Thesis for the Degree of Master of Science

Estimation and examination on target strength of Bambooleaf wrasse (*Pseudolabrus japonicus*) by Kirchhoff-ray mode model.

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(Kirchhoff-ray mode 모델을 이용한 황놀래기의 Target Strength 추정과 검증)

Advisor: Prof. Hyeon-Ok SHIN

by

Afriana Kusdinar

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Abstract

Fish target strength (TS) is a key parameter in the acoustic estimation of fish abundance. The fish TS could be estimated through by in-situ, ex-situ measurement with dual and split beam system, and numeric or theoretical models based on fish morphology. In general, measurements become a main approach to apply for fish abundance estimation.

Theoretical model estimation for fish TS is a powerful method to guide and verify the measurements, and substitute the measurement for the fish which is hard to apply the direct measurement method. In the experiment, TS patterns for the 20 samples (LT ranged from 13.7 to 21.3 cm) of live Bambooleaf wrasse (*Pseudolabrus japonicus*) was estimated theoretically with Kirchhoff ray mode model and TS values for 18 live fish samples were additionally measured around zero tilt angle of swimming aspect by a tethered method using 120 kHz to verify theoretical values.

The results of this study explained as follow: swim-bladder was easy to be covered by unexpected objects and destroyed during the frozen sample treatment and fail in extraction of swim-bladder morphology with X-ray photo; digitizing intervals to extract fish body and swim-bladder morphology in X-ray photos significantly affected on the calculation of TS pattern; TS pattern changes in the value range of a sound speed and density ratio for general fish flesh are relatively small within 1 dB; and there was a good agreement between measurement and theoretical calculation, and the correlation between averaged TS and BL could be finally calculated as $\langle TS120_{kHz} \rangle = 20\log TL - 71.6$ dB ($r^2=0.69$) with the theoretical method.

Introduction

Marine and fresh water resources have long been recognized as an important food source and more commonly as materials of economic activity in both industrials and artisanal societies. In fisheries areas, these resources have been exploited for decades, which further raises concern about the fish stocks sustainability in the future (Beverton, 1990). Hence, various methods has been used to determine the fish abundance in a waters column by research institutions regularly. Hydro-acoustic is a popular method to get the information on temporal and spatial fish distribution and abundance effectively and efficiently. This technique has become increasingly sophisticated and useful over the years (MacLennan and Simmonds, 2005). Field application of acoustic methods to estimate animal abundance requires information on the acoustic size, target strength or backscattering cross section of individual organisms (MacLennan, 1990; Thiebaux et al, 1991). Fish target strength is a key quantity in the acoustic assessment of fish abundance (Foote, 1987).

Empirical measurement of backscatter as a function of fish length have been extensively studied and used throughout the fisheries acoustics community. Moreover modeling acoustic backscatter provides a quantitative tool to examine variability in backscatter measurements, also improve estimation of target size, and improve discrimination among types of acoustic targets (Horne and Jech, 1999).

Fish target strength is influenced by biological factors, including length of the fish (Love, 1971; Nakken and Olsen, 1977; Foote and Traynor, 1988), presence of a swim-bladder (Clay and Horne, 1994), the tilt of the fish relative to the incident acoustic wave (Love, 1971; Nakken and Olsen, 1977; Blaxter and Batty, 1990), etc. In general, three techniques that used to measure the target strength of a swim-bladdered fish are: in-situ (i.e. in the habitat/fish natural environment), ex-situ (i.e. in controlled experiments), and numeric or theoretical models based on swim-bladder shape.

Development of backscatter models has provided the ability to manipulate variables over broader ranges than feasible with ex-situ experiments (Foote, 1985; Stanton, 1989; Clay and Horne, 1994). Backscatter models have been used in conjunction with ex-situ and in-situ measurements, and shown fair to an excellent agreement between model predictions and empirical measurements (Foote, 1985; Foote and Traynor, 1988; Clay and Horne, 1994; Sawada, 1999; Hazen and Horne, 2004).

Therefore, if a study conducted to use backscatter model, it should be considering some potentially affect the shape, volume, and density of a swim-bladder and thus backscatter measurements (Blaxter and Batty, 1990; Koumoundouros et al., 2000). The culmination of several backscatter modeling efforts represent by Kirchhoff-ray mode (KRM) model. KRM models used to investigate acoustic backscatter from individual and aggregations of aquatic organisms. Then, backscatter models can be used to calculate echo amplitudes for individuals or groups with known size distributions. The model predictions could be compare to measurements in the laboratory, in the survey field (actually in the water), and are finding new uses for backscatter models all the time.

The objectives of the present study are to estimate target strength (TS) of Bambooleaf wrasse (*Pseudolabrus japonicus*) with theoretical model, examine the TS value of the model by comparing with a measurement result, and then examine the characteristics of the backscatter model in the application for the fisheries abundance estimation.

Material and Method

Target fish

One of the potential marine resources to be developed as a food resource derived fish from Korea waters is Bambooleaf wrasse (*Pseudolabrus japonicus*). This species lives around reef-associated and distributes in northwest pacific countries commonly. The distribution in Korea waters covered southern Korea peninsular (i.e. Jeju island) and southern Japan Sea (Kim et al, 2001). However, information about the value of target strength for this species is rarely.

Fig. 1. Visualization of a live Bambooleaf wrasse; TL=8 cm.

Kirchhoff-ray mode (KRM) backscatter model

The culmination of several backscatter modeling efforts able to represent by the Kirchhoff-ray mode model. The Helmholtz-Kirchhoff integral used to develop an accurate and elaborate method to estimate backscattered sound from fish (Foote, 1985; Foote and Traynor, 1988). This approach was simplified by Clay (1991; 1992) who incorporated Stanton's (1989) finite bent cylinder equation and fluid- or gas-filled cylinders to model fish backscatter. And has been validated for length and tilt (Jech et al., 1995; Horne et al, 2000).

The Kirchoff ray-mode backscatter model (Clay and Horne, 1994) combines the breathing mode and Kirchoff approximation to estimate the intensity of sound backscattered by an object based on the speed of sound and density of the fish body and swim-bladder. Acoustic scattering length of fish body () and swim-bladder () could be estimated as fluid-filled half cylinder and gas-filled cylinder. It can be simply expressed by following functions:

$$L_b = f(f_r, \theta, S_b, \rho_w, \rho_b, c_w, c_b) \tag{1}$$

$$L_{sb} = f(f_r, \theta, S_{sb}, \rho_w, \rho_{sb}, c_w, c_{sb}) \tag{2}$$

Where, f_r is acoustic frequency, Θ is tilt angle, ρ is density, and c is sound speed. Subscript b, w, sb indicate fish body, water, and swim-bladder, respectively. The scattering length from the whole body is calculated by adding scattering amplitudes from the fish body and swim-bladder, coherently.

$$L_{fish} = L_b + L_{sb} \tag{3}$$

Then, target strength of fish could be computed by following equation:

$$TS = 20\log\left|L_{fish}\right| \tag{4}$$

Acoustic characteristics backscatterer model obtained through Kirchhoff-ray mode model, including shape of cylinder, density ratio (g), sound speed ratio (h) and frequency. The flowchart below explained the steps to estimate material characteristics.

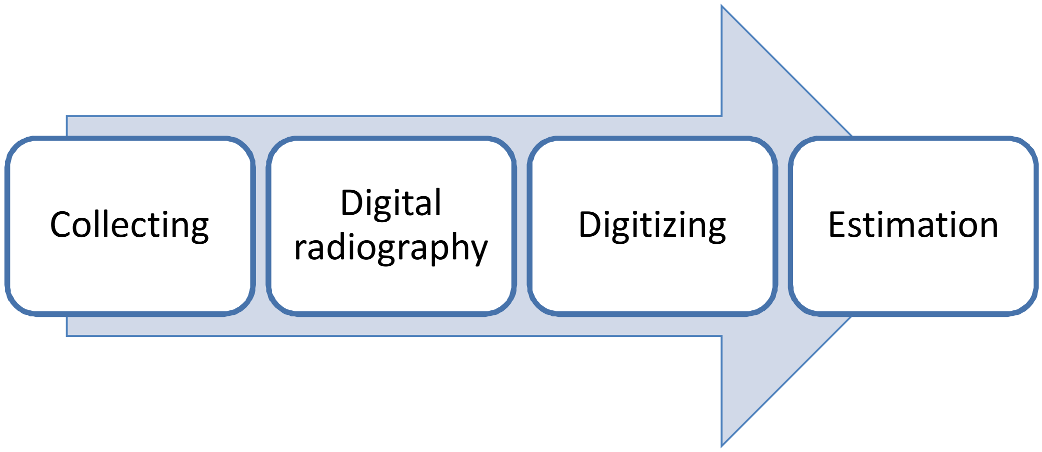


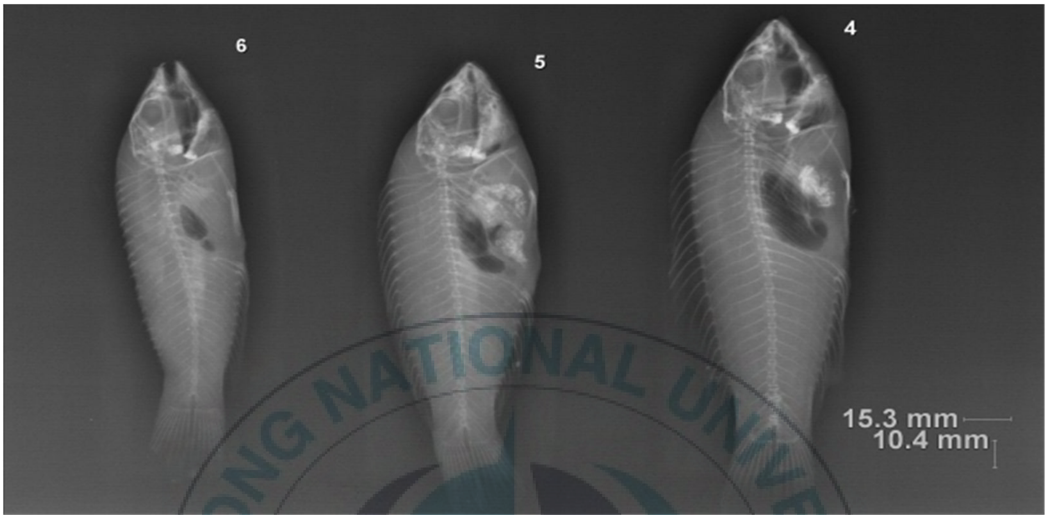
Fig. 2. Flow chart of acoustic scattering characteristics estimation using KRM model.

A total of 20 live fish were collected from Jeju waters in July 2010, ranging in fork length from 13.7 cm to 21.3 cm with an average length of 17.7 cm. After captured, the first kept in a tank with running seawater to 5-6 hours for keeping the condition well. All fish have been frozen during the imaging process necessary for backscatter modeling. Swim-bladders conditions should not be disturbed by physical pressures or other causes, so that keep its column as estimated natural shapes of swim bladder in water. The samples were frozen rapidly using dry ice chunks and added with alcohol after taken out of water. Then saved in a freezer with -40° temperatures prior to imaging process.

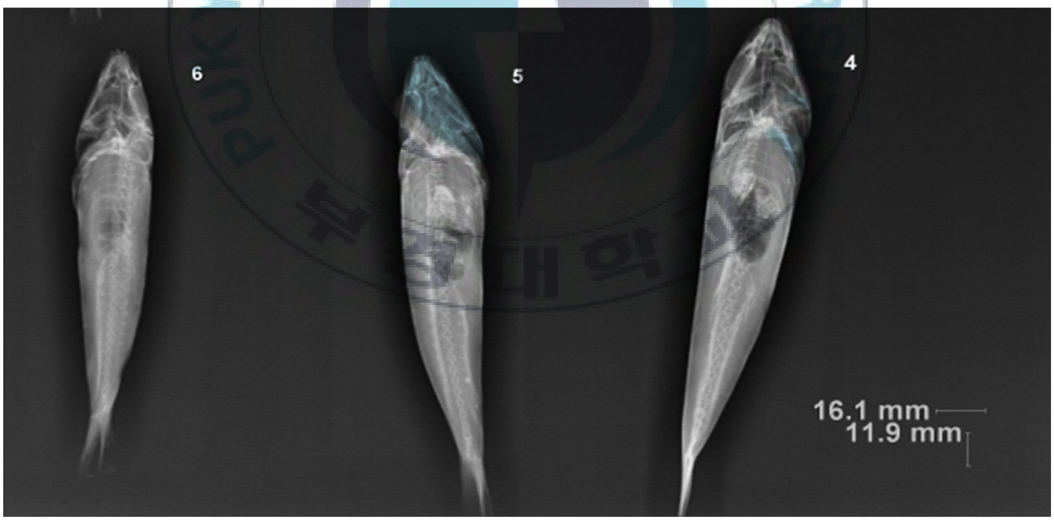
The selected fish were radio-graphed dorsally and laterally using a digital x-ray imaging system and rare earth film with a proportional scale. Radiographs images of the fish body and swim-bladder are presented in fig. 3. Radiographs of fish were used to measure swim-bladder and body morphology for use in the backscatter model. The dark-colored column is easily distinguished as the result of differential x-ray absorption by the air-filled swim-bladder in comparison to the rest of the fish body (Clay and Horne, 1994).

The x-ray images were traced and then projected to a standard length using the vertebral column as a ruler between the ventral and lateral views. Acoustic Bambooleaf wrasse models were constructed for each fish and then scaled to larger and smaller lengths for comparison to measurements target strengths. The X-ray radiographs were used to image fish bodies and swim-bladders used in KRM modeling.

Lateral and dorsal images of fish body and swim-bladder were traced and then digitized at 3-mm intervals relative to the fish axis, fins and tail were not included in the trace. Trace lines were smoothed and rotated so that the sagittal axis of the fish body was horizontal. The resulting dorsal and lateral images were elliptically interpolated into 3-mm-thick cylinders to give a three-dimensional representation of the fish body and swim-bladder (Clay and Horne, 1994). These digitized data were used to calculate the target strength from the tilt angle and frequency using an acoustic scattering model. The series of morphometric descriptors (including swim-bladder volume and area) were estimated using these three-dimensional fish representations. The ratio of the major to minor axes of the body and swim-bladder (maximum length and width) were measured on the lateral traces as an index of elongation.



(a) Lateral image



(b) Ventral image

Fig. 3. Example of x-ray images to measure swim-bladder and body morphology (lateral and ventral). The air-filled swim-bladder shown as a dark column within the fish body, and the different shades of gray represent structures of different densities within the fish body.

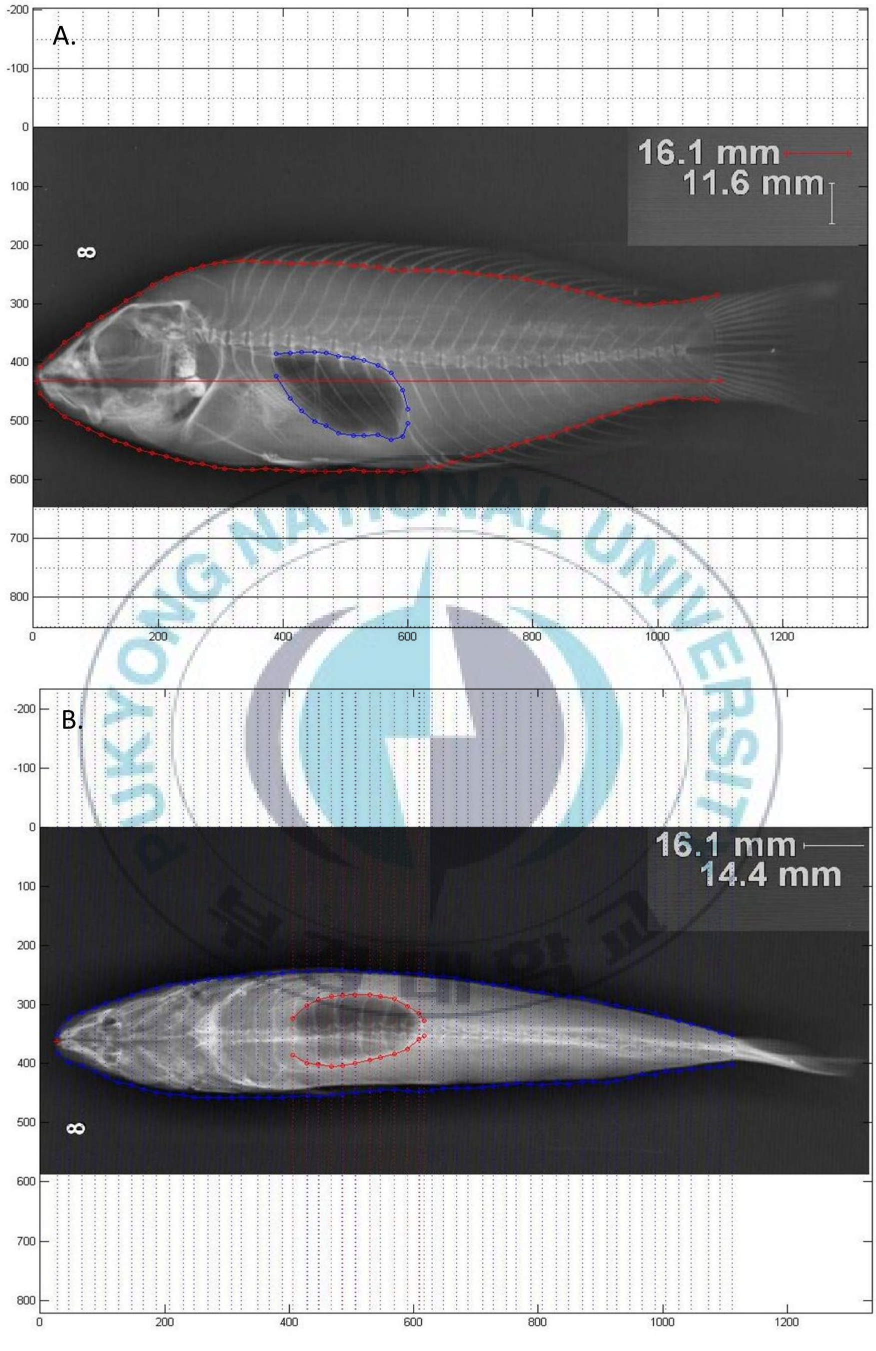


Fig. 4. A digitizing X-ray photo after coordinating process of body and swimbladder, lateral (a) and ventral (b) projection.

Target strength measurement

Target strength measurement was performed in 5mx5mx3m indoor tank filled with seawater. Split beam transducer (EK-60, SIMRAD) at 120 kHz was mounted in the top of the tank vertically and underwater camera prepared for monitoring the fish movement in the depth of about 3 meters horizontally. Calibrations conducted using a 60 mm copper sphere (38 kHz) and 23 mm copper sphere (120 kHz) calibration sphere prior to target strength measurements (Foote et al, 1987).

To acclimate with surface pressure, fish were kept in a tank for at least two hours prior to target strength measurements. Only fish that were swimming normally after 2-12 hours of acclimation were used in experiments. Fish were removed from the tank with a dip net and placed in a bucket filled with water to be hooked in a suspended frame. Fish were anesthetized with Ethyl 3-aminobenzoate methanesulfonate 98% (MS-222) to reduce struggling during transfer and while target strength measurements were recorded. The frame lowered slowly to ensure that the fish was out of the near field of the transducers (in 2 meters under both of transducers). By convention, positive tilt angles will represent a fish with a head up orientation and negative tilt angles will represent a fish with a head down orientation. But in this study the titl angle of fish was counted only for approximately 0°.

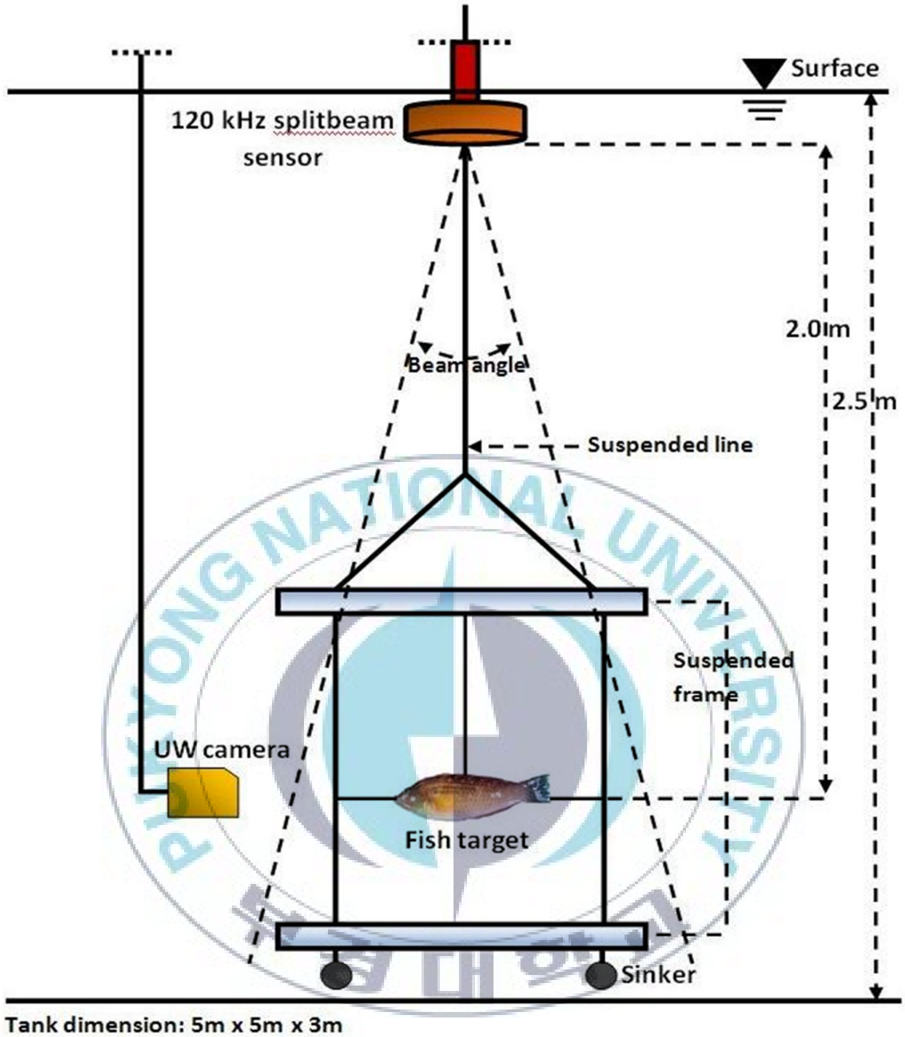


Fig. 5. Experimental configuration of target strength measurement.

Results and discussions

Problem in making samples for backscatterer model

A total of twenty samples of Bambooleaf wrasse have been selected to be sampled for backscatterer model. Some samples, however, are difficult to extract a swim-bladder shape by unexpected objects such as water. Two samples of x-ray photograph are shown in Fig. 6. (a) can be shown a swim-bladder shape and clearly defined, but another case such as (b) where the swim-bladder not defined well. The condition (b) will be a difficult when tried to extract swim-bladder shape and cause estimation errors.

During the sample treatment, the fish sample was deep frozen within 30 to 50 seconds with the shock freezing method and it were kept at -50^0 C until processed (Farrant et al. 1977; Ona 1990). But, swim-bladder is easy to be destroyed by external shocks and be percolated by water. The samples both of flesh and swim-bladder should possible clear identified visually as freeze sample or radiophotograph. Therefore, well-treatment during make the samples was important to prepare a good samples condition. ,

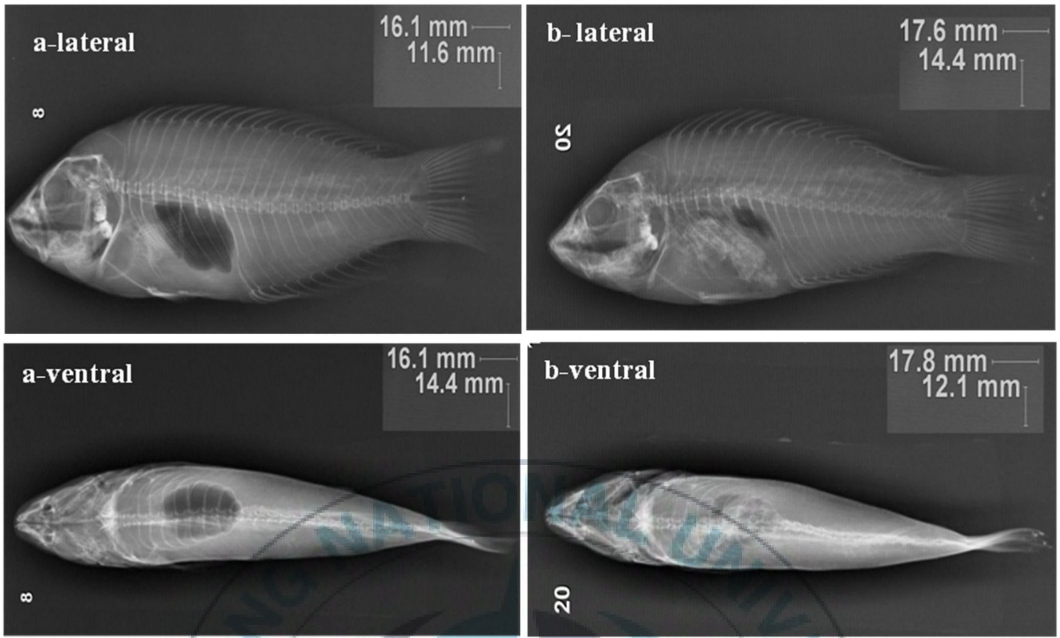
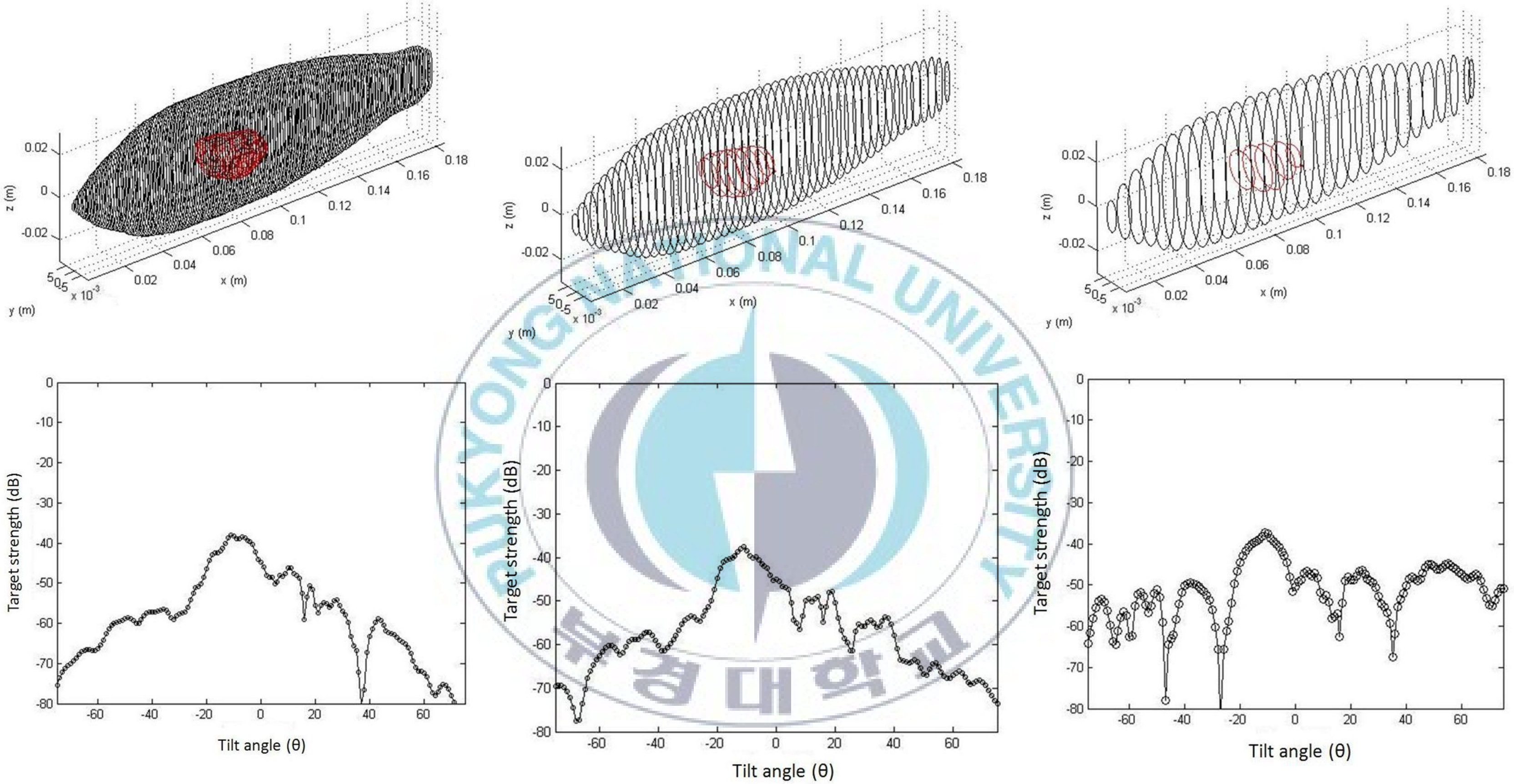


Fig. 6. Comparison between two cases swim-bladder radiographs. Sample (a) is easy to identify swim-bladder shape, but sample (b) disappear or difficult to identify the swim-bladder shape.

Influence on acoustic scattering pattern by digitizing interval

Acoustic scattering pattern at 120 kHz by digitizing interval of fish and swim-bladder shapes is shown in Fig. 6. The change of scattering pattern can be observed by setting the interval when slicing. The main lobe at about 10˚ tilt angle by swim-bladder has almost same shape. The patterns at broadside were, however, significantly changed by the digitizing interval. Actually the higher frequency has more complicated acoustic scattering patterns by shape of the target. The differences were generated from the construction and destruction of the acoustic scattering of each cylinder during the coherent summation. In this result, when applied sliced to fish and swim-bladder cylinder with interval 1.25 mm and 3.75 mm were shown a general scattering pattern.



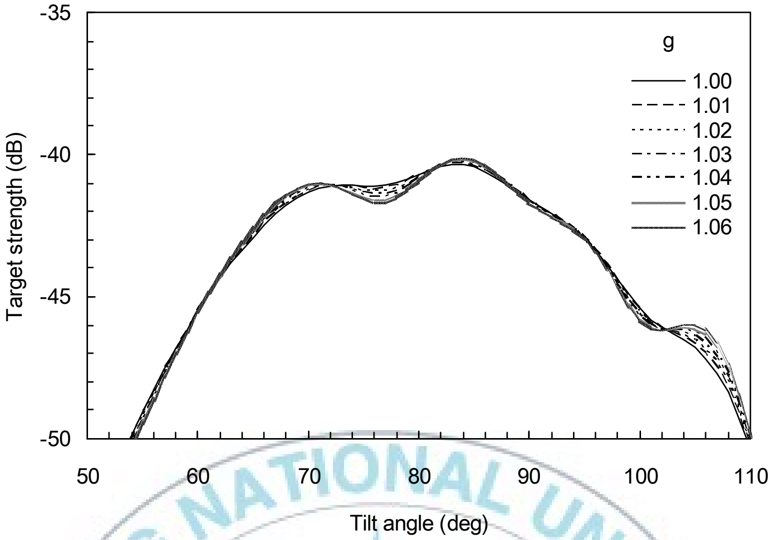
(a) 0.1λ interval (1.25mm) (b) 0.3λ interval (3.75mm) (c) 0.5λ interval (6.25mm)

Fig. 7. Scattering pattern changes by the digitizing intervals at 120 kHz (SL=18.4). (a) 0.1λ interval, (b) 0.3λ interval, (c) 0.5λ interval.

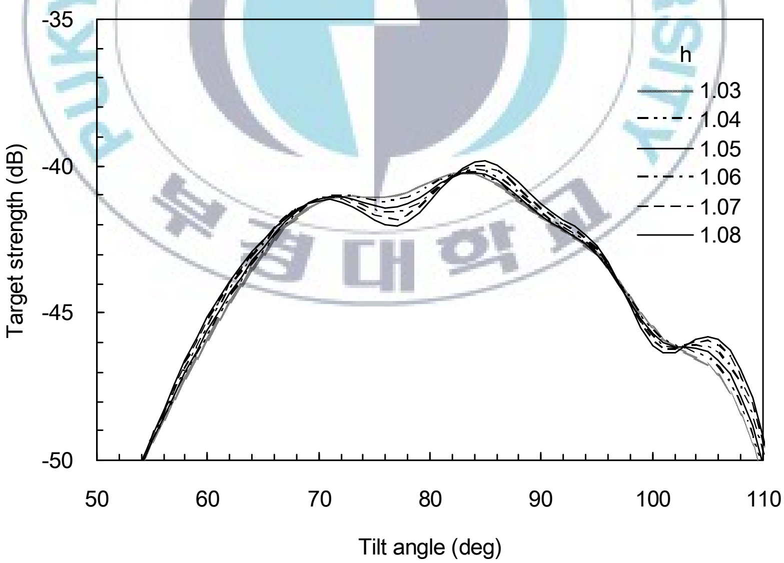
Effect for the acoustic scattering by density (g) and sound speed (h)

Acoustic scattering models have focused on the geometric aspect of the scattering model and assumed the known material properties, i.e. sound speed (h) and density contrasts (g). In many cases, values of *g* and *h* are adjusted within reasonable limits to fit the directly measured acoustic data. The *g* and *h* values used in the backscatter model calculations have not been measured for Bambooleaf wrasse. Medwin (2005) describes the fish flesh have *g* value from 1.03~ 1.06 and *h* values from 1.03 ~1.08.

Acoustic scattering pattern at 38 kHz by the change of g and h is shown in Fig. 7. The scattering pattern was not significantly affected by g and h values of fish flesh and the differences were within 1dB. The reason is that almost the whole of acoustic scattering of fish is generated from the swim-bladder. Insignificant differences in density and speed of sound through other organs or bones within the fish, which may influence scattering intensities and it is possible that differences in *g* and *h* values between species can result in target strength differences up to 10 dB (Horne and Jech, 2005). But, the most of coastal fishes that have general body length maybe not greatly affected by using g and h value for general fish.



(a) h = 1.05



(b) g = 1.03

Fig. 8. Scattering pattern changes by g and h at 38 kHz (SL=18.4).

Comparison of the backscatter model and measurement value

There were 18 samples of Bambooleaf wrasse prepared for measurement target strength for ex-situ experiment which has body length from 13.0 to 19.5 cm. Comparing result of target strength around 0^0 tilt angle estimated by theoretical model and measurement is shown in Fig. 8. Measurement values were slightly different from the model value at 0^0 tilt angle (bold line). The reason was that the fish tilt angle was not exactly controlled by the tethered method. The dotted lines indicated TS values from -5^0 to 5^0 of tilt angle. It is indicated that tilt angles of fish were controlled within $\pm 4^0$ and well agreed between theoretical values and measurement.

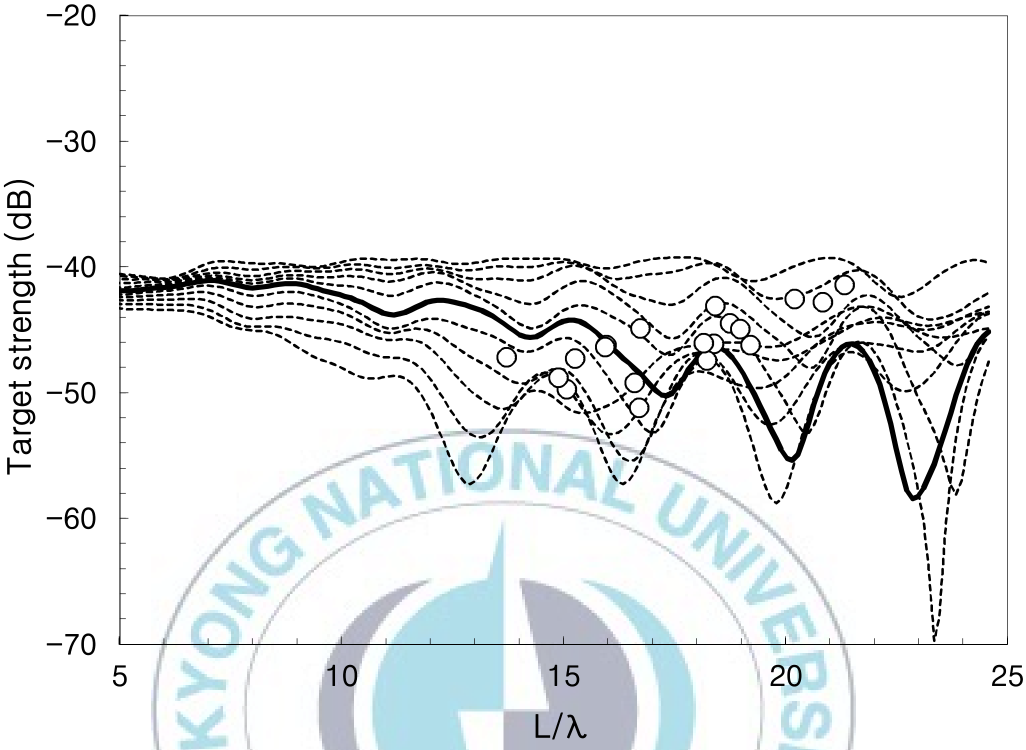


Fig. 9. Target strength of Bambooleaf wrasse in relationship to length L expressed in wavelength. Bold line and dotted lines indicate 0˚ and from -5˚ to 5˚ of fish tilt angle, respectively.

General formula estimated for 120 kHz

In order to establish general formula with theoretical model, TS patterns for 20 samples were estimated and swimming angle distribution is assumed to be (-5, 15) to calculated averaged TS. The regression between TS and BL was expressed by following equation (fig. 9).

$$\langle TS_{120kHz} \rangle = 20\log TL - 71.6 \quad (r^2 = 0.69) \qquad (5)$$

Actually, the r^2 value was influenced not only by sample conditions and digitizing errors, but also biological characteristics. The result was, however, indicated that the theoretical estimation has enough accuracy to establish the relationship between TS and BL.

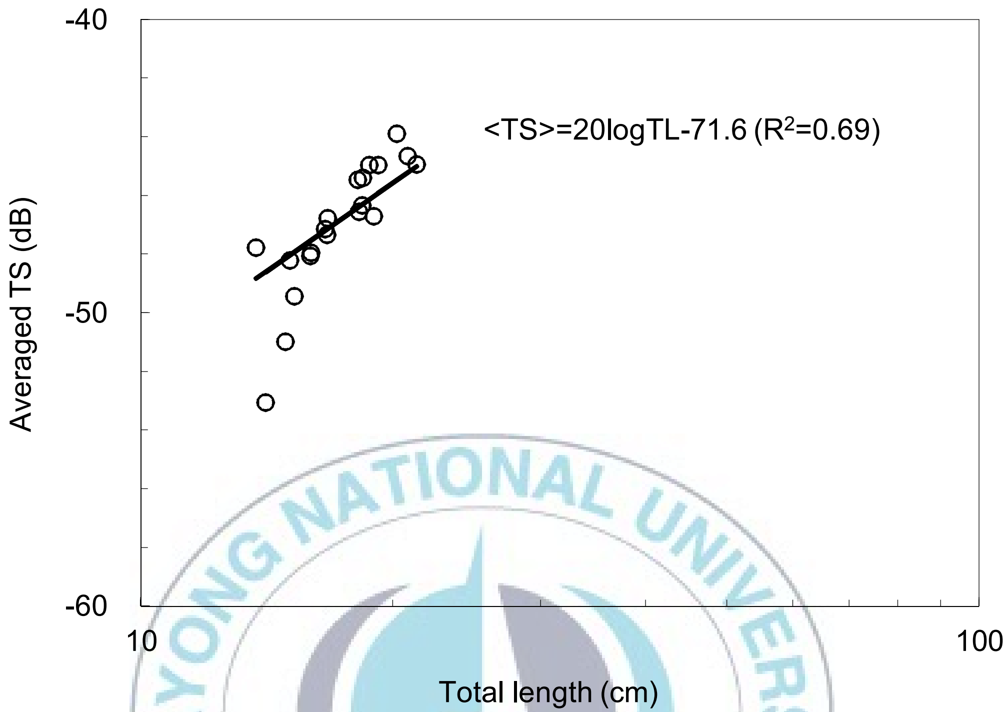


Fig. 10. TS - BL relationship of Bambooleaf wrasse at 120 kHz estimated by theoretical model. Solid lines represents TS = 20log (LT) + b.

The x-ray photographing can be shown the sample quality and sample treatment was an important procedure during making x-ray sample. Fish will wriggle when caught out of water, at that time set in the dry ice chunks immediately and wait several seconds till down. To make a better x-ray sample keep the natural shape, it is needed that the dry ice chunks are made small and smoothly not to press the fish body and handle the samples thoroughly and carefully until freeze.

The regression between TS and BL to estimate fish abundance, it is generally established with ex-situ TS measurements for wide size fish samples. In this study, the regression was, however, established with theoretical estimation results for 20 frozen samples. It is shown that theoretical model can be used to estimate the regression such as a measurement and has a potential use for acoustical fish abundance survey by an appropriate sample control to increase the accuracy.

Conclusion

This study conducted to estimate and examine target strength of Bambooleaf wrasse (*Pseudolabrus japonicus*) with the Kirchoff ray mode (KRM) model, examine the TS value of the model by comparing with an ex-situ measurement result. 20 frozen fish samples were prepared to take x-ray photograph for extracting coordinates of fish body and swim-bladder shape and TS patterns for the samples were calculated at 120kHz. TS around 0˚ fish tilt angle for 18 live fish samples were also measured with tethered method to verify the values estimated by the model.

As a result, swim-bladder was easy to be covered and destroyed by unexpected objects during the frozen sample treatment and fail in extraction of swim-bladder morphology with X-ray photo and the digitizing interval of fish body and swim-bladder shape significantly affected on the calculation of TS pattern, but in the value range of a sound speed and density ratio for general fish flesh are relatively small within 1dB. Between measurement and theoretical calculation, there was a good agreement and the general formula was tentatively calculated with the theoretical method could be calculated as $\langle TS120_{kHz} \rangle = 20\log TL - 71.6$ dB (r2=0.69). It is shown that theoretical model can be potentially used for acoustical fish abundance survey by an appropriate sample control to increase the accuracy.

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