area showing locations of target-strength data collection (A) and standard target calibration (B).
threshold (to minimize the bias against small targets), this relationship is adequate for all of our standard work. Using the regression for this region only, we have been able to maintain the residual deviation below 0.02 (~0.17 dB), and the mean residual for all data points has been <0.01 (~0.08 dB).

Data collection procedures

Initial tests of the echo-sounding system described above were carried out from the chartered fishing vessel FV “Morning Star”, in July and August 1984 during an echo-integration/midwater-trawl survey of the eastern Bering Sea. The temperature profile at the calibration site, 24 July 1985, in Makushin Bay, Unalaska Island, Alaska (Fig. 3), indicated a very strong, near-surface thermocline, with temperatures of about 10.2 °C at the surface, dropping to 9.0 °C at 2 m and to 6.5 °C at 10 m. Below this depth, there was a gradual decrease to 5.5 °C near the bottom at about 54 m. The calibration procedure involved suspending a 38.1-mm tungsten carbide (with 6 % cobalt binder) calibration sphere (Foote and MacLennan, 1984) approximately 28.5 m below the fin using fiberglass poles (Fig. 4). With the vessel anchored from the bow and stern, the fin, containing the transducer, was lowered from 2 to 20 m in the water column to examine the effect of transducer depth on system performance. Target-strength measurements of the standard sphere were made using both the split-beam procedure described above and the dual-beam technique.

On 2 August 1985, target-strength measurements and associated midwater-trawl data were collected in the eastern Bering Sea (Fig. 3). The acoustic targets were identified using a Diamond 1000 pelagic trawl. The vertical mouth opening of the trawl was 15 m, with 40.6-cm (16-inch) stretch measure mesh in the wings and mesh sizes ranging from 81.3 cm (32 inch) forward, to 8.9 cm (3.5 inch) in the codend. The codend was equipped with a 3.2-cm (1.25-inch) mesh liner. The target-strength measurements were collected at a vessel speed of about 1 knot.

For all target-strength analyses (both fish and standard-sphere measurements), the single-target acceptance criterion was half-amplitude pulsewidth. Because of differences in the location of sampling points and sampling frequency and the implementation of the pulsewidth measurement algorithm, some targets were accepted using one technique, and rejected using the other. This was particularly the case with small echoes, the wave form most affected by noise. In addition, for both the dual-beam and split-beam processors, if analysis is not completed by the time the next sync pulse occurs, the new pulse is ignored. For the comparisons presented in this paper, only targets that were accepted by both systems were included for analysis. For both systems, the beam-pattern threshold was set to ~3 dB, and the noise threshold was set at approximately twice the root mean square noise level. The pulsewidth acceptance window was 0.4 to 0.8 ms.

Results and discussion

The target voltages and beam-pattern measurements obtained with the split-beam technique were used to scale fish echo voltages to echo strength. The total sum-beam system response [source level, SL (dB reference 1 m) plus system-receiving response, SRR (dBV/1 V/micropascal)] was calculated as

\[ SL + SRR = \bar{V} - TS - 20 \log(\bar{h}), \]

where

- \( \bar{V} \) is the average voltage returned from the standard target (including correction of any deviation from 40 logR + 2 aR correction),
- \( TS \) is the target strength of the calibration sphere, and
- \( \bar{h} \) is the average of the beam-pattern estimates from the split-beam system.

This provided the calibration term necessary to convert echo voltages for the narrow sum beam (split beam and
dual beam) to echo strength. To complete the calibration of the dual-beam system, the wide-beam calibration term was adjusted until the target strength of the average scattering cross-section measurements from the dual-beam measurements of the standard sphere was approximately −42.25 dB to agree with the theoretical value. There was a 1.9 dB increase in total, sum-beam system response when the transducer was lowered from 2 to 20 m (Table 1). We have made previous measurements of the depth effect on transducer performance (before it was modified from a dual-beam-only transducer) using standard hydrophone calibration techniques. These studies indicated an overall increase of only 1.1 dB when the transducer was lowered from 2 to 20 m. Measurements using an anechoic pressure chamber indicated an increase of 0.7 dB between 2 and 15 m and only minor changes in total system response (+0.1 dB) between 15 and 60 m, at a temperature of 3°C. Variation in system response with depth is a function of the transducer design. The particular transducer used for these measurements was originally designed to operate at fixed depth near the surface. A new transducer is at present being made for use with the system. Its response should be less dependent on depth.

Target-strength measurements of the sphere collected using the dual-beam technique are much more variable than those derived using the split-beam technique. The standard deviation of the scattering cross-section estimates for the dual beam is approximately twice that of the split-beam measurements (Fig. 5). Similarly, the range of beam-pattern estimates derived from dual-beam data is much wider than that for the split beam (Fig. 6). In fact, 17% of the dual-beam standard target-strength measurements have beam-pattern estimates larger than the theoretical maximum of 0 dB. These data support the results of simulation analyses indicat-

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**Table 2. Comparison of total, sum-beam system response (source level, SL, plus system receiving response, SSR).** The theoretical target strength of the tungsten carbide sphere was −42.25 dB.

<table>
<thead>
<tr>
<th>Measurement method</th>
<th>Transducer depth (m)</th>
<th>Voltage Mean</th>
<th>Voltage s.d.</th>
<th>Beam pattern Mean</th>
<th>Beam pattern s.d.</th>
<th>SL + SRR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard target</td>
<td>2</td>
<td>1.19</td>
<td>0.05</td>
<td>0.93</td>
<td>0.04</td>
<td>44.4</td>
</tr>
<tr>
<td>Standard target</td>
<td>20</td>
<td>1.46</td>
<td>0.04</td>
<td>0.92</td>
<td>0.02</td>
<td>46.3</td>
</tr>
</tbody>
</table>

*Referenced to receiver output at 30 m.

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**Figure 5. Target-strength measurements of tungsten carbide sphere using the dual-beam and split-beam techniques.**
Table 3. Catch data for midwater trawl hauls made at target-strength data collection sites, and the results of walleye pollock target-strength analysis. Sunset occurred at 0857; sunrise at 1706 GMT.

Catch data

<table>
<thead>
<tr>
<th>Haul</th>
<th>Date</th>
<th>Time (GMT)</th>
<th>Position</th>
<th>Average headrope depth (m)</th>
<th>Walleye pollock</th>
<th>Other species</th>
<th>Catch (kg)</th>
<th>Pollock size</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Length (cm)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>s.d.</td>
</tr>
<tr>
<td>1</td>
<td>2 Aug 1985</td>
<td>0321</td>
<td>54°54.06'N 166°07.03'W</td>
<td>119</td>
<td>351</td>
<td>674</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>2 Aug 1985</td>
<td>1044</td>
<td>54°53.73'N 166°08.71'W</td>
<td>119</td>
<td>222</td>
<td>362</td>
<td>4</td>
<td>6</td>
</tr>
</tbody>
</table>

Target-strength data collection

<table>
<thead>
<tr>
<th>Sample</th>
<th>Date</th>
<th>Time (GMT)</th>
<th>Depth (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Transducer</td>
<td>Fish</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0835–1014</td>
<td>100</td>
<td>112–150</td>
</tr>
<tr>
<td>2</td>
<td>1200–1234</td>
<td>100</td>
<td>112–150</td>
</tr>
</tbody>
</table>

Target-strength measurement

<table>
<thead>
<tr>
<th>Sample</th>
<th>Split beam</th>
<th>Dual beam</th>
<th>90% conf. interval for TS((\bar{o})) in dB/fish(^b)</th>
<th>90% conf. interval for TS((\bar{o})) in dB/fish(^b)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(\bar{o})</td>
<td>TS ((\bar{o})) dB/fish</td>
<td>TS ((\bar{o})) dB/kg</td>
<td>Sample size</td>
</tr>
<tr>
<td>1</td>
<td>0.00551</td>
<td>-33.60</td>
<td>-30.90</td>
<td>1322</td>
</tr>
<tr>
<td>2</td>
<td>0.00716</td>
<td>-32.40</td>
<td>-29.80</td>
<td>363</td>
</tr>
</tbody>
</table>

*Weights not taken.

*The 90% confidence limits for TS(\(\bar{o}\)) are calculated as TS[\(\bar{o}\) ± \(t_{0.05}\)SD(\(\bar{o}\))], where \(t_{0.05}\) is from a table of critical values of the t-distribution.
ing that the dual-beam technique is more sensitive to the presence of noise than is the split-beam technique (Ehrenberg, 1979, 1983a).

Approximately 2.0 hours of dual-beam/split-beam target-strength measurements from a suitable aggregation of pollock were selected for analysis (Table 2). Two trawl hauls were made to identify the acoustic targets. The standard target measurements were made only to a transducer depth of 20 m, while the pollock target-strength measurements were made with the transducer at approximately 100 m. The standard sphere calibration data with the fin at 20 m was used to scale the pollock target-strength data. The approximate signal-to-noise ratio (SNR) was 25 dB, where SNR = 10 log (ä/4π) − N, and N is the root mean square noise level (dB). The target strengths of the mean scattering cross-sections estimated using the split-beam sample were higher than the dual-beam estimates (0.5 dB for sample 1; 0.6 dB for sample 2).

To examine the spatial distribution of the acoustic targets, running averages of the split-beam and dual-beam target-strength estimates were calculated. Because we wanted to examine long-term trends, we used a running average of 49 scattering cross-section values (Figs. 7 and 8). Because of the beam-pattern threshold value (−3 dB), a maximum of about three pings was accepted for each fish target. Therefore, each data point represents an average including at least 20 to 30 individual fish. These data suggest a definite aggregation of targets with different acoustic properties. This could be due to either an aggregation of fish by size or differential behavior of the same size fish, i.e., spatial differences in the tilt-angle distribution of the fish.

The beam-pattern estimates derived from sample 1 are compared using the two techniques (Fig. 9). Again, the effect of noise on the dual-beam procedures is apparent. The distribution of beam-pattern estimates from split-beam measurements is much closer to the theoretical distribution (assuming random spatial distribution of targets in the acoustic beam) than those from the dual beam.

Conclusions

Calibration of the towed transducer with a tungsten carbide sphere appears to be a reasonable calibration procedure for absolute calibration of an echo-sounding system, particularly with the new split-beam target-strength measurement capability. Because the beam position using the split-beam technique does not rely on amplitude information, the standard target measurements obtained using the split-beam technique are relatively insensitive to changes in system performance. The dual-beam system can also be used to make similar standard target measurements. However, close attention must be paid to the relative changes in system performance between the narrow- and wide-beam channels. One practical advantage of the calibration technique described here is that the requirement for placement of the calibration sphere in the exact center of the beam is not nearly as stringent as that for calibration.
procedures that do not allow independent measurement of the beam-pattern factor. Corrections for measurements of the calibration sphere away from the acoustic axis can be readily made. In addition, calibrations using the standard sphere provide the capability of examining depth effects on transducer performance, such as those observed for the present system.

The measurements of target strength of walleye pollock and of the standard sphere support the theoretical conclusions (Ehrenberg, 1979, 1983a) of superior performance by the split-beam over the dual-beam technique in the presence of noise. Beam-pattern and target-strength measurements of the standard sphere were considerably more variable using the dual-beam tech-

Figure 8. Target strength of running average of scattering cross-section (49 values) versus time for sample 2.

Figure 9. Beam-pattern measurements of walleye pollock from sample 1 using the dual-beam and split-beam techniques.
nique. In addition, the distribution of beam-pattern estimates for echoes received from walleye pollock using the split-beam system were more similar to those predicted theoretically than the distribution derived using the dual-beam technique.

Traynor and Williamson (1983) estimated the target strength of a walleye pollock 47 cm in length to be $-29.9$ dB/kg for daytime samples and $-32.7$ dB/kg at night. The night-time samples presented in this paper are intermediate between their night and day samples, ranging from $-29.8$ to $-30.9$ dB/kg for the split beam and $-30.0$ to $-31.5$ dB/kg for the dual beam. The target-strength estimates derived here have been compared with those derived from swimbladder morphology studies (Foote and Traynor, 1988). For the two samples from walleye pollock, the comparable values based on swimbladder measurements were about $-31.0$ to $-31.7$ dB/kg, depending on the assumed fish tilt-angle distribution. The general agreement of the target-strength estimates based on two completely independent techniques is encouraging.

Acknowledgements

The authors would like to thank Ed Nunnallee, Neal Williamson, and Bill Karp for their helpful discussions and review of the paper. We would also like to thank Dan Twohig and Neal Williamson for their aid in carrying out the field studies described here.

References


