Egyptian Journal of Aquatic Biology & Fisheries
Zoology Department, Faculty of Science,
Ain Shams University, Cairo, Egypt.
ISSN 1110 – 6131
Vol. 29(2): 2013 – 2027 (2025)
www.ejabf.journals.ekb.eg

Measurement and Analysis of Acoustic Target Strength of *Lutjanus gibbus* and *Cephalopholis formosa* Using Two Pulse Durations

Syahrul Purnawan[1, 2], Henry M. Manik[3*], Totok Hestirianoto[3], Khairul Amri[4]

[1]Department of Marine Sciences, Universitas Syiah Kuala, Banda Aceh 23111, Indonesia
[2]Marine Technology Study Program, IPB University, Bogor 16680, Indonesia
[3]Department of Marine Science and Technology, IPB University, Bogor, 16680, Indonesia
[4]Research Center for Fisheries, National Research and Innovation Agency, Jakarta 14430, Indonesia

[*]Corresponding Author: henrymanik@apps.ipb.ic.id

ARTICLE INFO
Article History:
Received: Jan. 16, 2025
Accepted: March 8, 2025
Online: April 9, 2025

Keywords:
Length-weight,
Pulse duration,
SED,
Reef fish,
TL-TS

ABSTRACT

Accurate fisheries acoustic surveys depend on species-specific target strength (TS) references. However, there are limited TS references for tropical reef-associated species. This study established TS–total length (TL) relationships for two commercially demersal fishes in Indonesian waters: *Lutjanus gibbus* (Humpback red snapper) and *Cephalopholis formosa* (Bluelined grouper). Using a Simrad EK-15 single-beam echosounder (200 kHz), TS measurements were conducted under laboratory conditions at two pulse durations (0.08 and 0.16ms) to assess methodological impacts. Both species of *L. gibbus* (TL: 17.4–42.1cm) and *C. formosa* (TL: 22.6–31.4cm) exhibited negative allometric growth ($b < 3$), indicating that body mass increases more slowly than length. *L. gibbus* showed a significant TS and TL relationships: TS=20.26·log(TL)-68.71 for 0.08 ms (R^2=0.841) and TS=19.88·log(TL)-72.12 for 0.16 ms (R^2=0.787). In contrast, *C. formosa* exhibited no significant TS-TL relationship: TS=24.64·log(TL)-73.51 for 0.08 ms (R^2=0.370) and TS=24.65·log(TL)-77.65 for 0.16 ms (R^2=0.329). Within adjusted regression, longer pulse durations reduced mean TS values by 3.94 dB (*L. gibbus*) and 4.13 dB (*C. formosa*), underscoring the need for standardized protocols in shallow-water acoustics. While robust TS models for *L. gibbus* enhance biomass estimation accuracy, the weak TS-TL linkage in *C. formosa* highlights the influence of biological variability and limited size ranges. This work advances sustainable fisheries management by providing foundational TS data for understudied species and quantifying pulse duration effects critical to survey design.

INTRODUCTION

Hydroacoustic has emerged as a fundamental technique in fisheries science, facilitating non-invasive, high-resolution monitoring of aquatic ecosystems **(Manik, 2016)**. By leveraging the principles of acoustic wave propagation within the water column **(MacLennan & Simmonds, 2013)**, these techniques enable the assessment of fish distributions and biomass, particularly in environments where traditional survey methods are constrained by depth and turbidity challenges **(Manik *et al*., 2006; Purnawan *et al*., 2024)**. By providing real-time, fishing-effort-independent data, acoustic technologies have become indispensable for estimating fish biomass and informing sustainable management practices **(Hidayat *et al.*, 2019; Amri *et al.*, 2023)**.

A critical component of acoustic surveys is the availability target strength (TS) references. TS quantifies the acoustic energy reflected by individual fish and serves as the linchpin for converting echo signals into biomass estimates **(Foote, 1980, 1991)**. TS values are influenced by fish intrinsic variables, including fish length, species, morphology and orientation **(Fernandes *et al.*, 2016; O'Driscoll *et al.*, 2018)**. Fish length is the most significant predictor, especially when fish orientation can be controlled during the measurement **(Dunning *et al.*, 2023)**. In general, fish length plays a dominant role in determining TS and remains a key factor in acoustic assessments **(O'Driscoll *et al.*, 2018; Domokos, 2021)**.

Beyond intrinsic fish properties, the accuracy of TS measurements is also affected by survey parameters such as frequency and pulse duration (τ). TS is frequency-dependent, with different frequencies influencing backscatter intensity and target detection, thereby affecting survey precision **(Stanton *et al.*, 2010; Yan *et al.*, 2024)**. Similarly, τ governs target separation and echo formation, and it can potentially alter TS measurements. Shorter τ enhances range resolution but increases susceptibility to ambient noise, whereas longer τ can introduce measurement bias, particularly in dense fish aggregations, leading to over- or underestimation of biomass, which is a critical concern for fisheries management **(Ona & Mitson, 1996; Godlewska *et al.*, 2011)**.

Modern echosounders, such as the Simrad EK-15, utilize automated τ selection ("auto" mode) to adjust pulse duration and optimize operational flexibility dynamically. However, these adjustments involve inherent trade-offs: a short τ improves spatial resolution at the cost of greater noise sensitivity, whereas a long τ risks compromising TS accuracy in densely populated schools. Although **Kubecka (1995)** found minimal effects of τ variations on TS, this conclusion, based on earlier studies, may not fully capture the complexities observed in more recent research **(Godlewska *et al.*, 2011)**. Consequently, further investigation is needed to fully understand how τ adjustments influence TS measurements, especially in dynamic field conditions.

Another major challenge in hydroacoustic surveys is the limited availability of species-specific TS references for the diverse fish communities within a given water body. Extensive TS datasets exist for temperate fish species **(Frouzova *et al.*, 2005; Gastauer *et al.*, 2017; Lin *et al.*, 2020)**. Meanwhile the paucity of TS data for tropical reef-associated taxa, particularly within highly diverse ecosystems such as Southeast Asia, still poses a significant challenge for biomass estimation in coral reef habitats **(Zhang *et al*., 2013; Gastauer *et al*., 2016; Purnawan *et al*., 2023).**

This study aimed to address these methodological gaps by establishing TS–total length (TL) relationships for two ecologically and commercially significant demersal species in Indonesia: the humpback red snapper (*Lutjanus gibbus*) and bluelined grouper (*Cephalopholis formosa*). Both fish species are widespread in Indo-Pacific waters, living in shallow and coral waters. They are commonly caught by traditional fishers using bottom longlines and consumed by local communities **(Panggabean *et al.*, 2023)**. Additionally, this research quantifies the influence of τ (0.08 ms vs. 0.16 ms) on TS variability, providing an empirical evidence to inform standardization efforts in tropical fisheries acoustics. By refining species-specific TS parameters and evaluating the methodological implications of τ selection, this work contributes to the advancement of hydroacoustic survey techniques. It enhances the accuracy of biomass estimation in reef-associated fish populations.

MATERIALS AND METHODS

1. Fish samples

This study analyzed 28 *L. gibbus* and 9 *C. formosa* specimens (Fig. 1). Samples were collected from local fishers at two major fish landing sites in Aceh, i.e. Lampulo Ocean Fishing Port (PPS) and Alue Naga Beach. Lampulo PPS is a large-scale fishing port, while Alue Naga Beach is a traditional landing site. Generally, fishermen in Alue Naga conduct one-day fishing activities using bottom longline **(Susanti *et al.*, 2022)**. All fish samples were received dead and brought to the Marine Acoustic Laboratory, Universitas Syiah Kuala.

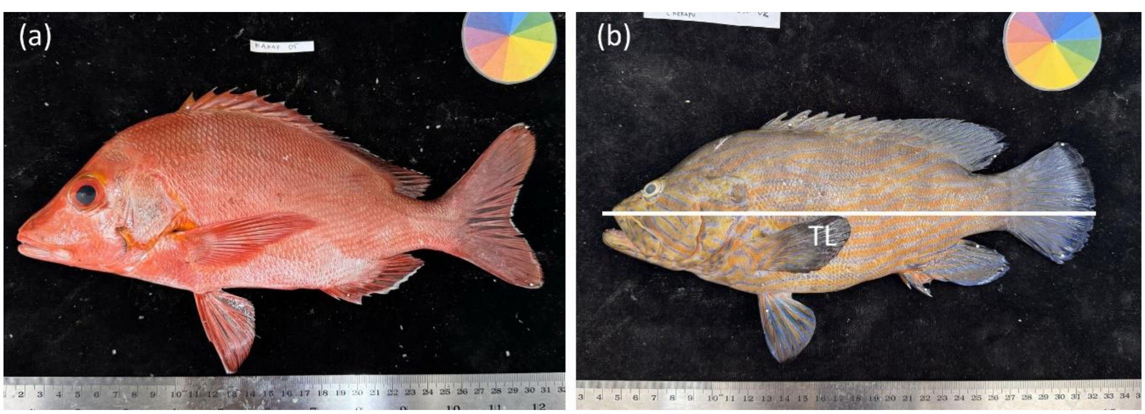

Fig. 1. Fish Samples: **(a)** *L. gibbus* (Humpback red snapper); **(b)** *C. formosa* (Blue-lined grouper)

Species identification was based on morphological traits referenced in established taxonomic guides **(Allen, 1985; Heemstra & Randall, 1993; White *et al.*, 2013)**. Before examination, samples underwent visual inspection to exclude individuals with physical damage that could bias morphometric measurements. TL (cm) was measured from the snout tip to the caudal fin's posterior margin (Fig. 2), and body mass (g) was also recorded. These parameters are essential for assessing growth dynamics via length-weight relationships (LWRs). LWR data for *L. gibbus* are available from some studies **(Prihatiningsih *et al.*, 2020; Panggabean *et al.*, 2023)**, however no scientific records exist for *C. formosa*. LWR was calculated using equation (1).

$$W = a \cdot TL^b \quad (1)$$

Where, W – wet weight of sample (g), TL – total length (cm), a – constant, b – growth exponent. Based on the value of b the growth factor can be determined based on:

b > 3: positive allometric,
b < 3: negative allometric,
b = 3: Isometric.

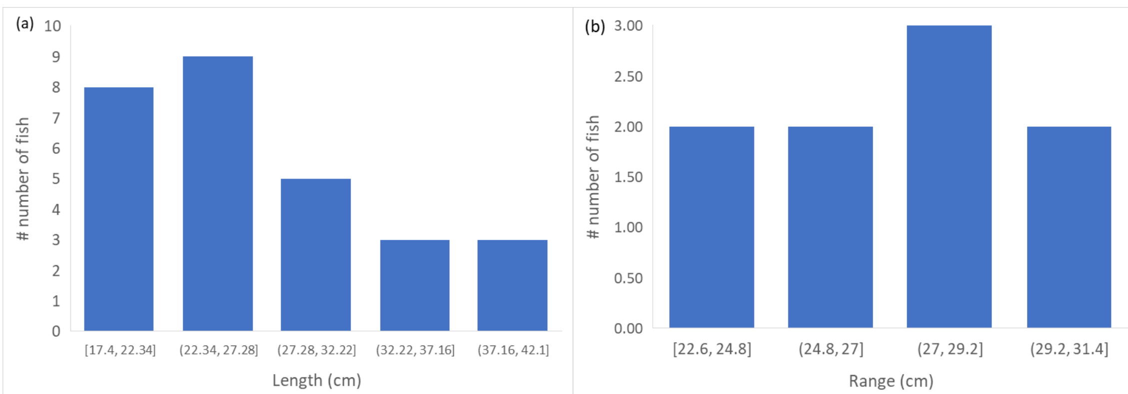

Fig. 2. Length distribution of fish samples: **(a)** *L. gibbus*, **(b)** *C. Formosa*

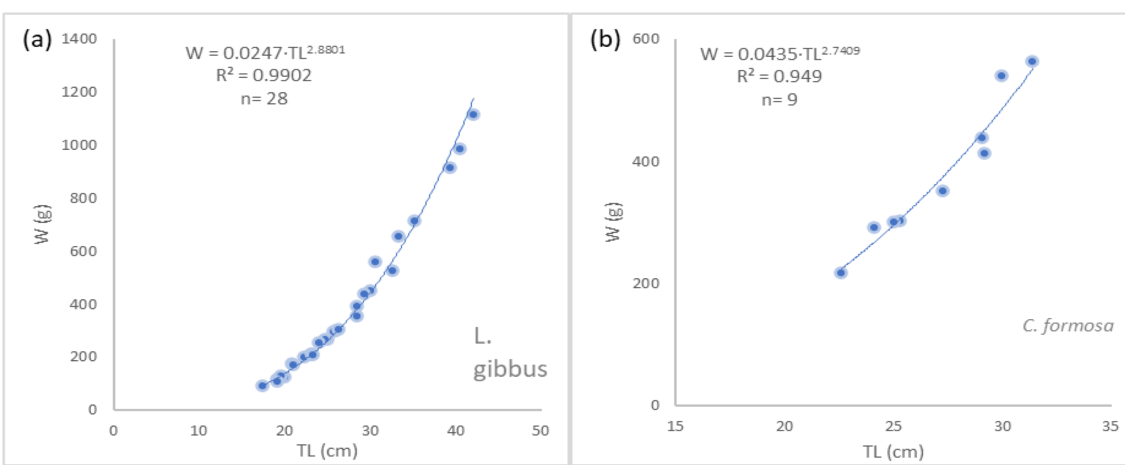

Fig. 3. LWR of fish: **(a)** *L. gibbus*; **(b)** *C. formosa*

Regression analysis showed that the LWR in *L. gibbus* followed the equation $W=0.0247 \cdot TL^{2.8801}$ with a coefficient of determination (R^2) of 0.990 and a sample size of

28 individuals. Meanwhile, in *C. formosa*, the LWR followed the equation $W=0.0435 \cdot TL^{2.7409}$ with R^2 of 0.949 based on 9 samples (Fig. 3). The growth exponent values (b< 3) in both species indicate a negative allometric growth pattern, where the increase in body mass is slower than the increase in body length **(Jisr *et al.*, 2018)**. The high coefficients of determination in both models confirmed that these regressions could describe the LWR well.

2. TS Measurement

Measurements were conducted in an acoustic water tank with a diameter of 3m and a depth of 3m (Fig. 4). These dimensions provided sufficient space for fish TS measurements using the tethering method. The head and tail of the fish were tied using 0.32mm diameter nylon strings to mimic the natural orientation of the fish and to ensure that the acoustic pulse hit the dorsal portion of the fish. A lead weight was attached to the ventral side of the fish, about 30cm apart, so that the echo of the fish and the weight could be distinguished during analysis.

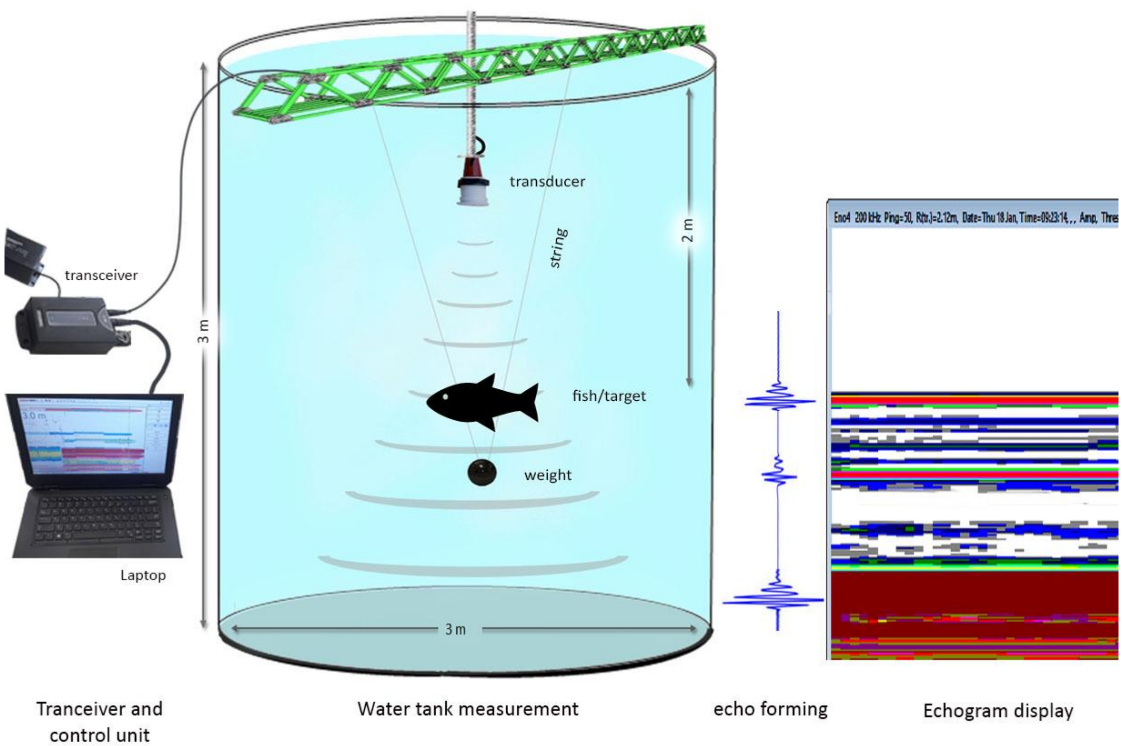

Fig. 4. Setup for TS measurement of fish tied up in a water tank. The system consists of a control unit, a transceiver, and a transducer that emits sound pulses. The target fish is tied using strings and weighted. Echoes from the fish, the weight and the bottom of the tank can be separated in the echogram

A Simrad EK-15 single-beam echosounder (frequency 200 kHz) was used for TS measurement of the sampled fish (Table 1). TS is defined as the logarithmic ratio of the intensity of acoustic waves reflected by the target (I_r, reflected intensity) to the intensity of acoustic waves incident on the target (I_i, incident intensity) **(MacLennan & Simmonds, 2013)**. The TS value was calculated using Equation (2).

$$TS = 10 \log I_r/I_i \tag{2}$$

The transducer was placed about 0.2m below the water surface and operated vertically. The target fish was placed about 2m from the water surface to ensure that the fish was outside the near-field region (eq. 3) and parallel to the main axis of the acoustic beam. Based on the equation, a near-field value of 0.32m (frequency 200 kHz, diameter 0.05m) was obtained. In addition, the distance between the fish and the bottom of the tank was kept at about 80cm to ensure clear separation and avoid reverberation effects from the bottom of the tank.

$$r = \frac{L^2}{\lambda} \tag{3}$$

Table 1. Parameters used in acoustic acquisition

System parameter	Detail
SIMRAD EK15 single-beam echosounder	
Transducer type	Single beam
Operating Frequency	200 kHz
Output power	45 Watt
Ping rate	2 ping/s
Pulse duration	0.08 & 0.16 ms
Beam width	26^{o}
Depth	2 m
Transducer gain	14.2 dB
Sonar5-Pro post-processing software	
Minimum target size	-70 dB
Minimum Echo Length	0.5
Maximum Echo Length	1.8
Maximum Allowable Detection Threshold	0.2

Before taking TS measurements, the transducer was initially calibrated using a 38mm tungsten sphere within τ 0.08ms, following the standard sphere calibration methodology **(Simmonds & Maclennan, 2007)**. The average TS measured from the standard sphere was consistent with the theoretical value. Furthermore, the minimum detection threshold was set to -70 dB per 1m² to eliminate background noise during TS measurements. Pulse durations of 0.08 and 0.16ms were chosen as they are appropriate for shallow marine environments where target fish naturally reside **(Kerdgari *et al.*, 2009)**.

Data were recorded at a ping rate of 2 pings/s for approximately 1min per fish per pulse duration, yielding around 120 ping data per treatment. Data recorded for one minute tend to produce homogeneous values due to the controlled conditions under which the fish were measured.

3. Data analysis

The files recorded by the Simrad EK-15 are saved in raw format by default and are then converted using a dongle for post-processing using Sonar5-Pro software. The Sonar5-Pro software was used to calculate TS values that were calculated based on single echo detection (SED) **(Balk & Lindem, 2019)**. Echo integration was done carefully to ensure that echoes from ballast were not included in the echo integration.

A total of 50 ping samples from each fish sample at each τ were analyzed to integrate and generate an average TS value. The average TS value was obtained by averaging the linear target strength values in the integration cell, by first converting the TS value into a backscatter cross-section ($\sigma bs=10^{(TS/10)}$) **(Foote, 1980)**. The calculation of TS with backscattering cross section σ in fish is expressed in the form of equation (4).

$$TS = 10 \log \sigma_{bs}/4\pi \qquad (4)$$

Where, sigma σ_{bs} is the backscatter cross-section of the fish. The value of σ_{bs} itself can be described as a quadratic function of fish length, which follows equation (5).

$$\sigma_{bs} = a\ TL^2 \qquad (5)$$

By combining equations (4) and (5), we obtained equation (6).

$$TS = a_{ts}\ log_{10}(TL, cm) + b_{ts} \qquad (6)$$

This analysis used two linear model fittings **(Boswell *et al.*, 2008)**. The second variant of the equation has a fixed slope of 20, as proposed by **Foote (1987)**. In this process, the constant value of b_{ts} is then changed to b_{20} (eq. 7).

$$TS = 20\ log_{10}(TL, cm) + b_{20} \qquad (7)$$

Where, a_{ts} is the slope (with 20 as the standard slope), and b_{ts} and b_{20} are the intercepts.

RESULTS AND DISCUSSION

1. TL-TS relationship

1.1. *Lutjanus gibbus*

The results of regression analysis using the ordinary least squares method showed a significant relationship between total length (TL) and the TS value obtained (Fig. 5). The relationship between TL and TS was expressed in the regression equation: TS=20.26·log(TL)-68.71 at τ =0.08 ms (R^2=0.841; *P*-value < 0.05). Meanwhile, at τ=0.16ms, the regression equation obtained was: TS=19.88·log(TL)-72.12 (R^2=0.787; *P*-value < 0.05). The regression model was standardized to 20·log(TL) form and resulted in TS=20·log(TL)68.35 for 0.08 ms pulse: (R^2=0.8406), and TS=20·log(TL)-72.28 for 0.16 ms pulse: (R^2= 0.7865).

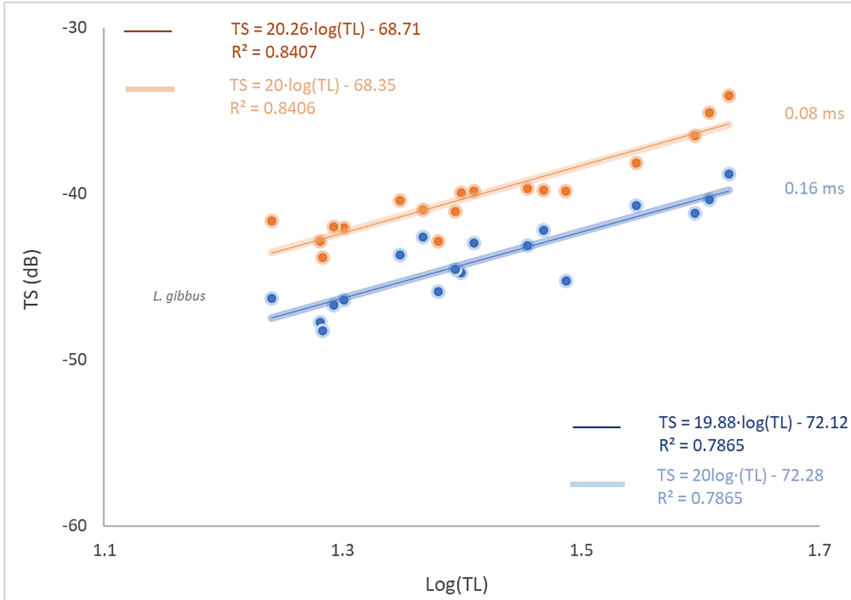

Fig. 5. TL-TS relationship for *L. gibbus*. The thin solid line shows the standard regression while the standardization regression is shown with the thick transparent line

These results show a significant relationship between fish total length and TS values with the coefficient of determination (R^2) indicating a robust model. The standardized model allows for a more systematic comparison between species, although it slightly reduces the R^2 value obtained. Overall, these results confirm that body length strongly predicts TS values in *L. gibbus*, with differences in acoustic pulse duration having a significant effect.

1.2. Cephalopholis formosa

TS measurements in *C. formosa* were performed using the same two pulse durations, 0.08 and 0.16ms (Fig. 6). At a pulse duration of 0.08ms, the relationship between TL and TS was expressed in a regression equation: TS=24.64·log(TL)-73.51 (R^2=0.370; *P*-value > 0.05). While at a pulse duration of 0.16ms, the regression equation obtained was: TS=24.65·log(TL)-77.65 (R^2=0.329; *P*-value > 0.05). After standardizing the model into the form TS=20·log(TL)-b20, it resulted in: TS=20·log(TL)-66.87 (R^2=0.3566) for 0.08ms pulse, while 0.16ms pulse resulted in TS=20·log(TL)-71.00 (R^2=0.3171).

The relationship between total fish length and TS values in *C. formosa* was not significant (*P*-value > 0.05), with a fairly low R^2 value indicating a weak model. This indicates that factors other than body length accounted for the variation in TS values, which is expected from the altered condition of the swim bladder in dead fish. The narrower length range of the *C. formosa* samples (22.6 to 32.8cm) may have influenced this. Standardization to 20·log(TL) also resulted in a weak model.

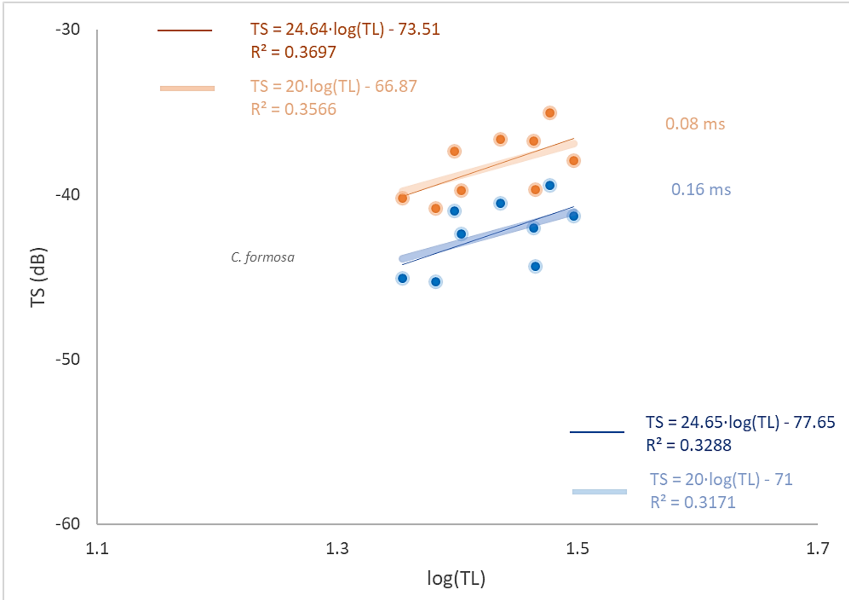

Fig. 6. TL-TS relationship for *C. formosa*. The thin solid line shows the standard regression while the standardization regression is shown with the thick transparent line

2. Variation of TS value

TS values are influenced by a variety of complex factors **(Domokos, 2021)**, but this study shows that fish size influences TS values, although the R^2 value is not high in *C. formosa*. Biological factors, such as physiological condition, gonadal development and differences in body mass, also contribute to variations in TS values. The condition of fish samples measured in the dead state can also contribute, especially to the varying state of the swimbladder **(Stanton *et al.*, 2010)**. The swimbladder is the dominant sound reflector in the fish's body **(Henderson & Horne, 2007)**. Other factors, including the limited number of samples and the narrower body length range, especially for *C. formosa*, need further attention compared to *L. gibbus*, which has a wider range.

Using two pulse durations in this study provided a significant difference (P-value < 0.05) with a mean difference of 3.94 dB ± 1.09 dB for *L. gibbus* and 4.13 ± 0.83 dB for *C. formosa*. These results differ from the study of **Kubecka (1995)**, who reported no significant difference in pulse length variation on TS values. The difference obtained from this study is most likely due to the acoustic energy distribution of the echo signal. Acoustic pulses that have a longer duration have greater total energy but are spread evenly along the pulse, so that the peak intensity of long pulses is lower than that of short pulses (Fig. 7). This causes the measured TS value to be smaller in the long pulse compared to the short pulse, which has a higher peak intensity. In addition, the internal structure of the fish, such as the swimbladder, may respond differently to the pulse duration. It is suspected that long pulses provide averaging over the entire body of the fish, while short pulses can be more sensitive to interference generated by the swimbladder. This high sensitivity allows short pulses to obtain a specific peak intensity from the swimbladder organ resulting in higher TS values **(Ye, 1996)**.

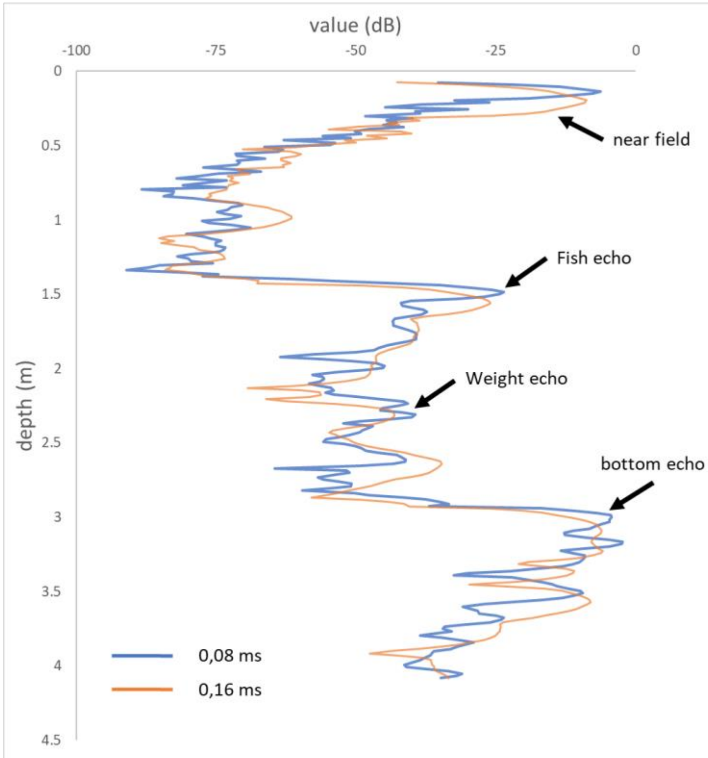

Fig. 7. Single echo of pulse duration 0.08 and 0.16ms. Reflections from fish, weight, bottom tank, and near-field can be identified

3. Implications for fisheries acoustic

Estimating fish biomass in marine environments relies heavily on TS as a scaling factor. The observed differences in TS values, specifically 3.94 and 4.13 dB, significantly impact biomass calculations. Therefore, the selection of pulse duration is crucial during acoustic surveys.

Measurements using shorter pulses yielded higher R^2 values for both fish species, indicating that shorter pulses provide higher spatial resolution and more precise acquisition of acoustic reflection details. However, shorter pulses are more susceptible to acoustic noise, particularly in natural marine habitats. Conversely, longer pulses offer greater stability against noise and are better suited for deeper water measurements, although they compromise resolution **(Ona & Mitson, 1996)**. Thus, the choice of pulse duration in field acoustic studies should consider the specific acoustic environment and the characteristics of the target species.

These findings have significant implications for fisheries management, particularly in the use of acoustics. Accurate TS data are essential for estimating fish biomass, mapping species distribution, and conserving fish stocks. It is important to note that these results were obtained from laboratory experiments conducted in a controlled environment at a distance of 2 meters from the transducer, which may differ slightly under actual field conditions **(Rodríguez-Sánchez *et al.*, 2016)**.

Field applications may require additional calibration to account for fish behavior and the complexity of aquatic ecosystems **(Henderson & Horne, 2007)**. Future studies could enhance the accuracy of TS measurements and validate the regression models by considering a larger sample size, a broader range of fish lengths, and measurements closer to natural habitat conditions. Further research into biological factors, such as gonad development, swimbladder condition, fish posture, and natural behavior, could deepen our understanding of the TL-TS relationship dynamics and its application in fisheries acoustics.

CONCLUSION

Both *L. gibbus* and *C. formosa*, showed a negative allometric growth pattern, with LWR: *L. gibbus* (W=0.0247·TL2.8801, R^2=0.99) and *C. formosa* (W=0.0435·TL2.7409, R^2=0.949). TL-TS analysis showed significant relationships in *L. gibbus* ($P<0.05$) for pulses of 0.08 and 0.16ms, while *C. formosa* was not significant ($P>0.05$). Regression normalization in *L. gibbus* resulted in TS=20·log(TL)-68.35 (R^2=0.8406) and TS=20·log(TL)-72.28 (R^2=0.7865). The difference in TS between pulse durations was found to be 3.94 dB (*L. gibbus*) and 4.13 dB (*C. formosa*), which might affect biomass estimation in acoustic fisheries. These findings emphasize the importance of pulse duration selection in improving the accuracy of TS measurements, with recommendations for further research in the field.

Further research should expand the range of sample lengths to include a representative length distribution of fish in the population. The R^2 value in this study emphasizes the need to take measurements and to consider biological factors such as gonad development and swimbladder.

ACKNOWLDGMENT

We thank Dr. Ir. Ichsan Setiawan, Head of the USK Marine Acoustics and Instrumentation Laboratory, for his support. We also express our gratitude to Muchlis, Muntazir, Agung Prasetiawan, Win Alfi, Siddiq Husaini, Said Faaris, and Aqil Hawari for their significant contributions to this research. This study was supported by LPDP.

REFERENCES

Allen, G.R. (1985). FAO species catalogue, Vol. 6. Snappers of the world: An annotated and illustrated catalogue of Lutjanidae species known to date. FAO Fisheries Synopsis No. 125, Rome.

Amri, K.; Priatna, A.; Ma'mun, A.; Setyadji, B.; Tirtadanu, S.; Suman, A.; Susanto, R.D.; Gaol, J.L.; Nababan, B.; Muchlizar; Pranowo, W.S. and Efizon, D. (2023). Evidence of spawning migration of protandrous longtail shad (Tenualosa macrura) in the Siak River estuarine, Indonesia. Ocean & Coastal Management, 231: 106384. DOI:10.1016/J.OCECOAMAN.2022.106384.

Balk, H. and Lindem, T. (2019). Sonar4 and Sonar5-Pro post processing systems operator manual version 605.8. CageEye A/S: Lindem Data Acquisition.

Boswell, K.M.; Kaller, M.D.; Cowan, J.H. and Wilson, C.A. (2008). Evaluation of target strength-fish length equation choices for estimating estuarine fish biomass. Hydrobiologia, 610(1): 113–123. DOI:10.1007/s10750-008-9425-x.

Domokos, R. (2021). On the development of acoustic descriptors for semi-demersal fish identification to support monitoring stocks. ICES Journal of Marine Science, 78(3): 1117–1130. DOI:10.1093/icesjms/fsaa232.

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

Fernandes, P.G.; Copland, P.; Garcia, R.; Nicosevici, T. and Scoulding, B. (2016). Additional evidence for fisheries acoustics: small cameras and angling gear provide tilt angle distributions and other relevant data for mackerel surveys. ICES Journal of Marine Science, 73(8): 2009–2019. DOI:10.1093/icesjms/fsw091.

Foote, K.G. (1980). Averaging of fish target strength functions. Journal of the Acoustical Society of America, 67(2): 504–515. DOI:10.1121/1.383915.

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

Foote, K.G. (1991). Summary of methods for determining fish target strength at ultrasonic frequencies. ICES Journal of Marine Science, 48(2): 211–217. DOI:10.1093/icesjms/48.2.211.

Frouzova, J.; Kubecka, J.; Balk, H. and Frouz, J. (2005). Target strength of some European fish species and its dependence on fish body parameters. Fisheries Research, 75(1): 86–96. DOI:10.1016/j.fishres.2005.04.011.

Gastauer, S.; Scoulding, B.; Fässler, S.M.M.; Benden, D.P.L.D. and Parsons, M. (2016). Target strength estimates of red emperor (Lutjanus sebae) with Bayesian parameter calibration. Aquatic Living Resources, 29(3): 301. DOI:10.1051/alr/2016024.

Gastauer, S.; Scoulding, B. and Parsons, M. (2017). Towards acoustic monitoring of a mixed demersal fishery based on commercial data: the case of the Northern Demersal Scalefish Fishery (Western Australia). Fisheries Research, 195: 91–104. DOI:10.1016/j.fishres.2017.07.008.

Godlewska, M.; Colon, M.; Jóźwik, A. and Guillard, J. (2011). How pulse lengths impact fish stock estimations during hydroacoustic measurements at 70 kHz. Aquatic Living Resources, 24(1): 71–78. DOI:10.1051/alr/2011104.

Heemstra, P.C. and Randall, J.E. (1993). FAO species catalogue, Vol. 16. Groupers of the world (Family Serranidae, Subfamily Epinephelinae). FAO Fish Synopsis No. 125(16), FAO, Rome.

Henderson, M.J. and Horne, J.K. (2007). Comparison of in situ, ex situ, and backscatter model estimates of Pacific hake (Merluccius productus) target strength. Canadian Journal of Fisheries and Aquatic Sciences, 64(12): 1781–1794. DOI:10.1139/f07-134.

Hidayat, E.F.; Pujiyati, S.; Suman, A. and Hestirianoto, T. (2019). Estimating potential zones of pelagic fish in WPPNRI 711 (study case of Natuna Sea). Journal of Natural Resources and Environmental Management, 9(1): 92–96. DOI:10.29244/jpsl.9.1.92-96.

Jisr, N.; Younes, G.; Sukhn, C. and El-Dakdouki, M.H. (2018). Length-weight relationships and relative condition factor of fish inhabiting the marine area of the Eastern Mediterranean city, Tripoli-Lebanon. Egyptian Journal of Aquatic Research, 44(4): 299–305. DOI:10.1016/j.ejar.2018.11.004.

Kerdgari, M.; Valinassab, T.; Jamili, S.; Fatemi, M.R. and Kaymaram, F. (2009). Reproductive biology of the Japanese threadfin bream, Nemipterus japonicus, in the Northern of Persian Gulf. Journal of Fisheries and Aquatic Science, 4(3): 143–149.

Kubecka, J. (1995). Effect of pulse duration and frequency bandwidth on fish target strength and echo shape in horizontal sonar applications. In: "XII Symposium on Hydroacoustics," Polish Naval Military Academy, Jurata, pp. 187–174.

Lin, P.; Chen, L.; Gao, X.; Wang, C.; Gao, X. and Kang, M. (2020). Spatiotemporal distribution and species composition of fish assemblages in the transitional zone of the Three Gorges Reservoir, China. Water, 12(12): 3514. DOI:10.3390/w12123514.

MacLennan, D.N. and Simmonds, E.J. (2013). Fisheries acoustics, Vol. 5. Springer Science & Business Media.

Manik, H. (2016). Acoustical measurement and Biot model for coral reef detection and quantification. Advances in Acoustics and Vibration, 2016. DOI:10.1155/2016/2350615.

Manik, H.; Furusawa, M. and Amakasu, K. (2006). Measurement of sea bottom surface backscattering strength by quantitative echo sounder. Fisheries Science, 72(3): 503–512. DOI:10.1111/j.1444-2906.2006.01178.x.

O'Driscoll, R.L.; Canese, S.; Ladroit, Y.; Parker, S.J.; Ghigliotti, L.; Mormede, S. and Vacchi, M. (2018). First in situ estimates of acoustic target strength of Antarctic toothfish (*Dissostichus mawsoni*). Fisheries Research, 206: 79–84. DOI:10.1016/j.fishres.2018.05.008.

Ona, E. and Mitson, R.B. (1996). Acoustic sampling and signal processing near the seabed: the dead zone revisited. ICES Journal of Marine Science, 53(4): 677–690. DOI:10.1006/jmsc.1996.0087.

Panggabean, A.S.; Prihatiningsih, T.; Taufik, M.; Nurdin, E.; Mahulette, R.T.; Nurulluddin; Chodrijah, U. and Pane, A.R. (2023). The stock status of Lutjanus gibbus (Forsskal, 1775) in Kupang waters, East Nusa Tenggara. E3S Web of Conferences, 442: 01001. DOI:10.1051/e3sconf/202344201001.

Prihatiningsih, P.; Kamal, M.M.; Kurnia, R. and Suman, A. (2020). The spawning season, growth, and mortality of humpback red snapper (Lutjanus gibbus (Forsskal, 1775)) in the Southern Banten waters, Indonesia. AACL Bioflux, 13(2): 1079–1089.

Purnawan, S.; Karina, S.; Kang, M. and Manik, H. (2023). Fish stock status assessment in Alue Naga waters using a 200 kHz single beam echosounder. ILMU KELAUTAN: Indonesian Journal of Marine Sciences, 28(1): 57–68. DOI:10.14710/ik.ijms.28.1.57-68.

Purnawan, S.; Manik, H.M.; Manik, A.S.; Elson, L. and Kang, M. (2024). Acoustic detection and quantification of fish in Lancang waters of Seribu Islands, Indonesia. ILMU KELAUTAN: Indonesian Journal of Marine Sciences, 29(2): 181–190. DOI:10.14710/ik.ijms.29.2.181-190.

Rodríguez-Sánchez, V.; Encina-Encina, L.; Rodríguez-Ruiz, A. and Sánchez-Carmona, R. (2016). Do close range measurements affect the target strength (TS) of fish in horizontal beaming hydroacoustics? Fisheries Research, 173: 4–10. DOI:10.1016/j.fishres.2015.03.020.

Simmonds, J.E. and Maclennan, D.N. (2007). Fisheries acoustics: Theory and practice: Second edition. Fisheries Acoustics: Theory and Practice. DOI:10.1002/9780470995303.

Stanton, T.K.; Chu, D.; Jech, J.M. and Irish, J.D. (2010). New broadband methods for resonance classification and high-resolution imagery of fish with swimbladders using a modified commercial broadband echosounder. ICES Journal of Marine Science, 67(2): 365–378. DOI:10.1093/icesjms/fsp262.

Susanti, E.; Mujiburrahmad, M. and Sahlida, A. (2022). Strategi adaptasi nelayan di Desa Alue Naga dalam menghadapi dampak perubahan iklim. SEPA: Jurnal Sosial Ekonomi Pertanian dan Agribisnis, 18: 125. DOI:10.20961/sepa.v18i2.46140.

White, W.; Last, P.; Dharmadi, D.; Faizah, R.; Chodrijah, U.; Iskandar, B.; Pogonoski, J. and Blaber, S. (2013). Market fishes of Indonesia. ACIAR.

Yan, N.; Mukai, T.; Hasegawa, K.; Yamamoto, J. and Fukuda, Y. (2024). Broadband target strength of arabesque greenling, Pacific sand lance, and pointhead flounder. ICES Journal of Marine Science, 81(1): 195–203. DOI:10.1093/icesjms/fsad195.

Ye, Z. (1996). Acoustic scattering from fish swimbladders. Journal of the Acoustical Society of America, 99(2): 785–792. DOI:10.1121/1.414656.

Zhang, J.; Chen, P.-M.; Chen, G.-B.; Fang, L.-C. and Tang, Y. (2013). Acoustic target strength measurement of banded grouper [Epinephelus awoara (Temming & Schlegel, 1842)] and threadsail filefish [Stephanolepis cirrhifer (Temming & Schlegel, 1850)] in the South China Sea. Journal of Applied Ichthyology, 29(6): 1453–1455. DOI:10.1111/jai.12361.