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MEASUREMENT OF TARGET STRENGTH VALUES OF CATFISH (*Clarias batrachus*) USING SIMRAD EK15 HYDROACOUSTIC METHOD UNDER CONTROLLED CONDITIONS

Pengukuran Nilai Target Strength Ikan Lele (*Clarias batrachus*) Menggunakan Metode Hidroakustik SIMRAD EK15 Kondisi Terkontrol

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ABSTRACT

Catfish (Clarias batrachus) is one of the main commodities in Indonesia's freshwater aquaculture industry. Accurate monitoring of fish growth and population is crucial to improving production efficiency and sustainability. Conventional methods such as physical weighing are often inefficient and may cause stress to the fish. Therefore, hydroacoustic technology offers a promising alternative due to its non-invasive nature and ability to provide real-time data. This study aims to estimate the Target Strength (TS) of catfish using hydroacoustic methods with a SIMRAD EK15 instrument under controlled environmental conditions. The measurements were conducted in a test tank where physical parameters such as temperature, salinity, and water clarity were maintained consistently to ensure reliable results. The experiment involved 13 catfish of various sizes, with body lengths ranging from 8.1 cm to 19.3 cm and weights from 4 to 37 grams. The measured TS values ranged from -64.81 dB to -59.89 dB. The results indicated a positive correlation between TS and both fish length and weight, suggesting that larger fish produced stronger acoustic backscatter signals. This study provides a valuable foundation for the application of hydroacoustic methods in catfish population surveys, both in controlled environments and natural waters. The findings can be adapted to support more efficient and sustainable fish farming practices through real-time, technology-based monitoring systems.

Keywords: Catfish, Echogram, Hydroacoustics, SIMRAD EK15, Target Strength

ABSTRAK

Ikan lele (*Clarias batrachus*) merupakan salah satu komoditas utama dalam budidaya perikanan air tawar di Indonesia. Pemantauan pertumbuhan dan populasi ikan secara akurat sangat penting untuk meningkatkan efisiensi dan keberlanjutan produksi. Metode konvensional seperti penimbangan fisik dinilai kurang efisien dan dapat menyebabkan stres pada ikan. Oleh karena itu, teknologi hidroakustik menjadi alternatif yang menjanjikan karena bersifat non-invasif dan mampu memberikan data secara real-time. Penelitian ini bertujuan untuk menghitung nilai Target Strength (TS) ikan lele menggunakan instrumen hidroakustik SIMRAD EK15 dalam kondisi lingkungan terkendali. Pengukuran dilakukan di dalam tangki uji dengan parameter lingkungan seperti suhu, salinitas, dan kejernihan air yang dijaga tetap stabil. Penelitian melibatkan 13 ekor ikan lele dengan variasi ukuran, memiliki panjang antara 8,1 cm hingga 19,3 cm dan berat antara 4 hingga 37 gram. Hasil pengukuran menunjukkan nilai TS berkisar antara -64,81 dB hingga -59,89 dB. Ditemukan korelasi positif antara nilai TS dengan panjang dan berat tubuh ikan, yang berarti semakin besar ukuran ikan, semakin kuat pantulan akustik yang dihasilkan. Studi ini memberikan dasar penting untuk penerapan metode hidroakustik dalam survei dan pemantauan populasi ikan lele, baik di lingkungan buatan maupun perairan alami. Hasilnya dapat diadaptasi untuk mendukung sistem pemantauan berbasis teknologi dalam budidaya ikan secara lebih efisien dan berkelanjutan.

Kata Kunci: Echogram, Hidroakustik, Ikan Lele, SIMRAD EK15, Target Strength

INTRODUCTION

Catfish (*Clarias bactractus*) is a crucial commodity in the Indonesian fisheries industry (Suyanto, 2007). Catfish production has increased significantly in recent years as a crucial component of the freshwater aquaculture sector. The Central Statistics Agency (2022) reports that catfish farming contributes approximately 40% of total aquaculture production in Indonesia, confirming its role as a vital source of animal protein for the community.

During the aquaculture process, routine monitoring of fish growth and health is crucial to achieving optimal productivity (Negara & Surya, 2017). Monitoring fish health and growth is crucial for maintaining optimal productivity in aquaculture (Gunawan & Elven, 2020). One way to monitor fish populations and growth is by measuring their biomass (Fauziyah et al., 2019). Conventional methods used to measure fish biomass, such as physical weighing, not only disturb the fish but also increase the risk of stress, injury, and infection (Cochrane, 2002). Therefore, more efficient and non-invasive alternative methods are needed to periodically monitor fish growth (Rani et al., 2024) (Abinaya et al., 2023).

One method that has been widely used to monitor fish biomass without physical disturbance is hydroacoustic technology (Priatna & Wijopriono, 2011). This technology works by sending sound waves from a device called an echosounder and then measuring the reflection of these sound waves off the fish's body (Mac Lennan & Simmonds, 1992). One hydroacoustic instrument frequently used to measure fish biomass is the EK15. The EK15 echosounder uses a high frequency (200 kHz) to detect underwater objects, such as fish, with high accuracy (Simrad, 2025).

A key parameter measured using an echosounder is Target Strength (TS), which is the strength of the signal reflected by the fish's body (Foote, 1987). Target strength (TS) is closely correlated with fish size and can be used to accurately estimate biomass (Dunning et al., 2023). Factors influencing target strength values can generally be divided into three categories: those originating from the target itself, environmental factors, and factors from the acoustic equipment used. In fish, target strength values can vary based on size, anatomical structure, swim bladder presence, behavior, and position or orientation in the water (Priatna & Wijopriono, 2011). Acoustic estimation techniques require acoustic backscatter data, or Target Strength (TS), for each target species (Dawson & Karp, 1990; Benoit-Bird et al., 2003; Zare et al., 2017).

Target strength values vary for each fish and are influenced by factors such as fish species, body shape, size (both length and weight), swim bladder presence, and the fish's position relative to the received acoustic waves (Hafidz, 2018). According to Manik (2010), the swim bladder is the main factor determining the target strength value in fish. Furthermore, there is a strong correlation between target strength value and total fish length (Frouzova et al., 2011).

Previous research on TS using freshwater fish targets has been conducted by Risandes et al. (2024) on snakehead fish (*Channa striata*) and catfish (*Clarias gariepinus*). Furthermore, research by Bakhtiar et al. (2020) examined trevally in a controlled environment. Several studies have identified that TS values are significantly influenced by the fish's physical size, body orientation to sound waves, and body structure (Godlewska et al., 2017; Lavery et al., 2019). In catfish, the smooth, scaleless body structure creates unique challenges in TS measurements. Catfish have different acoustic reflection characteristics compared to scaly fish, so proper instrument calibration is crucial for accurate results (Simmonds & MacLennan, 2021). The frequency used in the echosounder must also be adjusted to the characteristics of the fish to avoid distortion in TS measurements (Reynisson et al., 2018).

This study aims to measure the Target Strength value of catfish (*Clarias bactractus*) using hydroacoustic methods under controlled conditions. The controlled conditions used in this study aim to minimize factors that could affect the measurement results, such as water depth, temperature, and the fish's orientation to the sound source. Measurements were conducted in a laboratory using an echosounder specifically calibrated for catfish, with the aim of determining the relationship between fish size and TS values.

The results of this study are expected to contribute to the development of hydroacoustic technology in fish farming, particularly catfish, which have unique sound reflection characteristics. By accurately determining the TS value of catfish, farmers can monitor fish populations in real time without disturbing fish activity, ultimately improving production efficiency and fish welfare in aquaculture.

METHODS

Research Time and Location

This research was conducted on February 27, 2021, in the Water Tank Laboratory, Division of Marine Acoustics and Instrumentation, Department of Marine Science and Technology, Bogor Agricultural University.

Tools and Materials

The equipment used in this study included a SIMRAD EK15 single-beam echosounder, an Asus S46C laptop, and an iPhone 11 for documentation. Echoview and Microsoft Excel software were also used for data analysis. The materials used in this study consisted of 13 catfish (*Clarias batrachus*) ranging in size from 8 to 19 cm.

Instrument Calibration

Before recording catfish data, the first step was to set up the instrument calibration. This calibration process used a sphere as a target. A sphere is considered an ideal target because the energy it reflects is influenced by its surface area, and because it is an isotropic reflector, meaning it reflects echo waves evenly in all directions (Qomarudin, 2018). An illustration of the sphere recording can be seen in Figure 1 below.

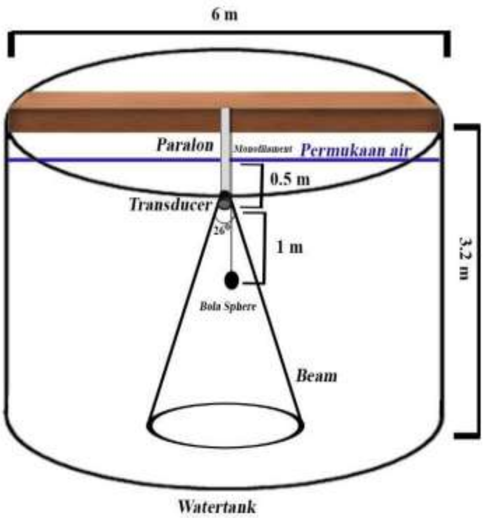

Figure 1. Tidal Data Collection

The fish biometric elements measured included total length (TL) and body weight. Total length was measured from the tip of the mouth to the outermost part of the fish's tail using a plastic ruler, as shown in Figure 2. Fish weight was measured using a digital scale.

Figure 2. Catfish (*Clarias batrachus*)

Acoustic Data Recording

Thirteen catfish were recorded using the hanging method. This method involves suspending the target with monofilament line and then suspending it below the transducer (as seen in Figure 3). Target strength (TS) values were measured by suspending each lobster individually. Each TS and SV target measurement took 5 minutes. These 5-minute measurements resulted in 160 pings on the echogram.

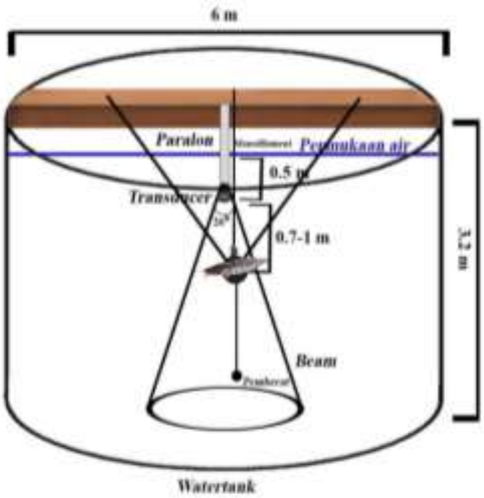

Figure 3. Illustration of Recording and Tying Catfish

The targets were tied using monofilament line. Monofilament thread is a single fiber made of synthetic materials such as nylon or polyester, commonly used in various applications such as fishing nets and textiles due to its high strength and water resistance (John, 2015). The use of monofilament thread ensures that the backscatter value of the thread used to tie the target is not affected by the target's backscatter, thus focusing the recording solely on the target.

Data Processing

Data recorded using the Simrad EK-15 is in *.raw format. Target Strength (TS) data is then processed using Echoview software, commonly used in hydroacoustic data analysis for fisheries and marine research, particularly in marine biota stock assessment (Kang, 2011). In Echoview, TS data is visualized as an echogram consisting of several pixels of different colors, depicting the backscatter strength of the target in decibels (dB). Next, all single catfish data were digitized, with each fish consisting of 160 pings. This data was then aligned and averaged to obtain the TS value. In the application of acoustic methods, target strength values have a linear relationship with the average fish length (Foote et al., 1987). Target strength calculations can be performed using the following equation:

$$\mathrm{TSi} = 10\log\frac{\mathrm{Ii}}{\mathrm{Ir}}$$

$$\mathrm{TSe} = 10\log\frac{\mathrm{Ei}}{\mathrm{Er}}$$

Where:

- Ii is the sound intensity level hitting the target object.
- Ir is the sound intensity level reflected back by the target object.
- TSe indicates the energy associated with the target strength.
- Ei is the amount of sound energy hitting the target object.
- Er is the sound energy reflected by the target and measured at a distance of 1 meter from the object.

RESULTS

Characteristics of Catfish (*Clarias batrachus*)

Catfish (*Clarias batrachus*) are characterized by their smooth, scaleless bodies, elongated bodies, and strong fins. This species is also known for its high adaptability to environments with low water quality and limited oxygen content.

According to Saanin (1984), catfish (*Clarias batrachus*) are classified as follows:

Kingdom: Animalia
Phylum: Chordata
Class: Actinopterygii
Order: Siluriformes
Family: Clariidae
Genus: Clarias
Species: *Clarias batrachus*

Physical Parameter Conditions of the Water Tank

Measurements were conducted in a cylindrical pool with a diameter of 6 meters and a depth of 3.2 meters. To ensure the stability and accuracy of the results, the physical parameters of the water were first checked. Observed parameters included temperature, salinity, and the speed of sound in the water.

Table 1. Physical Parameter Conditions of the Water Tank

Parameter	Value
Salinity	0
Temperature (°C)	25
Transducer depth (m)	0.5
Speed of sound (m/s)	1496.69
Distance of object to transducer (m) (TS)	0.7 – 1.0

Calibration with a Sphere

Before conducting fish measurements, the SIMRAD EK15 echosounder was calibrated using a sphere as an ideal reflection target. The sphere is isotropic, meaning it reflects acoustic waves evenly in all directions (Qomarudin, 2018). Calibration was performed at a depth of 1 meter from the transducer, and the recording results were displayed as an echogram (Figure 4).

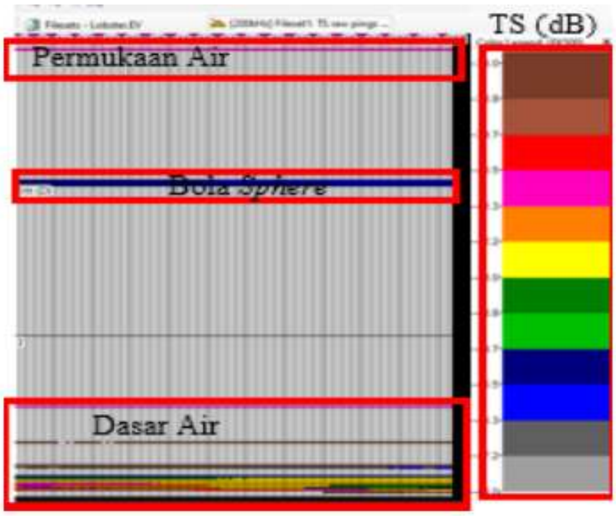

Figure 4. TS Values of the Sphere

The TS values of the sphere ranged from -44.22 dB to -46.96 dB, with a linear average of -45.36 dB. This value aligns with the manufacturer's TS standard of -45.00 dB for a 40 mm sphere (Solikin, 2015). Therefore, the calibration results were declared valid and used as a reference for TS correction in the study.

Table 2. Simrad EK 15 Echosounder Settings

Parameter	Value
Frequency (kHz)	200
Near field (m)	0.33
Sound speed (m/s)	1496
Pulse duration (ms)	0.080
Ping rate (ms)	1875
Temprature (°C)	25
Sphere (dB)	-45

Catfish Target Strength Measurement

An echogram is a recording containing a series of reflections or echoes produced by a target. This tool is used to visualize data obtained from an echosounder. In this study, the threshold value applied was in the range of -70 dB to -30 dB. An example of an echogram displaying the target strength of catfish can be seen in Figure 5.

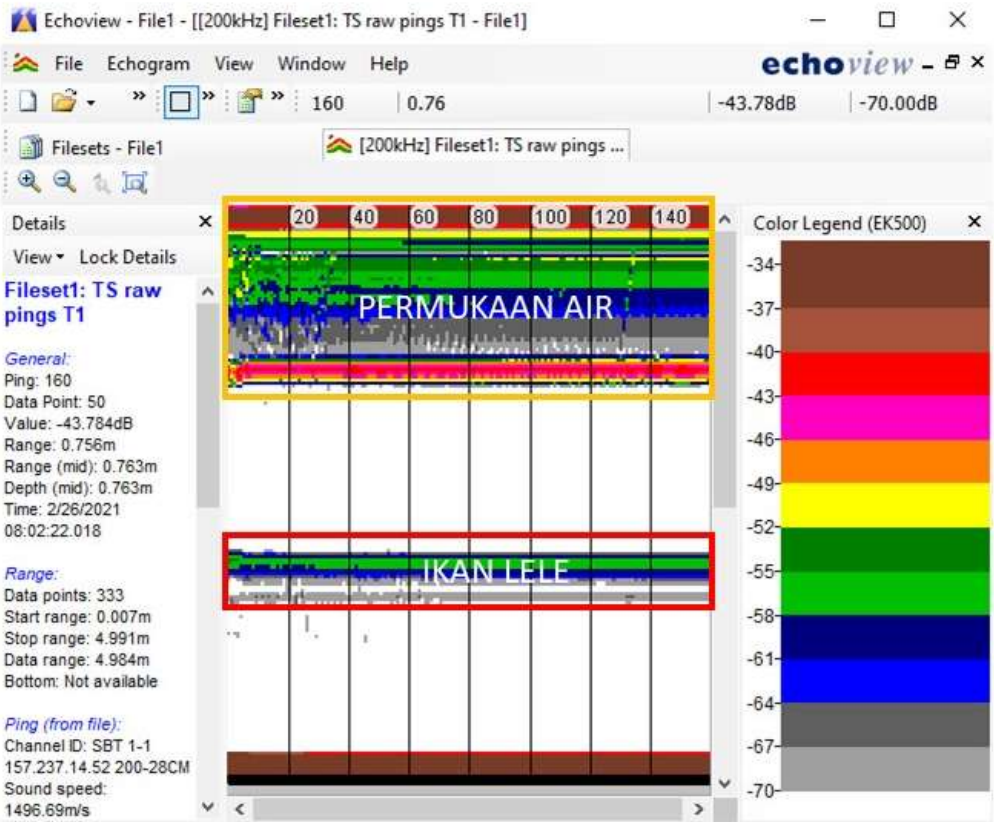

Figure 5. Echogram of Catfish

Data from the measurements of the length, weight, and target strength values of catfish are presented in Table 3. The table contains information on the weight, length, target strength values, and total data from 13 catfish samples. The catfish weighed between 4 and 37 grams, with lengths ranging from 8.1 cm to 19.3 cm. Meanwhile, the target strength values of catfish ranged from -64.81 dB to -59.89 dB.

Table 3. Catfish Sample Measurement Results

Catfish	Length (cm)	Weight (gr)	TS (dB)		TS Average (dB)
			Min	Max	
1	12.2	11	-62.13	-61.02	-61.48
2	17.9	30	-61.98	-58.67	-59.89
3	16.2	37	-61.72	-59.03	-60.88
4	16.4	24	-62.95	-60.37	-60.94
5	16	23	-63.38	-59.73	-61.04
6	10.5	6	-65.30	-61.97	-62.71
7	19.3	41	-61.02	-59.81	-60.37
8	19	37	-62.42	-59.64	-60.44
9	12	12	-64.98	-59.27	-61.42
10	15.9	21	-62.44	-60.02	-61.07
11	8.1	4	-66.93	-64.04	-64.81
12	10.2	7	-68.86	-60.25	-62.68
13	12.4	12	-67.79	-61.53	-63.59

Correlation between Catfish Length and Target Strength (TS) Value

A graph depicting the relationship between fish length and TS value can be seen in Figure 6. The points on the graph consist of x and y components, where the y value indicates TS in dB, while the x value indicates fish length in centimeters.

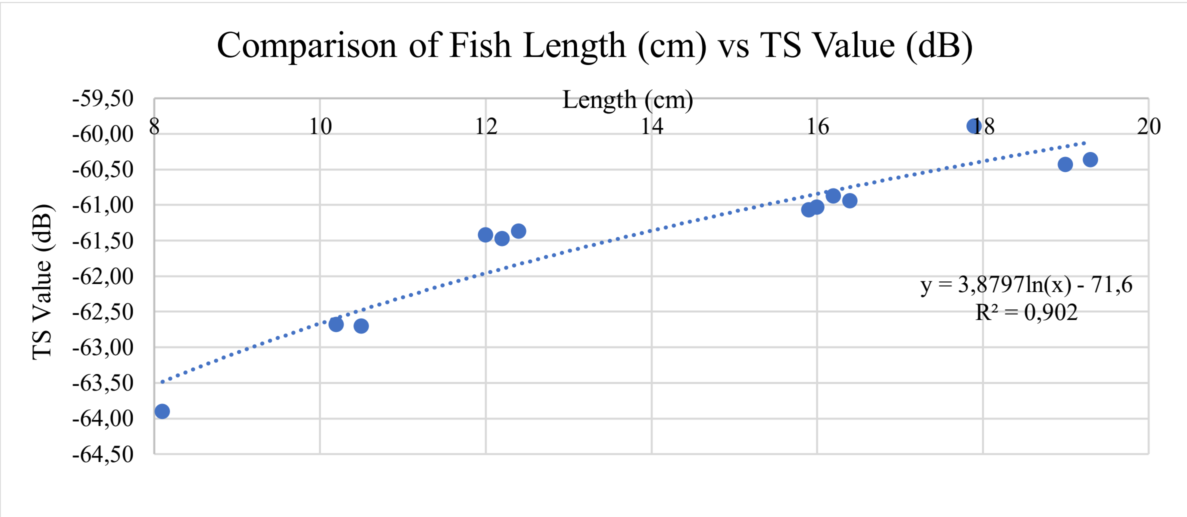

Figure 6. Graph of the Relationship between Catfish Length and TS Value

DISCUSSION

Correlation Analysis between Target Strength (TS) Values and Catfish Body Size

The results showed a strong positive correlation between Target Strength (TS) values and the length and weight of catfish (*Clarias batrachus*). TS values ranged from -64.81 dB to -59.89 dB, and showed an increasing pattern with increasing length and weight.

The coefficient of determination (R^2) between fish length and TS values was 0.902, and between fish weight and TS was 0.8746, indicating that 90% of the variation in TS values could be explained by body length, and 87% by body weight. This supports the findings of Foote (1987) and Frouzova et al. (2011), which stated that TS values are closely related to the geometric dimensions of fish, particularly body length.

In general, the larger the fish, the greater the acoustic cross-sectional area reflecting sound waves, resulting in higher TS values (closer to 0 dB). This relationship is logarithmic and is often used to model biomass estimation in natural waters using hydroacoustic approaches.

Special Challenges in Measuring TS in Catfish

The unique characteristics of catfish, such as their scaleless bodies and smooth skin, present unique challenges in measuring TS values. Unlike fish with scales, which have a more acoustically reflective body surface, catfish's body surface absorbs some sound waves, causing the reflection to be inhomogeneous.

Furthermore, the orientation of the fish's body relative to the direction of the incoming sound waves (incidence angle) also plays a significant role in influencing TS values. When the fish swims perpendicular to the transducer, the reflection tends to be stronger. However, if the fish is tilted or facing away from the sound source, the TS value can decrease drastically.

Other factors, such as the presence of the swim bladder, also affect the reflection results. According to Manik (2010), the swim bladder is the primary structure that reflects sound waves in the fish's body. In catfish, the relatively small and deep size and position of the swim bladder can result in lower TS values compared to other fish species with larger swim bladders closer to the body surface.

Data Validity and Reliability Through Calibration

Calibration is a crucial step in this research to ensure the accuracy of data obtained from the echosounder. The use of a sphere as an isotropic target in calibration ensures that the sound reflections received by the transducer truly originate from the target and are not from other interference.

The average TS value for the sphere was -45.36 dB, which is in line with the manufacturer's standard, which is approximately -45.00 dB for a 40 mm sphere (Solikin, 2015). Based on this calibration, all measured TS values for catfish were corrected and declared valid for further analysis.

Implications for Aquaculture Monitoring Technology

This research makes a significant contribution to the development of hydroacoustic technology in aquaculture. With specific TS value data for catfish, echosounders can be configured more precisely to non-invasively detect and estimate catfish populations.

This technology is highly beneficial in modern aquaculture because it:

- Minimizes stress on fish due to manual sampling.
- Enables real-time monitoring of fish growth and density.
- Saves labor and time compared to traditional methods such as routine weighing.
- Prevents overfeeding or underfeeding by providing more accurate biomass estimation data.

In the long term, this TS-based hydroacoustic system can be developed into an automated monitoring system in aquaculture ponds, integrated with environmental sensors and an automated feed control system. This aligns with the direction of aquaculture 4.0, or technology-based aquaculture.

Research Limitations and Consistency with Previous Research

This study makes an important contribution to the use of hydroacoustic technology to measure Target Strength (TS) values in catfish (*Clarias batrachus*). However, it still has several limitations that need to be considered to prevent overinterpretation of the results and to serve as a basis for further research.

One major limitation is the controlled laboratory environment (water tank). Although conditions such as temperature, salinity, and depth were stabilized, the results obtained may not fully represent natural conditions in aquaculture ponds or more dynamic open waters. Environmental factors such as water currents, lighting, and variations in fish behavior in natural ponds can significantly affect the accuracy of TS values.

Furthermore, the sample size used in this study was limited to 13 catfish of a specific size range. To develop a more comprehensive model of the TS relationship, further testing with a larger sample size and a wider variety of samples is necessary. The study also did not explicitly analyze the fish's body orientation during the measurements, even though the angle of sound waves can influence the acoustic reflection strength (TS).

Nevertheless, the results of this study align with and are consistent with several previous studies. As reported by Frouzova et al. (2011) and Sobradillo et al. (2019), there is a significant positive relationship between fish body size and TS values. This study also complements the findings of Hafidz (2018) and Manik (2010) regarding the influence of body structure and the presence of a swim bladder on fish acoustic responses.

Specifically, this study supports and strengthens the findings of Risandes et al. (2024) who studied the TS of snakehead fish and catfish (*Clarias gariepinus*). However, this study focused more on the species *Clarias batrachus* with an accurate calibration approach and strictly controlled physical parameters.

Therefore, despite several limitations, this study provides a strong scientific foundation for developing non-invasive catfish population estimation methods and expands the literature on the application of hydroacoustic technology in freshwater fish farming in Indonesia.

CONCLUSION

This study successfully measured the Target Strength (TS) value of catfish (*Clarias batrachus*) using hydroacoustic methods and SIMRAD EK15 instruments under controlled environmental conditions. The weight of the catfish used ranged from 4 grams to 37 grams, with a length between 8.1 cm and 19.3 cm. The TS values obtained were in the range of -64.81 dB to -59.89 dB. Correlation analysis showed a very strong positive relationship between the total length of the fish and the TS value, with a coefficient of determination (R^2) of 0.902, following the equation $y = 3.8797\ln(x) - 71.6$. The relationship between fish weight and TS value also showed a strong correlation with an R^2 of 0.8746 and the equation $y = 1.3583\ln(x) - 65.18$. These results indicate that larger fish produce stronger acoustic reflections. These findings provide a solid basis for the development of a catfish population survey method using hydroacoustic technology, which can be adapted for broader fish monitoring applications in natural waters.

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REFERENCES

Abinaya, N. S., Susan, D., & Sidharthan, R. K. (2022). Deep learning-based segmental analysis of fish for biomass estimation in an occulted environment. *Computers and Electronics in Agriculture, 197*, Article 106985. https://doi.org/10.1016/j.compag.2022.106985

Bakhtiar, D., Nadia, L., Zamdial, Z., & Anggoro, A. (2020). Pengukuran akustik target strength ikan selar bentong (*Selar boops*) secara terkontrol di perairan Pulau Tikus Kota Bengkulu. *Jurnal Enggano, 5*(2), 290–301. https://doi.org/10.31186/jenggano.5.2.290-301

Benoit-Bird, K. J., Au, W. W. L., Kiefer, D. A., & Ridgway, S. H. (2003). Acoustic backscattering by deepwater fish measured in situ from a manned submersible. *Deep-Sea Research Part I: Oceanographic Research Papers, 50*(2), 221–229.

Cochrane, K. L. (2002). *A fishery manager's guidebook: Management measures and their application* (Vol. 424). Food and Agriculture Organization.

Dawson, J. J., & Karp, W. A. (1990). In situ measures of target strength variability of individual fish. *Rapp. P.-V. Réun. Cons. Int. Explor. Mer, 189*, 264–273.

Dunning, J., Jansen, T., Fenwick, A. J., & Fernandes, P. G. (2023). A new in-situ method to estimate fish target strength reveals high variability in broadband measurements. *Fisheries Research, 261*, 106611. https://doi.org/10.1016/j.fishres.2023.106611

Fauziyah, N., Nirmala, K., Supriyono, E., & Hadiroseyani, Y. (2019). Evaluasi sistem budidaya lele: Aspek produksi dan strategi pengembangannya. *Jurnal Kebijakan Sosial Ekonomi Kelautan dan Perikanan, 9*(2), 129.

Foote, K. G. (1987). Fish target strengths for use in echo integrator surveys. *The Journal of the Acoustical Society of America, 82*(3), 981–987. https://doi.org/10.1121/1.395298

Frouzova, J., Kubecka, J., & Mrkvicka, T. (2011). Differences in acoustic target strength pattern between fish with one- and two-chambered swimbladder during rotation in the horizontal plane. *Fisheries Research, 109*(1), 114–118.

Godlewska, M., Wisniewolski, W., & Szyper, P. (2017). Acoustic estimation of fish biomass in freshwater lakes. *Hydrobiologia, 790*(1), 199–210.

Gunawan, Y., & Elven, T. M. A. (2020). Budidaya lele terpal sebagai alternatif peningkatan kesejahteraan buruh pabrik di Dukuh Rejosari. *Jurdimas (Jurnal Pengabdian kepada Masyarakat), 3*(2), 155–162. https://doi.org/10.33330/jurdimas.v3i2.664

Hafidz, M. (2018). *Pengukuran dan analisis hubungan TS-Frekuensi pada tongkol lisong (Auxis rochei) muda (FL: 16.4 cm) dengan frekuensi pita lebar 200–240 kHz* [Skripsi, Institut Pertanian Bogor].

Hamuna, B., Dimara, L., Pujiyati, S., & Natih, N. M. N. (2018). Hambur balik akustik permukaan substrat dasar perairan menggunakan echosounder bim tunggal. *Jurnal Kelautan, 11*(1), 31–37.

Islaminingdiah, F. N. (2017). *Perbandingan nilai target strength ikan bergelembung renang (tuna sirip kuning, Thunnus albacares) dan ikan tanpa gelembung renang (tongkol abu-abu, Thunnus tonggol)* [Skripsi, Institut Pertanian Bogor].

John, D. (2015). *Textile fibers and yarns: Properties and applications*. Textile Press.

Kang, M. (2011). Analysis of the ME70 multibeam echosounder data in Echoview – Current capability and future directions. *Journal of Marine Science and Technology, 19*(3), 312–321.

Lavery, A. C., Chu, D., & Moum, J. N. (2019). Acoustic observations of fish school distribution in aquaculture ponds. *Aquaculture, 512*, 73456.

MacLennan, D. N., & Simmonds, E. J. (1992). *Fisheries acoustics*. Chapman and Hall.

Manik, H. M. (2010). Measurement of acoustic reflection of tuna fish using echosounder instrument. *Ilmu Kelautan: Indonesian Journal of Marine Sciences, 14*(2), 84–88.

Negara, A., & Surya, N. B. (2017). Faktor-faktor yang mempengaruhi produksi budidaya ikan lele di Kota Denpasar. *Jurnal Ekonomi dan Bisnis Universitas Udayana, 6*(2), 755–788.

Priatna, A., & Wijopriono. (2011). Estimasi stok sumber daya ikan dengan metode hidroakustik di perairan Kabupaten Bengkalis. *Jurnal Penelitian Perikanan Indonesia, 17*(1), 1–10.

Qomarudin, Q., Pujiyati, S., & Hestirianoto, T. (2018). *Deteksi nilai hambur balik berbagai objek (bola sphere, keramba, dan dasar watertank) menggunakan instrumen single beam transducer* [Skripsi, Institut Pertanian Bogor].

Rani, S. V. J., Ioannou, I., Swetha, R., Lakshmi, R. M. D., & Vassiliou, V. (2024). A novel automated approach for fish biomass estimation in turbid environments through deep learning, object detection, and regression. *Ecological Informatics, 81*, 102663. https://doi.org/10.1016/j.ecoinf.2023.102663

Risandes, O., Brown, A., & Isnaniah, I. (2024). Perbandingan nilai target strength ikan gabus (*Channa striata*) dan ikan lele (*Clarias gariepinus*). *Jurnal Teknologi Perikanan dan Kelautan, 15*(2), 211–222. https://doi.org/10.24319/jtpk.15.211-222

Simmonds, E. J., & MacLennan, D. N. (2021). Advances in acoustic methods for fish biomass estimation. *Aquatic Living Resources, 33*, 23–29.

Simrad. (2025). *Simrad EK15 multi purpose scientific echo sounder*. https://www.simrad.online/ek15/sales/ek15_ds_en_a4.pdf

Sobradillo, B., Boyra, G., Martinez, U., Carrera, P., Peña, M., & Irigoien, X. (2019). Target strength and swimbladder morphology of Mueller's pearlside (*Maurolicus muelleri*). *Scientific Reports, 9*, 17311. https://doi.org/10.1038/s41598-019-53819-6

Suyanto, S. R. (2007). *Budidaya ikan lele*. Penebar Swadaya.

Wicaksono, A., & Susanto, I. D. W. (2014). Sistem otomasi penggerak kamera dengan motor step sebagai alat bantu kalibrasi alat ukur panjang. *Jurnal Otomasi dan Kontrol Institut, 6*(2), 105.

Zare, P., Kasatkina, S. M., Shibaev, S. V., & Fazli, H. (2017). In situ acoustic target strength of anchovy kilka (*Clupeonella engrauliformis*) in the Caspian Sea (Iran). *Fisheries Research, 186*, 311–318.