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Evaluating Target Strength of Puerulus Phase Scalloped and Ornate Spiny Lobsters Through *Ex Situ* Measurement and SDWBA Model

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ABSTRACT

Stock assessments using acoustic surveys face the challenge of improving measurement accuracy due to several bias factors such as high species diversity, body shape, and size. The target strength (TS) value reflects the object size (Total length (TL)). The size value was used to convert the weight of the object. Stock assessment of an object was obtained by multiplying the abundance of the object by its weight. TS measurements were performed on the individual of each species object and various sizes. Numerical data analysis using the best-fit linear regression technique was used to determine the relationship between total length and TS. There has been no research undertaken on the TS of *Puerulus.* The *ex situ* target strength of two *Puerulus* species, the scalloped spiny lobster (*Panulirus homarus*) and the ornate spiny lobster (*Panulirus ornatus*), has been successfully measured. The results indicated that the fit length-TS relationship for the scalloped spiny lobster with a total length (TL) of 18-21mm was $TS_{200kHz} = -137.595 + 61.75\log_{10}$ (TL) ($R^2 = 0.98$) and for the ornate spiny lobster was $TS_{200kHz} = -104.96 + 36.54\log_{10}$ (TL) ($R^2 = 0.95$). The use of the Stochastic Distorted Wave Born Approximation (SDWBA) Model to see the backscatter value on each body part shows that the straight body shape has a different backscatter value, especially on the cephalothorax. A comparison was made of the measured TS values *in situ* with the SDWBA model in the frequency range 160-240 kHz against the total length at the same frequency of 200 kHz. The results obtained from this comparison show almost the same TS value against the total length. These validated that the TS-length relationships can reduce bias in acoustic measurements by providing improved modeled TS estimates for the spiny lobster puerulus.

INTRODUCTION

The spiny lobsters are one of the class members of crustaceans that are considered excellent seafood and have a high economic value in their area of distribution, such as

Southeast Asia **(Chan, 1998)**. The hatched eggs of the spiny lobsters undergo a series of changes in shape (stages), starting from phyllosoma (larva stage), puerulus (post-larva stage), juvenile (young), and adult lobster. Puerulus of *P. ornatus* and *P. homarus* need about 4 to 7 months from hatching **(Chan, 1998; Dennis *et al*., 2001)**. In Indonesian seas, seven species of spiny lobster exist **(Kembaren *et al.,* 2021)**, with two species, *P. homarus* and *P. ornatus*, being captured at both the adult and puerulus stages for export and mariculture growth-out.

Regarding the exploitation of this organism, there are some regulations that have been issued by the Indonesian government. The current regulation is only allowing seed capture for domestic cultivation activities (Ministerial Regulation Number 16 of 2022), which previously also allowed for export commodities. Therefore, it's necessary to have management measures and regulations to accommodate the conservation and economic aspects of these species. Good fisheries management must control total catches in conjunction with the total of stocks that can be exploited.

Hydroacoustic technology can be used to estimate the stock of this resource in terms of its abundance, which is necessary to construct a sustainable lobster fishery **(Simmonds & MacLennan, 2005)**. Over the past ten years, there has been a significant increase in the utilization of echo sounders and echo integrators for fishing resource exploitation **(Lee & Shin, 1995; Yoon & Ha, 1998; Kim *et al.*, 2018)**. The accuracy of this technique is sufficient to be used in measuring the number of present aquatic life **(Benoit-Bird & Au, 2001)**. Active acoustic surveys provide an attractive alternative sampling method with fine-scale information on krill abundance and distribution over large geographic areas and extended time periods **(Simmonds & MacLennan, 2005; Reiss *et al*., 2008)**. Target strength (Ts) is crucial for converting volume backscattering strength into absolute biomass in order to acquire reliable acoustic assessments of stocks **(Simmonds & MacLennan, 2005; La *et al.*, 2014)**.

Several factors may impact the Ts value, such as transmitted acoustic frequency (f), body orientation relative to the incoming sound wave (k), density contrast (g), and sound speed contrast (h). Sound density contrast refers to the density of a body and the speed of sound in relation to the surrounding waters **(Stanton & Chu, 2000; Lavery *et al*., 2002; Demer & Conti, 2003; Lawson *et al*., 2006)**. Because Ts essentially depends on the ratio of wavelength to body length and uses frequency dependency to distinguish objects from other creatures, the frequency and body length are particularly crucial **(Amakasu & Furusawa, 2006; Calise & Skaret, 2011)**. In this study, split-beam echosounders were used to examine the connection between TS and puerulus length. Both the empirical formula TS vs. Log (TL) **(Foote *et al*., 1990a)** and the Stochastic Distorted Wave Born Approximation (SDWBA) model were used to compare the results. Although this method has been developed using broadband instruments, it has only been applied to Southern Ocean krill **(Demer & Conti, 2005; Calise & Skaret, 2011)**.

In the final section, an analysis of the body structure of the biota was conducted to find out the body parts that affect the TS value. One of the backscatter value models for the structure of peulurus can be approached using the method that has been used for euphausiids, namely based on the physical backscatter model **(Smith *et al.*, 2013)**. There have been many backscattered value models developed for euphausiid. **Smith *et al*. (2013)** in their study, they showed that euphausiid morphometrics can influence different backscatter values because the body-forming functions are different for each individual, such as shape, length, and orientation relative to the acoustic waves, and material properties. Further, the SDWBA model accounts for shape variability by providing a stochastic approach to handling phase variability along the body (as an adjustment to the DWBA defined by **Chu and Ye (1999)**) that changes with body orientation (relative to the incident plane wave).

The measurement of the TS of *Peleurus* in relation to its body parameters is instrumental in the accurate identification of its acoustic thresholds, which are utilized for the purpose of distinguishing the target from other objects. The precision of stock estimations derived from acoustic technology is determined by the calculation of abundance values from acoustic findings, with TS values assuming a crucial part in these calculations **(Simmonds & MacLennan, 2005)**. The results of precise stock measurements can undoubtedly provide a comprehensive description of the prevailing conditions. Consequently, informed policy decisions pertaining to the management and sustainability of lobster fisheries can be made with greater precision. This study aimed at recording the acoustics backscattering strength of the spiny lobster puerulus and understanding which body part most affects the TS. The result of this study would be useful as a reference for estimating the length of the spiny lobster species, as well as predicting their biomass. This research constitutes the first study to be conducted in this field due to the absence of previous research on acoustic backscattering of baby spiny lobster puerulus.

MATERIALS AND METHODS

1. Material

This research was conducted in August 2020 at Pelabuhan Ratu, West Java, Indonesia, because there were many activities of catching these biota, as well as supporting it to conduct research. The object of TS measurement was live *P. ornatus* (n=18) and *P. homarus* (n=35) in the puerulus stage. The movement of the puerulus stage is driven by the sea current, and with such a life cycle, the use of acoustic technology is possible to detect and measure its presence. The *P. ornatus* has visual characteristics, including a weight range of 0.14 to 0.24g, total length of 1.5 to 2.3cm, antenna length of 1.5 to 2 times the body length, and black or brown spots on the end of the spatula. On the other hand, the *P. homarus* has visual characteristics, including a weight range of 0.12 to 0.22g, total length of 1.8 to 2.3cm, and dark gray and milky white pigments resemble the shape of alternating lines to the tip of the antenna **(Junaidi, 2018)**. As pigment develops, it becomes brown spots without white lines (Fig. 1).

The selection of these species for the present study was based on the fact that in Indonesia, they are the dominant species and are extensively traded. During this phase, the high market demand for these species necessitates management efforts, one of which is to estimate their stocks. The utilization of hydroacoustic technology is a viable method for this purpose; however, the determination of species characteristics is contingent upon the availability of target strength (TS) values. Consequently, this study was undertaken to furnish a foundation for the calculation.

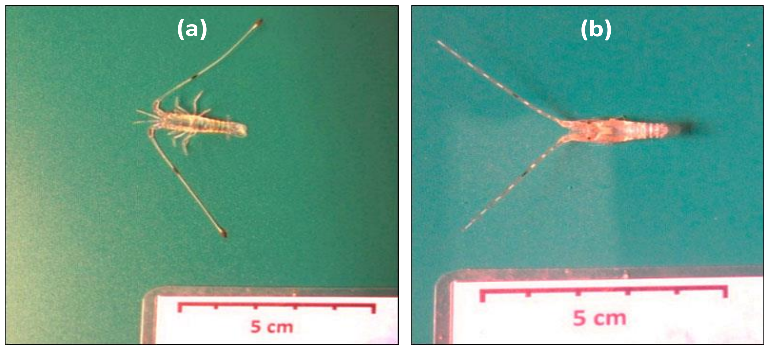
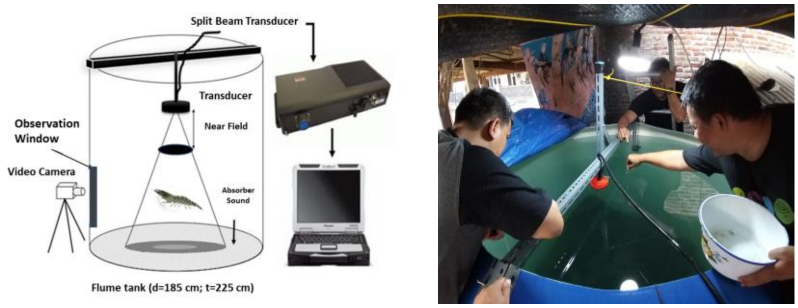


Fig. 1. Specimen of **(a)** Ornate spiny lobster (*P. ornatus*) and **(b)** Scalloped spiny lobster (*P. homarus*)

The characteristic of these two species in the larval stage is an organism that actively swims in the water column. Hydroacoustic measurements were conducted in a flume tank (Fig. 2). Absorbent foam was used at the bottom of the flume tank with the aim of creating an anechoic space that can reduce the background signal coherently so that the resulting echoes and side echoes can be minimized **(Amakasu & Furusawa, 2006)**. The experimental design is presented in Fig. (2). During this study, the total sample that we used consisted of 35 individuals of *P. homarus* (PH) and 18 individuals of *P. ornatus* (PO). The total lengths (TL) and numbers of samples used were 18mm (PH=7, PO=3), 19mm (PH=17, PO=4), 20mm (PH=6, PO=7), and 21mm (PH=5, PO=4). Individual puelurus were selected for experimental TS measurements based on their respective body conditions and shell integrity. The selected animals were snugly tethered with knots around the thickest portions of their bodies to limit body damage while being suspended in a 5800-liter flume tank (225cm height, 185cm diameter) (Fig. 2). These tethers use fishing line monofilament ($\rho \approx 1.2$g/ mL, 0.18mm diameter). The data collection was based on previous tethered studies published in the literature that also employed bistatic transducers **(Stanton *et al*., 1993; Stanton & Chu, 2000; Lavery *et al*., 2002; Lucca *et al*., 2021; Lucca & Warren, 2024)**.

All animals were tethered within the far field at distances of at least 50cm across all frequencies while also ensuring that r >($L^2_{body}/\lambda_{\mathrm{transmitted}}$, where r is a range, L body is the length of an elongated animal, and $\lambda_{\mathrm{transmitted}}$ is the acoustic wavelength of the transmitted frequency **(Steinberg, 1976)**. Side-view cameras (GoPro Hero 4) were utilized to measure animal orientation (θ) and estimate the position inside the beam pattern. Cameras were timed to all acoustic measurements, allowing still pictures to be directly aligned with each sent ping **(Lucca & Warren, 2024)**. A third-order Butterworth bandpass filter was used to reduce intermittent background noise **(Lavery *et al*., 2002)**. Pulse compression filtering was applied to improve signal-to-noise ratio (SNR) and exclude observations with SNR < 3 dB **(Stanton & Chu, 2000)**. Background noise was calculated by averaging amplitude measurements (in the frequency domain) from empty tanks with no animals present. The averaged observations were then incoherently removed from the Fourier-transformed, pulse-compressed animal signals.

The TL size of each puerulus was measured by a caliper, then tied and placed in the center of the beam transducer, and then sounded for 15-20 minutes. The data collection consisted of TS value and scattering volume (Sv) area. Parameter settings for the echo sounder system are presented in Table (1). Raw data in an echogram of backscattering strength were automatically recorded directly on the computer's hard disk.



(a) (b)

Fig. 2. (a) Experimental design of acoustic data acquisition; **(b)** The process of inserting an object

The target strength measurement process utilizes an active acoustic device, as illustrated in Fig. (2a), with the transducer in the center position of the flume tank. During the measuring process, the motion and position of the object relative to the axis of the transducer (Fig. 2b) were also monitored. This was done to ensure that the object remains within the sweep area of the acoustic beam.

Table 1. Setting of acoustic parameter

Parameter	**SIMRAD EK 80**
Frequency	CW 200 kHz//FM 160-260 kHz
Pulse duration	0.512 ms
Power transmit	150 watt
Sound speed	1542 m/s
Absorption coefficient	82.9 dB/km
SV threshold	-80 dB
TS threshold	-80 dB

2. Method

Target strength

Several steps are needed to be taken before collecting the data using the hydroacoustic method. These steps are taken to produce good data both in terms of accuracy and precision. Firstly, acoustic calibration using a spherical sphere (Tungsten WC-Co 38mm) was conducted to ensure the accuracy and precision of measurement. A tungsten carbide ball was used as a reference target for calibrating the system **(Demer & Conti, 2005)**. The tank's salinity and temperature were measured using a portable sensor (YSI Model 85) to compute the speed of sound (C) and absorption coefficient (dB/m). This value will be used as an input parameter in the SIMRAD-provided program during the calibration process. The data deviation from the beam model should, for good calibration, give an RMS value of less than 0.2 dB **(Kongsberg, 2023)**.

The acoustic estimation of abundance can be made rigorously if scattering as a function of size and frequency for an individual (i.e., Target Strength (*TS*)) is known **(Simmonds & MacLennan, 2005; Calise & Skaret, 2011)**. For the model, each puelurus was divided into several cross-sectional sections. The energy reflected by each segment was estimated separately and averaged for the entire animal. The scattering amplitude, f_{bs}, is related to the backscattering cross section of the target (σ_{bs}) and TS by the following relation **(Smith *et al*., 2013; Lucca & Warren, 2024)**.

$$TS = 10log_{10}|f_{bs}|^2 = 10log_{10}(\sigma_{bs}) \tag{1}$$

TS is a logarithmic measure of the proportion of the incident intensity backscattered from the target measured in units of dB relative to 1m^2. TS of an aquatic organism can either be measured directly (*in situ* or *ex situ*) or modelled **(Foote *et al*., 1990a; Lawson *et al*., 2006)**.

Acoustic data were processed using SONAR5-pro software, where the results of extraction are the values of target strength (TS) in decibels (dB). The average TS value for an object was calculated by averaging the extracted linear TS values. Using the average TS of measurement results indirectly removes outlier measurement data without changing or eliminating it. Individual mean TS values were used in least squares regression analysis to obtain a formulation of TS versus total length for the same species. The relationship between TS and total length was formulated using linear regression analysis, where TL was the independent variable and mean TS was the dependent variable. The normality test for pairs of TL and mean TS data as a condition for regression analysis was carried out previously using IBM Statistics 24 software. The linear relationship between mean TS and total length could be written in the simple form of the following formula and would be useful in applied work **(SC-CAMLR, 2005)**:

$$TS = m\ 10Log_{10}(L) + n, \tag{2}$$

Where, *m* and *n* are, respectively, the slope and intercept of the line, and *L* is the length of the object.

TS value of model SDWBA

The SDWBA model was developed specifically for the first time by **Demer and Conti (2003)** and refined later by **Demer and Conti (2003, 2005)**. The SDWBA model was developed from a deformed cylindrical model and widely used in modeling krill bodies **(Stanton & Chu, 2000; Reiss *et al*., 2008; Son *et al*., 2022)**. This model assumed that the targets are comprised of weakly scattering material and not moving actively. These models are parameterized using scatter properties measured using both experiments **(Stanto & Chu, 2000; Forman & Warren, 2010; Becker & Warren, 2014)** and inversion methods **(Lavery *et al*., 2002; Lawson *et al*., 2006)**. However, similar to tethered TS measurements, scattering model inputs have only been characterized for several nearshore species **(Forman & Warren, 2010)**.

Currently, the SDWBA model is the best model that can be used to approach the scatter values of euphausiids such as krill and has been adopted by the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) to estimate krill biomass stocks in the Antarctica **(Reiss *et al*., 2008)**. Based on the previous explanations, this study was organized to record the acoustics backscattering strength (TS) of the spiny lobster puerulus and understanding which body part most affects the TS. The result of this study would be useful as a reference for estimating the length of the spiny lobster species, as well as predicting their biomass.

The mean TS of measurement results is the average TS value obtained by extracting echogram data from measurements of each object size. The TS data extraction approach uses SONAR ver.5 Balk & Lindem Software. This method initiates by limiting the TS threshold value and the depth layer in which the object is set up. Furthermore, the data were extracted using the software echo counting process.

The researchers used a proven Stochastic Distorted Wave Born Approximation (SDWBA) model to explain the phase variability. This process was carried out to generate TS values at certain frequency intervals by taking into several aspects, such as fatness, density contrast, orientation, sound speed and shape. For some parameters that were not measured, the results of studies were used, following the outlines of **Chu and Wiebe (2005)**. The SDWBA model is applicable to all acoustic frequencies, orientation angles, and arbitrary shapes **(Stanton *et al*., 1993)**. The SDWBA model integrates the scattering function along the body's axis while accounting for the phase shift caused by the bent body. The model assumes weakly scattering targets, which is typical for euphausiids. The results of mean TS were then compared with predictions obtained from the SDWBA model **(McGehee *et al*., 1998; Demer & Conti, 2005)** and the difference was tested using an error quantity (E), defined as follows:

$$E_{200kHz} = \frac{\sum \sqrt{(TS_{mean} - TS_{SDWBA})^2}}{n} \quad (3)$$

Animal shape

This SDWBA model produces a visualization of the body structure of biota, which shows the level of roughness and hardness of the part of the biota since the value of TS can be affected by the hardness and roughness of an object. The puerulus in this study is described as the euphausiid shape using the taper function **(Smith *et al*., 2013)**. The SDWBA model may not accurately capture the phases of backscattered signals at angles other than normal incidence. The SDWBA model's TS predictions were validated for euphausiids, with a nearly broadside incidence with angles less than 15–30º. However, at larger angles, the model's predictions were about 5–10 dB lower than direct measurements **(McGehee *et al*., 1998)**. **Demer and Conti (2003)** provided three causes for phase variability: unpredictability in the field, complicated euphausiid shapes with changing radius, and euphausiid stretching during swimming.

To predict the empirical estimate of σbs of the SDWBA model, overall scattering angles and average all angles of incidence (SDWBA), were integrated. The parameters are assumed to be similar to krill shape (*euphausiid*) **(McGehee *et al*., 1998)**, c=1542 ms^{-1}, nondimensional contrast of sound speed and density (h = 1.0279 and g = 1.0357, respectively) from **Foote *et al*. (1990a)** and **Foote (1990b)**, and a random phase is selected from normal distribution (φ = N[θ, stdθ]) in degrees **(Demer & Conti, 2003)**. This experiment uses φ = N [10,3]. The krill shape that comes from krill was assumed proportionally to represent puerulus in this experiment (L=18–21mm).

The SDWBA model was simplified by **Stanton *et al.* (1993)** using only one integral. The single integration process assumes that the object has a body that forms a circle along its body, and the material properties of the object are considered constant throughout the body of the object. Therefore, integration follows the long body segment **(Stanton *et al*., 1993; Stanton & Chu, 2000)**, and the formulation can be stated as follows:

$$f_{bs} = \frac{k_1}{4} \int_{\vec{r}pos} a(\gamma_k - \gamma_\rho)\, e^{i2(\overrightarrow{k_i})_2 \cdot \vec{r}_{pos}} \frac{j_1(2k_2 a \cos\beta_{tilt})}{\cos\beta_{tilt}} \left| d\vec{r}_{pos} \right| \quad (4)$$

Where, a is the radius of the object's body along the animal's body (TL), k_1 refers to the acoustic wave, k_2 is the wave number inside the body, $ß_{tilt}$ is the tilt angle, (k_i) of a cross-section cylinder at each point axis, and j_1 is the Bessel function (orde-1). For a realistic shape model, it is made by measuring the length of the object, and then calculating the radius in multiples of 0.5mm from the object's body length. Each radius size and target length obtained from each object were then normalized in the size range of 0 to 1, where the value of 0 is the midpoint of the object on the x and y axes.

This measurement was conducted with the aim that the formed function could be applied to all sizes of objects. The radius measurement of the normalized body length consists of several body segments that are cut into pieces (described using the sixth-degree polynomial function (diameter vs TL) and the taper function (T=10)), then calculating the TS value of each piece by using Eq.1 and Eq.4 with several input parameters obtained from the SDWBA model. The relationship between the body segment piece and TS values can be seen from the function of a smoothly varying sixth-degree polynomial. Each of these sections would present the TS value, which describes the part of the body that provides the greatest backscattering value. The validation process was carried out by taking photos of the internal organs of the two objects.

RESULTS

The relationship of target strength (TS) and total length (TL)

The calibration process was carried out before the data collection. The root mean square value resulting from the calibration was 0.17 dB (RMS < 0.2 dB). According to the SIMRAD EK80 manual calibration (2023), this can indicate a relatively low level of measurement error. The data with the same total length were used to compare the TS values between two types of objects. However, the measurements were carried out on all samples where the data were used to establish the relationship between TL and TS. Furthermore, some statistical data descriptions were obtained as presented in Fig. (3). Distribution data follows normal distribution with significant values of 0.12 for *P. homarus* and 0.2 for *P. ornatus* ($P > 0.05$).

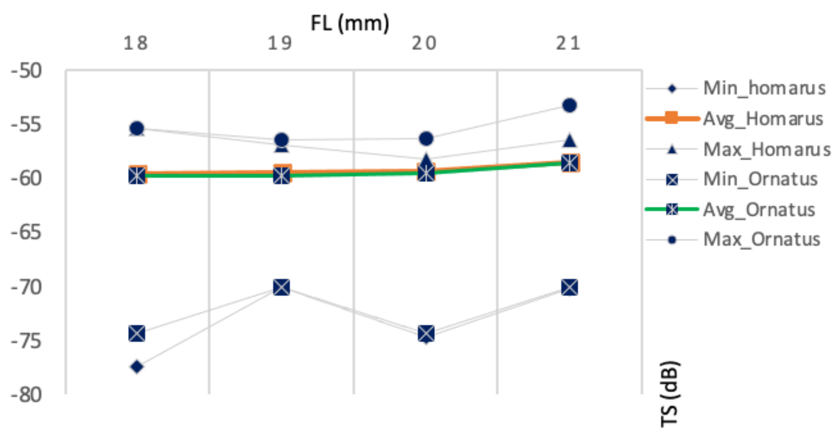


Fig. 3. Descriptive statistic data

The mean target strength (TS) value of the two types of lobster was found to be similar, as evidenced by the descriptive statistics in (Fig. 3). A comparison of the highest and lowest TS values at a given size is indicative of the differences between the two types of lobster. The use of the SDWBA model, which is based on several factors such as fatness, density contrast, orientation, sound speed, and shape, is an effective method of determining these differences. The results of the significance test between TS and TL values for each type of *Puerulus* (baby lobster) and the fit TS-length relationship are presented in Table (2) and Fig. (4) for the ornate spiny lobsters and in Table (3) & Fig. (5) for the scalloped spiny lobsters. The test results show several output tables, including coefficients and a model summary, to present the relationship between length (TL) and target strength (TS). Statistical analysis indicates a positive correlation between body size and backscatter value in *P.ornatus* lobsters.

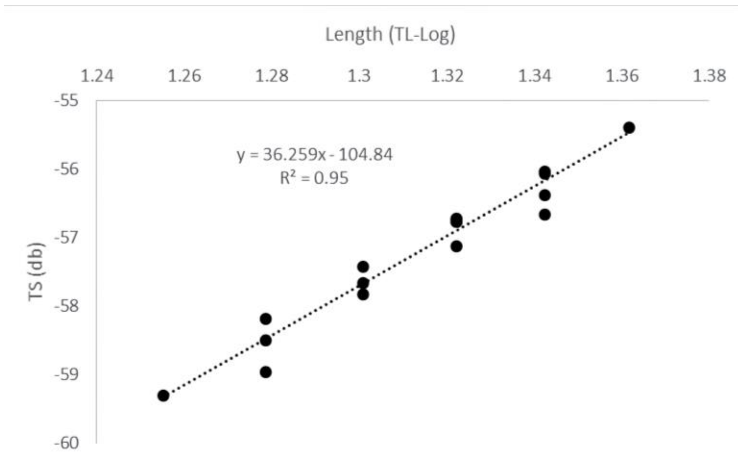


Fig. 4. The fit TS-length relationship for the ornate spiny lobster (*P. ornatus*)

The range of measurement results at the Target Strength (TS) value of -55 to -59 dB at a total length size (TL) of 18-21mm was considered. This suggests the presence of a positive allometric relationship, whereby each increase in the value of the dependent variable (TS) is directly proportional to the corresponding increase in the value of the independent variable (TL) (Fig. 4). As shown in Table (2), a significant correlation is observed between total length (TL) and target strength (TS) values, as indicated by a *P* less than 0.05.

Table 2. Result signification of TS and TL for ornate spiny lobster (*P. ornatus*)

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	-104.959	2.650		-39.606	.000
	TL_*P.Ornatus*	36.354	2.016	.976	18.035	.000

a. Dependent Variable: TS_*P.Ornatus*

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.976[a]	.953	.950	.23500

a. Predictors: (Constant), TL_ *P.Ornatus*

The result of the statistical analysis showed that the mean TS gives different values for each length, and the formulation based on Eq.1, which can be used to estimate the TS value from total length as follows: TS_{200kHz} = -104.96 + 36.54$\log_{10}$ (TL) (TL=18 to 21mm; R^2=0.95) with 95% coefficient determination (Table 2).

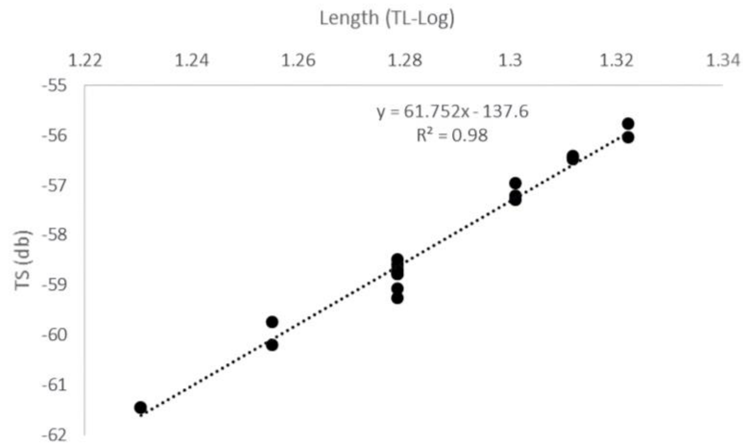


Fig. 5. The fit TS-length relationship for the scalloped spiny lobster (*P. homarus*)

Statistical study shows that there is a positive association between body size and backscatter value in *P. homarus* lobsters. The measurement results at a target strength (TS) value of -56 to -61.5 dB and a total length size (TL) of 18-21mm were examined. This indicates the presence of a positive allometric relationship, in which each rise in the dependent variable (TS) is directly proportionate to the corresponding increase in the independent variable (TL) (Fig. 5).

Table 3. Result signification of TS and TL for the scalloped spiny lobster (*P. homarus*)

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	-137.595	2.824		-48.731	.000
	TL_ *P.Homarus*	61.752	2.200	.990	28.065	.000

a. Dependent Variable: TS_*P.Homarus*

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.990[a]	.980	.979	.24983

a. Predictors: (Constant), TL_ *P.Homarus*

Based on the statistical result of scalloped spiny lobster, the regression formulation that generated from (Eq.1) this analysis was TS_{200kHz} = -137.595+61.75$\log_{10}$ (TL) (TL=18 to 21mm; R^2=0.98) with 98% (coef.determinan) (Table 3)

TS value of model SDWBA

The TS value of model SDWBA at a frequency of 160-240kHz was generated using the total length as the angle of the object to the transducer is considered constant using an average angle of $10^o\pm3$ deg. Fig. (6) shows the TS value obtained using SDWBA at a frequency of 160-240 kHz (EK80-200 kHz, FM mode) compared to the direct measurement TS and its error value. In this study, the results of CW (Continuous Wave) mode measurements only compares with model SDWBA. Furthermore, the SDWBA model at a frequency of 200 kHz produces the TS value of (18mm) -59.43±0.27 dB; (19mm) -59.2±0.30 dB; (20mm)-58.97±0.33 dB; and total length (21mm) -58.98 ±0.32 dB.

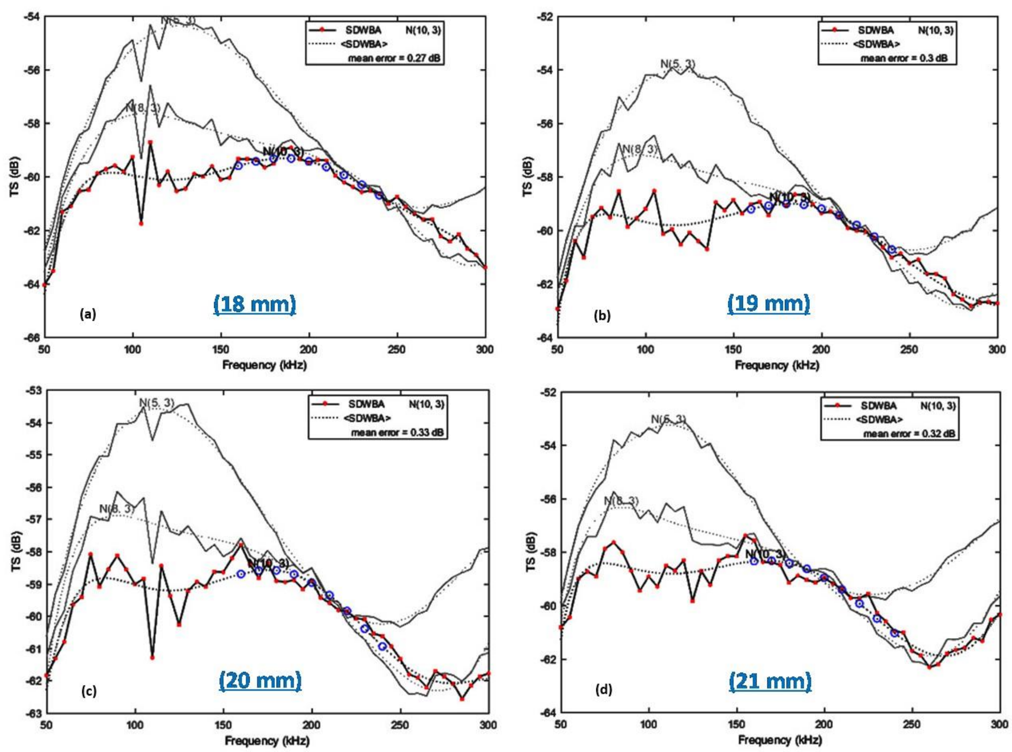


Fig. 6. Result from SDWBA Model (160-240 kHz), (a) 18mm, (b) 19mm, (c) 20mm, (d) 21mm

The mean target strength (TS) value obtained from the measurement results using the EK80-CW mode at a frequency of 200 kHz was compared to the calculated value from the SDWBA model (TL=18-21 mm) (Fig.7).

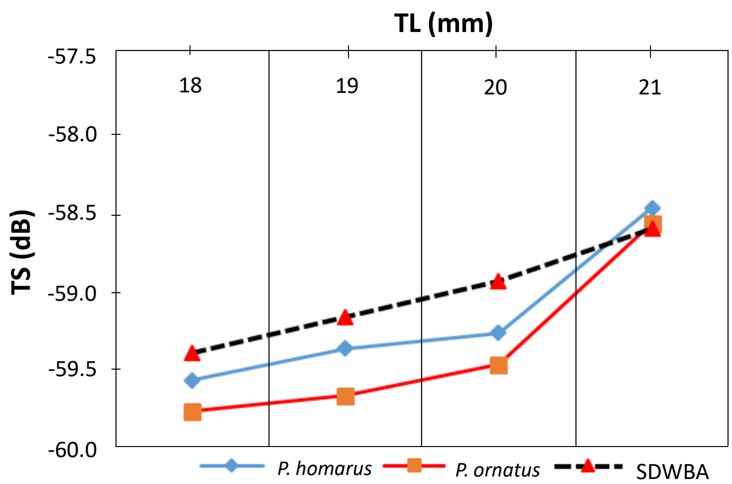


Fig. 7. Comparison between TS measured and SDWBA model

The comparison analysis of mean TS value and SDWBA showed that the average error quantity of *P. homarus* and *P. ornatus* were 0.03 and 0.18, which indicated that the results of the model and measurement are not much different (Table 4). This means that TS value can be approached using the SDWBA model.

Tabel 4. Error quantity Mean TS and SDWBA model

TL (mm)	MeanTS (dB)-200 kHz			E_*P. homarus*	E_*P. ornatus*
	P. homarus	***P. ornatus***	**SDWBA**		
18	-59.6	-59.8	-59.43	0.03	0.37
19	-59.4	-59.7	-59.2	0.01	0.17
20	-59.3	-59.5	-58.97	0.05	0.18
21	-58.5	-58.6	-58.63	0.03	0.01

Animal shape

Based on the results of measuring diameter along the body, the piecewise function of the body object is obtained as follows: $z = -1$ to -0.5, $a = 0.0002z + 0.10$, $R^2 = 0.92$; $z = -0.5$ to 0, $a = -0.0004z + 0.22$, $R^2 = 0.93$; $z = 0$ to 0.5, $a = 0.0001z + 0.02$, $R^2 = 0.86$; $z = 0.5$ to 1, $a = -0.0003z + 0.08$, $R^2 = 0.96$, where z and a(x) are the animal's length and normalized body diameter from -1 to 1. The visualization of objects at any size, where the zero value is the midpoint of length geometry and the object's body radius (Fig. 8).

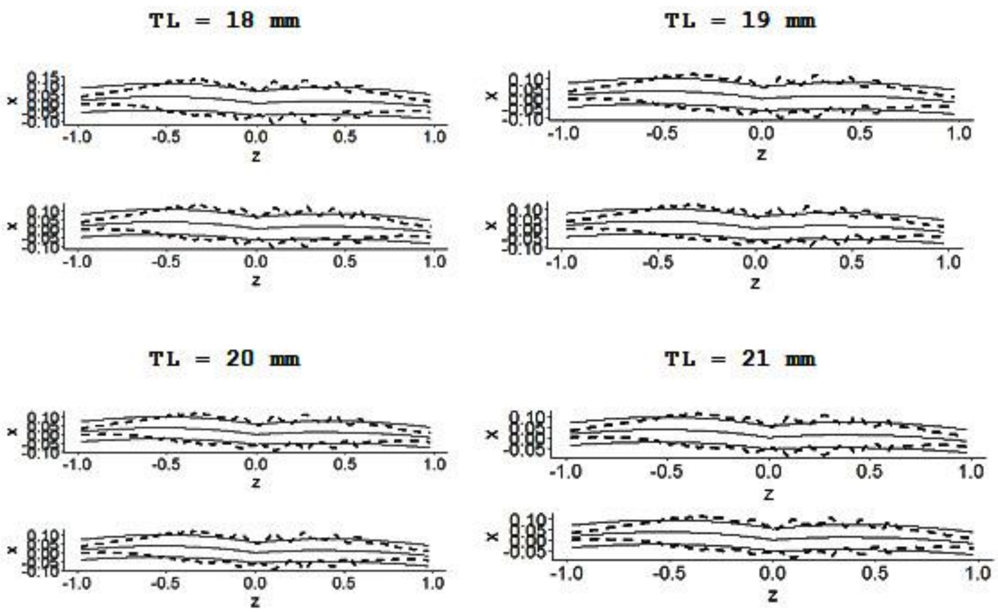


Fig. 8. Body shape of SDWBA model (solid line: norm_TL; dash line: norm_polyTS)

The polynomial shape function could provide a picture of shaping objects like euphausiids more clearly, where the characteristics of baby lobsters are assumed not to be different from euphausiids. From the results of calculating the TS model for body segments for each object size, the polynomial shape function is obtained as follows:

$TS = z^6 - 0.017z^5 + 0.282z^4 - 2.247z^3 + 8.313z^2 - 12.503z - 49.84$, $R^2 = 0.997$ (TL =18 mm);

$TS = z^6 - 0.0168z^5 + 0.2825z^4 - 2.2467z^3 + 8.313z^2 - 12.505z - 50.07$, $R^2 = 0.996$ (TL=19 mm);

$TS = z^6 - 0.0168z^5 + 0.2825z^4 - 2.2469z^3 + 8.314z^2 - 12.506z - 50.29$, $R^2 = 0.996$ (TL=20 mm);

$TS = z^6 - 0.0168z^5 + 0.2825z^4 - 2.247z^3 + 8.315z^2 - 12.508z - 50.50$, $R^2 = 0.996$ (TL=21 mm).

The obtained results indicated a highly significant relationship between the size of the object and the TS value, with a coefficient of determination (R^2) greater than 0.9 for all object sizes. The analysis of the four measurements revealed that the cephalothorax exhibited a higher TS value compared to the abdomen (Fig. 9).

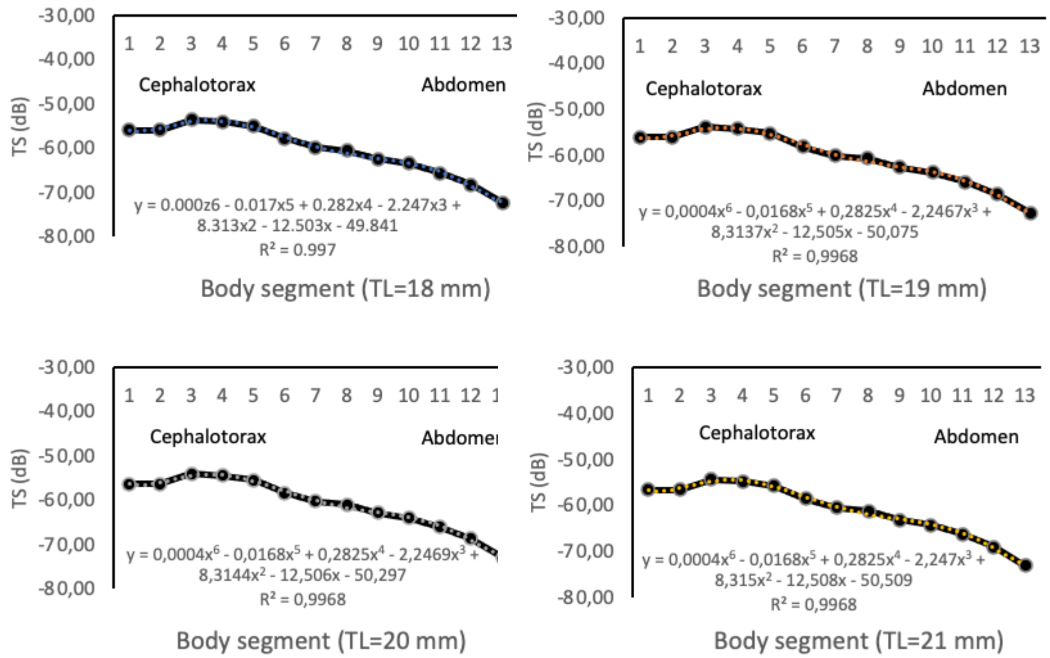


Fig. 9. Distribution of TS data in each body segment for each object body size

By averaging across these four measurements, the TS model for the body segments using the polynomial shape function would be as follows:

$TS = z^6 – 0.016z^5 + 0.282z^4 – 2.246z^3 + 8.31z^2 – 12.506z – 50.18$ $R^2 = 0.99$ (TL = 18-21 mm).

The polynomial equation shows that the relationship between TS and the body shape of the object has a close relationship with a value of $R^2 = 0.9968$ ($P<0.05$). When the body of the object was divided into 3 parts, namely the cephalothorax, abdomen and telson, the results showed differences in the TS values, as shown in Table (5).

Table 5. Description statistics of TS at body length

Body shape	Min	Max	Mean	Std
Cephalothorax	-56.59	-53.68	-55.28	0.98
Abdomen	-64.27	-57.92	-61.26	2.06
Telson	-73.14	-65.65	-69.17	2.94

As shown in Table (5), the average TS value for the cephalothorax section is -55.28 dB, the abdomen body section is -61.26 dB, and the telson section is -69.17 dB. This result provides a description of all sizes of the object of research conducted. The standard deviation of measurement of the TS of the lobster body is 0.98 dB (Cephalothorax); 2.06 dB (Abdomen) and 2.94 dB (Telson).

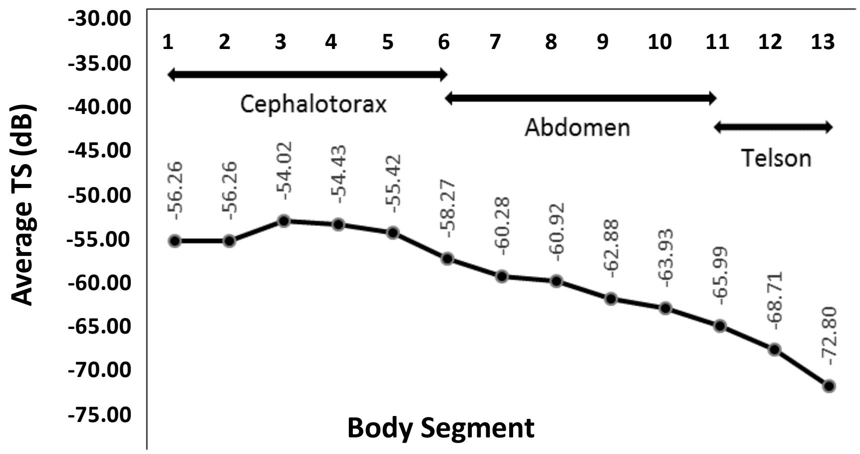


Fig. 10. The average TS in each body segment in the body object (TL=18-21mm)

The SDWBA model results indicate that the cephalotorax has values ranging from -55 to -56 dB, the abdomen has values varying from -58 to -63 dB, and the telson has values between -65 to -72 dB (Fig. 10). The observed variation in values is closely related to the hardness and shape of the different objects. Furthermore, the backscatter value of *P. homarus* was greater than that of *P. ornatus* at all sizes using the SDWBA model, as shown in Fig. (10), which is influenced by its harder body at the same size. Moreover, it is suspected that the cephalothorax has a greater backscattering strength than the abdomen because the cephalothorax is harder than other parts of the body. The presence of organs in both objects is indicative of this condition, with the cephalothorax exhibiting larger dimensions and a more pronounced hardness compared to other body parts, as evidenced by the horizontal and vertical cross-sections of both objects. The presence of a brown pigmentation on the object is an indication of hardened body parts (Fig. 11)

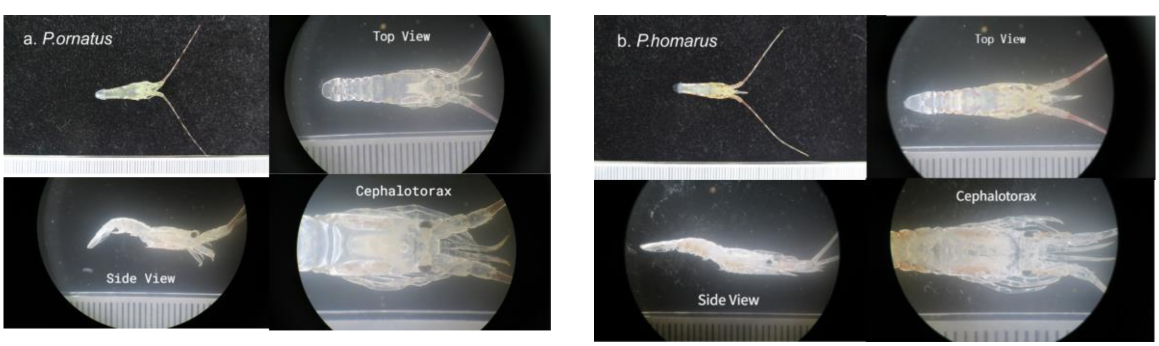


Fig. 11. *Puerulus* morphometry from top view, side view and cephalothorax of (a) *P. ornatus* and (b) *P. homarus*

DISCUSSION

A comprehensive dataset was collated, encompassing specimens of varying sizes, with the target strength (TS) value of *P. homarus* and *P. ornatus* being compared with their corresponding length measurements. The ice krill, spanning the juvenile to adult stage, exhibited characteristics that aligned with the overall length measurement method employed in this study. The findings of this study demonstrated that the total length (TL) of *P. ornatus* and *P. homarus* had a significant impact on the TS value, thereby indicating that the length of the baby lobster exerts a substantial influence on the final TS value (Figs. 4, 5). The TS value of *P. ornatus* and *P. homarus* could be explained by TL to a greater extent than 80% (Tables 2, 3). The TS value of an organism is influenced by several factors, including body size, body texture, the organism's constituent materials, and other organs that can store air in the body **(Bairstow *et al*., 2021)**. Biological variation in backscatter is dependent on behavioral, morphological, ontogenetic, and physiological factors **(Foote *et al*., 1990; Simmonds & MacLennan, 2005)**.

This study established that the TS value of *P. homarus* was higher than that of *P. ornatus* (Fig. 3). **Holthuis (1991)** stated that the body of the lobster consists of two main parts: the hard anterior cephalothorax and the jointed abdomen. An exoskeleton containing chitin is present in all parts of the body, and this is thin and soft in the joints to allow movement but hard in other parts. The study identified the hardness of the body texture as the primary factor influencing the TS values. The body structure of lobsters, particularly the cephalothorax, exhibited a higher level of hardness compared to other body parts (Figs. 8, 9). The study's findings revealed that the body structure of juvenile krill and baby lobsters exhibited different TS values, with the TS value of baby lobsters displaying a higher distribution value compared to that of juvenile krill. This disparity can be attributed to the distinct body texture and level of hardness exhibited by baby lobsters, which are characterized by higher levels of hardness, particularly in the cephalothorax region when compared to juvenile krill. Krill, a group of small shrimps, bear similarities to mysids in terms of their nutritional habits, including the consumption of holoplankton, and reach a size of 8-16mm in the juvenile phase **(Holthuis, 1991)**.

The SDWBA model has been developed as a means of predicting the TS value of an object's body structure across a range of frequency intervals. In order to forecast the TS, the SDWBA model's input parameters must be calculated, with these factors including the density contrast, sound speed contrast, orientation, fatness, and shape **(Lawson *et al*., 2006)**. A comparison of the TS values measured for both species and the SDWBA model reveals that there is no significant difference between the two (Fig. 7) **(Lawson *et al*., 2006)**. This is evidenced by the average error quantity, which is 0.03 for *P. homarus* and 0.18 for *P. ornatus* (Table 4). However, it is important to note that the TS can also be influenced by factors related to density and sound speed when the water temperature is modified (Fig. 6) **(Azzali *et al*., 2010; La *et al*., 2014)**.

The model result demonstrates that the value of TS increases with an object's length, exhibiting a strong correlation (R^2 >0.9, P<0.05) (Tables 2, 3). Additionally, the TS value does not differ significantly between lobster species of equivalent size. The study also found that the cephalothorax of the object produced larger TS values compared to other body parts, such as the abdomen and telson (Fig. 8 & Table 5). This finding is consistent with the anatomical characteristics of the object, where the cephalothorax is characterized by a harder shell compared to other parts (Fig. 10). The hardness of the shell is beneficial in protecting the vital organs of the object, such as the brain and digestive organs (Fig. 11).

The existence of a relationship between the TS value and the total length of *P. homarus* and *P. ornatus* allows us to use this value as a threshold to identify targets with other objects. Additionally, this can be used to convert length to weight, which has proven to be very useful in stock estimation based on acoustic abundance estimation. This is done to improve the accuracy of the calculations, resulting in stock estimates with minimal bias. A precise stock figure will facilitate the management and administration of sustainable fisheries. Research on target strength (TS) vs. total length (TL) in juvenile lobsters of the species *P. homarus* and *P. ornatus* in live conditions has not been conducted, making this a novelty in this study.

CONCLUSION

Research on live *Puerulus* (baby lobsters) measured *ex-situ* using a split-beam echosounder at a frequency of 200 kHz showed that the TS value of *P. homarus* was higher than that of *P. ornatus*. This is explained by the harder body characteristics of *P. homarus* in regard to *P. ornatus*. The TS values derived from the measurement results were found to be comparable to the SDWBA model results. The study concluded that body shape and size are the primary factors determining the TS value, particularly in the cephalothorax. These findings are expected to be of a significant value in enhancing the precision of acoustic detection and density estimation of baby lobsters. The scope of this study will be expanded in the future to include a greater number of samples and the collection of data at a range of frequencies.

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