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Chapter 6

Development of Quantitative Single Beam Echosounder for Measuring Fish Backscattering

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Angga Dwinovantyo and Steven Solikin

Additional information is available at the end of the chapter

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Abstract

Target strength (TS) of marine fish is a key factor for target identification and stock quantification. Validation of measurement and model comparisons in fisheries acoustics is difficult, due to the uncertainty in ground truth obtained in the ocean. To overcome this problem is to utilize laboratory measurements, where fish parameter is more well controlled. In this research, the dorsal-aspect TS of fish was measured as a function of the incidence angle in a water tank using a quantitative echo sounder. The measurement was compared with the theoretical prediction using the distorted-wave born approximation (DWBA) model. TS of fish was proportional to body length and the directivity of TS was strongly dependent on its orientation. Computational DWBA modeling, experimental details, and data/model comparison were presented.

Keywords: target strength, high resolution, sonar equation

1. Introduction

Underwater acoustics technologies are frequently used to measure the abundance and biomass of fish [1]. The quantitative relationship between the size of a fish and its target strength (TS) and the intensity of the echo returned from the fish are important [2]. The swim bladder of fish is responsible for most of the reflected sounds [3]. TS of fish was determined also by size and shape of swim bladder [4, 5]. The acoustic target strength of a fish is required to enable the performance of present and future sonar equipment to be determinates for fish targets. Target strength is a logarithmic measure of the energy scattered by an object back toward the source and is a function of the size, shape, orientation, and material properties of the target [6].

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A physical-based model of the acoustic scattering from the targets is required to convert acoustic backscatter measurements into units of fish density and biomass [7]. The physics-based scattering model requires input parameters describing the acoustic frequency of echo sounder system and the target (shape, length, orientation relative to the acoustic wave, and material properties) [8]. The properties of fish for acoustic modeling are ratio of fish density and seawater density (g) and ratio of the speed of sound in fish and the sound speed of seawater (h) [9, 10]. One purpose of this study was to examine the influence of material properties, specifically g and h, on model predictions of fish target strength (TS).

2. Material and methods

2.1. Measurement of fish target strength

Acoustic data were collected in the water tank of the Ocean Acoustics Laboratory Department of Marine Science and Technology Bogor Agricultural University. The echo sounder used in the studies was 200-kHz single-beam SIMRAD EK15. For the numerical model of distorted-wave born approximation (DWBA) purpose, we combine this instrument with 50 kHz. The specification of single-beam echo sounder was shown in **Table 1**. The echo sounder was calibrated with standard

Frequency [kHz]	200
Pulse duration [μs]	80
Ping rate [Hz]	40
Ping interval [ms]	500
Beam width [degrees]	26
Output power [W]	45
Bandwidth [Hz]	3088

Table 1. Specification of single-beam echo sounder Simrad EK15.

copper spheres as recommended by the manufacturer. The program designed was used to calibrate the single-beam units. Single-beam data were analyzed using Sonar 5 software (developed by Helge Balk and T. Lindem, Institute of Physics, the University of Oslo, Norway) and Matlab. This program used the algorithm to derive fish target-strength distributions from the measured distribution of peak voltage response from single-fish echoes (40 log R TVG function) [11]. Single-fish echoes are defined as echoes with less than twice the pulse length [11]. Due to the echo sounder-hardware noise and software limitation, we used −55 dB as the smallest target-strength group for the single-beam sonar. The method provides information for species identification, makes it possible to measure the fish length of individual fish, and provides information on fish behavior. Flow of research was shown in **Figure 1**. Beam pattern of transducer $B(\theta)$ is plotted on a decibel scale where the sound pressure as a function of spherical angle is

$$B(\theta) = 20 \log \left[\frac{2 J_1(\pi \frac{D}{\lambda}) \ \sin \ \theta}{\pi \ \frac{D}{\lambda} \ \sin \ \theta} \right] \tag{1}$$

θ is the angle of sound pressure from an axis perpendicular to the transducer center, D is transducer diameter, λ is wavelength of the sound, and $J_1$is first order Bessel function.

2.2. Physic-based scattering model

The theoretical scattering model used was distorted wave born approximation (DWBA). The DWBA model was originally used for weak scatterers such as zooplankton and micronecton. However, it has also been applied to fish. The DWBA model is valid for all acoustic frequencies, can be evaluated for all angles of orientation [12, 13], and can be applied to arbitrary shapes. DWBA model is valid when the incident acoustic wave is higher than the scattered value. Formulation of this model involved the incident acoustic wave number inside the integral. The amplitude of fish backscattering is given by

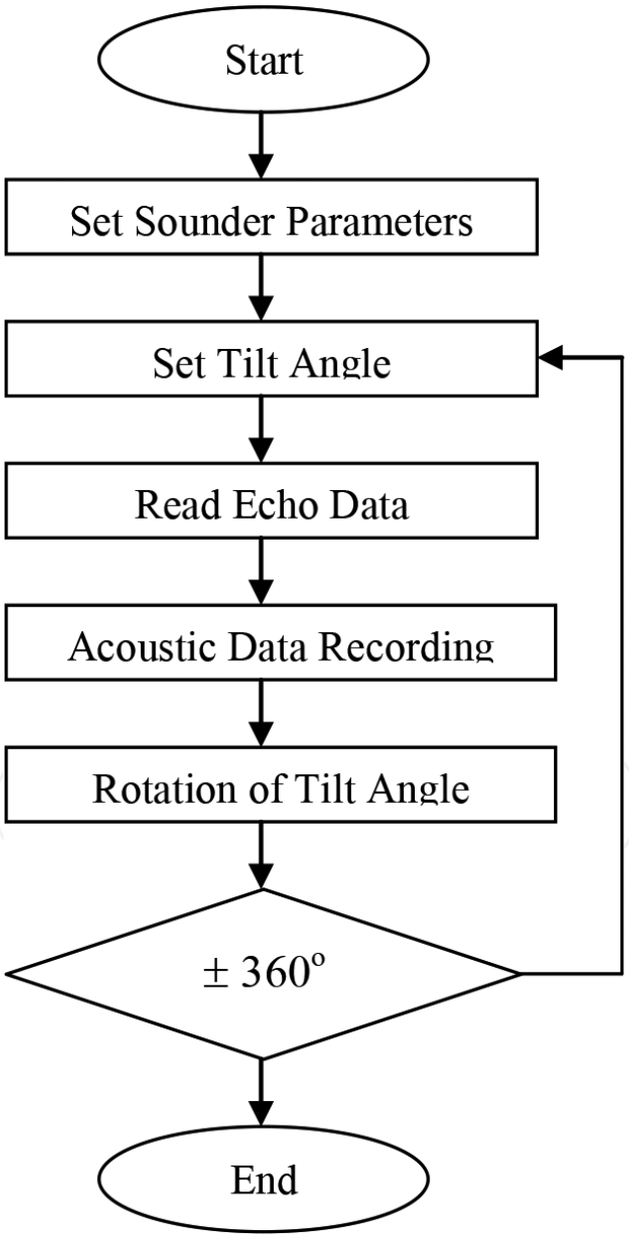


Figure 1. Flowchart of data acquisition system.

$$f_{bs} = \frac{k_1^2}{4\pi} \iiint_V (\gamma_\kappa - \gamma_\rho) e^{1\, i\, k_2 . r_0} dV \tag{2}$$

The terms γ_k and γ_ρ are compressibility k and ρ, and subscript v is parameter of the scattering volume.

$$\begin{aligned} \gamma_\kappa &\equiv \frac{\kappa_2 - \kappa_1}{\kappa_1} = \frac{1 - g\, h^2}{g\, h^2} \\ \gamma_\rho &\equiv \frac{\rho_2 - \rho_1}{\rho_2} = \frac{g - 1}{g} \end{aligned} \tag{3}$$

where

$$\kappa = \left(\rho\, c^2\right)^{-1}; \quad h = \frac{c_2}{c_1}; \quad g = \frac{\rho_2}{\rho_1} \tag{4}$$

This formulation is simplified to a line integral for underwater target that is axis symmetric at any point along the deformed axis. The line integral for finite-length cylinders is given by Refs. [14, 15]

$$f_{bs} = \int_{r_{\text{pos}}} \frac{k_1^2 a}{4k_2} \left(\gamma_k - \gamma_\rho\right) e^{2ik_2 r_{\text{pos}}} \frac{J_1(2k_2 a \cos\beta_{\text{tilt}})}{\cos\beta_{\text{tilt}}} |dr_{\text{pos}}| \tag{5}$$

where J_1 is Bessel function of the first kind, θ is incidence angle, k is incident wave number $= 2\pi/\lambda$, and λ is acoustic wave length. Target strength (TS) is the logarithmic of the backscattered signal

$$TS = 10 \log \sigma_{bs} = 10 \log |f_{bs}|^2 \tag{6}$$

where $\sigma_{bs} = |f_{bs}|^2$ is the backscattering cross section and f_{bs} is backscattering amplitude.

3. Results and discussions

Beam pattern of transducer in linear and decibel scales were shown in **Figure 2**. The main lobe has a higher power of about 40 dB from the first side lobes. This pattern is determined by acoustic frequency, size, shape, and phase of transducer. Maximum sensitivity of transducer along the main acoustic axis is 0 dB. Amplitude of side lobes is ranged from −80.0 to −40.0 dB. The maximum detection range of the echo sounder has been computed using signal to noise ratio, TS, frequency, electro acoustic efficiency, and acoustic power [16]. **Figure 3** shows that the detection range of echo sounder is about 220 m in depth and detectable breadth is 8 m from the acoustic axis. The noise resulted by research vessel is the largest because of the propeller noise. Signal to noise ratio (SNR) is the ratio of the echo power of the fish to the received noise power. Theoretical sphere target strength was numerically simulated for a 38.1-mm-diameter sphere of tungsten carbide. Theoretical and measurement of sphere ball target strength were shown in **Figure 4**. This figure explains that the measurement was suitable with theoretical value.

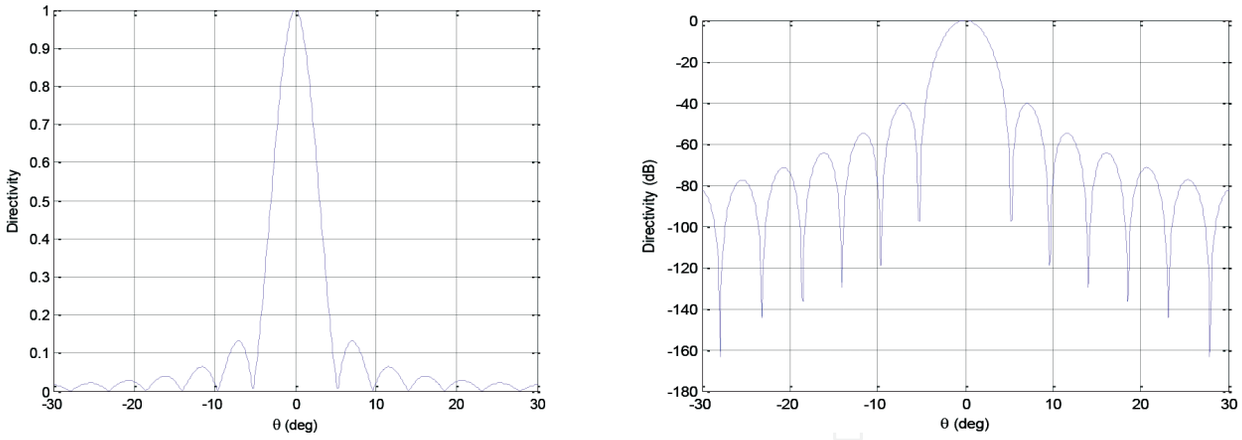


Figure 2. Beam pattern of transducer in linear (left) and decibel scale (right).

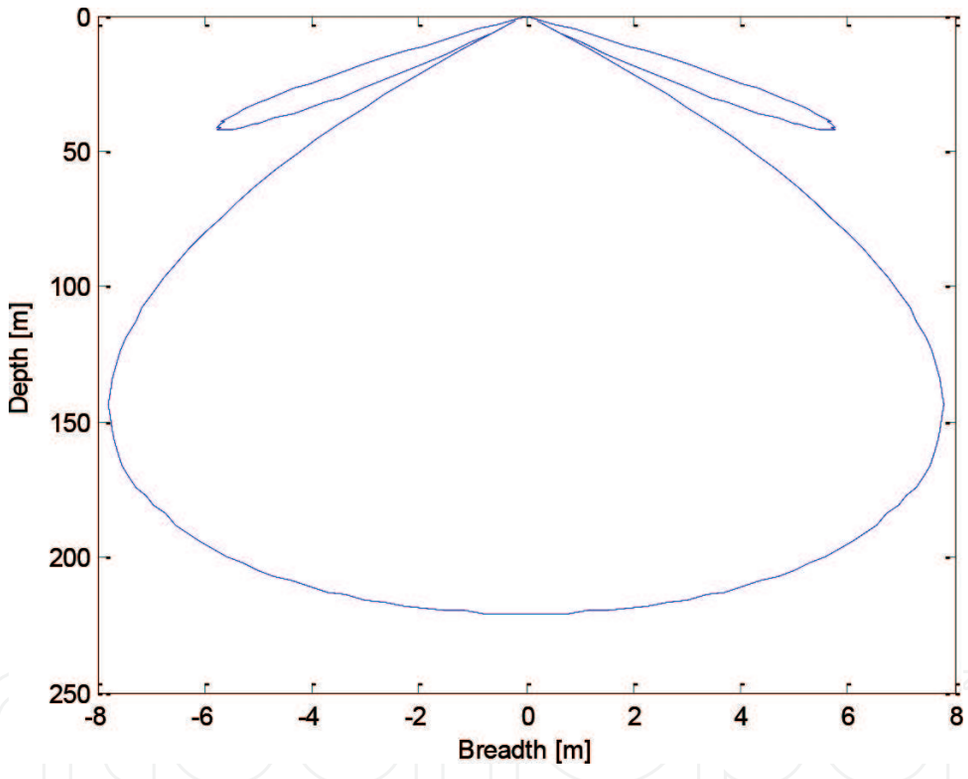


Figure 3. Detection range and detectable breadth of transducer.

Transmission loss measurement was shown in **Figure 5**. Increasing sound propagation range was followed by increasing transmission loss. The acoustic intensity/energy loss is due to spherical or geometrical spreading and attenuation. Acoustic ray propagation and its sound intensity level in several transducer depths were shown in **Figures 6** and **7**. The refraction of sound was caused by temperature gradients in the water, reflection from sea surface, sea bottom, and position of the target. Small changes in the temperature have significant influence on sound propagation. Acoustic detection of fish and seabed in the raw signal echogram and after filtering were shown in **Figures 8** and **9**, respectively. Target strength of fish ranged between −53.0 and −32.9 dB was shown in **Figures 10** and **11**, and volume backscattering signal was shown in **Figure 12**.

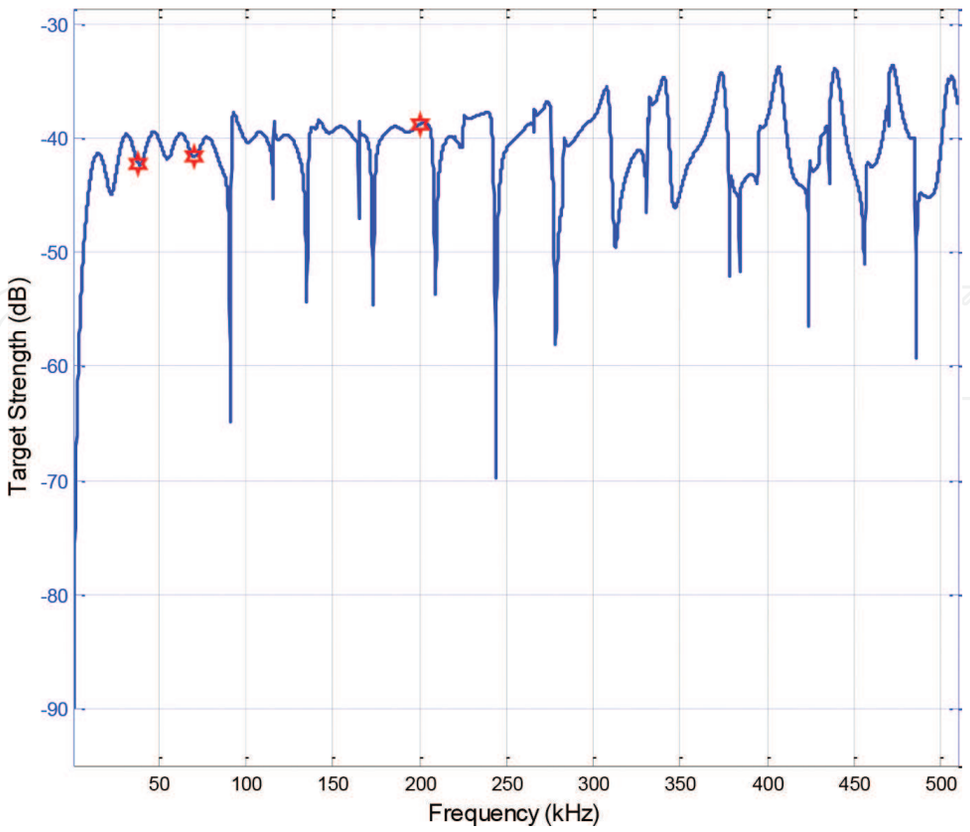


Figure 4. Measurement (*) and theoretical target strength (−).

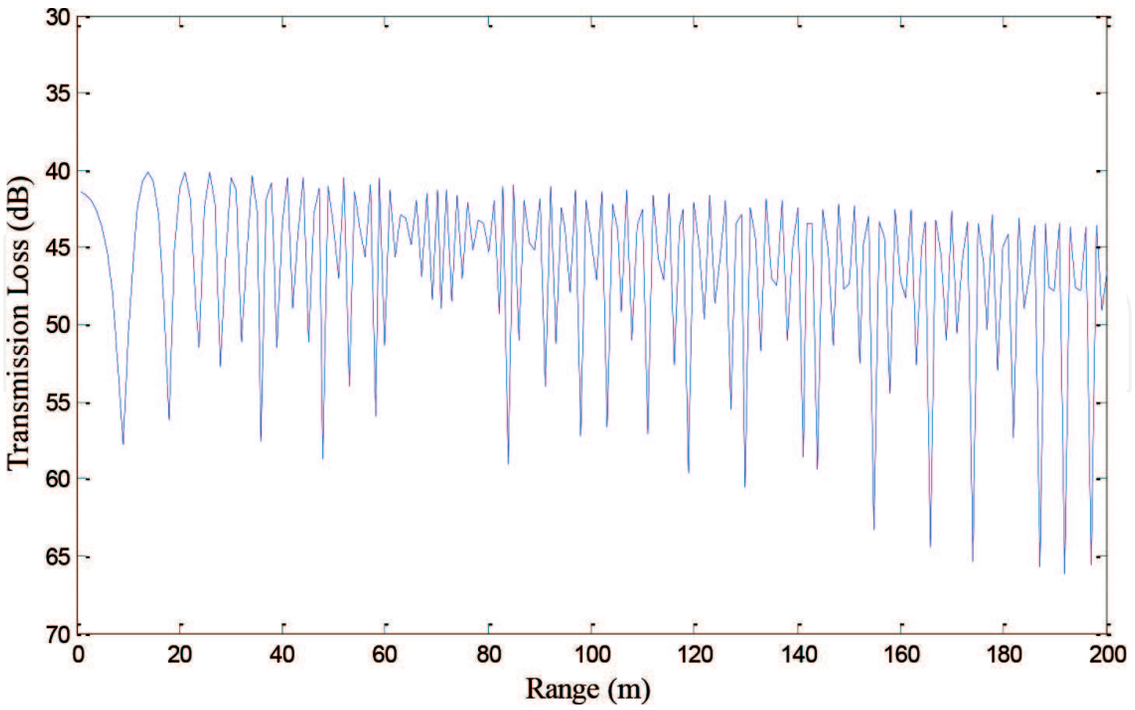


Figure 5. Sound transmission loss.

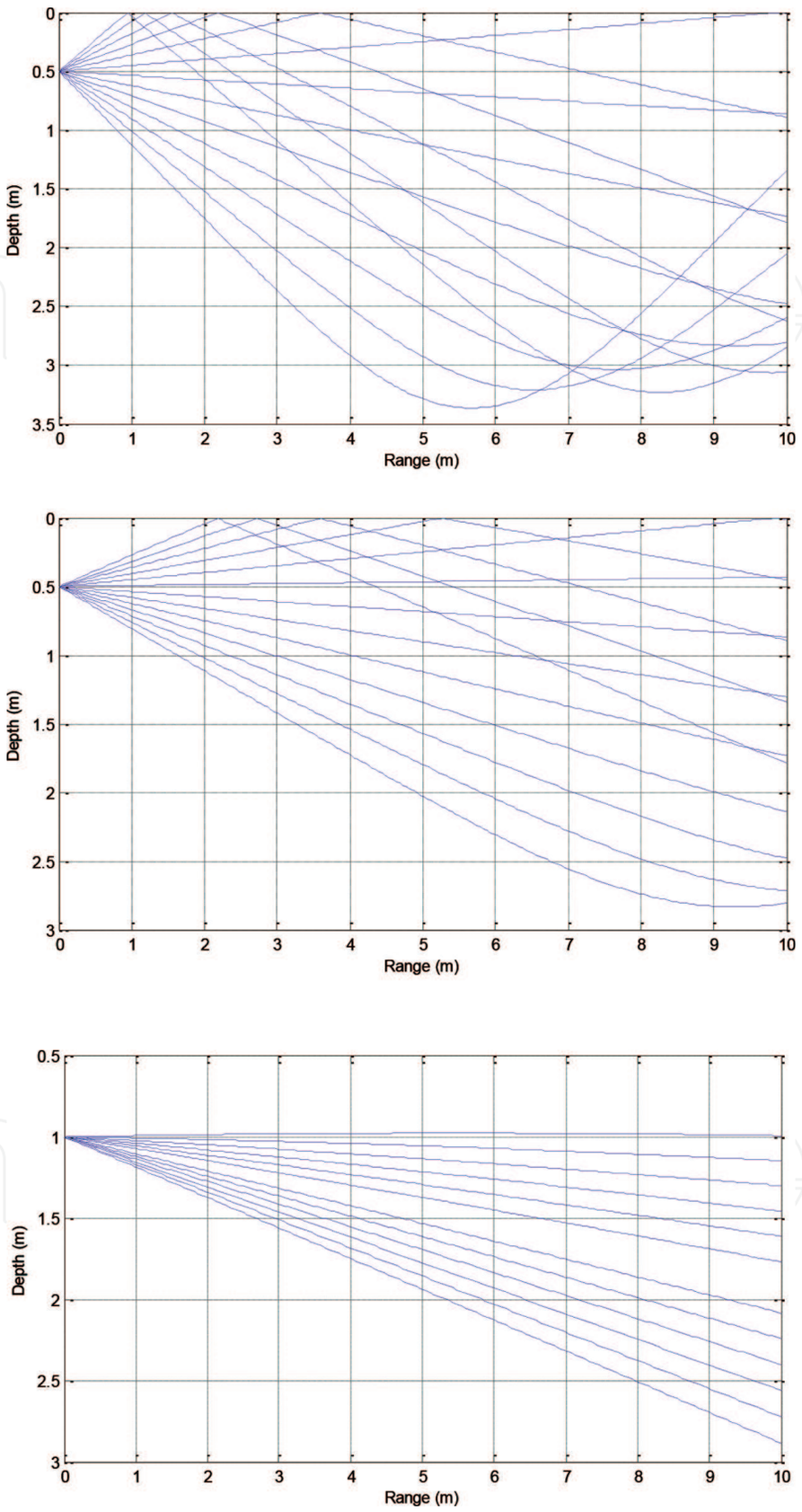


Figure 6. Acoustic ray propagation.

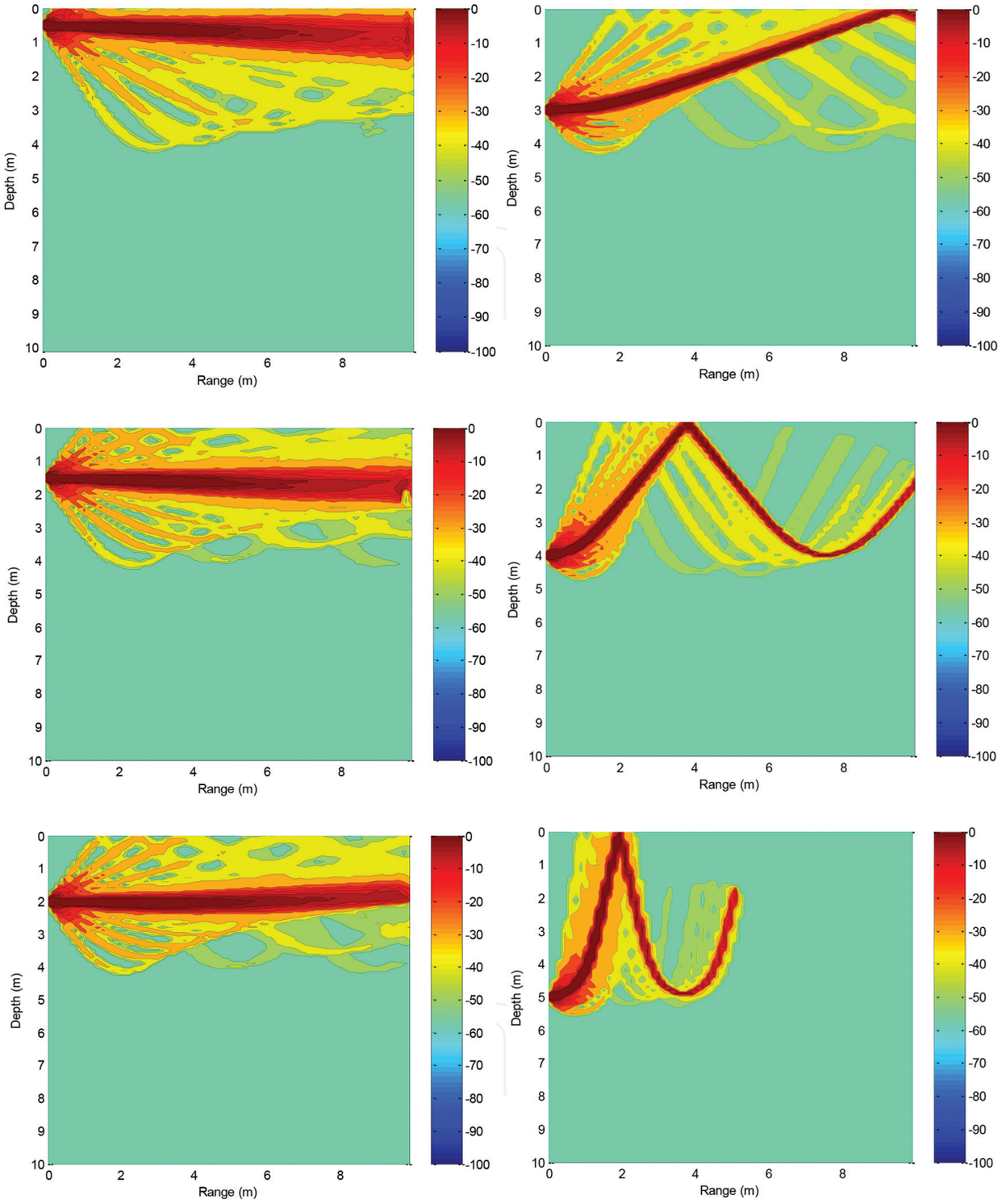


Figure 7. Sound intensity level for transmitter depth of 0.5, 1.5, 2, 3.0, 4.0, and 5.0 m.

Measurement of target strength (TS) in laboratory was conducted using 10 dead fish. The TS value for fish was determined by the tilt angle and acoustic frequency. The values of TS_{max} and TS_{avg} as functions of linear value of fish length are plotted in **Figure 13**. The values of TS_{max} and the TS_{avg} at 50 kHz were higher than those at 200 kHz. Positive

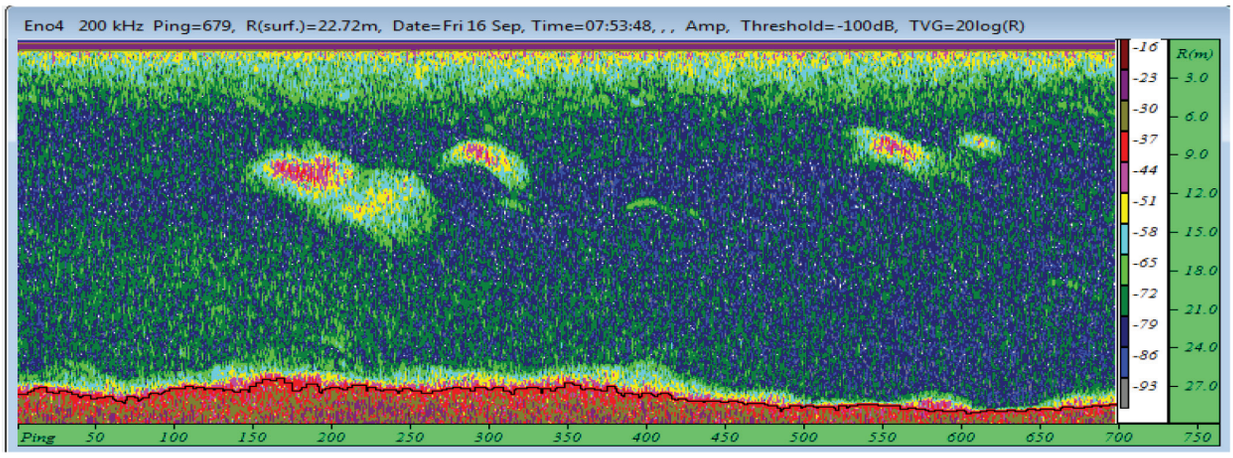


Figure 8. Raw data echogram.

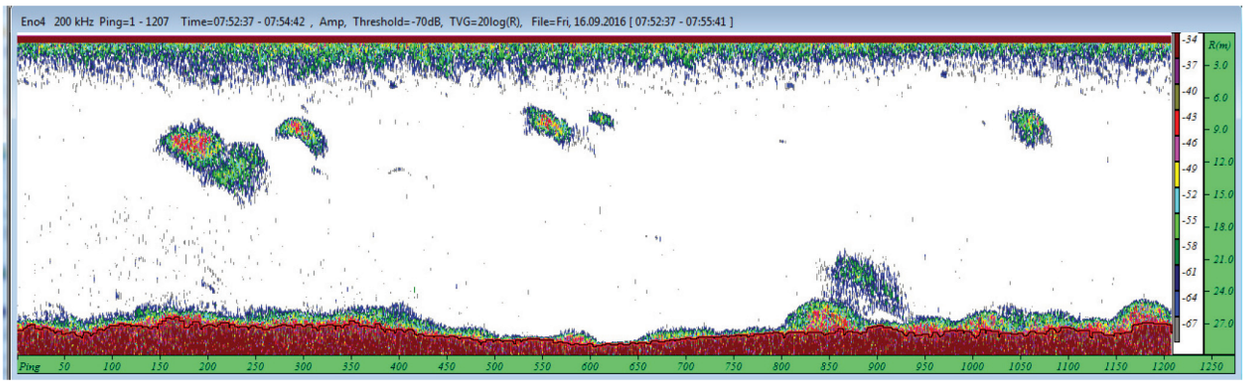


Figure 9. Echogram filtered.

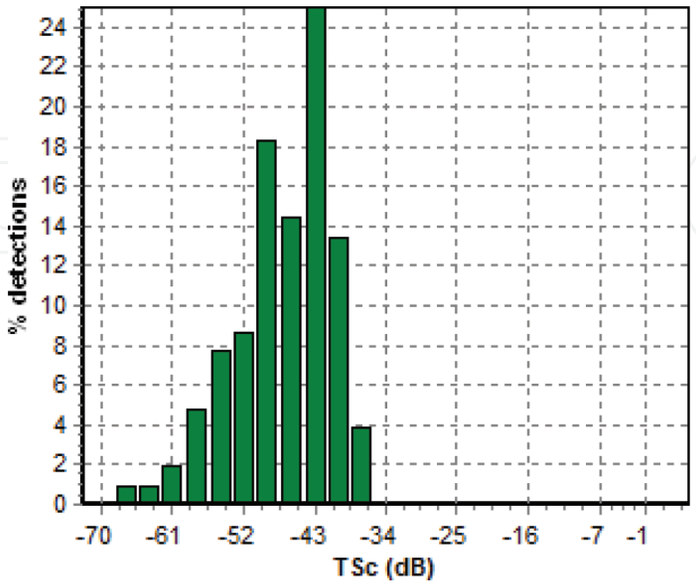


Figure 10. Target strength histogram.

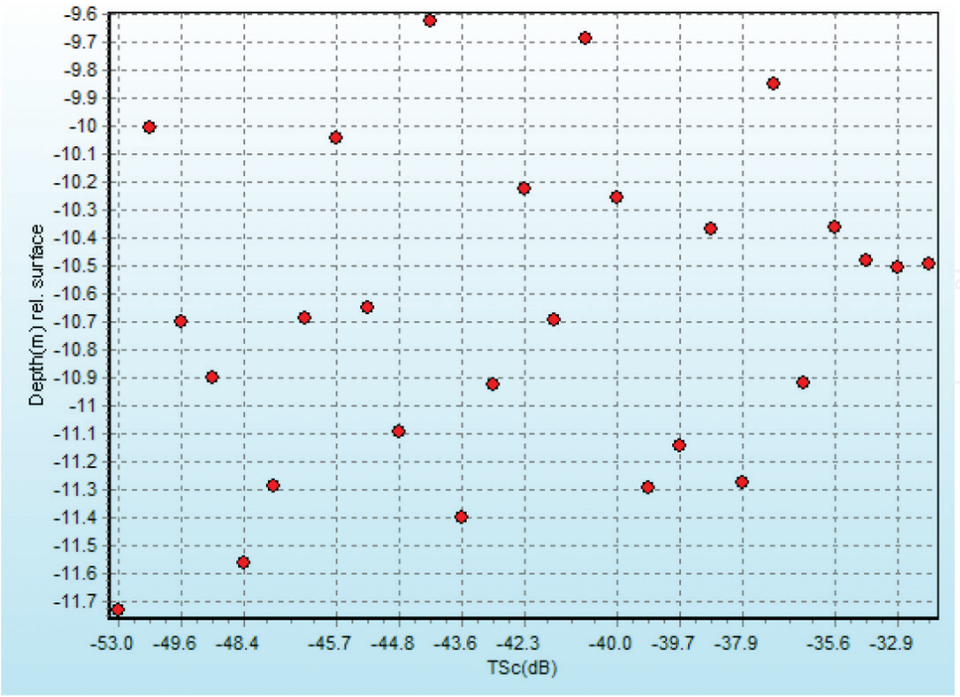


Figure 11. Target strength versus depth.

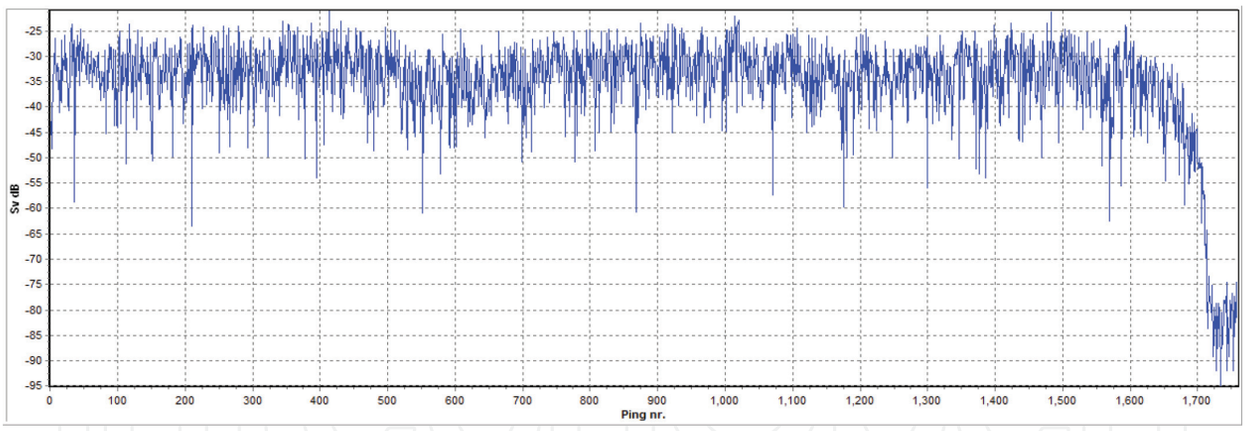


Figure 12. Volume backscattering (SV) signal.

correlation was found between TS values and fish length at both 50 and 200 kHz. The best fit regression lines of TS_{ave} are $TS_{ave} = 19.81 \log (FL) - 98.2$, $r = 0.96$ (**Figure 13**; left side) and $TS_{ave} = 19.56 \log (FL) - 96.47$, $r = 0.96$ (**Figure 13**; right side). A small discrepancy was found in TS_{max} and TS_{ave}. The slope of TS_{max} was close to 20, suggesting that the acoustic backscattering was proportional to the square of fish or body length. For TS quantification, acoustic threshold was applied (**Figure 14**), and application of single echo detector was shown in **Figure 15**.

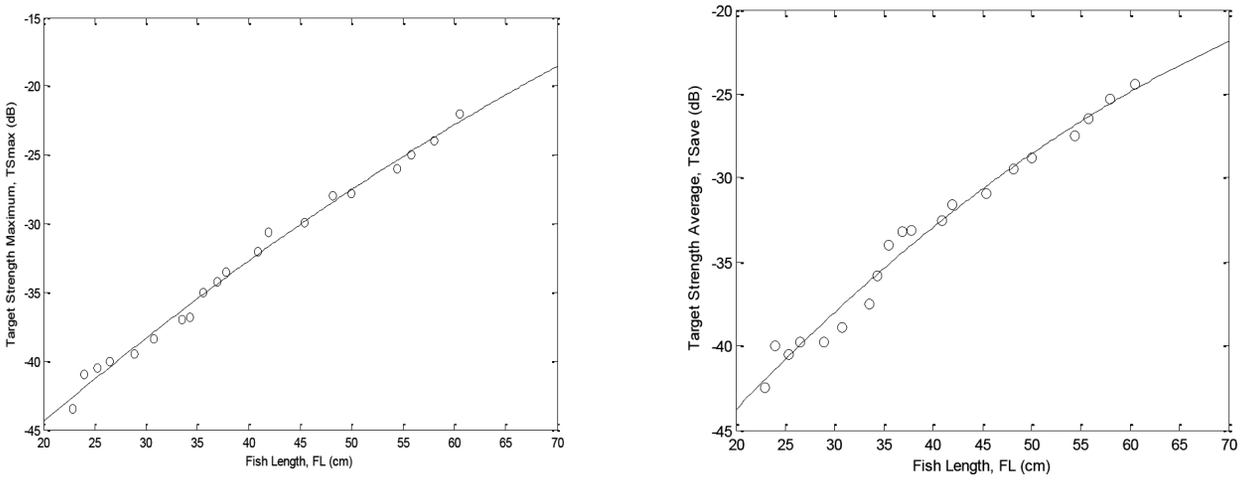


Figure 13. Relationship between TS and fish length (FL).

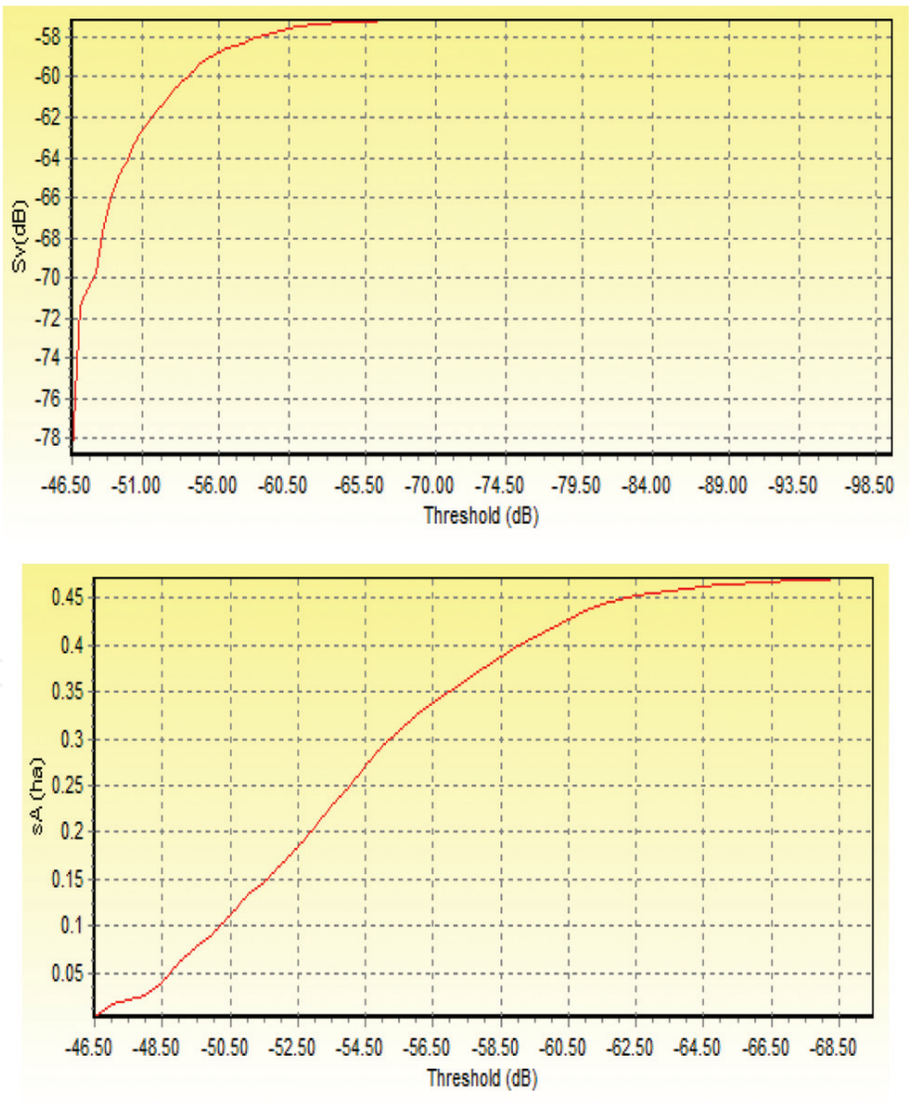


Figure 14. Threshold application for SV and SA modes.

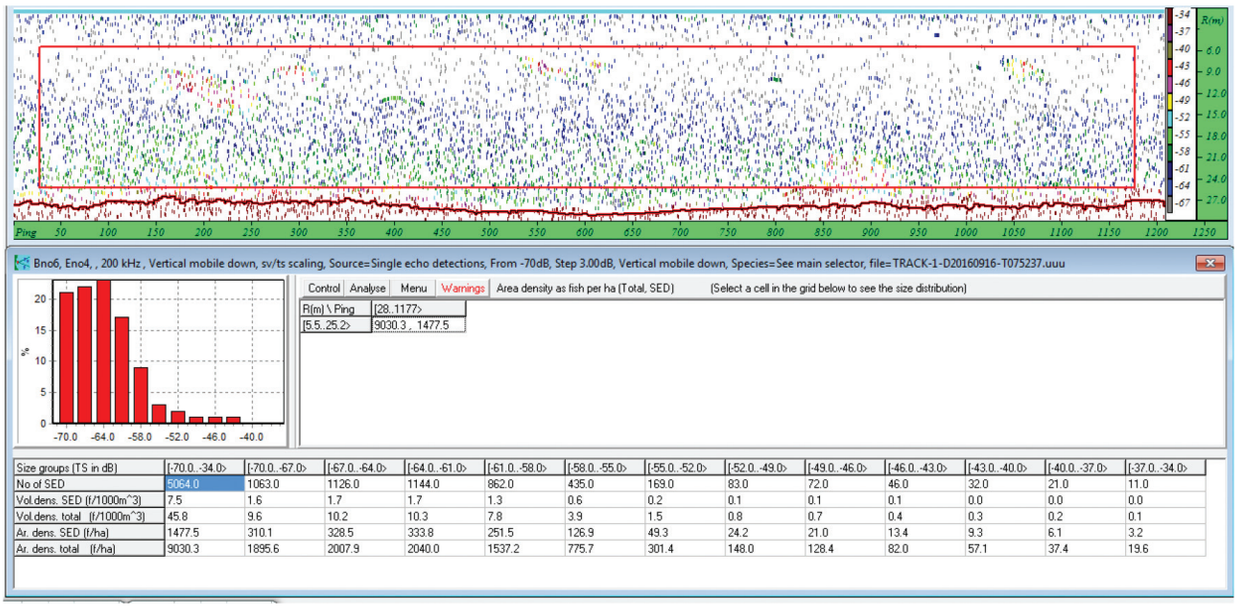


Figure 15. Single echo detector for TS detection.

Typical examples of TS as a function of incidence angle at frequencies 50 and 200 kHz are shown in **Figure 16**. The variations of TS value with incidence angle are displayed at 0° (main lobe) at both frequencies. The side lobes are displayed at a small discrepancy at two frequencies. The peaks were sharp, suggesting that slight changes in the incidence angles of fish have a major effect on the TS value.

Target strength of fish is important for fish stock estimation. The measurement of fish density uses TS as a scaling factor and instrument parameters. In fact, individual TS depends upon physical and biological factors such as tilt angle, length, acoustic frequency, physiology, and morphology [17].

Acoustic backscattering using the DWBA model requires accurate values of sound speed and density of fish. This is caused by a weakly scattering organism whose material properties vary from surrounding water. Acoustic scattering predictions with the tilt angle are measured for fish of angle increment from 0 to 360°. The comparison between DWBA model and measurement was agreed upon on the main lobe, but in the side lobe, there is some discrepancy. It was found the acoustic backscattering is strongly dependent on incidence angle and frequency. This result is suitable for the previous research using DWBA for zooplankton and squid applications [18, 19]. Target strength for several fish were shown to increase significantly from 0° to 90° and from 180° to 270° for all frequencies. In the future, the phase parameter of DWBA should be included in TS computation. This is the first research to measure the incidence angle of Indonesian fish in an experimental water tank and ocean field to apply a theoretical target scattering model using DWBA. We confirm that application of single-beam echo sounder is possible for accurate TS measurement.

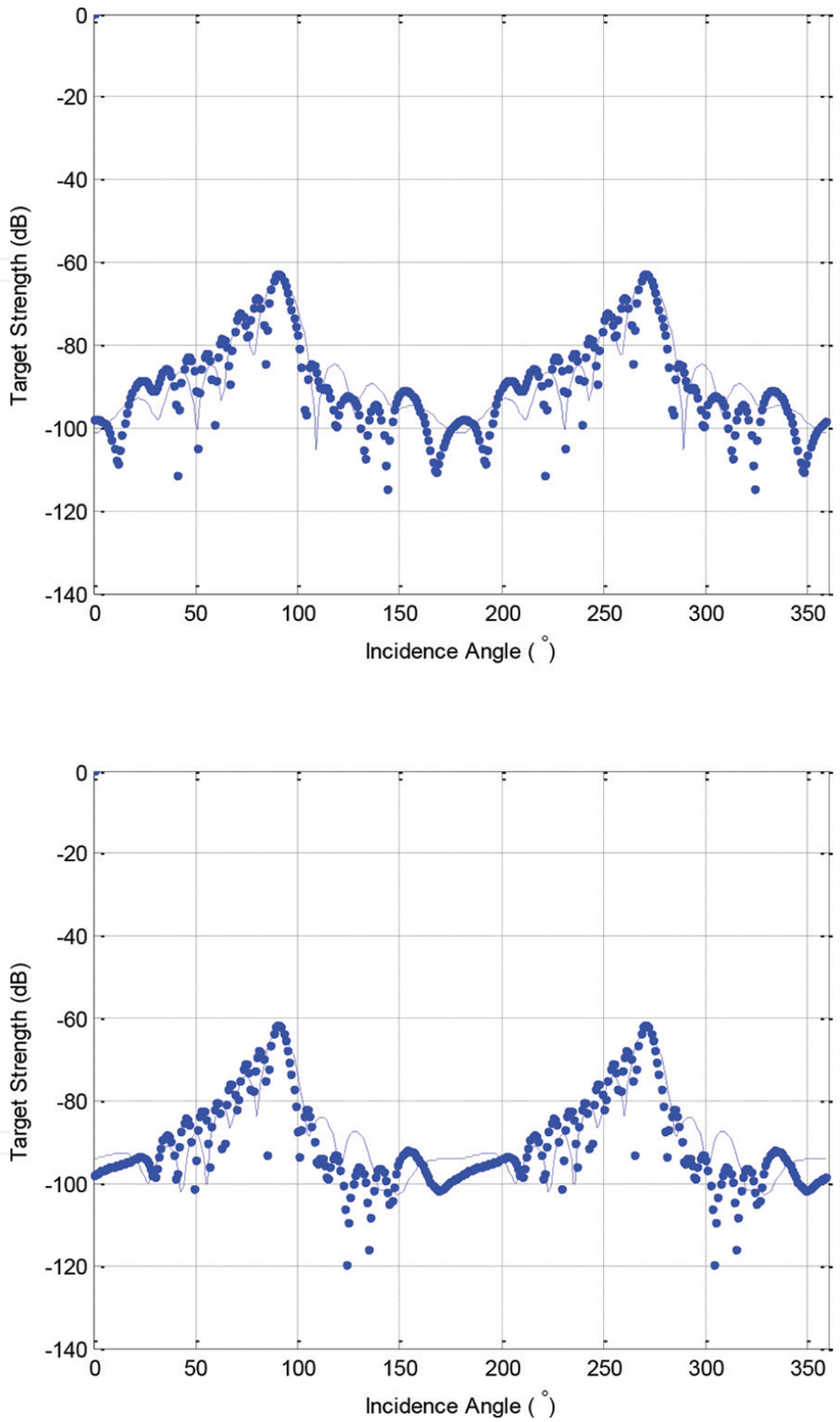


Figure 16. DWBA numerical model (-) and measurement (●) of TS values as a function of tilt angle at 50 (upper) and 200 kHz (lower).

4. Conclusion

The results indicated that TS of fish was determined by incidence angle of acoustic wave, fish length, and frequency of sonar instrument. TS will increase with the length of the animal. TS information are useful for quantifying fish stock in the field using quantitative echo sounder. The validation of DWBA model to measure target strength is confirmed with the laboratory experiment using single-beam echo sounder.

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