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Acoustic Model of Body and Swim Bladder for Target Identification

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ABSTRACT

This paper discusses the Target Strength (TS) results offish from *in situ* measurement at the life sea habitat compared to acoustic model. *In situ* measurement of fish Selarboops (*Oxeye scad*) and Megalaspiscordyla (*Torpedo scad*) have been deployed using Scientific Echo Sounder. Laterally and dorsally X-ray imaged of fish have been deployed to perform fish body and swim bladder morphology. Length, height, width, upper surface, volume, and tilt angle for swim bladder to fish body have been measured for acoustic model of Kirchhoff-ray mode (KRM) implementation. The TS results from modeling simulation were compared with TS data from *in situ* measurement. The consistency is achieved, which are Megalaspiscordyla produce higher TS than Selarboops and swim bladder shows significant contributions to the TS value compared to the fish body.

Keywords

Swim bladder, Target Strength, X-ray, KRM model, Acoustic model.

1. INTRODUCTION

TargetStrength (TS) can be measured *in situ*, experimentally, or modeled based on fish anatomy. Backscatter models allow the effects of length, tilt, depth, and frequency on TS to be quantified and to be examined throughout a continuous range for each variable [1], [2]. The examining factor in isolation is difficult. The effect of one factor cannot be separated from other factors.

The swim bladder is considered to be responsible for most acoustic backscattering energy [3] and consequently its TS. Natural variations in swim bladder volume and shape may cause variation in fish TS. The important factors that are assumed to alter the TS significantly are stomach content, gonads, body-fat content, pressure, and tilt angle as in [4].

An air-filled swim bladder contribute up to 90% of backscattered sound [3], [5]. Theoretical calculation of TS is possible using the exact shape of the swim bladder [6]. Length, tilt, and depth influence the shape or orientation of the swim bladder and a major influence on TS and also influence the amount of sound reflected by fish [2].

In this paper, the acoustic models based on morphology is used to calculate the TS and compared to TS data from *in situ* measurement. The accuracy of acoustic assessment is improved by relationship between fish biology and TS.

We have conducted a series of *in situ* studies of Selarboops (*Oxeye Scad*) and Megalaspiscordyla (*Torpedo) Scad*) using scientific echo sounder that were reported in [7]-[11]. One of the research conclusion is Megalaspiscordyla even with a smaller size produce higher TS than Selarboops at the same depth. The results of *in situ* shows a consistent supported with its morphology when deployed X-rays as reported in [11].

The swim bladder of Megalaspiscordyla is bigger than Selarboops. Therefore, the wider upper surface and the greater volume on Megalaspiscordyla allow accepting and returning more emitted echo. Also, the smaller tilt angle of swim bladder on Megalaspiscordylawill produce higher TS value.

In this research, X-ray images of fish body and its swim bladder have been used in the development of fish acoustic model. Emphasis has been given in the implementations of the Kirchhoff-ray mode (KRM) model and then compared to results from *in situ* measurement.

Preliminary study of target strength using commercial fish of *Rastrelligerkanagurta*, *Atule mate*, and *Thunnustonggol* has been conducted through *in situ* and *ex situ* measurement as reported in [12]. KRM model for target strength identification be conducted in this study. Furthermore, these results are important to identify the fish abundance and stock assessment in the sea.

2. MODEL

Kirchhoff-ray mode (KRM) has been reported for several years. Recently, emphasis has been given on the swim bladder depth dependence [13] and swimming direction [14]. Need to understand KRM formula for fish body and fish swim bladder [15].KRM backscatter is modeled the fish body as a set of fluid and swim bladder as gas filled cylinders [16].

KRM as a backscatter model has been validated for length and tilt [17]. Numeric and analytic models estimate backscatter as a function of biological or physical factors of interest. Backscatter models augment experimental measures by predicting echo amplitudes from individuals under known conditions.

KRM backscatter models have been used to characterize frequency- and behavior-dependent backscatter of individual and aggregations of fish as in [15], [18]. Species-specific characteristics and metrics that facilitate the discrimination of species using acoustic [19] and illustrate the sensitivity of species-specific backscatter to assumptions of tilt-angle and material properties (densities and sound contrasts) had been identified [20].

Visualization of results include backscatter response surfaces over a designed range of aspect angle, lengths, and carrier frequencies [15], [17] and in interactive representations of fish bodies, swim bladders, and the corresponding acoustic backscatter [18]. Quantity variability in backscatter intensities had been deployed [21]. Echo sounder properties with fish anatomy, backscatter model predictions, and fish trajectories to visualize factors that influence patterns in backscatter data can be integrated [22].

Digitized images of the fish swim bladder and body has been used with KRM model to estimate the backscatter employing a low mode cylinder solution and a Kirchhoff-ray approximation. The morphology of the fish swim bladder and fish body obtained by dissection or X-rays is used to construct finite cylinders. The coordinates has been transformed from x–z Cartesian coordinates to u–v coordinates relative to the incident wave front. Backscattering cross-sections from each finite cylinder are summed over the whole swim bladder or body and then added coherently.

For the swim bladder which *ka*, (*k* is wave number and *a* is radius of swim bladder), is more than 0.2, a low mode cylinder solution is used. TS for swim bladder and fish body are given in (1) and (2), respectively [15].

$$\ell(f) = -i \frac{R_{fs}\,(1-R_{wf}^2)}{2\sqrt{\pi}} \sum_{j=0}^{N-1} A_{sb}\left[k_{fb}\,a(j)+1\right]^{1/2}\left[e^{-i(2k_{fb}V_U(j)+\psi_{sb}))}\right]\Delta u(j) \quad (1)$$

$$\ell(f) = -i \frac{R_{wf}}{2\sqrt{\pi}} \sum_{j=0}^{N-1}\left[k\,a(j)\right]^{1/2}\left[e^{-i2kV_U(j)} - (1-R_{wf}^2)\,e^{i(-2kV_U(j)+2k_{fb}(V_U(j)-V_L(j)+\psi_{fb}))}\right]\Delta u(j) \quad (2)$$

Scattering amplitude as a function of carrier frequency represents by*l(f)*. Parameter *k* is the wave number (*2π/λ*), *λ* is the acoustic wavelength, *a* is the cylinder radius, and *Δu(j)* is the incremental distance between the midpoint of each (j^{th}) cylinders. The subscripts *fb*, *w*, and *sb* indicate fish body, water, and swim bladder respectively

Besides that, there are several components in KRM modeling; density ratio of fish body to water, density ratio of swim bladder to fish body, sound speed ratio of fish body to water, sound speed ratio of swim bladder to fish body, reflection coefficient of fish body to water interface, and reflection coefficient of swim bladder to fish body interface.

Wave number *k* is depending on frequency *f* and sound speed *c* on water, fish body, or swim bladder. Empirical amplitude adjustment for small *ka*, empirical phase adjustment for small *ka* on swim bladder, and empirical phase adjustment for small *ka* on fish body need to define.

Backscattering cross-section σ_{bs} is computed from the complex scattering length *l(f)* expressed in (3). Therefore, reduced scattering length is calculated by using (4).

$$\sigma_{bs}(f) = |\,\ell(f)\,|^2 \quad (3)$$

$$SL = \frac{|\ell(f)|}{TL} \quad (4)$$

Equation (5) and (6) are reduced backscattering cross-section and reduced target strength, respectively.

$$\sigma_{bs} = \frac{|\ell(f)|^2}{TL^2} \quad (5)$$

$$TS = 20\log_{10}\left[\frac{\ell(f)}{TL}\right] \quad (6)$$

The scattering lengths for the fish body and swim bladder were computed individually. Finally, whole fish scatter can be summed from fish body and swim bladder, therefore, given by

$$\ell_{wf}(f) = \ell_{fb}(f) + \ell_{sb}(f) \quad (7)$$

This model has been applied to compute TS for Selarboops and Megalaspiscordyla. Fish body and swim bladder will be considered in the model to develop accurate and valid results.

3. METHODOLOGY

In fisheries application, TS data are collected by *in situ* measurement using sonar or echo sounder. TS value, depth, and position of targeted fish observed at every ping using echogram.

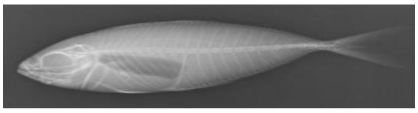
In situ measurement of Selarboops and Megalaspiscordyla as shown in [10] has been deployed using Furuno FQ-80 Scientific Echo Sounder. The net cage 3 cm x 3 cm x 3 cm placed in the vessel KK Senangin II at South China Sea, Terengganu, Malaysia. *In situ* measurement method and procedure was described in our publication before [7]-[9].

The acoustic model of fish has been developed. The first step is to determine the morphology of fish and its swim bladder. Process of X-ray of fish has been deployed at Health Centre of UniversitiTeknologi Malaysia.

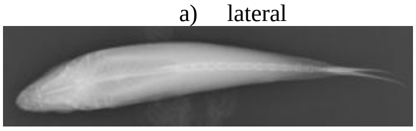
Fish morphology, position and size of swim bladder of Selarboops can be viewed as X-ray images as shown in Figure 1 for laterally and dorsally. Figure 2 shows the X-ray images of Megalaspiscordyla for laterally and dorsally.

Figure 3 shows that anatomy of fish and the gas-filled of swim bladder. Procedure in detail of X-ray in lateral and dorsal positions, as well as the upper surface and volume, weight and length of fish body and swim bladder, and the results has been reported in [11].

Fish total length, fork length, height or width, and weight were measured. This paper is focusing on fish TS identification employing KRM model. Density *ρ* and sound speed *c* of water *w*, fish body *fb*, and swim bladder *sb* must be described earlier.

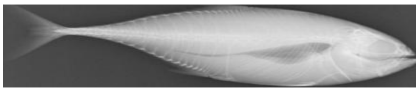


a) lateral



b) dorsal

Fig. 1: X-ray images of Selarboops [11]



a) lateral

b) dorsal

Fig. 2:X-ray images Megalaspiscordyla [11]

Fig. 3: Swim bladder observation

Reference [14] and [16] have mentioned density (kg/m^3) and sound speed (m/s) of *w*, *fb*, and *sb*. Frequency 38 kHz is used. Density of fish body and swim bladder has been determined by ratio between weight per kg and volume per m^3. Density of water, fish body, swim bladder andsound speed in the water used to calculate for sound speed in the fish body and swim bladder.

Fish body and swim bladder has been divided into any length pieces. The number of bits (*N*) and $\Delta u(j)$ are proportional. Fish body of Selarboops with fork length 13 cm divided into 7 pieces, whereas Megalaspiscordyla with fork length 19 cm divided into 11 pieces. Details of model characteristic for fish body and its swim bladder for both fish are listed in Table 1.

Table 1.Data of fish for model

	Selar boops	Megalaspis cordya
Fish length (cm)	16	23
Fork length (cm)	13	19
Max height of *fb* (cm)	4.5	5
Weight (g)	50	135
Volume of *fb* (cm^3)	61	113
$\Delta u(j)$ of *fb* (cm)	1.73	1.73
Pieces of *sb*	4	5
$\Delta u(j)$ of *sb* (cm)	0.87	1.73

Radius of fish body $a(j)$, upper surface V_U, lower surface V_L, radius of swim bladder a_{sb}, and $vu(j)$ were described from conversion of Cartesian x-y coordinate system to u-v fish cantered coordinate system. These values vary depending on individual pieces. Value*asb* and *afb* has been obtained as in [23].

The KRM model developed in the Matlab program to identify the backscattering cross section and the TS of both fish species in term of fish body, swim bladder, and whole body.

4. RESULTS AND DISCUSSION

In situ TS measurement of Selarboops has been conducted at 38 kHz with the average of TS is -44.49 dB. Otherwise, Megalaspis is -43.06 dB. These results can be shown in our publication before as in [10]and compared to results from KRM model.

X-ray images of both fish on lateral and dorsal have been conducted as published before as in [11]. Total body volumes are 61 and 113 cm^3 for Selarboops and Megalaspiscordyla respectively.

Swim bladder volume of Selarboops is 3.4 cm^3 or 5.6% of its total fish body and the swim bladder's tilt angle to the body length is 18^0. Otherwise, swim bladder volume of Megalaspiscordyla is 5.1 cm^3 or 4.5% of its total fish body and the swim bladder's tilt angle to the body length is 8^0.

Higher volume and less swim bladder tilt angle in Megalaspiscordyla enable to accept more sound and produce higher reflects the echo and higher TS than Selarboops. Detail of fish body and swim bladder characteristics of two fish shown in Table 2.

The MATLAB program used to simulate the KRM model for TS identification either fish body and swim bladder for each species. TS swim bladder (*TSsb*) is higher than TS fish body (*TSfb*) for both fish. TS is most influenced by *TSsb* than *TSfb*, therefore any researcher focusing on *TSsb*. Megalaspiscordyla have a consistence results on a series facts morphology and its TS; longer *sb*, higher the percentage of long *sb* to *fb*, greater *sb* volume, and produce higher TS.

Table 2.Fish body and swim bladder

	Selar boops	Megalaspis cordyla
Length of *sb* (cm)	3.47	8.64
Length ratio of *sb* to *fb* (%)	26.67	45.45
Max height of *sb* (cm)	2.3	2.5
Max height ratio of *sb* to *fb* (%)	51	50
Volume of *sb*(cm^3)	3.4	5.1
Volume ratio of *sb* to *fb* (%)	5.6	4.5
Upper surface of *fb* (cm^2)	43.9	71
Upper surface of *sb* (cm^2)	5.9	14
Upper surface of *sb* to *fb* (%)	13.5	19.7
Angle of *sb* to fish length (^{0})	18	8

The results of Matlab programs have been produced backscattering cross section values and the TS as shown in Table 3. *TSsb* is larger than *TSfb*both on Selarboops and Megalaspiscordyla. Swim bladder plays an important role in determining the TS compared to fish body. It is also seen that the TS Megalaspiscordyla greater than Selarboops.

Table 4 shows the comparison between the obtained TS from *in situ* measurement and calculations using model. TS Megalaspiscordyla is higher than Selarboops which are 1.43 dB on *in situ* and 1.66 dB on model. TS from modelis higher than TS from *in situ*. This result agrees with Jech which TS from model is higher than TS from *in situ* and relatively consistent [23].

Table 3.Simulation results

	Selar boops	Megalaspis cordyla
TSfb (dB)	-50.17	-47.02
TSsb (dB)	-33.97	-32.43
TS (dB)	-35.22	-33.56

Table 4.Comparison

	Selar boops	Megalaspis cordyla
TS from *in situ* (dB)	-44.49	-43.06
TS from model (dB)	- 35.22	-33.56

TS differences between *in situ* and model are 9.27 dB for Selarboops and 9.50 dB for Megalaspiscordyla. These results shows that the differences TS from *in situ* and model is consistent. Furthermore, target strength identification using model for any fish can be conducted.

5. CONCLUSION

In situ TS measurement using echo sounder has been deployed using FQ-80. X-ray imaged has been deployed to observe fish body and swim bladder morphology. Length, width, height, volume, tilt angle, and percentage of swim bladder to fish body has been measured. Analysis for TS identification also has been deployed using model. The agreement is good, Megalaspiscordyla produce higher TS than Selarboops and swim bladder plays significant role in determining the TS compared to fish body.

Next research is carried out by model for TS calculations involving the number of pieces of varies in the fish body and swim bladder to obtain the optimal TS value and the ideal pieces length. The model will be also applicable for other species.

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