

Angle-dependent target strength variability of Kawakawa (*Euthynnus affinis*) measured Ex Situ using broadband echosounder

Moh. Rafli Furqan Hidayat¹, Henry Munandar Manik^{2*}, Totok Hestirianto², and Syahrul Purnawan³

¹Marine Technology Study Program, Institut Pertanian Bogor. Jl. Raya Darmaga, Bogor 16680, West Java, Indonesia

²Department of Marine Science and Technology, Faculty of Fisheries and Marine Science, Institut Pertanian Bogor. Jl. Raya Darmaga, Bogor 16680, West Java, Indonesia

³Department of Marine Sciences, Faculty of Marine and Fisheries, Universitas Syiah Kuala, Banda Aceh 23111, Indonesia

Abstract. Accurate target strength (TS) measurements are essential for understanding fish acoustic backscatter, which is influenced by factors such as frequency and orientation. This study analyzed TS values of Kawakawa (*Euthynnus affinis*) samples (fork length 27.4 cm) using a broadband echosounder and examined the effect of different tilt angles on TS. Measurements were conducted in an acoustic tank with a Simrad EK80 Wide Band Transceiver equipped with a split-beam transducer over the 160-260 kHz range. Dead fish samples were positioned under the transducer at tilt angles of -45°, 0°, and +45°, and data were processed using ESP3 software. Results showed angle-dependent TS variations: at 0°, TS ranged from -31.72 dB to -19.00 dB; at +45°, from -40.86 dB to -22.88 dB; and at -45°, from -41.33 dB to -24.37 dB. These findings demonstrate that TS is strongly dependent on fish orientation, emphasizing the utility of broadband acoustics for detailed fish characterization.

1 Introduction

Kawakawa (*Euthynnus affinis*) is one of the most economically important pelagic fish species in Indonesian fisheries and is heavily exploited, raising concerns about overfishing and ecosystem degradation [1]. Inaccurate stock assessments contribute significantly to unsustainable fisheries management, highlighting the need for reliable biomass estimation methods. Hydroacoustic techniques have emerged as a leading tool for water column surveys due to their non-invasive nature, ability to cover large spatial scales, and capacity to provide real-time data [2, 3].

The acoustic technology approach is an estimation method that relies on basic information about sound reflections from a target, referred to as Target Strength (TS). TS represents the intensity of acoustic energy emitted by a sonar system, such as an echosounder,

* Corresponding author: henrymanik@apps.ipb.ac.id

which interacts with the target organism and is then reflected back to the receiver. TS defined as the logarithmic measure of acoustic backscatter from an individual fish, as expressed in Equation (1) in the materials and methods section. Together with volume backscattering strength (Sv), serves as a scaling factor for converting acoustic signals into fish abundance and biomass estimates. TS is affected by multiple factors, including acoustic frequency, fish size, body orientation, measurement geometry, and environmental conditions. In situ TS measurements are challenging because of uncertainties in fish identity, orientation, and behavior. Therefore, controlled ex situ experiments in laboratory tanks provide a robust approach to isolate the effects of frequency and tilt angle.

Furthermore, broadband systems, such as the Simrad EK80, allow investigation of TS-frequency relationships that cannot be resolved using traditional narrowband systems [4]. However, to date, no broadband TS measurements of *Euthynnus affinis* under controlled conditions have been reported, representing a critical knowledge gap.

2 Materials and methods

2.1 Fish samples collection

Fish samples were collected from local fishermen at the landing sites of Pelabuhan Perikanan Nusantara (PPN) Palabuhanratu in Sukabumi, Indonesia. A total of thirteen fish specimens with different fork lengths were measured in this study. The fish were dead at the time of collection. During transport, specimens were stored in coolbox to maintain freshness and minimize post-mortem degradation. All measurements were performed on the same day as collection. Prior to acoustic measurements, specimens underwent careful visual inspection to ensure that they were free of external abnormalities, deformities, or physical damage that could affect acoustic reflection responses. However, the detailed broadband TS analysis at three different tilt angles presented in this paper focuses on one representative specimen with a fork length of 27.4 cm.

2.2 Experimental setup

The experiment was conducted from 8 to 14 June 2025 in the Acoustic Water Tank Laboratory at IPB University. A Simrad EK80 wideband transceiver with a split-beam transducer was mounted in a downward looking configuration at the top of the tank, operating over a frequency range of 160–260 kHz. One *Euthynnus affinis* specimen with a fork length of 27.4 cm was suspended beneath the transducer and positioned at three predefined tilt angles relative to the horizontal plane: -45° , 0° , and $+45^\circ$. The TS values reported in this study therefore represent repeated measurements from this single individual. The experimental setup is shown in Figure 1.

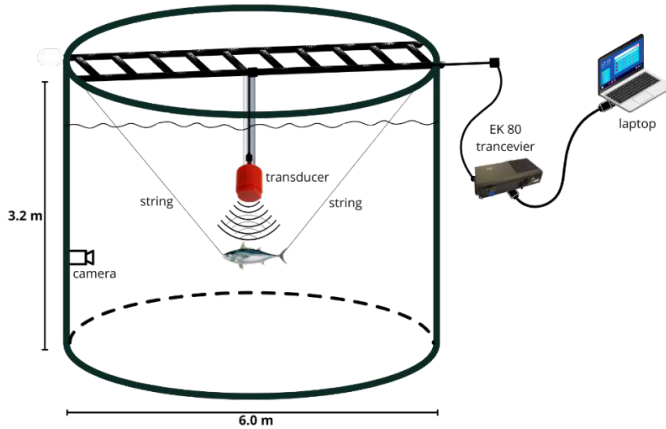


Fig. 1. Experimental setup for measuring fish TS in a water tank

2.3 Data acquisition and processing

Data acquisition was performed using the tethered method, in which each fish was suspended with monofilament line in a freshwater-filled tank. The transducer was mounted on a vertical pole at a fixed target depth of 0.8 m to minimize near field effects. Environmental parameters, including water temperature and depth, were recorded during each measurement session. Prior to data collection, system calibration was conducted using a standard 38.1 mm diameter tungsten carbide sphere at a reference frequency of 200 kHz [5]. The detailed technical specifications of the broadband echosounder system employed in this study are summarized in Table 1. These parameters define the acoustic transmission characteristics and data acquisition settings that govern the quality and reliability of the recorded TS measurements.

Table 1. Broadband Echosounder Instrument Specifications

No	Parameter	Value
1	Frequency	CW 200 kHz/FM 160- 260 kHz
2	Pulse Duration	0.512 ms
3	Power Transmit	90 watt
4	Sound speed	1499.39 m/s
5	Absorption coefficient	7.4 dB/km
6	TS threshold	-60 dB
7	Near Field	39 cm

Raw acoustic data were recorded using a frequency range of 160-260 kHz and processed using ESP3 software to extract TS values in decibels (dB) with 10 kHz frequency intervals. Data processing was restricted to the 0.8 m depth layer to eliminate surface noise originating from the near field region of the transducer. Target strength was defined as :

$$TS = 10 \log (\sigma_{bs}) \tag{1}$$

Where σ_{bs} was represented the measured backscattering cross-section of an individual target. The linear TS values were subsequently used to calculate the mean TS [6]:

$$Mean TS = 10 \log \left(\frac{1}{N} \sum_{i=1}^N 10^{TS_i/10} \right) \tag{2}$$

Where N was the number of pings data collection for one fish.

2.4 Statistical analysis

The relationship between target strength (TS) and wideband frequency in *Euthynnus affinis* is inherently non-linear, as acoustic scattering responses are governed by complex interactions between incident acoustic waves and the fish's morphological structure. These interactions include variations in the ratio of body dimensions to acoustic wavelength as well as changes in target orientation during measurement [7]. The Simrad EK80 broadband system transmits signals over a continuous frequency range, enabling detailed observation of TS spectral characteristics that cannot be resolved using conventional narrowband systems [8]. As a result, TS values exhibit frequency dependent fluctuations that form curved response patterns, which cannot be adequately described using linear models. Therefore, the TS-frequency relationship in this study was modeled using a third order polynomial regression, expressed as:

$$TS(F) = af^3 + bf^2 + cf + d \quad (3)$$

where $TS(f)$ is the target strength at frequency f , and a , b , c , d are regression coefficients. Model performance was evaluated using the coefficient of determination (R^2).

3 Results

3.1 Calibration

The calibration results of the wideband echosounder system, using a 38.1 mm diameter tungsten carbide sphere at a reference frequency of 200 kHz, are shown in Figure 2. The measured sphere TS value was -39.40 dB, which is in close agreement with the factory reference value of -40.40 dB. This small deviation of 1.0 dB falls within the acceptable tolerance range for standard sphere calibration procedures, indicating stable and reliable acoustic system performance during the experiment. These results confirm that the instrument was properly calibrated and that the acquired TS measurements can be considered accurate for subsequent broadband analysis [9].

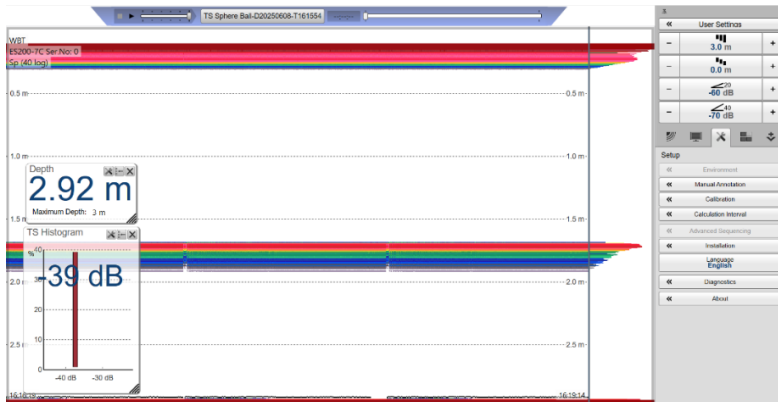


Fig. 2. Sphere ball calibration using SIMRAD EK 80

3.2 TS variability at -45° tilt

At a tilt angle of -45°, as shown in Figure 3, the target strength (TS) of *Euthynnus affinis* ranged from -41.33 to -24.37 dB. Third-order polynomial regression produced strong

TS–frequency relationships across the 160-260 kHz sub-bands, with coefficients of determination (R^2) ranging from 0.92 to 0.99. The highest regression performance was observed in the 230-240 kHz frequency band ($R^2 = 0.9856$). The relatively high TS variability at this orientation suggests that the downward tilt reduces the effective acoustic cross-sectional area relative to the incident sound wave, thereby decreasing the amount of backscattered energy received by the transducer [10].

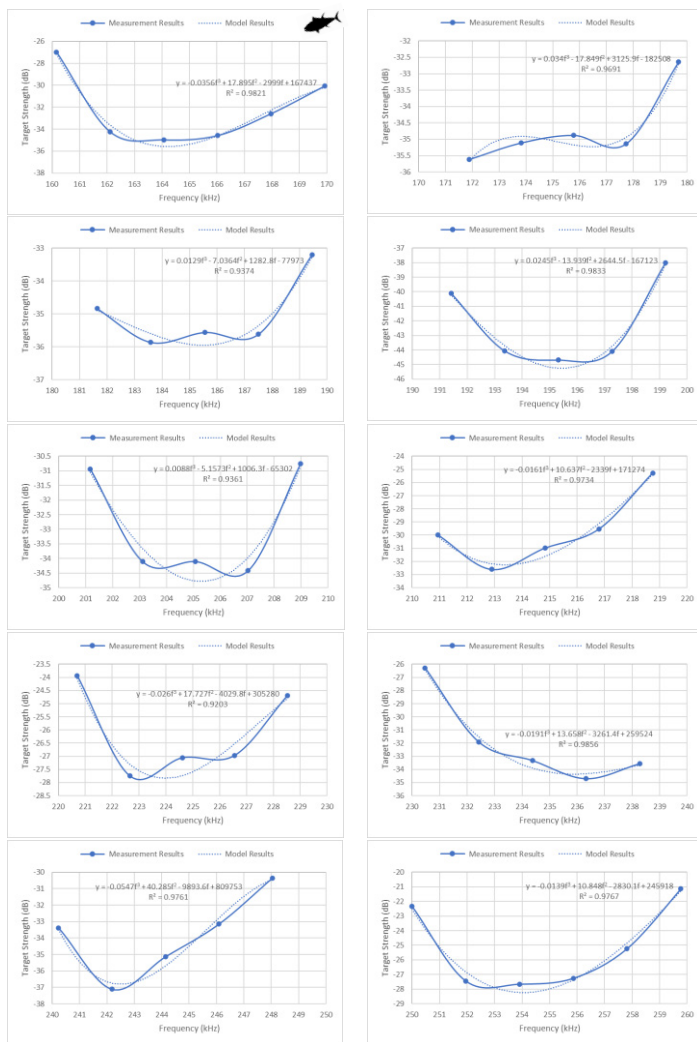


Fig. 3. Results TS variability at -45° tilt

3.3 TS variability at 0° tilt

At the horizontal orientation (0°), as shown in Figure 4, the average target strength (TS) of *Euthynnus affinis* exhibited a clear increasing trend with frequency across the 160-260 kHz range. TS increased from -31.72 dB in the 210-220 kHz frequency band to -19.00 dB in the 250-260 kHz band, reflecting enhanced acoustic backscatter intensity at higher frequencies. The third-order polynomial regression model yielded coefficients of

determination (R^2) ranging from 0.9309 to 0.9946, indicating that the TS-frequency relationship at this orientation is well described by a nonlinear model.

This trend is consistent with fisheries acoustic scattering theory, where increasing frequency corresponds to shorter wavelengths and improved resolution of the fish's internal morphological structures. At 0° , the longitudinal axis of the fish body is nearly perpendicular to the direction of the incident acoustic wave, resulting in a maximum effective scattering cross-section and stronger, more coherent backscatter [11]. These findings confirm that fish orientation is a primary determinant of TS values and explain why the 0° orientation is commonly used as a reference in TS measurements.

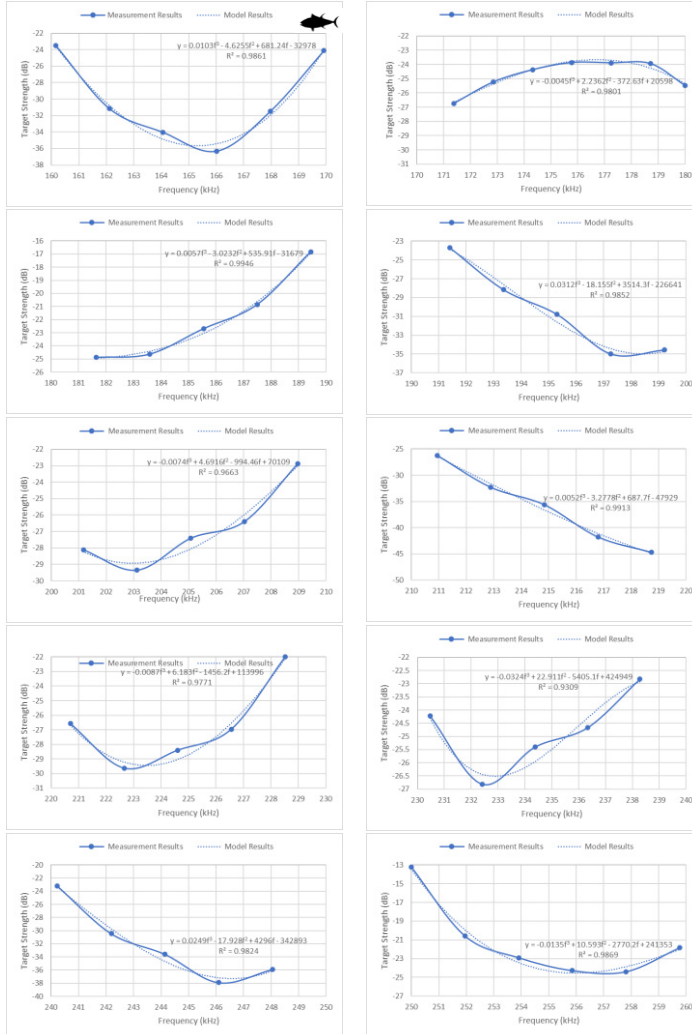


Fig. 4. Results TS variability at 0° tilt

3.4 TS variability at 45° tilt

At a tilt angle of $+45^\circ$, as shown in Figure 5, the average target strength (TS) was consistently lower than that observed at the 0° orientation, with values ranging from -22.88 to -40.86 dB across the full frequency band. The third-order polynomial regression model exhibited an

excellent fit, yielding a maximum coefficient of determination of $R^2 = 0.996$ in the 200–210 kHz frequency band, which was the highest among all tested orientations.

The systematic reduction in TS at the $+45^\circ$ orientation highlights the strong sensitivity of acoustic scattering to fish orientation. At oblique angles, the effective acoustic cross-section of the fish relative to the incident wave is reduced due to the increased contribution of specular reflection and a decrease in direct backscatter toward the transducer. Furthermore, the broadband response demonstrates that orientation effects are frequency dependent, varying with the relationship between acoustic wavelength and the morphological dimensions of the fish body.

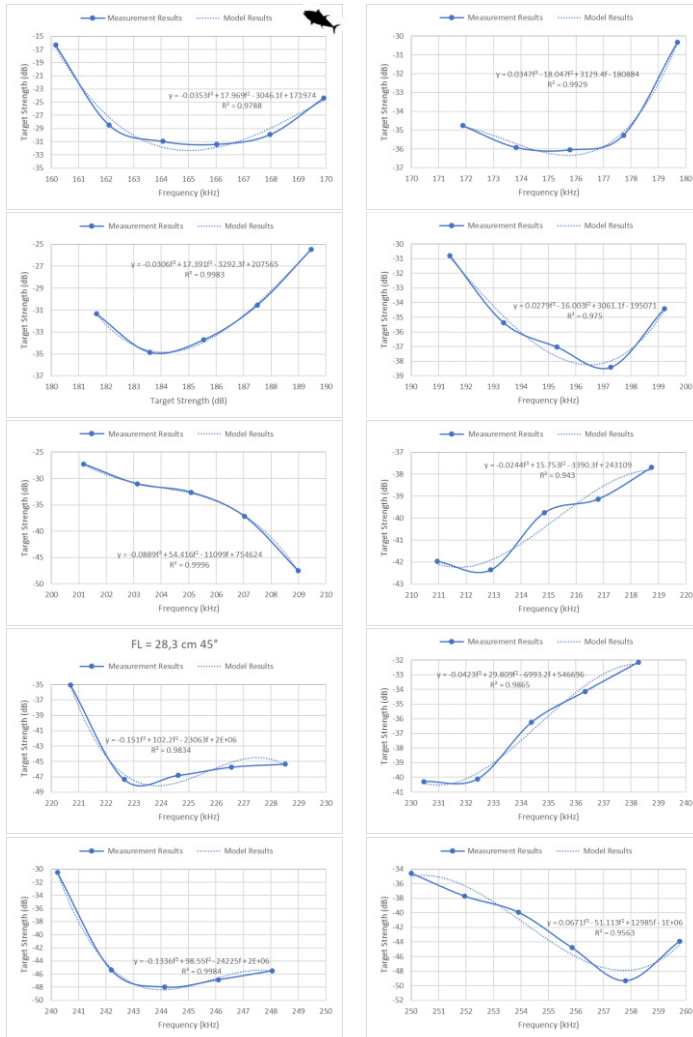


Fig. 5. Results TS variability at 45° tilt

4 Discussion

The results demonstrate that the target strength (TS) of *Euthynnus affinis* is strongly dependent on both acoustic frequency and tilt angle [12]. The highest TS values were

observed at the 0° orientation, consistent with theoretical predictions that maximum acoustic backscatter occurs when the fish body axis is perpendicular to the incident acoustic wave. In contrast, lower TS values at -45° and +45° reflect a reduction in effective scattering cross-section caused by angular misalignment and morphological irregularities of the fish body [12].

The application of a third-order polynomial regression model yielded very high coefficients of determination ($R^2 = 0.920-0.9996$ across the frequency range), indicating that the TS-frequency relationship of *Euthynnus affinis* is inherently nonlinear and can be well described by this model. This finding aligns with contemporary fisheries acoustics theory, which emphasizes that acoustic scattering responses arise from complex interactions between acoustic wavelength and fish morphological dimensions [12].

The consistently strong polynomial relationships across all orientations highlight the advantages of broadband acoustic analysis in resolving frequency-dependent TS dispersion behavior. Notably, the highest R^2 value (0.9996) was observed at the +45° orientation within the 200-210 kHz frequency band, suggesting a particularly stable acoustic response and indicating that this frequency range may be optimal for TS-based characterization of *Euthynnus affinis*. These results are consistent with previous broadband studies on Chub Mackerel (*Scomber japonicus*), which reported decreasing TS fluctuations and increasing stability at higher frequencies [13]. Overall, broadband TS measurements of *Euthynnus affinis* provide valuable contributions to improving fish stock assessment methodologies in Indonesian fisheries.

5 Conclusion

Ex situ broadband target strength (TS) measurements of *Euthynnus affinis* (27.4 cm), conducted with a Simrad EK80 over 160-260 kHz at three tilt angles (-45°, 0°, +45°), revealed that the acoustic backscatter of the fish is highly dependent on both frequency and orientation. TS values ranged from -41.33 to -19.00 dB, and third-order polynomial regression consistently produced robust TS-frequency models with $R^2 > 0.93$. These results highlight the importance of accounting for fish orientation in acoustic biomass estimation and demonstrate the potential of broadband systems to enhance fisheries acoustic assessments.

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